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Trip Characteristics and Traffic Assignment

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Trip Characteristics and Traffic Assignment

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Trends in Travel to the Central Business District by Residents of the Washington, D.C., Metropolitan Area, 1948 and 1955

JACOB SILVER,[1] Transportation Economist, Division of Highway Planning, Bureau of Public Roads

This paper evaluates the changes that took place between 1948 and 1955 in the relationship of the central business district to the metropolitan area. Many of the findings presented here, which are based on quantitative data, confirm the unsupported views of persons concerned with the changing urban structure.

Although the number of trips destined to the central business district increased during the 7-year period, the proportion of total area trips to the central area declined. Suburbanization, accompanied with development of commercial establishments, has had a definite impact upon the business center of the city. Although the central business district remained a major terminus for residents trips, it was less so in 1955 than in 1948.

● CENTRAL business districts in today's metropolitan areas are taking on new meaning in the urban structure. In the past 2 decades the urban population has increased at a very rapid rate, with a general tendency on the part of families to live farther from the central city. With this expansion has come a development of new outlying commercial and service facilities which, with an increased number of new employment centers outside the central business district (CBD), are now carrying on functions formerly associated with the central area.

What has been the impact of the growth of these functions upon the CBD and the travel to it? The need for information to answer this question has become increasingly important in order that planners and legislators may have a better understanding of the changing urban relationships in this very complex section of cities. From the data obtained from the 1948 and 1955 home-interview travel surveys[2] which were sponsored by the Regional Highway Planning Committee for metropolitan Washington, D.C., in cooperation with the Bureau of Public Roads, an attempt has been made to measure this impact as it relates to travel.

SUMMARY OF FINDINGS

The most important travel characteristic reflecting the change in the relative economic character of the CBD between 1948 and 1955 was the decreasing proportion of trips to the CBD in relation to total travel. The pattern in which the percentage of intra-area trips destined to the CBD decreased progressively with distance and varied with socioeconomic conditions and historical trends in a lateral direction around the CBD remained similar in both years. In 1955, however, residents of each of the geographical subdivisions studied made a smaller proportion of their intra-area trips to the CBD than in 1948. Although the CBD remained a land-use complex of major trip attraction, it was less an attractor of trips in 1955 than in 1948.

Of those residents who did make trips to the CBD, the more important changes in the geographical pattern of their distribution took place with distance from the central

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[1] This paper was presented at the 38th Annual Meeting of the Highway Research Board, Washington, D.C., January 1959.

[2] The procedures used in these studies are described in the "Manual of Procedures for Home Interview Traffic Study," which is available by purchase from the Public Administration Service, 1313 East 60th Street, Chicago, Ill.

area rather than with direction. Although there were fluctuations in the directional distribution of CBD trips, the pattern in 1955 remained approximately the same as in 1948. The pattern of distribution as related to distance indicated a more significant shift, however, as an increasing percentage of the CBD trips were made by individuals residing at greater distances from the central area. These changes followed a pattern related to the distribution of population and residential growth, and also to the increasing uniformity in the frequency of trips per dwelling unit.

As indicated by the number of trips for each purpose, the functions carried on within the central area were changing. The retail segment of the CBD became relatively less important as the number of trips for non-retail activity increased and those for shopping decreased.

This does not imply that shopping trips to the central area will decline until they become insignificant. The volume of shopping trips should increase if greater accessibility to the central area is provided and shopper convenience is improved. Nevertheless, by providing the same attracting forces outside the CBD that previously caused residents to make trips to the CBD, a greater choice in direction of movement has been given area residents.

Of those residents who were attracted to the central area for one purpose or another, the most notable change was the increasing use of the private automobile. The general increase in automobile ownership permitted a greater use of this mode of travel for all purposes for which trips would be attracted to the CBD. As automobile ownership increases in those subdivisions that were among the lowest in 1955, and as the number of trips to the CBD by individuals residing at greater distances from the CBD where transit service is less convenient increases, the use of the private automobile in traveling to the CBD should increase even more.

In Washington, D.C., as in other cities, many CBD functions have expanded into the fringe area surrounding the CBD because of increasing costs of land, rent, taxes, etc. As a result, many of the travel characteristics peculiar to the central area have become apparent in the fringe area. To obtain a more comprehensive picture of travel to the CBD, this area should be analyzed in future studies.

SCOPE OF STUDY

The metropolitan area of Washington, D.C., included in the 1948 transportation study is shown in Figure 1. To develop travel data to the central area and to determine the relative effects of distance as well as direction upon a person's travel to the CBD, the study area was subdivided into rings and sectors. Sector divisions of the 1948 survey were used to indicate direction and 2-mile rings, as measured from the Zero Milestone,[3] were used to show distance. Together they make up what henceforth will be called ring-sectors, and all trip data were grouped into these subdivisions. Ring-sectors are comprised of a number of transportation zones grouped according to the distance from the CBD of each zone's 1948 centroid of population. Because of the location of the centroids of population and the irregular shapes of transportation zones, the stippled areas in Figure 1 tend to overlap the distance rings.

The area of the repeat study in 1955 was extended beyond the 1948 limits because of the growth in residential development. To have comparable data for a trend analysis, however, only those trips by persons residing within the 1948 area were used. This procedure did not bias the 1955 data to any great extent since the 1948 area included residents who made 92 percent of the trips within the 1955 cordon and 95 percent of the residents trips destined to the CBD.

The Washington CBD, as defined in this analysis, is shown in Figure 2. Trips to this area, included in the study, were average weekday trips related to the traveler's

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[3] Although Zero Milestone was not the exact center of the CBD, it was chosen for use in this study because it had been employed in an earlier study "Travel to Commercial Centers of the Washington Metropolitan Area," by Gordon B. Sharpe, Highway Research Board Bulletin 79, 1953.

zone of residence, even though the trips may have originated elsewhere. Although the trip zone of origin would provide a truer picture of direction and distance of actual travel to the CBD, experience in sampling has shown that place of residence and distribution of population are more stable and reliable factors when determining travel characteristics, both for the purpose of estimating future travel patterns to the CBD and for comparing travel patterns in two or more cities.

The trip purposes studied were limited to three groups: work, shop, and other. The category of "other" included business, medical-dental, school, social, recreation, eat meal, change mode of travel, serve passenger, and home trips.

There were several reasons for this grouping of trip purposes: first, for the purposes of analysis, it was simpler; second, trips to work and to shop are the purposes most closely associated with trips to the CBD; and third, residents making trips for each of the reasons grouped in the "other" category made less than 20 percent of such trips to the CBD on an average weekday.

The modes of travel analyzed included automobile driver, automobile passenger, taxi passenger and mass-transit passenger. Trips by taxi and truck operators in the course of their daily work and all pedestrian travel were excluded. Pedestrian trips, however, must be kept in mind in any discussion of data concerning trips coming from within the first 2-mile ring.

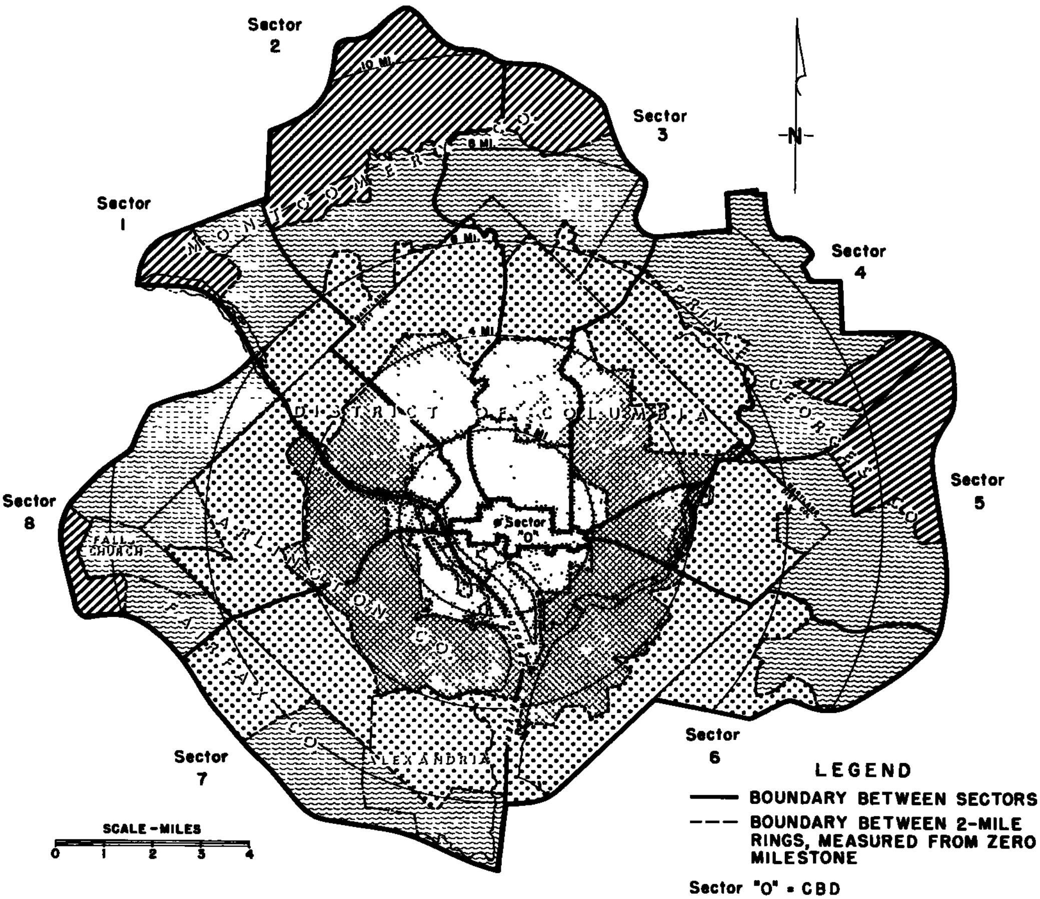


Figure 1. 1948 Washington, D.C. metropolitan transportation study area, by ring-sectors.

CHARACTERISTICS OF STUDY AREA

Though there were changes within the Washington CBD, such as buildings demolished, parking facilities created, new office buildings erected, etc., the basic physical outline did not change greatly between 1948 and 1955, and it continued to have the commercial and employment functions associated with this complex type of land use. In addition, the CBD also houses many Federal Government activities, which are a major source of employment for area residents.

The number of persons employed in the CBD remained almost constant, increasing less than 2 percent between 1948 and 1955 (189,100 to 192,800 persons employed).[4] Employment opportunities, however, had increased outside the CBD at a greater rate than within. The proportion within the CBD decreased from 31 to 27 percent, or from a ratio of 1 job for every 6 persons to 1 for every 8 persons living in the area.

Retail sales within the CBD remained approximately the same, about $367 million for each of the 2 years. This is not a true comparison, however, when considering the changed value of the dollar. It was found that prices in 1955 had increased generally by 11.4 percent over 1948. When adjusted by the Consumer Price Index for metropolitan Washington as published by the Bureau of Labor Statistics, 1955 retail sales amounted to $325 million, or a relative loss of 11 percent, as measured in 1948 dollars. Moreover, even though retail sales for the metropolitan area increased, the proportion of these sales made within the CBD, on a constant dollar basis, decreased from 26 to 19 percent. Since the close of World War II, population growth in the Washington, D.C., area has followed the general trend of most large metropolitan areas in the United States. Between 1948 and 1955, population within the area, as determined by the travel studies, increased 31 percent, from 1,110,000 to 1,454,000 persons (Table 1). Approximately 95 percent of this growth occurred beyond 4 miles of the CBD.

A comparison of the percentage distribution of population and dwelling units between 1948 and 1955 reveals that the more significant relative changes occurred between the 2-mile distance rings rather than between sectors around the CBD. The relative distribution of population had changed between rings by as much as 6 percentage points from what it had been in 1948, while 7 of the 9 sectors changed less than 1 percentage point (Table 1). Population growth was extending outward from the CBD with no major shifting

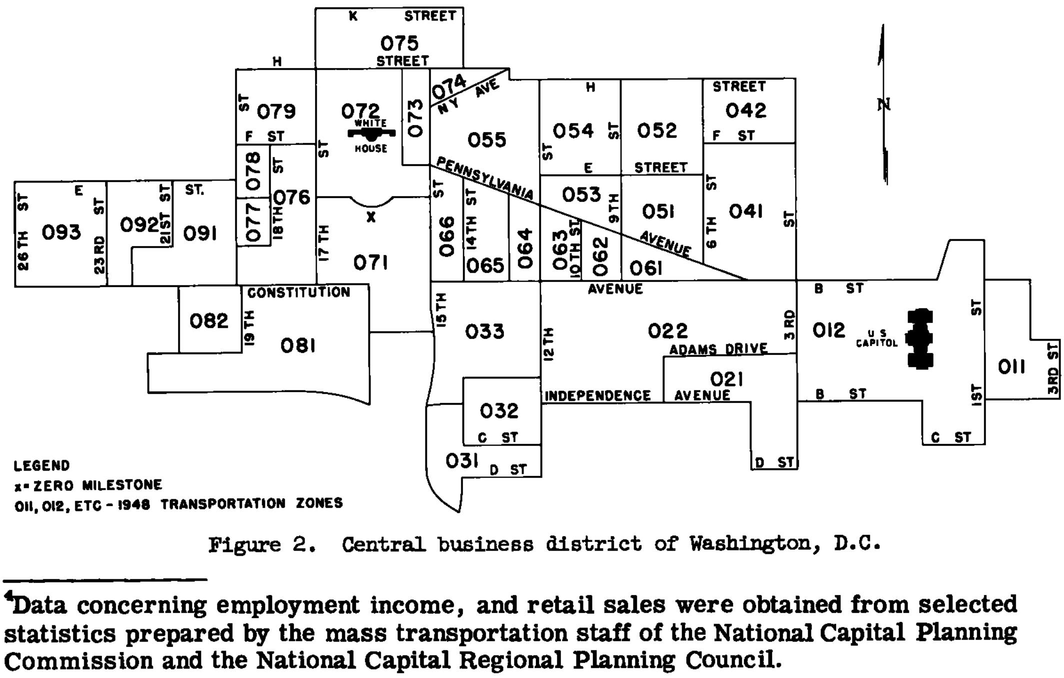


Figure 2. Central business district of Washington, D.C.

[4]Data concerning employment income, and retail sales were obtained from selected statistics prepared by the mass transportation staff of the National Capital Planning Commission and the National Capital Regional Planning Council.

of residents from one sector of the study area to another. The distribution of dwelling units followed the same general pattern as population.

ANALYSIS OF DISTANCE AND DIRECTION FACTORS

The volume of intra-area travel by residents in 1955 increased 42 percent over what it had been in 1948 (Table 2). Trips to the CBD, on the other hand, increased only 4 percent, or from 255,338 to 265,659. In addition, residential (dwelling unit) growth had increased 44 percent (336,181 to 485,108), or at a rate slightly greater than trip growth (Table 1). While this resulted in a less than 2 percent decrease in total area trips per dwelling unit, trips per 100 dwelling units destined to the CBD decreased 28 percent (76 to 55).

Of greatest significance was the decrease in the proportion of trips destined to the CBD. Although there was a 4 percent increase in the actual volume, the percentage relationship of these trips to total area travel had decreased from 14.9 to 10.9 percent which presents a picture of decreasing trip orientation to the CBD.

TABLE 1

POPULATION, DWELLING-UNIT, AND DENSITY DATA FOR 1948 AND 1955, GROUPED BY RINGS AND SECTORS SURROUNDING THE CENTRAL BUSINESS DISTRICT

	Population				Dwelling units				Number of dwelling units per residential acre, 1955[1]
	1955		1948		1955		1948		
Area	Number	Percent	Number	Percent	Number	Percent	Number	Percent	
Rings (mi)									
0-2	268,256	18.4	271,468	24.5	105,494	21.8	89,357	26.5	65.7
2-4	279,293	26.1	354,912	32.0	137,610	28.3	108,491	32.4	22.3
4-6	433,848	29.8	305,163	27.5	134,789	27.8	86,120	25.6	10.2
6-8	284,938	19.6	145,627	13.1	83,039	17.1	42,556	12.7	6.5
8-10	88,102	6.1	32,681	2.9	24,176	5.0	9,657	2.8	4.7
Total area	1,454,437	100.0	1,109,851	100.0	485,108	100.0	336,181	100.0	12.5
Sectors									
0	5,910	0.4	6,291	0.6	3,323	0.7	2,767	0.8	195.5
1	57,565	4.1	43,146	3.9	22,267	4.6	13,205	4.0	7.8
2	173,748	12.0	129,236	11.7	67,256	13.9	44,715	13.3	9.9
3	367,558	25.3	321,147	29.1	128,400	26.5	98,476	29.3	21.5
4	212,025	14.5	153,803	13.7	63,672	13.1	42,927	12.6	13.8
5	150,466	10.4	107,168	9.6	41,816	8.6	27,704	8.3	16.7
6	210,034	14.3	157,408	14.2	66,642	13.7	44,163	13.1	20.6
7	149,753	10.3	115,869	10.4	51,923	10.7	40,016	11.9	9.9
8	127,378	8.7	75,783	6.8	39,809	8.2	22,208	6.7	5.1
Total area	1,454,437	100.0	1,109,851	100.0	485,108	100.0	336,181	100.0	12.5

[1] No comparable data available for 1948.

TABLE 2

TRIPS TO THE CENTRAL BUSINESS DISTRICT DURING 1948 AND 1955, CLASSIFIED BY PURPOSE AND MODE OF TRAVEL

Mode of travel	Trip comparisons	Work trips		Shopping trips		Other trips		All trips	
		1955	1948	1955	1948	1955	1948	1955	1948
Automobile driver	Total intra-area trips	272,097	164,109	108,458	45,847	777,700	418,824	1,158,255	628,780
	Trips to CBD	42,189	31,545	5,944	3,828	34,207	21,108	82,340	56,481
	Percentage of trips to CBD	15.5	19.2	5.5	8.3	4.4	5.0	7.1	9.0
	1955 percentage/1948 percentage	81		66		88		79	
	1955 trips to CBD/1948 trips to CBD	1.34		1.55		1.62		1.46	
Automobile passenger	Total intra-area trips	105,879	59,065	51,020	22,793	434,116	274,285	591,015	356,143
	Trips to CBD	33,419	19,125	4,472	3,581	12,552	12,010	50,443	34,716
	Percentage of trips to CBD	31.6	32.4	8.8	15.7	2.9	4.4	8.5	9.7
	1955 percentage/1948 percentage	98		56		66		88	
	1955 trips to CBD/1948 trips to CBD	1.75		1.25		1.05		1.45	
Taxi passenger	Total intra-area trips	13,550	10,017	2,974	1,901	41,572	34,558	58,096	46,476
	Trips to CBD	7,043	5,653	1,578	1,319	4,250	4,601	12,871	11,573
	Percentage of trips to CBD	52.0	56.4	53.1	69.4	10.2	13.3	22.2	24.9
	1955 percentage/1948 percentage	92		77		77		89	
	1955 trips to CBD/1948 trips to CBD	1.25		1.20		92		1.11	
Mass-transit passenger	Total intra-area trips	183,857	219,003	29,765	39,619	408,060	419,576	621,682	678,198
	Trips to CBD	79,441	94,543	19,241	25,683	21,323	32,342	120,005	152,568
	Percentage of trips to CBD	43.2	43.2	64.6	64.8	5.2	7.7	19.3	22.5
	1955 percentage/1948 percentage	1.00		1.00		68		86	
	1955 trips to CBD/1948 trips to CBD	84		75		66		79	
All modes	Total intra-area trips	575,383	452,194	192,217	110,160	1,661,448	1,147,243	2,429,048	1,709,597
	Trips to CBD	162,092	150,866	31,235	34,411	72,332	70,061	265,659	255,338
	Percentage of trips to CBD	28.2	33.4	16.2	31.2	4.4	6.1	10.9	14.9
	1955 percentage/1948 percentage	84		52		72		73	
	1955 trips to CBD/1948 trips to CBD	1.07		91		1.03		1.04	

Since this study involves measurement of the effects of distance and direction from the central area on the travel patterns to the CBD, an analysis was made to determine the "degree of trip orientation" to the CBD of the trips made by residents of each ring-sector. This was accomplished by comparing the percentage of residents trips for each ring-sector destined to the CBD with the average percentage for the total area. Residents of the ring-sectors whose percentage of trips to the CBD exceeded the average for the total area could be said to have a greater than total area average orientation to the CBD. On the other hand, residents of those ring-sectors having a percentage of trips to the CBD below the average would be considered less oriented than the area as a whole. The percentages were then ranked in class intervals of 0 to 20, 20 to 40, and 40 percent or more above or below the total area average for each of the 2 years. Figure 3 illustrates the relative orientation of trips to the CBD by residents of each ring-sector in the manner just described.

The degree of trip orientation was then compared for the 2 years to ascertain whether the general relationship of trips to the CBD had been maintained even though the percentage had decreased. In both years there were definite geographic areas which maintained a high degree of trip orientation. Residents who had a higher than average orientation in 1948, with few exceptions, retained this relative rank in 1955. Moreover, there were instances where the percentage of trips to the CBD decreased at a rate much less than that which was indicated by the average for the total area. As a result, these residents trips ranked even higher in relative orientation than they had in 1948. An example of this situation occurred in sectors 1, 2, and 3 (Figure 3).

TRIP PURPOSES

The volume of residents intra-area work trips in 1955 increased 27 percent over that of 1948 (452,194 to 575,383). Work trips to the CBD, however, increased only 7 percent, from 150,866 to 162,092 (Table 2). As a result, the percentage of work trips

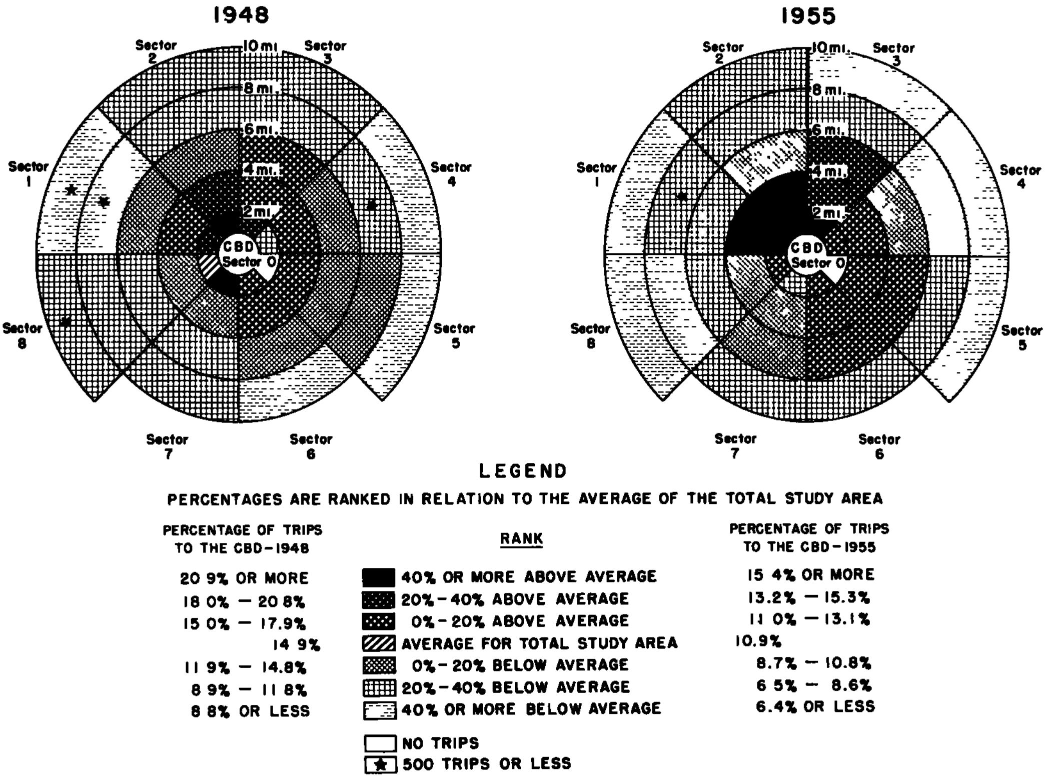


Figure 3. Percentage of intra-area trips to the CBD by residents of each ring-sector.

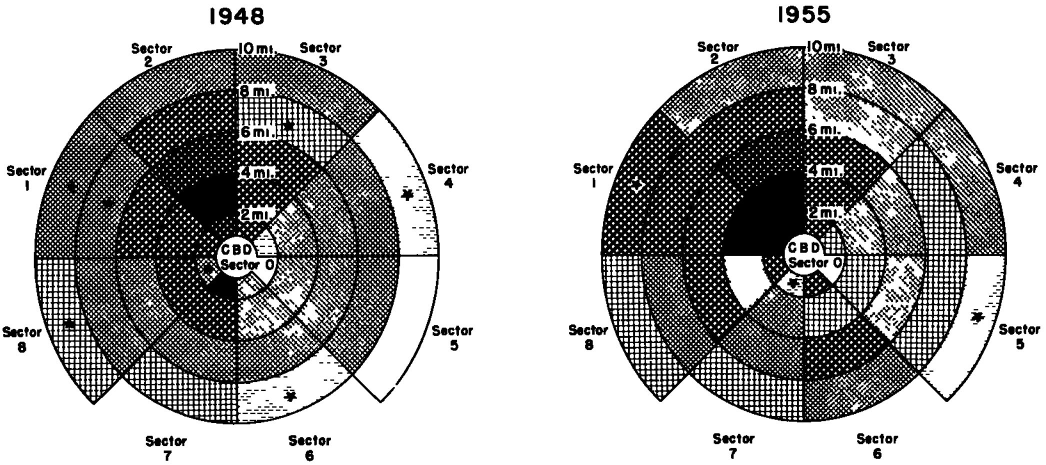
destined to the CBD decreased from 33.4 to 28.2 percent, or a 1955 to 1948 change ratio of 0.84. Although the CBD work trips decreased in relative importance since 1948, they had not decreased as much as shopping trips which had a change ratio of 0.52 or as much as "other" trips which had a change ratio of 0.72.

In each of the purpose categories, the proportion of CBD trips by mass transit decreased while trips by automobile increased (Table 3). In actual volume, work trips

TABLE 3

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT FOR VARIOUS PURPOSES IN 1948 AND 1955, CLASSIFIED BY MODE OF TRAVEL

Purpose of trip	Automobile-driver trips		Automobile-passenger trips		Taxi-passenger trips		Mass-transit passenger trips		All trips	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
Work	26.0	20.9	20.6	12.7	4.4	3.7	49.0	62.7	100.0	100.0
Ratio, 1955/1948	1.24	----	1.62	----	1.19	----	.78	----	----	----
Shop	19.0	11.1	14.3	10.4	5.1	3.9	61.6	74.6	100.0	100.0
Ratio, 1955/1948	1.71	----	1.38	----	1.31	----	.83	----	----	----
Other	47.3	30.1	17.3	17.1	5.9	6.6	29.5	46.2	100.0	100.0
Ratio, 1955/1948	1.57	----	1.01	----	.89	----	.64	----	----	----
All purposes	31.0	22.1	19.0	13.6	4.8	4.5	45.2	59.8	100.0	100.0
Ratio, 1955/1948	1.40	----	1.40	----	1.07	----	.76	----	----	----



LEGEND

PERCENTAGES ARE RANKED IN RELATION TO THE AVERAGE OF THE TOTAL STUDY AREA

PERCENTAGE OF TRIPS TO THE CBD-1948	RANK	PERCENTAGE OF TRIPS TO THE CBD-1955
46.9% OR MORE	40% OR MORE ABOVE AVERAGE	39.6% OR MORE
40.2% — 46.8%	20%-40% ABOVE AVERAGE	33.9% — 39.5%
33.5% — 40.1%	0%-20% ABOVE AVERAGE	28.3% — 33.8%
33.4%	AVERAGE FOR TOTAL STUDY AREA	28.2%
26.7% — 33.3%	0%-20% BELOW AVERAGE	22.6% — 28.1%
20.0% — 26.6%	20%-40% BELOW AVERAGE	16.9% — 22.5%
19.9% OR LESS	40% OR MORE BELOW AVERAGE	16.8% OR LESS
	NO TRIPS	
	★ 500 TRIPS OR LESS	

Figure 4. Percentage of intra-area work trips to the CBD by residents of each ring-sector.

by mass transit decreased from 94,543 to 79,441 (Table 2). However, the 1955 to 1948 change ratio indicated that mass-transit work trips had an index of 1.00. The decreasing use of mass transit for travel to work was a general trend throughout the study area and not particularly characteristic of only the work trips to the CBD. This same characteristic applied to shopping trips to the CBD by mass transit.

The increasing proportion of work trips to the CBD by automobile passengers indicated a greater use of car pools. In the Washington study area, mounting congestion, increased costs in driving and parking, and less convenient transit service in suburban areas have done much to encourage the forming of car pools by residents who must travel to the CBD day after day.

The volume of shopping trips within the study area increased 74 percent between 1948 and 1955 (110,160 to 192,217 trips). In contrast, the number destined to the CBD decreased 9 percent from 34,411 to 31,235 trips (Table 2). This decrease in the number of CBD shopping trips was reflected in the relative decline in the dollar volume of retail sales discussed earlier.

This decline in the volume of CBD shopping trips, however, does not so vividly illustrate the decreased importance of the CBD for shopping as does the comparison between 1948 and 1955 of the percentage of total area shopping trips destined to the CBD (31 percent in 1948 and 16 percent in 1955). This sizable decrease reflects the increasing development as well as the attraction of commercial concentrations outside the CBD.

The CBD shopping trip ratio of automobile passengers to that of automobile drivers decreased from an average of 94 passengers in 1948 to 75 passengers for every 100 automobile drivers in 1955. This was in contrast to the trend for work trips which increased from an average of 61 automobile passengers in 1948 to 79 for every 100 automobile drivers in 1955.

From these comparisons there is an indication of a decrease in the number of family trips made to the CBD for shopping. The physical layout and the facilities offered in the outlying shopping centers were more conducive to family shopping than those located in the CBD.

Since trips classified as "other" include a wide range of purposes, any comparisons of 1948 and 1955 data should be qualified. "Other" trips to the CBD increased 3 percent in 1955 over what they had been in 1948 (70,061 to 72,332). Compared to the 45 percent increase in the total intra-area trips for this group (Table 2), the increase in trips to the CBD was small.

As was also found for work and shopping trips, the proportion of "other" trips to the CBD had decreased relative to the total number of "other" residents trips. This comparison applies to an average of a group of purposes, and some purposes were above and some below this average.

Notable for "other" trips to the CBD was the comparatively large increase in the volume of automobile-driver trips (62 percent), whereas there was a comparatively slight increase in the volume of automobile-passenger trips (5 percent). As in shopping trips, group and family trips to the CBD compared with those made to other parts of the study area appeared to be relatively less, and those that were made by an individual (such as a visit to a doctor or a business trip) were apparently increasing. A separate geographical grouping of residents with a high degree of trip orientation was found for each of the three trip purposes studied (Figures 4-6). As indicated in Figure 4, the largest continuous area of residents with an above average work trip orientation was located in both study years within sectors 1,2, and 3. On the other hand, Figure 5 which shows the same information for shopping trips indicates that residents having an above average trip orientation for shopping were located within an entirely different geographical grouping. Hence, the degree of orientation varied between trip purposes within any one ring-sector.

Between 1948 and 1955 there was no major shifting of these geographical groupings of above-average orientation from one part of the study area to another, even though the percentage of trips destined to the CBD decreased for each purpose. There were, however, extensions of the relative rank of above-average orientation which had existed in 1948 among residents in ring-sectors closer to the CBD. In the case of shopping and "other" trips, no radial pattern of above-average orientation extended beyond a radius of 6 miles in 1955 as was the case for work trips.

MODES OF TRAVEL

The major change observed in residents choice of mode of travel to the CBD was the increased use of private automobiles and conversely the decreased use of mass transit (Table 3). The volume of automobile-driver and automobile-passenger trips to the CBD in 1955 had approximately the same percentage increase over that of 1948, 46 and 45 percent, respectively (Table 2). As has been pointed out, the increased proportion of automobile-passenger trips in the work category offset the lesser proportions in the other categories. The over-all average of the number of automobile passengers to the number of automobile drivers traveling to the CBD remained approximately the same, 61.5 automobile passengers to every 100 automobile drivers in 1948 and 61.3 in 1955.

The volume of taxi-passenger trips to the CBD by residents increased 11 percent, from 11,573 to 12,871 trips (Table 2).

There was a decrease in the percentage of trips destined to the CBD for each mode of travel. The mode of travel with the greatest relative change was automobile-driver trips, which had a change ratio of 0.79 (Table 2). Even though the volume of automobile-driver trips to the CBD increased 46 percent over the period 1948 to 1955, trips to places outside the CBD had increased by an even greater percentage (88 percent).

The trip purposes for each travel mode indicate two significant characteristics (Table 4). First, approximately one-half to two-thirds of the total volume of trips by each mode of travel in 1948 and 1955 were to work. Second, with the exception of automobile-driver trips, each of the modes of travel studied had a greater percentage

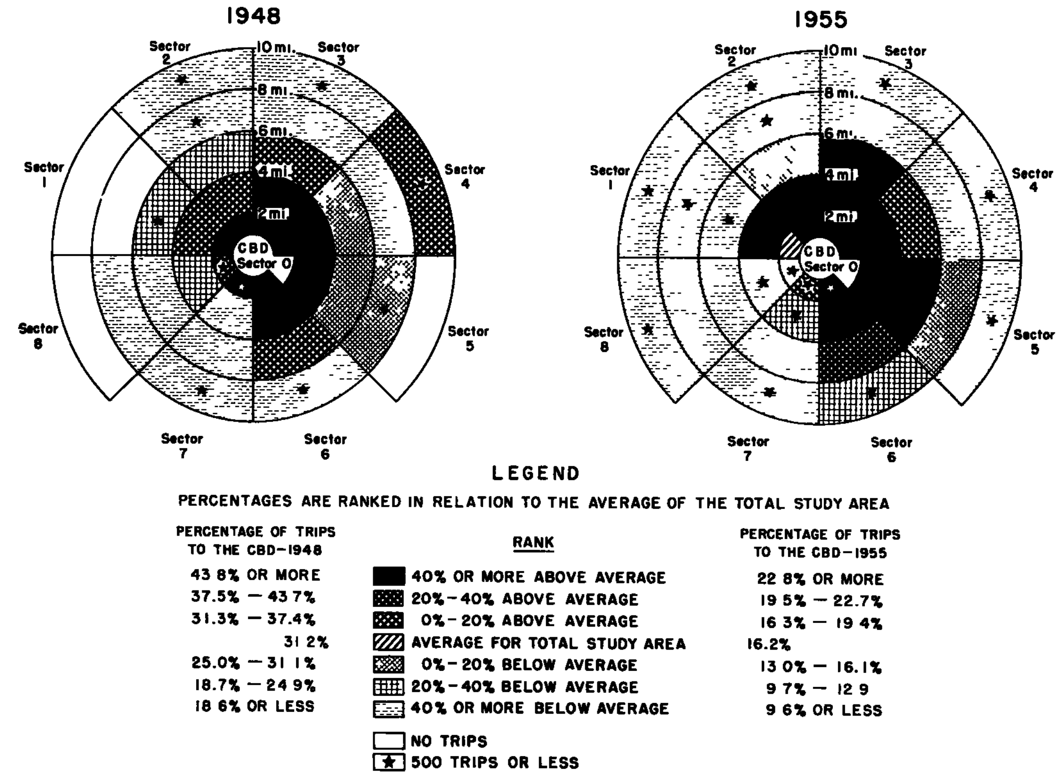


Figure 5. Percentage of intra-area shopping trips to the CBD by residents of each ring-sector.

of trips to work in 1955 and a smaller percentage for "other" purposes than was the case in 1948.

The increase in the percentage of automobile-driver trips made for "other" purposes reflects the increase of automobile ownership (61 cars per 100 dwelling units in 1948 and 79 in 1955). With the increased availability of an automobile as well as a general

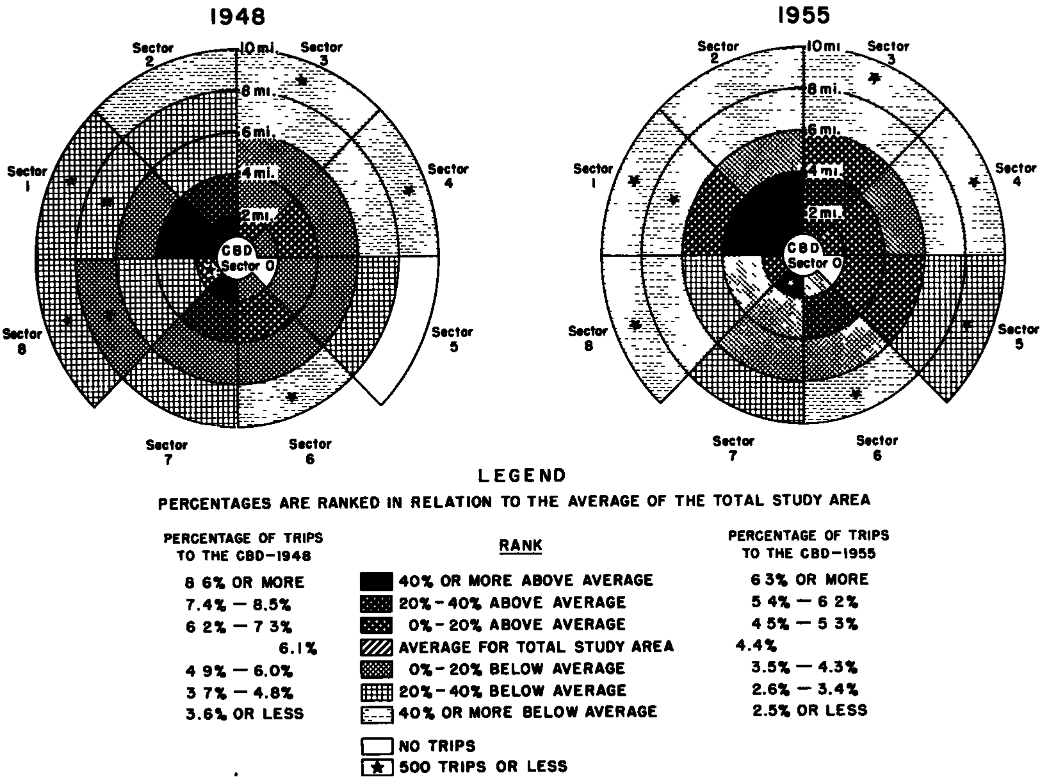


Figure 6. Percentage of intra-area "other" trips to the CBD by residents of each ring-sector.

TABLE 4

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT BY VARIOUS MODES OF TRAVEL IN 1948 AND 1955, CLASSIFIED BY PURPOSE

Mode of travel	Work trips		Shopping trips		Other trips		All trips	
	1955	1948	1955	1948	1955	1948	1955	1948
Automobile driver	51.2	55.9	7.2	6.8	41.6	37.3	100.0	100.0
Ratio, 1955/1948	.92	------	1.06	------	1.12	------	------	------
Automobile passenger	66.2	55.1	8 9	10.3	24.9	34.6	100.0	100.0
Ratio, 1955/1948	1.20	------	.86	------	.72	------	------	--- --
Taxi passenger	54.7	48.8	12.3	11.4	33.0	39.8	100 0	100.0
Ratio, 1955/1948	1.12	------	1.08	------	.83	------	------	------
Mass-transit passenger	66.2	62.0	16.0	16.8	17.8	21.2	100.0	100.0
Ratio, 1955/1948	1.07	------	.95	------	.84	------	------	------
All modes of travel	61.0	59.1	11.8	13.5	27.2	27.4	100.0	100.0
Ratio, 1955/1948	1.03	- ----	.87	------	.99	------	------	------

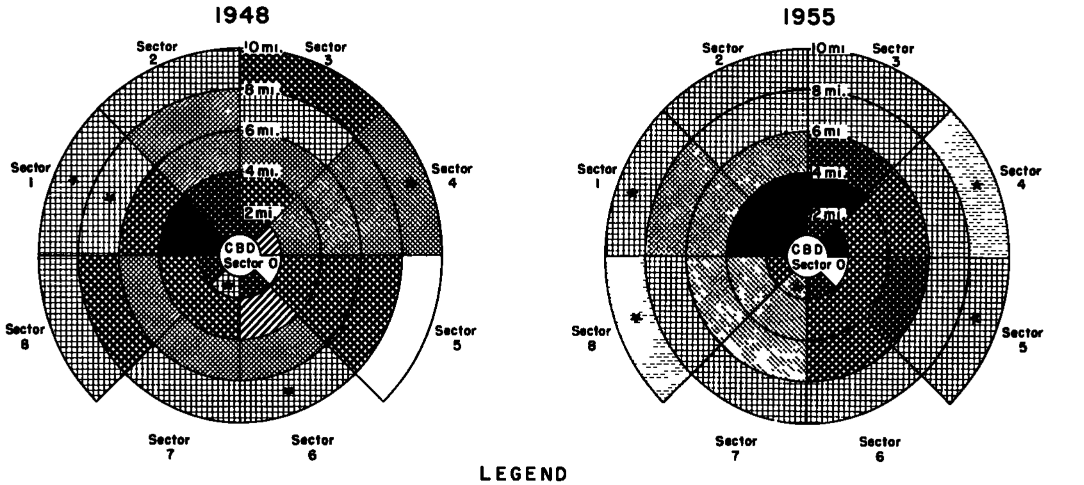
trend of an increase in the number of individuals licensed to drive, there was the tendency to drive to the luncheon engagement or to the night school in the CBD.

The degree of trip orientation that residents had in 1948 and 1955 indicated that there was a separate geographical grouping of ring-sector residents with above-average orientation for each of the modes used in traveling to the CBD (Figures 7-10). However, many of the radial patterns of above-average orientation, as seen in 1948 for each mode, were not so apparent in 1955. Residents beyond 6 miles showed a greater tendency to have a lower degree of trip orientation to the CBD in 1955 for each of the modes of travel than they had in 1948. Thus, the general relationship (rank) between ring-sector residents and the CBD, as related to the average percentage for each mode of travel, changed and a geographical regrouping took place rather than an extension of the relative rank of orientation, as in purpose of trip. The pattern in 1955 appeared to be more of a readjustment of travel, linked possibly with the growth of new centers of attraction outside the CBD as well as increased automobile ownership.

The percentage of total CBD trips made by residents of each ring-sector is illustrated in Figures 11 and 12. As is indicated, there were many changes between 1948 and 1955 in the relative distribution of residents trip purposes and the modes used to travel. These changes and others as they relate to distance and direction from the CBD are discussed in the sections that follow.

ANALYSIS OF DISTANCE FACTOR

The attitude of residents concerning distances from the central part of the city may change, even in so short a period as 7 years. A travel distance of 10 miles to the CBD in 1955 was not considered unusual, whereas in 1948 residents would have felt that the distance was too great. This changed attitude did not develop simultaneously in all directions from the CBD. Therefore, the averages used in discussing distance ring



LEGEND

PERCENTAGES ARE RANKED IN RELATION TO THE AVERAGE OF THE TOTAL STUDY AREA

PERCENTAGE OF TRIPS TO THE CBD—1948	RANK	PERCENTAGE OF TRIPS TO THE CBD—1955
12.7% OR MORE	40% OR MORE ABOVE AVERAGE	10 0% OR MORE
10 9% — 12 6%	20%-40% ABOVE AVERAGE	8 6% — 9.9%
9 1% — 10.8%	0%-20% ABOVE AVERAGE	7 2% — 8 5%
9 0%	AVERAGE FOR TOTAL STUDY AREA	7.1%
7 2% — 8.9%	0%-20% BELOW AVERAGE	5.7% — 7.0%
5 4% — 7.1%	20%-40% BELOW AVERAGE	4.3% — 5.6%
5 3% OR LESS	40% OR MORE BELOW AVERAGE	4.2% — OR LESS
	NO TRIPS	
	★ 500 TRIPS OR LESS	

Figure 7. Percentage of intra-area automobile driver trips to the CBD by residents of each ring-sector.

characteristics vary to a certain extent between sectors of a ring.

In this study of the effects of distance upon residents travel, several changes of a significant nature are apparent. The first, as seen in Table 5, is a decrease in the actual volume of trips to the CBD by residents within 4 miles of the CBD and an increase in the number of residents trips beyond this distance. Secondly, as brought out in Table 5, there was a decrease of approximately the same magnitude, 3 percent, in the proportion of trips destined to the CBD by residents of each of the rings.

TABLE 5

TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO PURPOSE AND DISTANCE OF RESIDENCE FROM THE CBD

Trip purpose comparisons	0 to 2 miles		2 to 4 miles		4 to 6 miles		6 to 8 miles		8 to 10 miles		Total area	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
Work trips												
Total intra-area trips	101,239	107,962	161,175	155,674	175,317	125,071	106,331	51,452	31,321	12,035	575,383	452,194
Trips to CBD	31,944	37,387	47,592	54,504	50,363	41,508	24,256	14,153	7,937	3,314	162,092	150,866
Percentage of trips to CBD	31 6	34 6	29 5	35 0	28 7	33 2	22 8	27 5	25 3	27 5	28 2	33 4
1955 percentage/1948 percentage	91	--------	84	--------	86	--------	83	--------	92	--------	84	--------
1955 trips to CBD/1948 trips to CBD	85	--------	87	--------	1 21	--------	1 71	--------	2 39	--------	1 07	--------
Shopping trips												
Total intra-area trips	16,557	13,599	30,452	31,674	66,744	42,297	52,801	18,483	19,663	4 107	192,217	110,160
Trips to CBD	7 545	8,936	10,062	12,040	9,725	9,907	3,337	2,847	566	681	31,235	34,411
Percentage of trips to CBD	45 6	65 7	27 6	38 0	14 6	23 4	6 3	15 4	2 9	16 6	16 2	31 2
1955 percentage/1948 percentage	69	--------	73	--------	62	--------	41	--------	17	--------	52	--------
1955 trips to CBD/1948 trips to CBD	84	--------	84	--------	98	--------	1 17	--------	83	--------	91	--------
Other trips												
Total intra-area trips	226,002	218,085	397,988	376,868	532,231	366,204	377,624	152,482	127,603	33,604	1,661,448	1,147,243
Trips to CBD	17,313	19,751	21,914	25,394	21,461	18,467	8,912	5,586	2,732	863	72,332	70,061
Percentage of trips to CBD	7 7	9 1	5 5	6 7	4 0	5 0	2 4	3 7	2 1	2 6	4 4	6 1
1955 percentage/1948 percentage	85	--------	82	--------	80	--------	65	--------	81	--------	72	--------
1955 trips to CBD/1948 trips to CBD	88	--------	86	--------	1 16	--------	1 60	--------	3 17	--------	1 03	--------
All purposes												
Total intra-area trips	343,798	339,646	595,615	564,216	774,292	533,572	536,756	222,417	178,587	49,746	2,429,048	1,709,597
Trips to CBD	56,802	66,074	79,568	91,938	81,549	69,882	36,505	22,586	11,235	4,868	265,659	255,338
Percentage of trips to CBD	16 5	19.5	13 4	16 3	10 5	13 1	6 8	10 2	6 3	9 8	10 9	14 9
1955 percentage/1948 percentage	85	--------	82	--------	80	--------	67	--------	.64	--------	73	--------
1955 trips to CBD/1948 trips to CBD	86	--------	87	--------	1 17	--------	1 62	--------	2 31	--------	1 04	--------

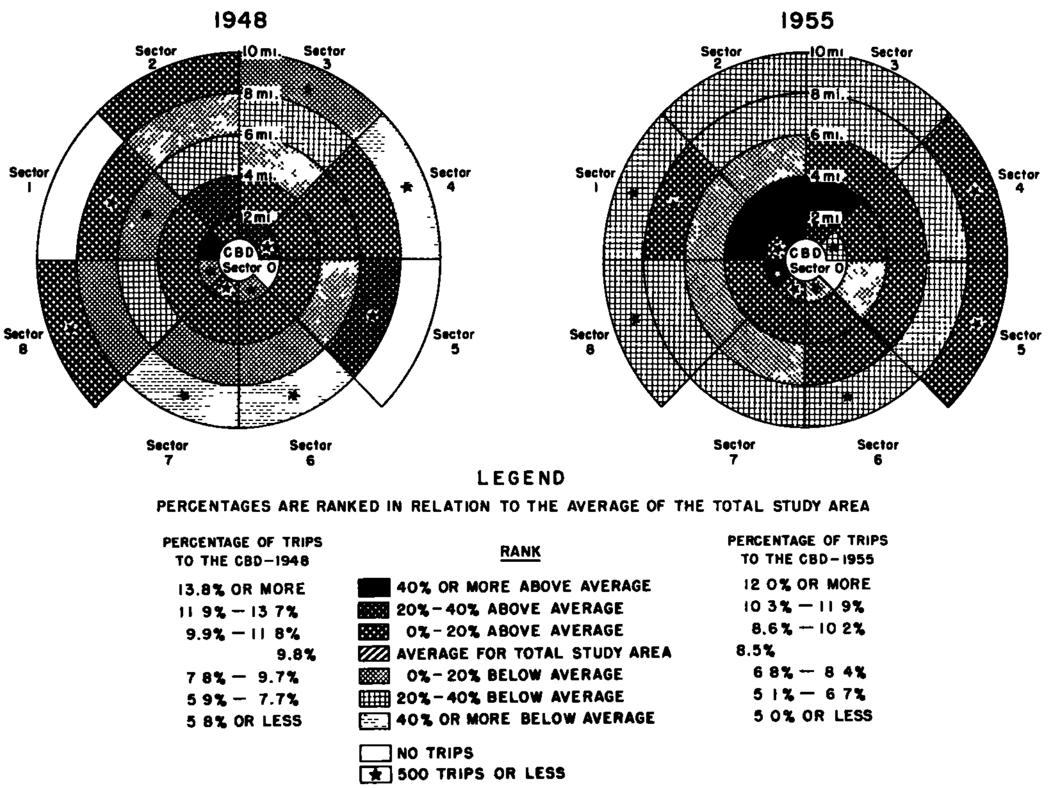
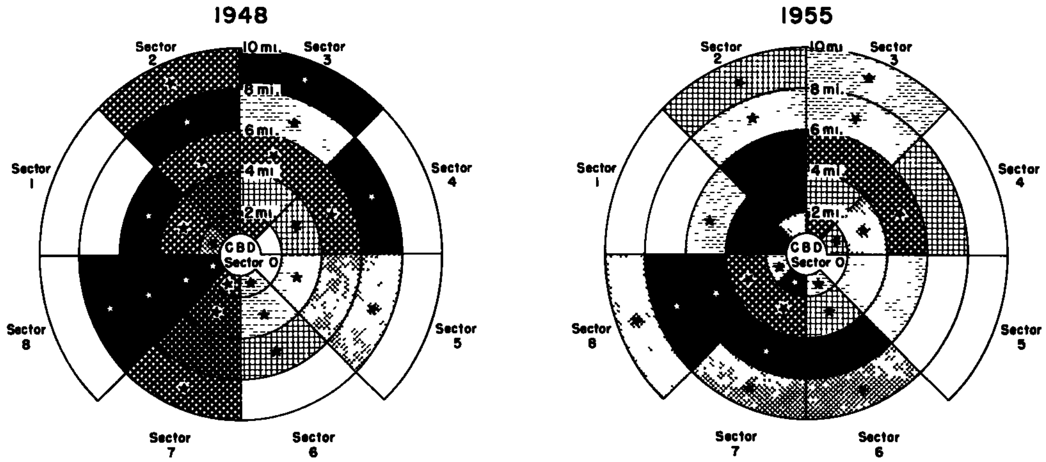


Figure 8. Percentage of intra-area automobile passenger trips to the CBD by residents of each ring-sector.

The pattern in which the percentage of trips destined to the CBD decreased was also significant (Table 5). In 1955 the percentage for each of the first three distance rings was approximately the same as the percentage for the next outer ring in 1948. For example, in 1955, residents within 2 miles of the CBD made 16.5 percent of their total trips to the CBD; this was approximately the same percentage as for residents within 2 to 4 miles of the CBD in 1948. If this trend were to continue for the following 7 years, the residents within 2 miles of the CBD in 1962 would make approximately the same percentage of trips to the CBD in residents 2 to 4 miles from the CBD made in 1955, or 13 percent; residents 2 to 4 miles and 4 to 6 miles from the CBD would make 10 and 6 percent, respectively, of their trips to the CBD in 1962. The percentage of trips to the CBD by residents 6 to 8 and 8 to 10 miles from the CBD did not fit the pattern of change just described. The percentage for both rings was approximately the same in each year. This similarity in the two outer rings, which are basically suburban, suggests that residents of suburban areas tend to have a more similar orientation to the CBD than urban areas closer to the CBD.

A significant factor in the distribution by distance of residents CBD trips was the leveling off which occurred between 2 to 4 miles and 4 to 6 miles of the CBD (Table 6 and Figure 13), a characteristic also observed in the distribution of dwelling units. In 1948, the major proportion of trips to the CBD were made by residents within 2 to 4 miles of the CBD. At that time, residents of this ring accounted for 91,938 or 36 percent of the total trips to the CBD. In 1955, however, the number of CBD trips made by residents within 2 to 4 miles had decreased and similar trips made by residents within 4 to 6 miles had increased. As a result, the number of trips from the two rings were about the same, 79,568 and 81,549, respectively.

This characteristic of residents trips to the CBD is important in estimating future trip distribution. Theoretically, it is altogether possible that total trips to the CBD made by residents of each of the five distance rings could approach, although not reach,



LEGEND

PERCENTAGES ARE RANKED IN RELATION TO THE AVERAGE OF THE TOTAL STUDY AREA

PERCENTAGE OF TRIPS TO THE CBD-1948	RANK	PERCENTAGE OF TRIPS TO THE CBD-1955
35.0% OR MORE	40% OR MORE ABOVE AVERAGE	31 2% OR MORE
30 0% — 34.9%	20%-40% ABOVE AVERAGE	26 7% — 31 1%
25.0% — 29 9%	0%-20% ABOVE AVERAGE	22 3% — 26 6%
24.9%	AVERAGE FOR TOTAL STUDY AREA	22.2%
19 9% — 24 8%	0%-20% BELOW AVERAGE	17 8% — 22.1%
14 9% — 19.8%	20%-40% BELOW AVERAGE	13 3% — 17.7%
14.8% OR LESS	40% OR MORE BELOW AVERAGE	13 2% OR LESS
	NO TRIPS	
	★ 500 TRIPS OR LESS	

Figure 9. Percentage of intra-area taxi passenger trips to the CBD by residents of each ring-sector.

a more uniform distribution. Over a period of time the level of trip distribution found between the 2- to 4- and 4- to 6-mile rings would just extend outward at a lower percentage level through the 6- to 8- and possibly the 8- to 10-mile rings. As the percentage of CBD trips by residents residing between 6 and 10 miles of the CBD increases, there will be a relative decrease in the percentage of the total CBD trips made by residents within 6 miles of the CBD.

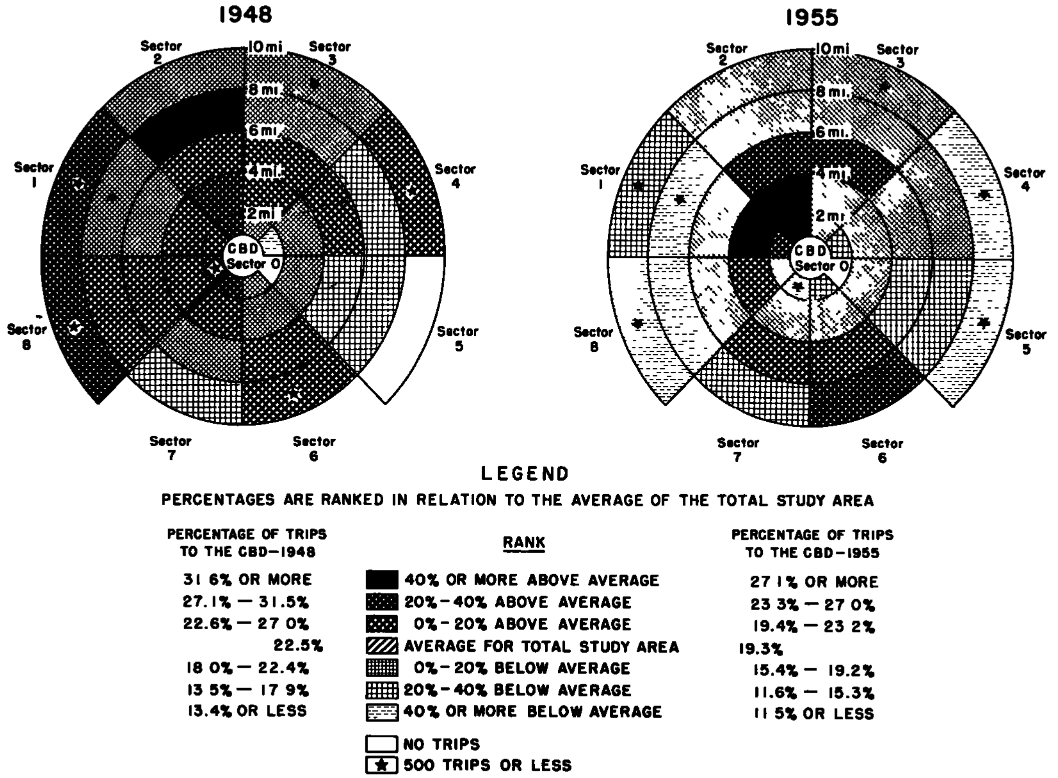


Figure 10. Percentage of intra-area mass-transit passenger trips to the CBD by residents of each ring-sector.

TABLE 6

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO PURPOSE AND DISTANCE OF RESIDENCE FROM THE CBD

Distances from CBD	Work trips		Shopping trips		Other trips		All purposes	
	1955	1948	1955	1948	1955	1948	1955	1948
0–2 miles	19.7	24.8	24.2	26.0	23.9	28.2	21.4	25.9
2–4 miles	29.3	36.1	32.2	35.0	30.3	36.2	30.0	36.0
4–6 miles	31.1	27.5	31.1	28.7	29.7	26.4	30.7	27.4
6–8 miles	15.0	9.4	10.7	8.3	12.3	8.0	13.7	8.8
8–10 miles	4.9	2.2	1.8	2.0	3.8	1.2	4.2	1.9
Total area	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Two observations support this possible trend in residents trip distribution. The first was the greater uniformity in the number of CBD trips per 100 dwelling units throughout the five distance rings in 1955 (Table 7); the range in the number of trips was from 44 to 61, or a difference of 17. In 1948, the range in the number of trips among distance rings was from 50 to 85, or a difference of 35.

The second observation has to do with the increase in the proportion of dwelling units located between 6 and 10 miles of the CBD (Table 1). In 1948, this area contained 15.5 percent of the total dwelling units within the study area; by 1955, the proportion had increased to 22.1 percent. Each consecutive ring circumscribed a much larger area than the preceding ring. Even though residential density per acre is progressively less

TABLE 7

NUMBER OF TRIPS PER 100 DWELLING UNITS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO PURPOSE AND DISTANCE OF RESIDENCE FROM THE CBD

Distances from CBD	Work trips		Shopping trips		Other trips		All purposes	
	1955	1948	1955	1948	1955	1948	1955	1948
0-2 miles	30.3	41.8	7.2	10.0	16.4	22.1	53.8	73.9
2-4 miles	34.6	50.2	7.3	11.1	15.9	23.4	57.8	84.7
4-6 miles	37.4	48.2	7.2	11.5	15.9	23.4	60.5	81.1
6-8 miles	29.2	33.3	4.0	6.7	10.7	13.1	44.0	53.1
8-10 miles	32.8	34.3	2.3	7.1	11.3	8.9	46.5	50.3
Average, total area	33.4	44.9	6.4	10.2	14.9	20.8	54.8	76.0

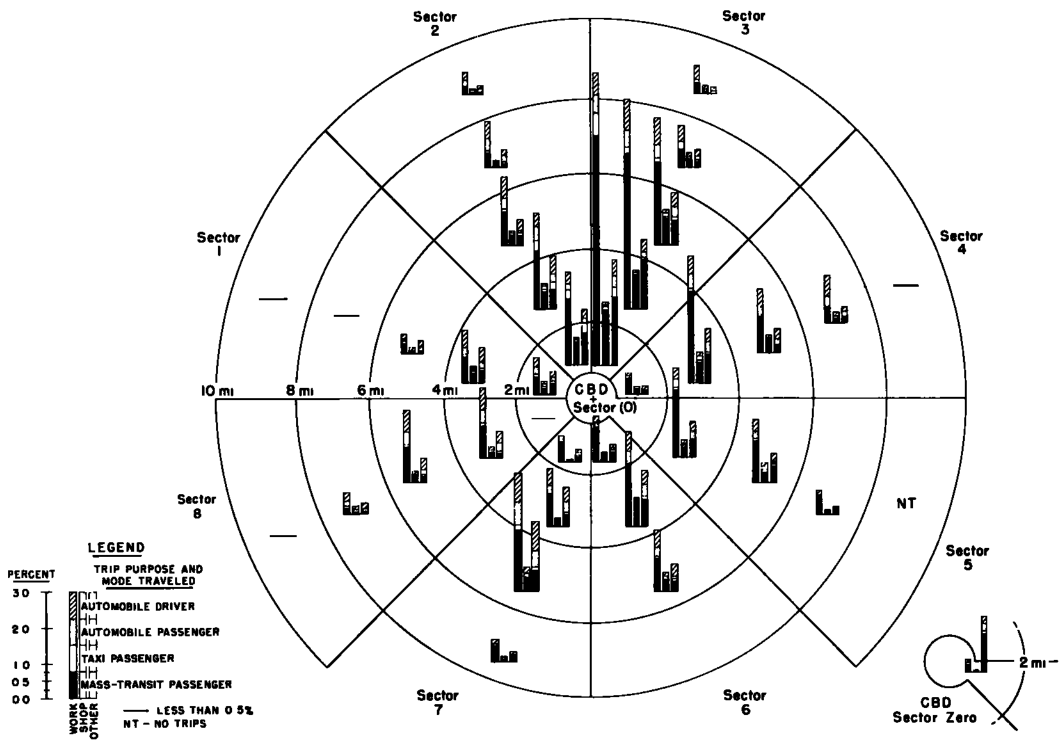


Figure 11. Relation of residents trips of each ring-sector to total area trips made to the central business district in 1948, according to purpose and mode of travel.

as distance from the CBD increases, the larger area of each consecutive ring permits a corresponding increase in the number of residences within each ring when fully developed. This has occurred in the 2- to 4- and 4- to 6-mile distance rings. In 1955, the densities within these rings were 22.3 and 10.2 dwelling units per acre, respectively, but the total number of residences for the 2 rings were nearly equal, 137,610 and 134,789.

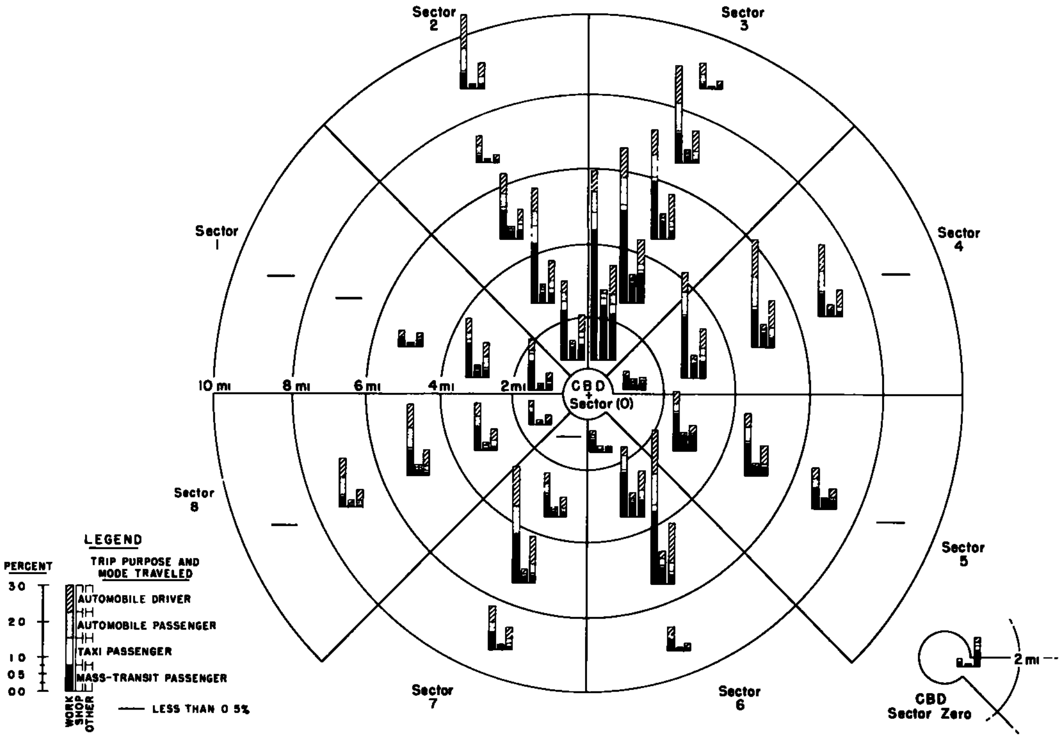


Figure 12. Relation of residents trips of each ring-sector to total area trips made to the central business district in 1955, according to purpose and mode of travel.

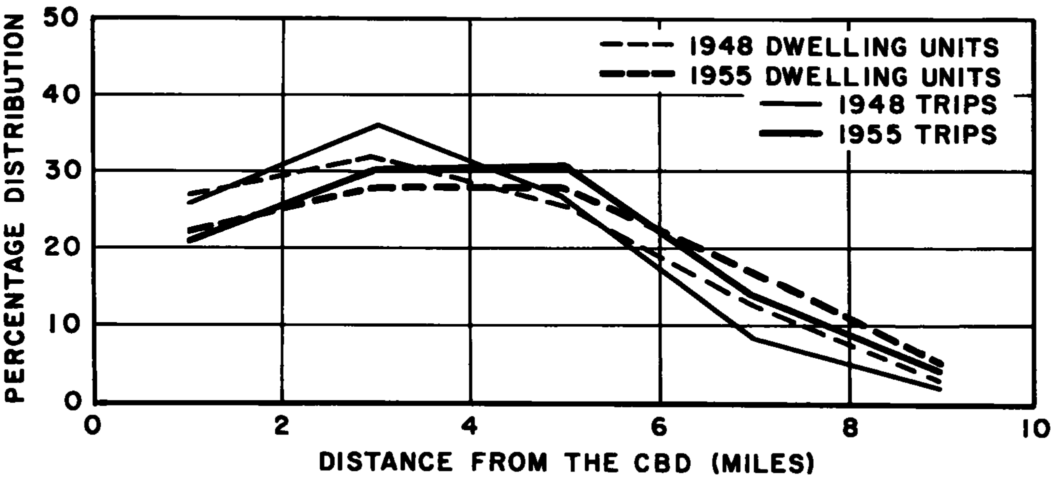


Figure 13. Percentage distribution of trips to the central business district of Washington, D.C., compared to that of dwelling units, by distance of residence from the CBD average weekday-1948 and 1955.

It there continues to be an increasing similarity in the frequency of CBD trips per 100 dwelling units, and if it is assumed that the residential development within 6 miles of the CBD will become more static as less land is available for new development, and the residential development between 6 and 10 miles of the CBD continues at a high rate of increase because of the open land available, then, theoretically, there would be a greater increase in the number of trips from the outer rings than from those closer to the city center. The percentage of total CBD trips by residents located between 6 and 10 miles of the CBD will increase, and this would cause a relative decrease in the proportion of total CBD trips made by residents within 6 miles of the CBD.

TRIP PURPOSES

Between 1948 and 1955, a change took place in the percentage distribution of residents trip purposes that was related to distance from the CBD (Table 8). In 1948 the proportion of residents trips to the CBD for work increased with distance from the CBD. The reverse was true of "other" trips. The proportion of trips for shopping, however, varied only slightly with distance; the difference between the nearest ring and the farthest ring from the CBD was only 0.5 percent.

The pattern of trip distribution in 1955 remained about the same as 1948 for work and "other" trips. In contrast, the percentage of CBD trips for shopping decreased with distance, from 13.3 percent within 2 miles of the CBD to 5.0 percent within 8 to 10 miles of the CBD. This comparison shows the effect of increased commercial development outside the CBD, especially in the suburban communities.

Work Trips

In 1955 there was no concentration of residents making work trips to the CBD in any single concentric distance ring as was the case in 1948. As shown in Table 6 for 1948, residents 2 to 4 miles from the CBD had made the largest proportion of the total work trips destined to the CBD (36.1 percent). By 1955, however, the percentage distribution had changed, and there was only a 2 percent difference between the proportion of trips made by the residents within 2 to 4 and 4 to 6 miles of the CBD (29.3 and 31.1 percent,

TABLE 8

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO TRIP PURPOSE OF MODE TRAVELED AND DISTANCE OF RESIDENCE FROM THE CBD

Mode of travel and trip purpose	0 to 2 miles		2 to 4 miles		4 to 6 miles		6 to 8 miles		8 to 10 miles		Total area	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
Automobile-driver trips to—												
Work	45.0	48.4	46.4	54.8	50.3	55.2	58.4	64.0	66.6	70.1	51.2	55.8
Ratio, 1955/1948	93	---	85	---	91	---	91	---	95	---	92	---
Shop	3.8	6.5	8.7	5.9	8.2	7.4	7.4	6.9	2.1	9.2	7.2	6.8
Ratio, 1955/1948	58	---	1.47	---	1.11	---	1.07	---	23	---	1.06	---
Other	51.2	45.1	44.9	39.3	41.5	37.4	34.2	29.1	31.3	20.7	41.6	37.4
Ratio, 1955/1948	1.14	---	1.14	---	1.11	---	1.18	---	1.51	---	1.11	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Automobile-passenger trips to—												
Work	54.5	51.6	63.0	52.7	68.0	56.8	72.8	61.2	75.0	56.2	66.2	55.1
Ratio, 1955/1948	1.06	---	1.20	---	1.20	---	1.19	---	1.33	---	1.20	---
Shop	12.0	6.1	8.7	10.3	9.4	11.7	7.3	9.6	5.3	20.1	8.9	10.3
Ratio, 1955/1948	1.97	---	84	---	80	---	76	---	26	---	86	---
Other	33.5	42.3	28.3	37.0	22.6	31.5	19.9	29.2	19.7	23.7	24.9	34.6
Ratio, 1955/1948	79	---	76	---	72	---	68	---	83	---	72	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Taxi-passenger trips to—												
Work	56.1	51.3	56.8	47.1	50.1	48.7	57.7	30.7	33.5	87.7	54.7	48.8
Ratio, 1955/1948	1.09	---	1.21	---	1.03	---	1.88	---	38	---	1.12	---
Shop	9.1	10.4	11.6	10.4	18.8	14.1	11.6	17.3	8.4	---	12.3	11.4
Ratio, 1955/1948	88	---	1.12	---	1.33	---	67	---	---	---	1.08	---
Other	34.8	38.3	31.6	42.5	31.1	37.2	30.7	52.0	58.1	12.3	33.0	39.8
Ratio, 1955/1948	91	---	74	---	84	---	59	---	4.72	---	83	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mass-transit passenger trips to—												
Work	60.0	59.0	65.9	63.0	70.3	63.0	73.2	64.3	76.0	74.2	66.2	62.0
Ratio, 1955/1948	1.02	---	1.05	---	1.12	---	1.14	---	1.02	---	1.07	---
Shop	17.0	15.9	16.1	16.3	16.1	18.5	13.4	18.4	11.1	17.7	16.0	16.8
Ratio, 1955/1948	1.07	---	99	---	87	---	73	---	63	---	95	---
Other	23.0	25.1	18.0	20.7	13.6	18.5	13.4	17.3	12.9	8.1	17.8	21.2
Ratio, 1955/1948	92	---	87	---	74	---	77	---	1.59	---	84	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All modes of travel to—												
Work	56.2	56.6	59.8	59.3	61.8	59.4	66.4	62.7	70.7	68.2	61.0	59.1
Ratio, 1955/1948	99	---	1.01	---	1.04	---	1.06	---	1.04	---	1.03	---
Shop	13.3	13.5	12.7	13.1	11.9	14.2	9.2	12.6	5.0	14.0	11.8	13.5
Ratio, 1955/1948	99	---	97	---	84	---	73	---	36	---	87	---
Other	30.5	29.9	27.5	27.6	26.3	26.4	24.4	24.7	24.3	17.8	27.2	27.4
Ratio, 1955/1948	1.02	---	1.00	---	1.00	---	99	---	1.37	---	99	---
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

respectively. The changes that occurred during the 7-year period are illustrated graphically in Figure 14. As work trips made up a major portion of the total CBD trips, it is apparent that residents work trips were an important factor in the leveling of the distribution curve.

In the future an increasing percentage of CBD work trips is expected to be made by residents of the outer rings, extending the plateau of percentage distribution at a lower percentage level over an even wider area than in 1955. As shown in Table 7, the range among distance rings for work trips destined to the CBD per 100 dwelling units was only half as great in 1955 as it was in 1948. If this range of difference were to be maintained or decreased even more, then those rings with the greatest future growth in residential

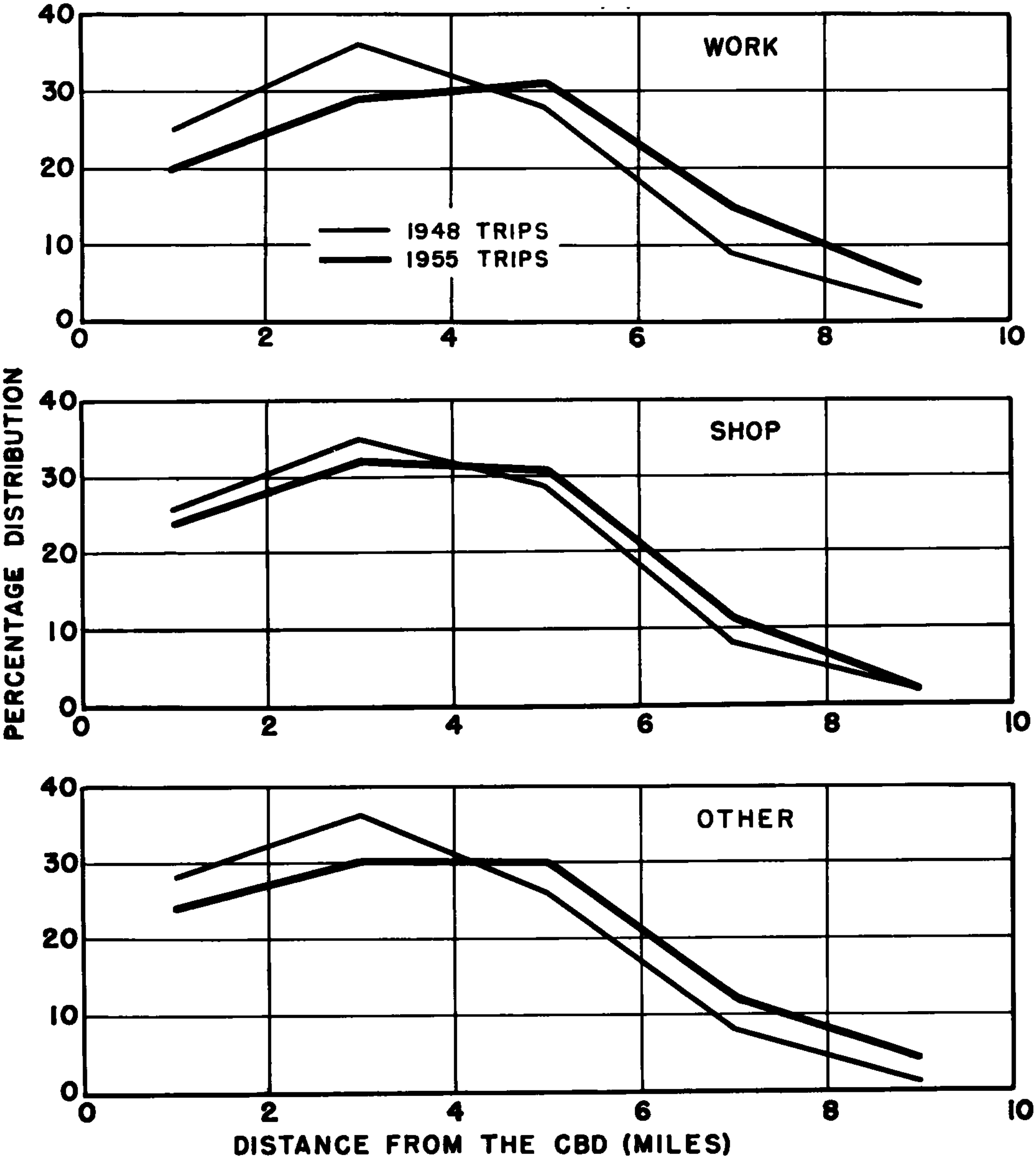


Figure 14. Percentage distribution of trips to the central business district of Washington, D.C., by purpose and distance of residence from the CBD average weekday-1948 and 1955.

development would tend to have the largest increases in residents work trips to the CBD.

On the basis of present day residential development, it is expected that the majority of future dwelling units will be constructed in the outer rings, thereby increasing the relative percentage of total work trips to the CBD from these areas. This is already apparent in the increased proportion of the total work trips made to the CBD by residents of the 6- to 8-mile ring. In 1948, residents of this ring made 9.4 percent of the CBD work trips as compared with 15.0 percent in 1955.

Although the volume of residents work trips destined to the CBD in 1955 decreased within 4 miles of the CBD and increased beyond this distance, the percentage made to the CBD by residents of each distance ring decreased (Table 5). It should be noted also that trips made by residents within 2 miles and within 8 to 10 miles of the CBD had approximately the same change ratio, 0.91 and 0.92, respectively. Because of distance, it would be expected that a greater decrease in residents trips would be found in the 8- to 10-mile ring than in the area between 2 and 8 miles.

The explanation of this relationship was found by examining the trips made by residents of sector 2 of the 8- to 10-mile ring. Residents of this sector, as will be mentioned later, had an above-average orientation of intra-area work trips that were destined to the CBD. Residents of this ring-sector also accounted for over one-half of the trips made by residents of this ring. Because of the small number of trips made by residents of the other sectors of this ring, residents of sector 2 greatly influenced the results for this ring. It is possible that as residential development increases in the other sectors of the 8- to 10-mile ring, that are less oriented to the CBD than sector 2, a change ratio more in line with the travel distance will occur.

Another change which took place during the 7-year period was the shift in mode of travel to work (Table 9). For both years, the general pattern was for the percentages of automobile-driver and automobile-passenger work trips to increase with distance from the CBD while the percentages of work trips made by taxi passengers and mass-transit passengers decreased with distance. However, in 1955, the most significant difference was the decreasing distance in which mass transit was the dominant mode used to travel to work. In 1948, residents within 6 miles of the central area made 50 percent or more of their work trips to the CBD by mass transit. In 1955 this percentage applied to a 4-mile radius.

TABLE 9

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL OF TRIP PURPOSE AND DISTANCE OF RESIDENCE FROM THE CBD

Trip purpose and mode of travel	0 to 2 miles		2 to 4 miles		4 to 6 miles		6 to 8 miles		8 to 10 miles		Total area	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
Work trips by												
Automobile drivers	14.7	10.3	20.5	19.4	29.8	25.7	38.0	35.1	44.3	44.4	26.0	20.9
Ratio, 1955/1948	1.43		1.06		1.16		1.08		1.00		1.24	
Automobile passengers	11.7	7.7	17.7	11.7	22.8	15.2	29.3	20.1	33.4	21.4	20.6	12.7
Ratio, 1955/1948	1.52		1.51		1.50		1.46		1.56		1.62	
Taxi passengers	8.8	6.5	4.9	3.2	3.0	2.8	1.4	1.3	.7	4.5	4.4	3.7
Ratio, 1955/1948	1.35		1.53		1.07		1.08		.16		1.19	
Mass-transit passengers	64.8	75.5	56.9	65.7	44.4	56.3	31.3	43.5	21.6	29.7	49.0	62.7
Ratio, 1955/1948	.86		.87		.79		.72		.73		.78	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Shopping trips by												
Automobile drivers	5.3	5.8	18.1	9.5	25.1	14.5	35.2	18.9	20.0	28.2	19.0	11.1
Ratio, 1955/1948	.91		1.91		1.73		1.86		.71		1.71	
Automobile passengers	10.9	3.8	11.6	10.4	16.3	13.0	21.3	15.7	33.4	37.3	14.3	10.4
Ratio, 1955/1948	2.87		1.12		1.25		1.36		.90		1.38	
Taxi passengers	6.0	5.5	4.8	3.2	5.8	3.4	2.0	3.7	2.3		5.1	3.9
Ratio, 1955/1948	1.09		1.50		1.71		.54				1.31	
Mass-transit passengers	77.8	84.9	65.5	76.9	52.8	69.1	41.5	61.7	44.3	34.5	61.6	74.6
Ratio, 1955/1948	.92		.85		.76		.67		1.28		.83	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Other trips by—												
Automobile drivers	30.8	18.2	43.0	29.9	57.8	39.2	60.6	40.4	60.5	50.4	47.3	30.1
Ratio, 1955/1948	1.69		1.44		1.47		1.50		1.20		1.57	
Automobile passengers	13.3	12.0	17.3	17.7	17.8	18.8	21.8	24.3	25.5	34.8	17.3	17.1
Ratio, 1955/1948	1.11		.98		.95		.90		.73		1.01	
Taxi passengers	10.1	9.1	6.0	6.2	4.3	4.8	2.0	5.8	3.3	2.4	5.9	6.6
Ratio, 1955/1948	1.10		.97		.90		.34		1.38		.89	
Mass-transit passengers	45.8	60.7	33.7	46.2	20.1	37.2	15.6	29.5	10.7	12.4	29.5	46.2
Ratio, 1955/1948	.75		.73		.54		.53		.86		.64	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All purposes by												
Automobile drivers	18.4	12.0	26.4	21.0	36.6	27.7	43.2	34.4	47.0	43.2	31.0	22.1
Ratio, 1955/1948	1.53		1.26		1.32		1.26		1.09		1.40	
Automobile passengers	12.1	8.5	16.9	13.2	20.7	15.8	26.7	20.6	31.5	26.0	19.0	13.6
Ratio, 1955/1948	1.42		1.28		1.31		1.30		1.21		1.40	
Taxi passengers	8.8	7.1	5.1	4.0	3.7	3.4	1.6	2.7	1.4	3.5	4.8	4.5
Ratio, 1955/1948	1.24		1.28		1.09		.59		.40		1.07	
Mass-transit passengers	60.7	72.4	51.6	61.8	39.0	53.1	28.5	42.3	20.1	27.3	45.2	59.8
Ratio, 1955/1948	.84		.83		.73		.67		.74		.76	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

It should be noted that the percentage of residents work trips made by mass transit in 1955 for any given distance ring was approximately the same as the percentage in 1948 for the next outer ring. For example, in 1955, residents within 2 miles of the CBD made 64.8 percent of their work trips by mass transit; in 1948 residents within 2 to 4 miles made approximately the same percentage, 65.7. This same relationship follows regardless of distance ring. If this same pattern were to continue in the 7 years following 1955, then by 1962 only the residents within 2 miles of the CBD would make over 50 percent of their work trips to the CBD by mass transit.

Shopping Trips

The percentage distribution of residents shopping trips to the CBD changed less between the five distance rings than the distribution of work or "other" trips, even though there was a decrease in the total volume of shopping trips to the CBD between 1948 and 1955. Of the relative changes that did take place, however, the most significant was the apparent leveling off of the peak of trip distribution within 2 to 4 miles of the CBD (Figure 14). Residents within 2 to 4 and 4 to 6 miles of the CBD in 1955 made 32.2 and 31.1 percent, respectively, of the shopping trips to the CBD (Table 6).

In the previous discussion of work trips it was mentioned that with growth in residential development beyond 6 miles of the CBD, the leveling of the distribution curve would likely extend over an even wider area than in 1955, and this would result in a more uniform distribution of residents work trips to the CBD. In the case of shopping trips, however, there is no basis for such speculation.

Between 1948 and 1955 the average number of daily shopping trips to the CBD per 100 dwelling units decreased in each of the 2-mile rings, and the percentage decrease became progressively greater with distance from the central area (Table 7). It is evident that residents, particularly those within the first three distance rings, were patronizing stores outside the CBD for many of their needs and relied on the CBD stores for shopping goods merchandise or for items where a greater selection was desired. In the case of the outlying communities (beyond 6 miles of the CBD), residents had ready access to major shopping areas which could supply practically all of their needs. Two department stores had a suburban branch in 1948, and these were relatively small in sales floor area. By 1955, one or more branches had been established by each of the large department stores and by many of the large specialty stores.

In 1948 the area between 6 and 10 miles of the CBD contained approximately 52,200 dwelling units and accounted for a total of 22,600 intra-area shopping trips; of this number, 3,500 were made to the CBD. By 1955 the number of dwelling units had increased to 107,200 and intra-area shopping trips had increased to 72,500; yet, of these trips, only 3,900 were to the CBD. The percentage of intra-area shopping trips destined to the CBD decreased during the 7-year period from 15.6 to 5.4 percent, a change ratio of 0.35.

Of the changes in mode of travel, the most significant was the decreased distance from the CBD in which mass transit accounted for one-half or more of residents shopping trips to the CBD (Table 9). In 1948 residents within 8 miles of the CBD used mass transit for more than half of their trips; in 1955, the same ratio applied only to residents within 6 miles.

Mass-transit passenger travel, although decreasing in the relative percentage of total shopping trips destined to the CBD, nevertheless accounted for about three-fourths of all shopping trips made to the CBD by residents within a 2-mile radius and two-thirds of such trips by residents within 2 to 4 miles of the CBD. These high percentages were maintained because of the large number of well distributed, converging transit lines which provided the more densely populated rings with convenient passenger service to the retail core of the CBD.

The only group to show an increase between 1948 and 1955 in the percentage of shopping trips by mass transit were residents of the 8- to 10- mile ring. This apparent inconsistency may be due to sample variability, as the total number of shopping trips to the downtown area by residents of this ring was relatively small, the calculated figure being 681 in 1948 and 566 in 1955. Since the sampling rate was 1 in 20 in this area in 1948 and 1 in 10 in 1955, the number of residents interviewed was only 34 in the first year and 56 in the second year. When broken down by mode of travel, therefore, the reliability of the data on mode of travel for this ring is not great.

Other Purpose Trips

The volume of CBD trips made for purposes other than to work or shop by residents within a 4-mile radius of the CBD decreased between 1948 and 1955. Beyond 4 miles, however, there was an increase in the number of such trips. The distribution pattern followed closely that of work and shopping trips (Table 6 and Figure 14).

Because of the diverse purposes included in the "other" category, it is difficult to do any more than speculate on the future position of the distribution curve. As a group, however, these trip purposes had several of the trend characteristics observed in the distribution of work trips. First, the range between the ring with the largest and the one with the smallest number of "other" trips to the CBD per 100 dwelling units decreased from 14 trips in 1948 to 6 in 1955 (Table 7), and second, residents beyond 6 miles were making an increasing proportion of total "other" trips to the CBD (Table 6).

With increased residential development in the outer rings and decreasing differences between rings in trips per dwelling unit, the distribution curve over a period of time might be expected to parallel that of work trips. In any discussion of future trends, the several purpose categories that make up "other" trips must be considered. Trips for purposes of social-recreation, eat meal, and business are not quite so rigid in their directional movement, and there is greater opportunity for choice of destination than there is for work trips.

The percentage of total intra-area "other" trips that were made to the CBD decreased for residents of each ring (Table 5). With the exception of trips made by residents 8 to 10 miles of the CBD, the percentage change indicated by the change ratio shown in Table 5 increased with distance. In the case of the residents within the 8- to 10-mile ring, the proportion of intra-area trips made to the CBD was already very small.

Within each ring the change in the distribution pattern of travel modes to the CBD for "other" purposes varied somewhat from that which was indicated for work and shopping purposes. In neither of the latter two purposes did any of the separate modes of travel other than mass-transit passenger have a percentage of residents trips to the CBD greater than 50 percent in any of the distance rings. Automobile-driver trips to the CBD, however, were the dominant mode of travel by residents 8 to 10 miles of the CBD in 1948, and this same characteristic applied to residents beyond 4 miles of the CBD in 1955.

It was previously noted that for working and shopping trips there was a reduction during the 7-year period in the area in which half or more of the CBD trips were made by mass transit. In the case of "other" purposes, only residents within 2 miles of the CBD

TABLE 10

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND DISTANCE OF RESIDENCE FROM THE CBD

Distances from CBD	Automobile driver		Automobile passenger		Taxi passenger		Mass-transit passenger	
	1955	1948	1955	1948	1955	1948	1955	1948
0–2 miles	12.6	14.1	13.6	16.2	39.0	40.6	28.8	31.3
2–4 miles	25.5	34.2	26.6	35.0	32.2	31.9	34.2	37.2
4–6 miles	36.3	34.8	33.5	31.8	23.2	20.6	26.5	24.3
6–8 miles	19.2	13.7	19.3	13.4	4.4	5.4	8.6	6.3
8–10 miles	6.4	3.7	7.0	3.6	1.2	1.5	1.9	.9
Total area	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

were in the 50 percent or more category in 1948. By 1955, the use of the private automobile had increased to the point that even residents at this distance made less than 50 percent of their total "other" purpose trips by mass transit.

MODES OF TRAVEL

In 1948 and 1955, the proportion of total residents trips to the CBD made by mass-transit passengers and taxi passengers decreased with distance from the CBD while those made by automobile drivers and automobile passengers increased (Table 9). The major change which did take place between 1948 and 1955 was a shift in the mode of travel. In 1955, there was a smaller percentage of total residents trips to the CBD in each ring that were made by mass-transit passengers, whereas the proportion of the CBD trips made by automobile drivers and automobile passengers increased.

In the subsequent discussion of taxi-passenger trips, it must be kept in mind that only residents taxi trips are included in this study. A very large proportion of taxi-passenger trips are made by nonresidents (transients and tourists).

Automobile Drivers

The percentage distribution of trips to the CBD, classified according to mode of travel and distance, is shown in Table 10 and Figure 15. There was approximately the same percentage of automobile-driver trips to the CBD made by residents 2 to 4 and 4 to 6 miles from the CBD in 1948, 34.2 percent and 34.3 percent, respectively. This similarity disappeared in 1955. Residents within 4 to 6 miles made by far the largest percentage of automobile-driver trips to the CBD, 36.3 percent.

Although residents of the 2- to 4-mile ring had a substantially smaller average number of automobile-driver trips to the CBD per 100 dwelling units in 1948 than that observed for residents of the 4- to 6-mile ring (Table 11), the 2- to 4-mile ring included more dwelling units. This offsetting factor accounted for the similar percentage of the total automobile-driver trips destined to the CBD by residents of these two rings in 1948.

In contrast, the 4- to 6-mile ring in 1955 contained approximately as many dwelling units as the 2- to 4-mile ring. This characteristic, plus the fact that in 1955 residents 4 to 6 miles from the CBD continued to make approximately the same number of automobile-driver trips to the CBD per 100 dwelling units as they did in 1948, while the number of trips per 100 dwelling units in the 2- to 4-mile ring decreased. These factors caused the change in the distribution pattern in 1955.

The general tendency in 1948 and 1955 was for the average number of automobile-driver trips to the CBD per 100 dwelling units to increase for the first few rings and then remain at about the same level beyond 6 miles of the CBD. With an increase in residential development in the outer two rings, the percentage distribution curve for automobile drivers might tend to flatten beyond 4 miles and possibly

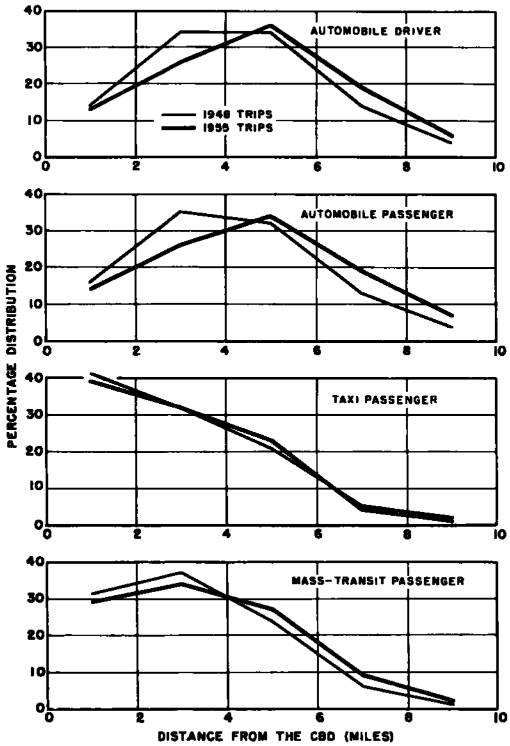


Figure 15. Percentage distribution of trips to the central business district of Washington, D.C. by mode of travel and distance of residence from the CBD average weekday-1948 and 1955.

extend over a greater distance than in 1948. This trend appeared to be taking place in 1955, as residents 6 to 8 and 8 to 10 miles from the CBD made one-fourth (25.6 percent) of the total automobile-driver trips to the CBD. This compares with 17.4 percent in 1948.

The relationship between distance and the proportion of intra-area automobile-driver trips destined to the CBD remained the same during the period between 1948 and 1955; as distance from the CBD increased, the percentage of total intra-area automobile-driver trips destined to the CBD decreased (Table 12). The percentage from each ring, however, was less in 1955 than in 1948.

The volume of automobile-driver trips to the CBD made by residents 6 to 8 miles from the CBD varies greatly for both years from those made by residents within 8 to 10 miles of the central area. Residents of both rings, however, made approximately the same percentage of their total intra-area automobile-driver trips to the CBD, 7.0 and 7.4 percent in 1948, and 5.1 and 5.0 percent in 1955.

With respect to the purposes for which residents made automobile-driver trips to the CBD, there was a general shift in the relative importance of work and "other" trips (Table 8). The proportion of residents automobile-driver trips destined to the CBD for "other" purposes increased in each ring between 1948 and 1955, while the percentage for work decreased. By 1955, the percentage for "other" purposes had increased in the first two rings so that it was the principal purpose for residents within a 2-mile radius and ranked second for residents in the 2- to 4-mile ring. Work trips remained the dominant purpose for residents beyond 4 miles of the central area.

Automobile Passengers

The distribution pattern of residents automobile-passenger trips to the CBD in 1948 and 1955 was similar to that of automobile-driver trips to the CBD (Table 10 and Figure 15). A comparison of the change ratio for automobile-driver and automobile-passenger trips (Table 12), however, shows that the proportion of residents automobile-passenger trips to the CBD changed less between 1948 and 1955 than did the proportion of automobile-driver trips.

The major difference in the purpose distribution was that automobile-passenger work trips had become even more common in 1955 than they had been in 1948. Residents beyond 2 miles of the CBD made 63 percent or more of their total automobile-passenger trips to the CBD in 1955 for purposes of work. In the area beyond 6 miles, approximately 3 out of 4 residents traveling to the CBD as automobile passengers went there to work. In 1948 only residents of the 6- to 8-mile ring made over 60 percent of their automobile-passenger trips to the CBD for this purpose.

TABLE 11

NUMBER OF TRIPS PER 100 DWELLING UNITS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND DISTANCE OF RESIDENCE FROM THE CBD

Distances from CBD	Automobile driver		Automobile passenger		Taxi passenger		Mass-transit passenger	
	1955	1948	1955	1948	1955	1948	1955	1948
0-2 miles	9.9	8 9	6 5	6 3	4.8	5.3	32 7	53 5
2-4 miles	15 2	17.8	9.7	11 2	3 0	3 4	29.8	52 3
4-6 miles	22 2	22 5	12.5	12.8	2.2	2.8	23.6	43.1
6-8 miles	19 0	18 2	11 8	10 9	7	1 5	12 5	22.5
8-10 miles	21.9	21.7	14 6	13.1	.6	1.8	9.3	13.7
Average, total area	17 0	16 8	10 4	10 3	2.7	3 4	24.7	45.4

TABLE 12

TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND DISTANCE OF RESIDENCE FROM THE CBD

Mode of travel comparisons	0 to 2 miles		2 to 4 miles		4 to 6 miles		6 to 8 miles		8 to 10 miles		Total area	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
Automobile driver trips												
Total intra-area trips	96,933	65,207	243,930	191,562	402,803	232,776	308,297	110,909	106,292	28,326	1,158,255	628,780
Trips to CBD	10,431	7,960	20,978	19,315	29,859	19,345	15,787	7,763	5,285	2,098	82,340	56,481
Percentage of trips to CBD	10 8	12 2	8 6	10 1	7 4	8 3	5 1	7 0	5 0	7 4	7 1	9 0
1955 percentage/1948 percentage	89	--------	85	--------	89	--------	73	--------	68	--------	79	------
1955 trips to CBD/1948 trips to CBD	1 31	--------	1 09	--------	1 54	--------	2 03	--------	2 52	--------	1 46	------
Automobile passenger trips												
Total intra-area trips	57,770	41,676	132,184	110,496	195,841	127,611	152 354	62,056	52,866	14,304	591 015	356,143
Trips to CBD	6,846	5,612	13,407	12,137	16,890	11,055	9,763	4,648	3,537	1,264	50,443	34,716
Percentage of trips to CBD	11 9	13 5	10 1	11 0	8 6	8 7	6 4	7 5	6 7	8 8	8 5	9 7
1955 percentage/1948 percentage	88	--------	92	--------	99	--------	85	--------	76	--------	88	------
1955 trips to CBD/1948 trips to CBD	1 22	--------	1 10	--------	1 53	--------	2 10	--------	2 80	--------	1 45	------
Taxi passenger trips												
Total intra-area trips	20,986	17,653	18,624	16,888	11,100	8,873	5,983	2,416	1,403	646	58,096	46,476
Trips to CBD	5,018	4,704	4,140	3,692	2 988	2,387	570	619	155	171	12 871	11,573
Percentage of trips to CBD	23 9	26 6	22 2	21 9	26 9	26 9	9 5	25 6	11 0	26 5	22 2	24 9
1955 percentage/1948 percentage	90	--------	1 01	--------	1 00	--------	37	--------	42	--------	89	------
1955 trips to CBD/1948 trips to CBD	1 07	--------	1 12	--------	1 25	--------	92	--------	91	--------	1 11	------
Mass-transit passenger trips												
Total intra-area trips	168,109	215,110	200,877	245,270	164,548	164,312	70,122	47,036	18,026	6,470	621,682	678,198
Trips to CBD	34,507	47,798	41,043	56,794	31,812	37,095	10,385	9,556	2,258	1,325	120,005	152,568
Percentage of trips to CBD	20 5	22 2	20 4	23 2	19 3	22 6	14 8	20 3	12 5	20 5	19 3	22 5
1955 percentage/1948 percentage	92	--------	.88	--------	85	--------	73	--------	61	--------	86	------
1955 trips to CBD/1948 trips to CBD	72	--------	72	--------	.86	--------	1 09	--------	1 70	--------	.79	------

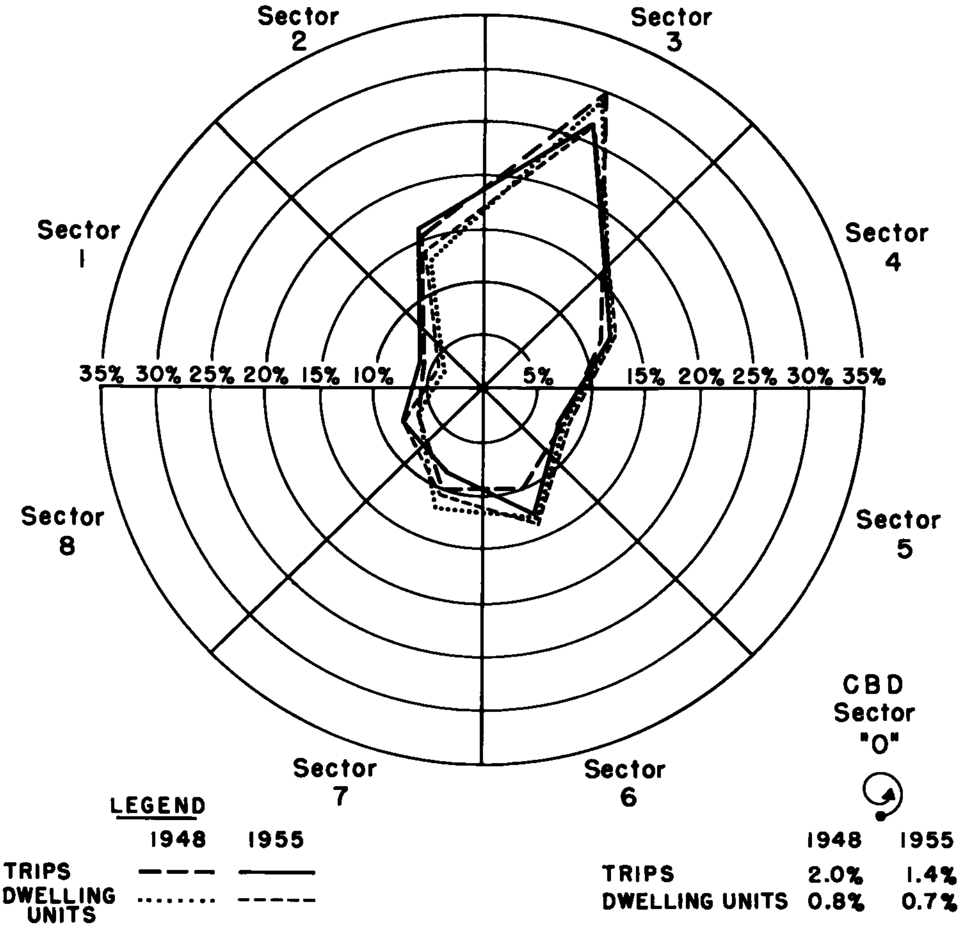


Figure 16. Percentage distribution of trips to the central business district of Washington, D.C. compared to that of dwelling units, by sectors of residence average weekday-1948 and 1955.

Taxi Passengers

In comparison with other modes of travel, the percentage distribution of residents taxi-passenger trips made to the CBD changed only slightly between 1948 and 1955 (Table 10 and Figure 15). The largest percentage of reported taxi-passenger trips to the CBD were made by residents living closest to the CBD; those living within 4 miles made 72.5 percent of the total taxi trips to the CBD in 1948 and 71.2 percent in 1955.

The number of taxi-passenger trips to the CBD per 100 dwelling units was less in each distance ring in 1955 than it had been in 1948 (Table 11), and in 1955 the number of trips per 100 dwelling units decreased with distance from the CBD. Because of this relationship, residential development beyond 4 miles of the CBD should have little effect on the percentage distribution of taxi-passenger trips to the CBD in the future.

Of significance was the change which occurred in the proportion of taxi-passenger trips made to the CBD by residents beyond 6 miles of the CBD (Table 12). Although there were relatively few taxi-passenger trips made to the CBD by residents 6 to 8 and 8 to 10 miles from the central area, residents of both rings more than doubled the number of trips in the 7-year period. The percentage of total area trips going to the CBD, however, decreased. As indicated by the change ratio given in Table 12, this decrease in percentage between 1948 and 1955 for the outer two rings was in sharp contrast to the percentage change for the first three rings.

Apparently the purposes for which taxi-passenger trips were made were less influenced by distance from the CBD than they were by other characteristics peculiar to the residents of the ring (Table 8). The erratic nature of the percentages for the 8- to 10-mile ring is probably due to the small sample of taxi-passenger trips.

One trend in the purpose distribution was apparent in that the percentage of residents taxi-passenger trips to work increased in all but the 8- to 10-mile ring. By 1955, 50 percent or more of the taxi-passenger trips made to the CBD by residents within 8 miles of the CBD were for the purpose of work.

Mass-Transit Passengers

Of the four modes of travel studied, mass-transit passenger travel was the only mode that decreased in the over-all volume of trips destined to the CBD. The residents accounting for this decrease lived within a 6-mile radius of the central area (Table 12). Residents within this area still accounted for 92.8 percent of the mass-transit passenger trips destined to the CBD in 1948 and 89.5 percent in 1955 (Table 10 and Figure 15).

The decrease in the number of mass-transit passenger trips to the CBD per 100 dwelling units which occurred in each ring was equally significant (Table 11). Since the

TABLE 13

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO PURPOSE AND SECTOR OF RESIDENCE

Sectors	Work trips		Shopping trips		Other trips		All purposes	
	1955	1948	1955	1948	1955	1948	1955	1948
0	0.3	0.6	0.5	0.3	4.2	5.8	1.4	2.0
1	6.5	5.4	5.6	6.6	7.4	7.6	6.6	6.1
2	16.7	15.2	14.3	16.9	15.9	16.3	16.2	15.7
3	27.1	32.2	30.0	30.7	24.5	25.0	26.7	30.0
4	12.4	11.8	13.5	13.7	12.0	10.0	12.4	11.6
5	7.1	8.3	9.4	7.8	7.6	7.3	7.5	8.0
6	12.0	9.8	16.0	12.1	12.0	10.3	12.5	10.2
7	8.9	9.5	6.1	7.5	8.9	11 8	8.6	9.9
8	9 0	7.2	4.6	4.4	7 5	5 9	8.1	6.5
Total area	100.0	100.0	100.0	100 0	100.0	100.0	100.0	100.0

number of trips per dwelling unit by automobile driver, automobile passenger, and taxi passenger changed only slightly, trips by mass transit accounted for the major proportion of the decrease within each ring. When residents changed their mode of travel to the CBD, it was usually a change from mass-transit to one of the other modes.

In both years, as distance from the CBD increased, there was a progressive decrease in the number of mass transit passenger trips per dwelling unit. This was in contrast to automobile-driver and automobile-passenger trips (Table 11).

A change did occur in the relationship of distance and the percentage of residents intra-area mass-transit passenger trips destined to the CBD (Table 12). In 1948, about the same proportion of CBD trips to total area trips was found for each 2-mile ring. By 1955, however, the proportion of residents mass-transit passenger trips destined to the CBD was progressively smaller with increased distance.

Work trips in both years accounted for the major proportion of mass-transit passenger trips to the CBD (Table 8), and the proportion increased for each ring between 1948 and 1955. In contrast, the proportion of mass-transit shopping trips to the CBD decreased for each ring except for the area closest to the CBD.

ANALYSIS OF DIRECTION FACTOR

The sector subdivisions used in this study are much like a watershed of a stream. In general, along these sector divisions flow the major inbound and outbound CBD traffic. As a result, the radial patterns of traffic provide still another means, besides distance, in analyzing the characteristics of travel to the CBD.

In the study of sectors, a different approach is taken from that used in the study of rings. The variation in distances from the CBD was the major criterion for interpreting much of the information in the ring analysis. In the study of sectors, the radial growth and distribution of population, socioeconomic characteristics and historical trends come into play in influencing the patterns that develop and the changes which take place. It has been said that "... the different types of residential areas tend to grow outward along rather distinct radii, and new growth on the arc of a given sector tends to take on the character of the initial growth in that sector...."[5]

Although there was a shifting between sectors, there were no major changes in the over-all pattern of residents CBD trip distribution by sectors as there had been by 2-mile rings (Table 13). The percentage of trips to the CBD from 7 of the 9 sectors varied no more than ± 1.6 percentage points from what it had been in 1948, and even though the percentage of CBD trips made by residents of sector 3 decreased slightly due to the relative increases in the other sectors, the major peak in residents trip distribution remained in sector 3.

This pattern of distribution and the relative changes which took place between the two years are very similar to that which occurred for population and dwelling units, and it suggests a close relationship between the distribution of residents trips to the CBD and the distribution of residential development (Figure 16). It did not necessarily follow, however, that residents of a sector with a large number of trips to the CBD per dwelling unit also made a large percentage of all residents CBD trips (Tables 13 and 14). It was not only the number of trips per dwelling unit that affected the pattern of distribution, but also the amount of residential development.

A change did appear to be taking place in the travel pattern of certain groups of contiguous sectors, which in 1948 had practically the same percentage of total trips destined to the CBD (Table 15). In 1948 the percentage of CBD trips made by residents of sectors 1, 2, and 3 ranged from 16.0 to 16.4 percent; that by residents of sectors 4, 5, and 6 ranged from 13.5 to 14.3 percent; and that by residents of sectors 7 and 8 ranged from 12.3 to 12.5 percent. By 1955, all the percentages had decreased, and the decrease was such that the range between percentages for these sector groups was somewhat larger than in 1948.

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[5] The Structure and Growth of Residential Neighborhoods in American Cities. Federal Housing Administration, Washington, D.C., 1939, p. 114.

TABLE 14

NUMBER OF TRIPS PER 100 DWELLING UNITS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO PURPOSE AND SECTOR OF RESIDENCE

Sectors	Work trips		Shopping trips		Other trips		All purposes	
	1955	1948	1955	1948	1955	1948	1955	1948
0	15.4	32.9	4.9	4 0	91 9	148 0	112 2	184 9
1	47 5	61 1	7.8	17.3	24.1	40.3	79 4	118.8
2	40 2	51 3	6 7	13.0	17.1	25.6	64 1	89.9
3	34.2	49.4	7.3	10.7	13.8	17.8	55.3	77.9
4	31 5	41.6	6 6	11.0	13 6	16.3	51.8	68.9
5	27.3	45 3	7 0	9.6	13.1	18 3	47 4	73.3
6	29 3	33 4	7.5	9 4	13.1	16 3	49 9	59.1
7	27.7	35 8	3 7	6 5	12.4	20 7	43 8	62.9
8	36.7	48 9	3.6	6.7	13.6	18 6	53.9	74.3
Average, total area	33 4	44 9	6.4	10 2	14.9	20.8	54.8	76.0

It is difficult to say whether these differences between the 1948 and 1955 pattern were due to a trend that was taking place or to chance. If, however, these differences persist or increase, they may indicate a breaking up of the groups and the beginning of new sector groupings with a similar orientation of intra-area trips destined to the CBD.

TRIP PURPOSES

The change in the percentage distribution of CBD trip purposes varied from sector to sector (Table 16). The over-all trend, however, was one of decreasing differences between sectors in the proportion of residents trips for work and "other" purposes. Excluding trips made by residents of sector zero, the range between the highest and the lowest percentage of CBD work trips decreased from 14.4 percent in 1948 to 10.6 percent in 1955. More striking was the decrease in the range for "other" trips, 11.1 to 5.4 percent.

Shopping trips, on the other hand, increased slightly in the percentage range among sectors. The spread among the percentages in 1948 was 6.9 percent, and in 1955 it was 8.4 percent. This characteristic of shopping trips can be attributed to the unbalanced development of commercial facilities among the sectors. An example of this is indicated by the distribution of trip purposes for residents of sectors 5 and 6. The area included by these sectors had a relatively sparse development of major commercial activity in relation to residential growth prior to the 1948 study, and comparatively few shopping concentrations had been added by 1955. The result, as indicated in Table 16, was that residents of these sectors maintained a higher percentage of their trips to the CBD for purposes of shopping than did the residents of the other sectors.

Work Trips

The 1955 distribution pattern among the sectors of residents work trips to the CBD varied no more than ± 2.2 percentage points in all sectors, except sector 3, from the corresponding percentage in 1948 (Table 13 and Figure 17). Although the percentage made by residents of sector 3 decreased, the large number of residents of this sector still accounted for the major peak in the pattern of work trip distribution (32.2 percent in 1948 and 27.1 percent in 1955).

Figure 18 shows the relationship between the number of CBD work trips per 100 dwelling units of a sector in 1948 and 1955 and the number of employment opportunities per 100 dwelling units in that sector. With some exceptions, the general trend in each of the years was for the number of CBD work trips per 100 dwelling units to decrease as the number of employment opportunities per 100 dwelling units in a given sector increased. Employees tend to work at locations closer to their place of residence if there is an opportunity to do so, or conversely, they tend to live in the vicinity of their work.

In comparing the positions of the plotted symbols in Figure 18 for the two years, it is seen that for a given sector the plotted symbols for 1955 fall to the left of those for 1948, except in the case of sector 7. The reason for this relation is that the rate of residential development in each of the sectors except sector 7 exceeded the rate of growth in employment opportunities in the corresponding sector.

The percentage of residents intra-area work trips destined to the CBD decreased in all sectors with the exception of sector 1 (Table 15). The amount of decrease varied with each sector, resulting in a new geographic relationship between sectors 1 through 5. Beginning with sector 1 and following around the central area through sector 5, it is apparent that there was a continual decrease between sectors in the proportion of 1955 intra-area work trips destined to the CBD. Although there are exceptions, this transition appears to be one from sectors with high average family incomes and with a large proportion of professional and white-collar employees to one of lower average family incomes and a large proportion of blue-collar employees. Thus, there is an indirect inference that an increasing number of employment opportunities were afforded blue-collar employees outside the CBD in 1955.

The increase in automobile ownership caused a decline in the proportion of mass-transit work trips made by sector residents (Tables 17 and 18). For example, in both 1948 and 1955 the average number of automobiles owned per 100 dwelling units by residents of sectors 0, 3, 5, and 6 was below the study area average. On the other hand, the percentage of work trips by mass transit for residents of each of these sectors was well above the average. As the number of automobiles owned per dwelling unit increased between 1948 and 1955 in all sectors, except sector zero, there was a decrease, with the exception of sectors 0 and 1, in the proportion of work trips by mass transit and a corrsponding increase in those by automobile.

TAB

TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND
RESI

Trip purpose comparisons	Sector 0		Sector 1		Sector 2		Sector 3	
	1955	1948	1955	1948	1955	1948	1955	1948
Work trips:								
Total intra-area trips	1,662	2,127	27,354	21,940	73,913	54,815	150,090	135,349
Trips to CBD	511	911	10,581	8,071	27,075	22,952	43,895	48,609
Percentage of trips to the CBD	30.7	42.8	38.7	36.8	36.6	41.9	29.2	35.9
1955 percentage/1948 percentage	.72	-------	1.05	-------	.87	-------	.81	-------
1955 trips to CBD/1948 trips to CBD	.56	-------	1.31	-------	1.18	-------	.90	-------
Shopping trips:								
Total intra-area trips	544	156	12,242	7,287	31,426	20,334	36,848	24,597
Trips to CBD	163	112	1,745	2,289	4,476	5,816	9,354	10,570
Percentage of trips to the CBD	30.0	71.8	14.3	31.4	14.2	28.6	25.4	43.0
1955 percentage/1948 percentage	.42	-------	.46	-------	.50	-------	.59	-------
1955 trips to CBD/1948 trips to CBD	1.46	-------	.76	-------	.77	-------	.88	-------
Other trips:								
Total intra-area trips	4,172	5,490	93,861	66,189	255,963	176,614	377,695	314,107
Trips to CBD	3,054	4,094	5,365	5,321	11,531	11,427	17,691	17,524
Percentage of trips to the CBD	73.2	74.6	5.7	8.0	4.5	6.5	4.7	5.6
1955 percentage/1948 percentage	.98	-------	.71	-------	.69	-------	.84	-------
1955 trips to CBD/1948 trips to CBD	.75	-------	1.01	-------	1.01	-------	1.01	-------
All purposes:								
Total intra-area trips	6,378	7,773	133,457	95,416	361,302	251,763	564,633	474,053
Trips to CBD	3,728	5,117	17,691	15,681	43,082	40,195	70,940	76,703
Percentage of trips to the CBD	58.5	65.8	13.3	16.4	11.9	16.0	12.6	16.2
1955 percentage/1948 percentage	.89	-------	.81	-------	.74	-------	.78	-------
1955 trips to CBD/1948 trips to CBD	.73	-------	1.13	-------	1.07	-------	.92	-------

Shopping Trips

The distribution pattern of sector residents shopping trips to the CBD in 1955 did not change materially from that in 1948 (Table 13 and Figure 17); six of the sectors had a change within ±1.5 percentage points. The largest relative change, an approximate 4 percent increase, took place in sector 6, and was caused by a population increase of approximately 53,000 persons, the second largest increase in the study area. The residents of sector 6 were not served as adequately by major suburban shopping facilities as were other sectors. With few new commercial developments in this sector between 1948 and 1955, and with the large increase in population, there was an increase in the number of CBD trips.

The number of commercial concentrations increased in the various sectors, and thus contributed in part to the decrease in the number of shopping trips per dwelling unit. The increasing uniformity of CBD shopping trips by sector residents illustrates, however, that the central area continued to offer certain shopping advantages that were not satisfied elsewhere (Table 14). If residents trips of sectors 0, 7, and 8 are excluded, the range between the sector with the greatest number of shopping trips per dwelling unit and the sector with the least number was only 1.2 trips. In 1948 the range was 7.9 trips.

Although the actual volume of intra-area shopping trips increased between 1948 and 1955, it is apparent from the change ratio (Table 15) that the orientation of these trips by residents of each sector had changed significantly. The percentage of intra-area shopping trips to the CBD in 1955 decreased by one-third for residents in all sectors, and for residents in six of the sectors the percentage decreased by one-half or more.

Shopping trips for the two years by residents of sector 8 illustrate an extreme of this decreasing percentage of intra-area trips to the CBD. This sector is relatively more suburban in character than many of the other sectors at similar distances from the CBD. In 1948, 1,497 or 15.6 percent of 9,586 shopping trips by residents of sector

LE 15

1955, CLASSIFIED ACCORDING TO PURPOSE AND SECTOR OF
DENCE

Sector 4		Sector 5		Sector 6		Sector 7		Sector 8		Total area	
1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
85,549	66,587	51,641	40,752	72,810	51,684	58,006	45,624	54,358	33,316	575,383	452,194
20,067	17,842	11,426	12,560	19,520	14,744	14,393	14,310	14,624	10,867	162,092	150,866
23.5	26.8	21.1	30.8	26.8	28.5	24.8	31.4	26.9	32.6	26.2	33.4
.88	-------	.72	-------	.94	---- --	.79	-------	.83	-------	.84	----------
1.12	-------	.91	-------	1.32	-------	1.01	-------	1.35	-------	1.07	----------
23,936	13,302	12,852	7,631	19,675	10,242	25,213	17,025	29,481	9,586	192,217	110,160
4,223	4,723	2,947	2,665	4,995	4,152	1,913	2,587	1,419	1,497	31,235	34,411
17.6	35.5	22.9	34.9	25.4	40.5	7.6	15.2	4.8	15.6	16.2	31.2
.50	-------	.66	-------	.63	-------	.50	-------	.31	-------	.52	----------
.89	-------	1.11	-------	1.20	-------	.74	-------	.95	-------	.91	----------
238,828	139,503	131,616	93,144	197,096	122,839	178,191	138,605	184,026	90,752	1,661,448	1,147,243
8,683	7,009	5,463	5,083	8,704	7,187	6,429	8,287	5,412	4,129	72,332	70,061
3.6	5.0	4.2	5.5	4.4	5.9	3.6	6.0	2.9	4.5	4.4	6.1
.72	-------	.75	-------	.75	-------	.60	-------	.64	-------	.72	----------
1.24	-------	1.07	-------	1.21	-------	.78	-------	1.31	-------	1.03	----------
348,313	219,392	196,109	141,527	289,581	184,765	261,410	201,254	267,865	133,654	2,429,048	1,709,597
32,973	29,574	19,836	20,308	33,219	26,083	22,735	25,184	21,455	16,493	265,659	255,338
9.5	13.5	10.1	14.3	11.5	14.1	8.7	12.5	8.0	12.3	10.9	14.9
.70	-------	.71	-------	.82	-------	.70	-------	.65	-------	.73	----------
1.11	-------	.98	-------	1.27	-------	.90	-------	1.30	-------	1.04	----------

8 were destined to the CBD. In 1955 intra-area shopping trips had increased to 29,481, but the volume to the CBD remained approximately the same as in 1948 (1,419 trips), a drop from 15.6 to 4.8 percent.

There are certain geographic factors which had a great effect on trips to the CBD by residents of Virginia, especially shopping trips. It would be well, therefore, to discuss more fully sectors 7 and 8 which make up the Virginia portion of the study area. Although 2 of the 4 bridges across the Potomac River lead directly to the CBD, there was a low orientation in the 1948 study of shopping trips to the CBD by residents of sectors 7 and 8 compared with similar trips made by residents of the other sectors (Table 15). The relatively low percentages of shopping trips to the CBD became more pronounced in 1955 as increased suburban commercial development took place.

This recent history of shopping trips by residents of sectors 7 and 8 illustrates a lesser dependency on the Washington CBD for shopping purposes than was the case for other sectors. The Potomac River, because of its restricting effect on direct travel, is a psychological as well as a physical barrier to travel by Virginians to the Washington CBD. As a result, several large commercial concentrations, such as that found in the Clarendon section of Arlington, had developed before the 1948 study, and they were

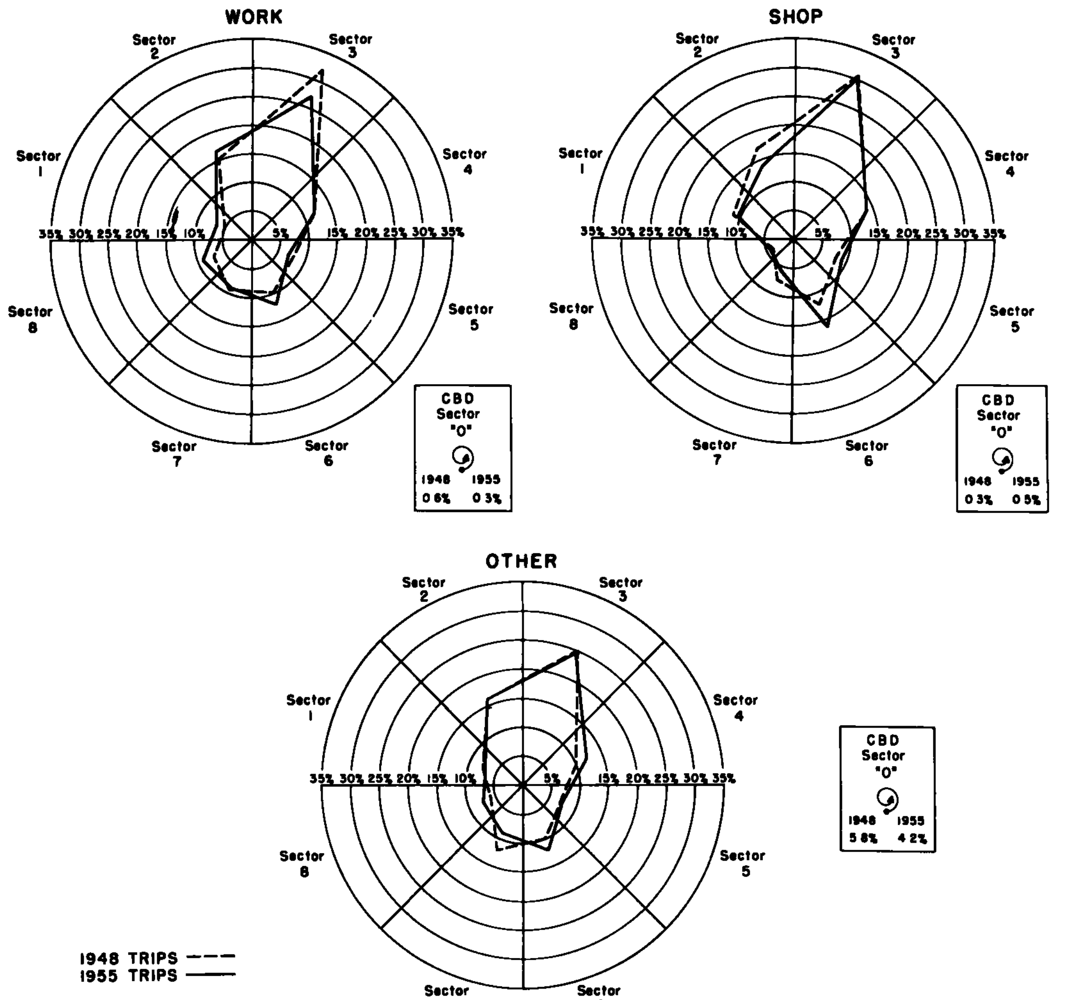

Figure 17. Percentage distribution of trips to the central business district of Washington, D.C., by purpose and sectors of residence average weekday-1948 and 1955.

serving many of the retail needs of Virginia residents. Since that time, these centers have been greatly augmented by other regional as well as neighborhood type retail concentrations. Thus, there appeared to be an even lower orientation of shopping trips to the CBD in 1955.

The close tie that is usually considered to exist between shopping trips to the CBD and mass transit is largely substantiated by the data for 1948 (Table 18). In 1948, residents of each of the 9 sectors made 60 percent or more of their CBD shopping trips by mass transit. This relation had changed by 1955 when only sectors 3, 4, and 5 maintained as high a percentage. Even in these three sectors, the percentage was less in 1955 than it had been in 1948.

The variation between sectors in the percentage change in mode of travel might best be explained by comparing the CBD shopping trips made by residents of sectors 3 and 7. Sector 3 had convenient mass-transit service, and there was a below area average increase in automobiles owned per 100 dwelling units (24.0 percent). Between 1948 and 1955, the percentage of CBD shopping trips by mass transit decreased from 82.9 to 72.0 percent in sector 3. Even with this decrease, the percentage remained high. In contrast, trips made by residents of sector 7 changed radically. Sector 7 had a relatively less convenient mass-transit system than sector 3, but there was a very large increase in the number of automobiles per 100 dwelling units (54.0 percent). In 1948 mass transit carried nearly two-thirds (62.1 percent) of all the residents of sector 7 destined to the CBD for shopping. By 1955 the proportion was slightly more than one-third (37.5 percent).

Other Purpose Trips

As mentioned previously in the study of distance rings, it is possible only to make generalizations of the changes that took place in the "other" trip purpose category. This group, however, did show a similarity in several characteristics that were found for work and shopping trips.

The pattern of "other" trip purpose distribution changed only slightly between 1948 and 1955. Trips by residents of 4 of the 9 sectors in 1955 were within ± 0.5 percent of the 1948 percentage, and 3 other sectors were within ± 1.7 percentage points (Table 13 and Figure 17). As in work and shopping trips, the peak trip distribution was in sector 3 which had the largest number of residents.

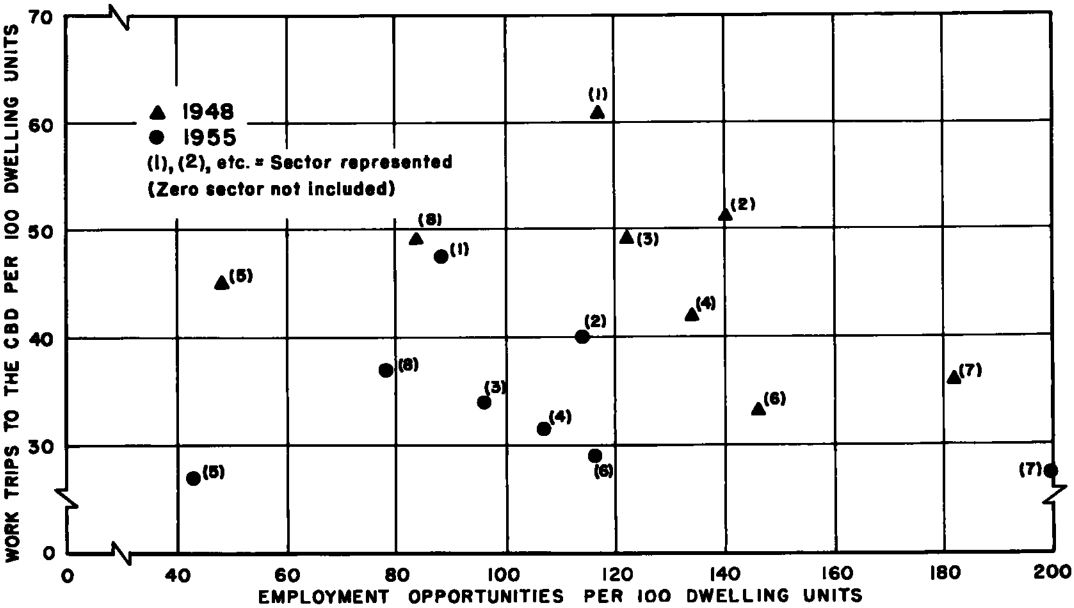

Figure 18. Relation of the number of employment opportunities to the number of work trips to the CBD per 100 dwelling units, by sectors of residence-1948 and 1955.

TAB

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENT
ACCORDING TO TRIP PURPOSE OF MODE

Trip purpose of mode of travel	Sector 0		Sector 1		Sector 2		Sector 3	
	1955	1948	1955	1948	1955	1948	1955	1948
Automobile-driver trips to—								
Work	-----	14.2	54.5	49.1	55.3	55.3	50.5	62.5
Ratio, 1955/1948	-----	-----	1.11	-----	1.00	-----	.81	-----
Shop	-----	-----	5 9	8.0	5.9	6.2	6 2	6.1
Ratio, 1955/1948	-----	-----	.74	-----	.95	-----	1 02	-----
Other	100.0	85.8	39.6	42.9	38.8	38.5	43.3	31.4
Ratio, 1955/1948	1.17	-----	.92	-----	1.01	-----	1.38	-----
Total	100.0	100.0	100 0	100.0	100.0	100.0	100.0	100.0
Automobile-passenger trips to—								
Work	-----	17.2	44.7	51 6	63.3	58.6	71.3	57.2
Ratio, 1955/1948	-----	-----	.87	-----	1.08	-----	1.25	-----
Shop	8.8	-----	9.2	11.4	10.5	9.9	8.1	10.3
Ratio, 1955/1948	-----	-----	.81	-----	1.06	-----	.79	-----
Other	91.2	82.8	46.1	37.0	26.2	31.5	20.6	32.5
Ratio, 1955/1948	1.10	-----	1.25	-----	.83	-----	.63	-----
Total	100.0	100 0	100.0	100.0	100.0	100.0	100.0	100.0
Taxi-passenger trips to —								
Work	21.3	18.1	60.2	41.5	60.8	48.8	58.3	59.8
Ratio, 1955/1948	1.18	-----	1.45	-----	1.25	-----	.98	-----
Shop	7.4	-----	9.6	15.2	4.7	12.6	15.6	8.4
Ratio, 1955/1948	-----	-----	.63	-----	.37	-----	1 86	-----
Other	71.3	81.9	30 2	43.3	34.5	38.6	26.1	31.8
Ratio, 1955/1948	.87	-----	.70	-----	.89	-----	.82	-----
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mass-transit passenger trips to—								
Work	17.7	18.5	69.9	54.5	68.9	58 8	64.7	64.6
Ratio, 1955/1948	.96	-----	1.28	-----	1.17	-----	1.00	-----
Shop	3.4	3.2	13.0	20.3	15.0	19.6	17 7	16.4
Ratio, 1955/1948	1.06	-----	.64	-----	.77	-----	1.08	-----
Other	78.9	78.3	17.1	25.2	16.1	21.6	17.6	19.0
Ratio, 1955/1948	1.01	-----	.68	-----	.75	-----	.93	-----
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All modes of travel to—								
Work	13.7	17.8	59.8	51.5	62.8	57.1	61.9	63.4
Ratio, 1955/1948	.77	-----	1.16	-----	1.10	-----	.98	-----
Shop	4.4	2.2	9.9	14.6	10.4	14.5	13.2	13.8
Ratio, 1955/1948	2.00	-----	.68	-----	.72	-----	.96	-----
Other	81 9	80.0	30.3	33.9	26.8	28.4	24.9	22.8
Ratio, 1955/1948	1.02	-----	.89	-----	.94	-----	1.09	-----
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The number of "other" purpose trips to the CBD per 100 dwelling units decreased for residents of all sectors (Table 14), and the trend was toward greater uniformity in the distribution of trips per dwelling unit between each of the sectors, particularly sectors 3 through 8.

The distribution of modes of travel by which "other" purpose trips were made indicates a large increase in the percentage of trips by automobile drivers for each sector between 1948 and 1955 (Table 18). Here again, this change in mode of travel was apparently due to an increase in the automobile ownership ratio. In 1948 residents of only two sectors, 1 and 8, made 40 percent or more of their CBD "other" purpose trips as automobile drivers. At that time, these two sectors contained the largest number of automobiles per dwelling unit. With an increase in the number of automobiles owned, residents of each sector in 1955, except sector zero, made 40 percent or more of their "other" purpose trips as automobile drivers.

MODES OF TRAVEL

In 1948 and 1955, there was an inverse relationship between automobile ownership and the percentage of residents CBD trips made by mass-transit passengers. If the sectors are listed in accordance with automobiles owned per 100 dwelling units from

LE 16

RAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED
OF TRAVEL AND SECTOR OF RESIDENCE

	Sector 4		Sector 5		Sector 6		Sector 7		Sector 8		Total area	
	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
	52.4	60.1	44.6	54.3	44.4	56.7	53.1	46 7	56.0	59.2	51.2	55.9
	.87	-----	.82	-----	.78	-----	1.14	-----	.95	-----	.92	-----
	8.3	7.0	12.1	7.5	10.1	7.5	7.5	8.7	4.2	5.1	7.2	6.8
	1.19	-----	1.61	-----	1.35	-----	.86	-----	.82	-----	1.06	-----
	39.3	32.9	43.3	38.2	45.5	35.8	39.4	44.6	39.8	35.7	41.6	37.3
	1.20	-----	1.13	-----	1.27	-----	.88	-----	1.12	-----	1.12	-----
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	72.8	52.0	72.7	57.1	63.0	51.4	62.9	51.4	73.2	66.2	66.2	55.1
	1.40	-----	1.27	-----	1.23	-----	1.22	-----	1 11	-----	1.20	-----
	6.8	14.6	10.4	13 7	14.2	11.1	7.6	8.2	5.1	6.0	8.9	10 3
	.47	-----	.76	-----	1.28	-----	.93	-----	.85	-----	86	-----
	20.4	33.4	16 9	29.2	22.8	37.5	29.5	40.4	21.7	27.8	24 9	34 6
	.61	-----	.58	-----	.61	-----	.73	-----	.78	-----	.72	-----
	100.0	100.0	100.0	100.0	100.0	100 0	100.0	100.0	100 0	100 0	100.0	100 0
	36.6	57.1	64.2	38.3	57.9	17.0	22.0	41.7	56.3	60 0	54.7	48.8
	.64	-----	1.68	-----	3.41	-----	.53	-----	.94	-----	1 12	-----
	16.9	28.6	17.9	26.0	19.6	10 3	24.6	-----	12.5	-----	12 3	11 4
	.59	-----	.69	-----	1.90	-----	-----	-----	-----	-----	1.08	-----
	46.5	14.3	17.9	35 7	22.5	72.7	53.4	58.3	31.2	40.0	33.0	39.8
	3.25	-----	50	-----	.31	-----	92	-----	.78	-----	83	-----
	100 0	100 0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100 0	100.0	100.0
	63.0	62.7	60.4	66.3	66.3	59.0	77.6	65 4	81.6	72.1	66.2	62.0
	1.01	-----	.91	-----	1.12	-----	1.19	-----	1.13	-----	1 07	-----
	19 0	19 4	17 8	13 7	18.2	20.1	9.0	12.6	10.8	14 8	16.0	16 8
	.98	-----	1 30	-----	.91	-----	.71	-----	.73	-----	.95	-----
	18.0	17.9	21.8	20.0	15.5	20.9	13.4	22 0	7.6	13.1	17.8	21.2
	1.01	-----	1.09	-----	.74	-----	.61	-----	.58	-----	.84	-----
	100.0	100.0	100.0	100 0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	60.9	60.3	57.6	61 9	58.8	56.5	63.3	56.8	68.2	65.9	61 0	59.1
	1.01	-----	.93	-----	1 04	-----	1.11	-----	1.04	-----	1.03	-----
	12.8	16.0	14 9	13.1	15.0	15.9	8.4	10.3	6.6	9 1	11 8	13.5
	.80	-----	1.14	-----	.94	-----	.82	-----	.73	-----	87	-----
	26.3	23.7	27.5	25.0	26.2	27.6	28.3	32.9	25.2	25.0	27.2	27.4
	1.11	-----	1.10	-----	.95	-----	.86	-----	1.01	-----	99	-----
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

the highest to the lowest and then by the percentage of residents CBD trips made by mass-transit passengers (Table 18) from the lowest to the highest, it will be seen that for both years the sequence of the sectors was nearly the same. Exceptions to this sequence were sectors 4 and 7 in 1948 and 1, 2, and 7 in 1955.

Since there was a general tendency for smaller percentages of mass-transit passenger trips to be made by residents of sectors with a greater number of automobiles owned per dwelling unit, it followed that with increased automobile ownership within each sector, with the exception of sector zero, the percentage of CBD trips by mass transit decreased. The changes which occurred within each sector in the percentage distribution of mode of travel to the CBD resulted in an increasing similarity of these percentages between sectors (Table 18).

To illustrate this increasing uniformity, residents of sectors 1 through 6 (District of Columbia and Maryland) were considered as one group, and residents of sectors 7 and 8 (Virginia) were considered as a second group. Residents of sector zero were excluded in the analysis. In the first group, the range between the sector with the smallest and that with the largest percentage of residents CBD trips by automobile drivers was 15.9 percent in 1948 and 8.0 percent in 1955. If sector 3 is omitted from the comparison, the range is 13.5 percent in 1948 and only 2.6 percent in 1955. Group 2 indicated the same trend; there was a range of 8.0 percent in 1948 and only 1.4 percent in 1955.

The range between sectors in the percentage of residents CBD trips by mass-transit passengers decreased for group 1 from 24.6 percent in 1948 to 12.5 percent in 1955; sectors in group 2 decreased from 9.7 to 5.7 percent. The range in the percentage of trips by automobile passengers decreased in the first group of sectors, but increased slightly in the second group. The range for taxi passengers remained stable between 1948 and 1955 for both groups of sectors.

Automobile Drivers

The percentage of intra-area automobile-driver trips destined to the CBD decreased for residents of each sector (Table 19). The largest decreases occurred for the trips by residents of sectors with the greatest number of automobiles owned per dwelling unit in 1948 and 1955, sectors 1 and 8.

The pattern of distribution of automobile-driver trips by residents of each sector varied only slightly from what it had been in 1948 (Table 20 and Figure 19), even though automobile ownership increased by various amounts in each sector with the exception

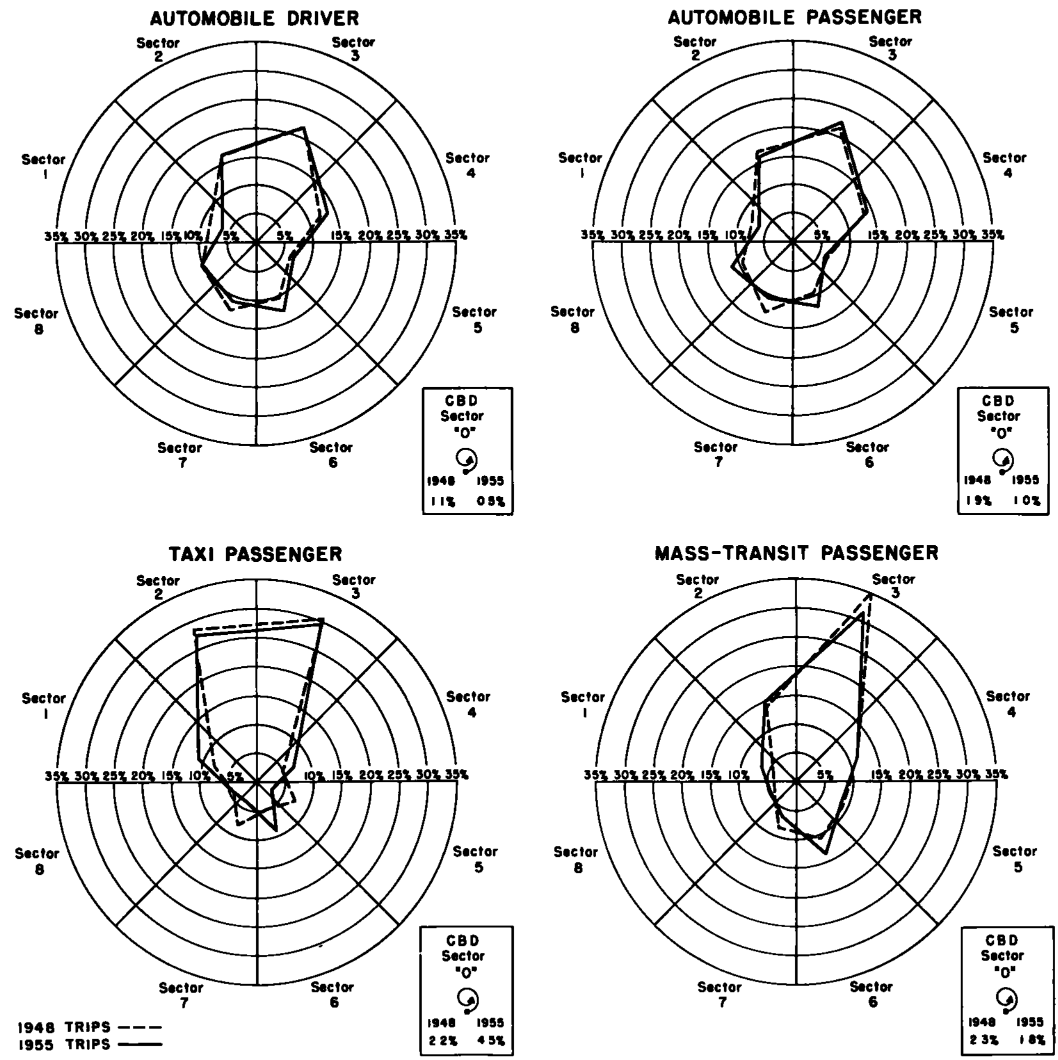

Figure 19. Percentage distribution of trips to the central business district of Washington, D.C., by mode of travel and sectors of residence average weekday-1948 and 1955.

of sector zero. The percentage distribution changed within ± 1.6 percentage points of what it had been in 1948 in 7 of the sectors, and in 3 sectors the change was within ± 0.2 percent. Sector 3 still maintained the major peak of residents automobile-driver trips; however, because of the greater distribution of automobiles and the use thereof in comparison to taxis and mass transit, the peak in sector 3 is seen to be less extreme in both years than the distribution pattern of the latter two modes of travel.

With the increased number of automobiles owned per dwelling unit, there was a smaller difference between sectors in the number of automobile-driver trips to the CBD per dwelling unit (Table 21). The range between the sector with the greatest number of trips and that with the least decreased by over 50 percent in 1955 (25.3 trips in 1948 and 10.8 in 1955).

The relationship between the number of automobiles owned per dwelling unit and the percentage of intra-area automobile-driver trips destined to the CBD changed between 1948 and 1955, as shown in Figure 20. In 1948, the plotted symbols indicate no apparent trend. In 1955, however, the percentage of intra-area automobile-driver trips destined to the CBD was generally less for those sectors that had the greater number of automobiles per dwelling unit.

TABLE 17

AVERAGE ANNUAL FAMILY INCOME FOR 1955 AND AVERAGE NUMBER OF AUTOMOBILES OWNED PER 100 DWELLING UNITS, GROUPED BY SECTOR OF RESIDENCE

Sectors	Average income, 1955 [1]	Number of automobiles owned per 100 dwelling units		
		1955	1948	Ratio, 1955/1948
0	$4,300	19	23	0.83
1	10,100	96	86	1.12
2	9,900	82	70	1.17
3	5,600	62	50	1.24
4	5,900	88	71	1.24
5	4,800	70	52	1.35
6	5,400	73	53	1.38
7	7,200	91	59	1.54
8	8,300	109	91	1.20
Average, total area	6,700	79	61	1.30

[1] Figures for 1948 are not shown because the data for the 2 years are not comparable.

Although work continued to be the dominant purpose for which automobile-driver trips were made to the CBD, the change in the percentage distribution of trip purposes for each of the sectors indicated a general tendency for work trips to decrease in relative importance while "other" trips increased (Table 16). Sectors 1 and 7, the two sectors with the highest percentage of 1948 CBD automobile-driver trips made for "other" purposes, were the exceptions.

Another change which occurred was the decrease in the range of purpose distribution for work and "other" purposes between five of the sectors (Table 16). In 1948 residents of sectors 1, 2, 4, 7, and 8 had a range in the percentage of their CBD automobile-driver trips for work of 13.4 percent; for "other" purposes, it was 11.7 percent. In 1955 these ranges had decreased to 3.6 percent for work and 1.0 percent for "other" trips. It is interesting to note that these sectors also included the residents who had the highest average incomes in the study area as well as the greatest number of automobiles owned per dwelling unit.

Automobile Passengers

The relative changes between 1948 and 1955 in the distribution pattern of sector residents CBD automobile-passenger trips were generally small (Table 20 and Figure 19); six of the sectors had a change that was within ± 1.5 percentage points of the 1948 figure. As indicated in Figure 19, the distribution of residents trips in both years showed a pattern very similar to that of automobile-driver trips; and although sector 3 contained the major peak of automobile-passenger trip distribution, as in automobile-driver trips, the peak was not so extreme as the distribution of mass-transit passenger trips.

The relative relationship between the number of automobiles owned and the number of automobile-passenger trips to the CBD per dwelling unit remained approximately the same, even though the number of automobiles owned increased in each sector except sector zero, and the range of trips per dwelling unit had decreased (Figure 21). The trend in 1955 as in 1948 was for the greater number of automobile-passenger trips to the CBD per dwelling unit to be found in those sectors having the largest number of automobiles per dwelling unit.

The proportion of intra-area automobile-passenger trips to the CBD (Table 19) decreased in each of the sectors. Residents of sectors 3 and 6, however, maintained approximately the same percentage. They also had the smallest amount of change in the percentage of their intra-area automobile-driver trips destined to the CBD.

While residents of most sectors made an increasing proportion of their CBD automobile-driver trips for "other" purposes and a decreasing percentage for work, residents automobile-passenger trips showed an opposite tendency (Table 16). As mentioned earlier, car pools were much more common in 1955 than in 1948. In 1948, residents of only one sector made over 60 percent of their CBD automobile-passenger trips to work. By 1955 residents of 7 sectors were in the over 60 percent group, and 4 of these sectors exceeded 70 percent.

TAB

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENT
ACCORDING TO MODE OF TRAVEL OF TRI

Mode of travel of trip purpose	Sector 0		Sector 1		Sector 2		Sector 3	
	1955	1948	1955	1948	1955	1948	1955	1948
Work trips by—								
Automobile drivers	-------	9.8	28.2	30.2	28.0	22.8	20.4	15.6
Ratio, 1955/1948	-------	-------	.93	-------	1.23	-------	1.31	-------
Automobile passengers	-------	12.5	13.5	17.3	18.9	14.9	18.5	8.9
Ratio, 1955/1948	-------	-------	.78	-------	1 27	-------	2.08	-------
Taxi passengers	24.1	5.2	8.2	4.8	8.0	7.0	5.0	4.4
Ratio, 1955/1948	4.63	-------	1.71	-------	1 14	-------	1.14	-------
Mass-transit passengers	75.9	72.5	50.1	47.7	45.1	55.3	56.1	71.1
Ratio, 1955/1948	1.05	-------	1 05	-------	.82	-------	.79	-------
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Shopping trips by—								
Automobile drivers	-------	-------	18.6	17.5	18.0	10.1	11.9	7.0
Ratio, 1955/1948	-------	-------	1.06	-------	1.78	-------	1.70	-------
Automobile passengers	28.2	-------	16.9	13.5	18.9	9.9	9.8	7.3
Ratio, 1955/1948	-------	-------	1.25	-------	1.91	-------	1.34	-------
Taxi passengers	26.4	---- --	7.9	6.2	3.8	7.2	6.3	2.8
Ratio, 1955/1948	-------	-------	1.27	-------	.53	-------	2.25	-------
Mass-transit passengers	45.4	100.0	56.6	62.8	59.3	72.8	72.0	82.9
Ratio, 1955/1948	.45	-------	.90	-------	.82	-------	.87	-------
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Other trips by—								
Automobile drivers	14.5	13.1	40.5	40.0	46.2	31.8	43.5	21.8
Ratio, 1955/1948	1.10	-------	1.01	-------	1.45	-------	2.00	-------
Automobile passengers	15.5	13.4	27.3	18.8	18.4	16.1	13.2	14.0
Ratio, 1955/1948	1.16	-------	1.45	-------	1.14	-------	.94	-------
Taxi passengers	13.5	5.2	8.1	7.6	10.6	11.2	5.6	6.4
Ratio, 1955/1948	2.60	-------	1.07	-------	.95	-------	.88	-------
Mass-transit passengers	56.5	68.3	24.1	33.6	24.8	40.9	37.7	57.8
Ratio, 1955/1948	.83	-------	.72	-------	.61	-------	.65	-------
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All purposes by—								
Automobile drivers	11.9	12.3	31.0	31.7	31.9	23.5	25.1	15.8
Ratio, 1955/1948	.97	-------	.98	-------	1.36	-------	1.59	-------
Automobile passengers	13.9	12.9	18.0	17.2	18.7	14.5	16.0	9.8
Ratio, 1955/1948	1.08	---- --	1.05	-------	1.29	-------	1.63	-------
Taxi passengers	15.5	5.1	8.1	6.0	8.3	8.3	5.3	4.7
Ratio, 1955/1948	3 04	-------	1.35	-------	1.00	-------	1.13	-------
Mass-transit passengers	58.7	69.7	42.9	45.1	41.1	53.7	53.6	69.7
Ratio, 1955/1948	.84	-------	.95	-------	.77	-------	.77	-------
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Taxi Passengers

There appears to have been a slightly greater shifting between sectors in the percentage distribution of residents CBD taxi-passenger trips than was indicated in the distribution of residents trips by the other modes of travel; 4 of the 9 sectors had a percentage change greater than ± 3.0 percentage points (Table 20 and Figure 19). Nevertheless, in 1955 as in 1948, approximately 60 percent of the taxi-passenger trips destined to the CBD were made by residents of adjacent sectors 2 and 3. As taxi-passenger trips made by visitors were not reported in this study, sector zero does not appear to have a large percentage of taxi-passenger trips.

Except for sectors 0, 4, and 6, taxi-passenger trips per dwelling unit decreased between 1948 and 1955 (Table 21). With this decrease, although the difference between sectors was small, the geographical relationship between residents of sectors 1 through 5 appeared to be greater than was apparent in 1948. In 1955 the number of taxi-passenger trips per dwelling unit decreased continuously in the sectors from 1 through 5. This transition again appeared to be one from sectors with high average family incomes to one of lower average family incomes. In addition, the relatively lower number of taxi-passenger trips per dwelling unit made by Virginia residents may partially be

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RAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED
P PURPOSE AND BY SECTOR OF RESIDENCE

Sector 4		Sector 5		Sector 6		Sector 7		Sector 8		Total area	
1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
28.5	22.9	23.8	16.0	23.0	22.2	33.2	23.1	33.7	32.4	26.0	20.9
1.25	-------	1.49	-------	1.04	-------	1.44	-------	1.04	-------	1.24	-------
25.6	13.4	20.0	10.4	19.5	11.7	23.1	16.0	28.9	19.9	20.6	12.7
1.91	-------	1.92	-------	1.67	-------	1.44	-------	1.45	-------	1.62	-------
1.7	1.9	2.3	2.7	3.4	.7	.7	2.7	2.2	3.0	4.4	3.7
.90	-------	.85	-------	4.86	-------	.26	-------	.73	-------	1.19	-------
44.2	61.8	53.9	70.9	54.1	65.4	43.0	58.2	35.2	44.7	49.0	62.7
.72	-------	.76	-------	.83	-------	.74	-------	.79	-------	.78	-------
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
21.4	10.1	24.9	10.3	20.4	10.4	35.2	23.7	26.3	20.3	19.0	11.1
2.12	-------	2.42	-------	1.96	-------	1.49	-------	1.30	-------	1.71	-------
11.3	14.3	11.1	11.8	17.2	9.0	21.1	14.2	20.7	13.0	14.3	10.4
.79	-------	.94	-------	1.91	-------	1 49	-------	1.59	-------	1.38	-------
3.7	3.5	2.4	8.7	4.5	1.5	6.2	-------	5.1	-------	5.1	3.9
1.06	-------	.28	-------	3.00	-------	-------	-------	-------	-------	1.31	-------
63.6	72.1	61.6	69.2	57.9	79.1	37.5	62.1	47.9	66.7	61.6	74.6
.88	-------	.89	-------	.73	-------	.60	-------	.72	-------	.83	-------
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
49.4	31.9	48.3	27.8	53.0	28.7	55.1	38.1	64.6	51.4	47.3	30.1
1.55	-------	1.74	-------	1.85	-------	1.45	-------	1.26	-------	1.57	-------
16.6	21.9	9.7	13.2	15.8	17.5	24.2	21.7	23.2	22.0	17.3	17.1
.76	-------	.74	-------	.90	-------	1.12	-------	1.06	-------	1.01	-------
4.9	1.2	1.3	6.2	2.9	6.1	4.0	6.4	3.3	5.2	5.9	6.6
4.08	-------	.21	-------	.48	-------	.63	-------	.64	-------	.89	-------
29.1	45.0	40.7	52.8	28.3	47.7	16.7	33.8	8.9	21.4	29.5	46.2
.65	-------	.77	-------	.59	-------	.49	-------	.42	-------	.64	-------
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
33.1	23.0	30.7	18.2	30.5	22.1	39.6	28.1	41.0	36.1	31.0	22.1
1.44	-------	1.69	-------	1.38	-------	1.41	-------	1.14	-------	1.40	-------
21.4	15.5	15.9	11.3	18.2	12.9	23.2	17.7	26.9	19.8	19.0	13.6
1.38	-------	1.41	-------	1.41	-------	1.31	-------	1.36	-------	1.40	-------
2.8	2.0	2.0	4.4	3.4	2.3	2.1	3.6	2.7	3.2	4.8	4.5
1.40	-------	.46	-------	1.48	-------	.58	-------	.84	-------	1.07	-------
42.7	59.5	51.4	66.1	47.9	62.7	35.1	50.6	29.4	40.9	45.2	59.8
.72	-------	.78	-------	.76	-------	.69	-------	.72	-------	.76	-------
100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TAB

TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND
SECTOR OF

Mode of travel comparisons	Sector 0		Sector 1		Sector 2		Sector 3	
	1955	1948	1955	1948	1955	1948	1955	1948
Automobile driver trips:								
Total intra-area trips	1,141	1,032	65,152	40,488	186,146	105,257	226,023	136,638
Trips to CBD	442	628	5,483	4,965	13,725	9,459	17,776	12,138
Percentage of trips to the CBD	38.7	60.9	8.4	12.3	7.4	9.0	7 9	8 9
1955 percentage/1948 percentage	.64	-------	.68	-------	.82	-------	.89	-------
1955 trips to CBD/1948 trips to CBD	.70	-------	1.10	-------	1.45	-------	1.46	-------
Automobile passenger trips:								
Total intra-area trips	905	1,055	33,062	22,552	92,274	58,784	122,682	80,125
Trips to CBD	520	662	3,184	2,708	8,071	5,837	11,383	7,545
Percentage of trips to the CBD	57.5	62.7	9.6	12.0	8.7	9.9	9.3	9.4
1955 percentage/1948 percentage	.92	-------	.80	-------	.88	-------	99	-------
1955 trips to CBD/1948 trips to CBD	.79	-------	1.18	-------	1 38	-------	1 51	-------
Taxi passenger trips:								
Total intra-area trips	824	259	4,785	3,535	13,571	10,251	20.688	15,337
Trips to CBD	578	259	1,439	935	3,565	3,309	3,765	3,557
Percentage of trips to the CBD	70.1	100.0	30.1	26.4	26.3	32 3	18.2	23.2
1955 percentage/1948 percentage	.70	-------	1.14	-------	.81	-------	78	-------
1955 trips to CBD/1948 trips to CBD	2.23	-------	1.54	-------	1.08	-------	1 06	-------
Mass-transit passenger trips:								
Total intra-area trips	3,508	5,427	30,458	28,841	69,311	77,471	195.240	241,953
Trips to CBD	2,188	3,568	7,585	7,073	17,721	21,590	38,016	53,463
Percentage of trips to the CBD	62.4	65.7	24.9	24.5	25.6	27.9	19 5	22.1
1955 percentage/1948 percentage	.95	-------	1.02	-------	.92	-------	.88	-------
1955 trips to CBD/1948 trips to CBD	.61	-------	1.07	-------	.82	-------	.71	-------

due to the greater cost of taxi transportation to the CBD than for similar distances in the District of Columbia.

The percentage of intra-area taxi-passenger trips destined to the CBD decreased for residents of each sector, with the exception of sectors 1, 4, and 6. It is not known why the latter sectors did not have the same general trend as the others, for an increase in the proportion of residents trips by any of the modes was unusual. The only other increase was mass-transit passenger trips destined to the CBD by residents of sector 1.

TABLE 20

PERCENTAGE DISTRIBUTION OF TRIPS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND SECTOR OF RESIDENCE

Sectors	Automobile driver		Automobile passenger		Taxi passenger		Mass-transit passenger	
	1955	1948	1955	1948	1955	1948	1955	1948
0	0.5	1.1	1.0	1.9	4.5	2.2	1.8	2.3
1	6.6	8.8	6.3	7.8	11.2	8.1	6.3	4.6
2	16.7	16.8	16.0	16.8	27.7	28.6	14.8	14.2
3	21.6	21.5	22.6	21.7	29.3	30.7	31.7	35.1
4	13.3	12.0	14.0	13.3	7.1	5.0	11.7	11.5
5	7.4	6.6	6.2	6.6	3.1	7.7	8.5	8.8
6	12.3	10.2	12.0	9.7	8.8	5.2	13.3	10.7
7	10.9	12.5	10.5	12.8	3.8	7.9	6.6	8.4
8	10.7	10.5	11.4	9.4	4.5	4.6	5.3	4.4
Total area	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND RESIDENCE

Sector 4		Sector 5		Sector 6		Sector 7		Sector 8		Total area	
1955	1948	1955	1948	1955	1948	1955	1948	1955	1948	1955	1948
172,247	83,868	82,702	39,873	131,493	64,564	143,757	89,014	149,594	68,046	1,158,255	628,780
10,919	6,797	6,089	3,704	10,124	5,769	8,994	7,072	8,788	5,949	82,340	56,481
6 3	8.1	7.4	9.3	7.7	8 9	6 3	7.9	5.9	8 7	7.1	9 0
.78	-------	.80	-------	.87	-------	80	-------	68	-------	.79	---------
1.61	-------	1.64	-------	1.75	-------	1.27	-------	1.48	-------	1.46	---------
88,698	43,457	39,833	22,750	68,490	37,844	70,273	52,440	74,798	37,136	591,015	356,143
7,049	4,601	3,146	2,291	6,031	3,352	5,283	4,455	5,776	3,265	50,443	34,716
7 9	10.6	7.9	10.1	8 8	8.9	7.5	8 5	7.7	8.8	8 5	9 7
.75	-------	.78	-------	.99	-------	.88	-------	.88	-------	88	---------
1 53	-------	1.37	-------	1.80	-------	1.19	-------	1 77	-------	1 45	---------
4,964	3,354	4,450	4,649	5,202	4,890	1,866	3,035	1,746	1,166	58,096	46,476
917	580	403	887	1,138	600	483	911	583	535	12,871	11,573
18.5	17.3	9.1	19.1	21 9	12 3	25.9	30 0	33.4	45 9	22.2	24.9
1.06	-------	.48	-------	1.78	-------	.87	-------	.73	-------	.89	---------
1.58	-------	.45	-------	1.90	-------	.53	-------	1 09	-------	1.11	---------
82,404	88,713	69,124	74,255	84,396	77,467	45,514	56,765	41,727	27,306	621,682	678,198
14,088	17,596	10,198	13,426	15,926	16,362	7,975	12,746	6,308	6,744	120,005	152,568
17.1	19.8	14.8	18.1	18.9	26.1	17.5	22.5	15.1	24.7	19.3	22.5
.86	-------	.82	-------	.90	-------	.78	-------	61	-------	.86	---------
.80	-------	.76	-------	.97	-------	.63	-------	.94	-------	.79	---------

Although the percentage distribution of trip purposes for which CBD taxi-passenger trips were made shifted in each of the sectors, the most significant change was the decrease in the percentage of "other" purpose residents trips in 8 of the 9 sectors (Table 16). Taxi-passenger work trips increased in 5 of the 9 sectors, and in 6 of the 9 sectors, 56 percent or more of the taxi-passenger trips were to work.

TABLE 21

NUMBER OF TRIPS PER 100 DWELLING UNITS TO THE CENTRAL BUSINESS DISTRICT IN 1948 AND 1955, CLASSIFIED ACCORDING TO MODE OF TRAVEL AND SECTOR OF RESIDENCE

Sectors	Automobile driver		Automobile passenger		Taxi passenger		Mass-transit passenger	
	1955	1948	1955	1948	1955	1948	1955	1948
0	13 3	22.7	15 6	23 9	17.4	9.4	65.8	128.9
1	24.6	37.6	14 3	20 5	6.5	7.1	34.1	53.6
2	20.4	21.2	12.0	13 1	5 3	7.4	26 3	48.3
3	13 8	12.3	8.9	7.7	2.9	3.6	29.6	54.3
4	17 1	15.8	11.1	10.7	1 4	1.4	22.1	41.0
5	14 6	13 4	7 5	8.3	1.0	3.2	24.4	48 5
6	15.2	13 1	9 0	7.6	1.7	1.4	23 9	37.0
7	17.3	17.7	10.2	11.1	9	2.3	15.4	31.9
8	22.1	26.8	14.5	14.7	1.5	2.4	15.8	30.4
Average, total area	17.0	16.8	10.4	10.3	2.7	3.4	24.7	45.4

Mass-Transit Passengers

As in the other modes of travel, there was a shifting between sectors in the relative distribution of total residents mass-transit passenger trips to the CBD (Table 20 and Figure 19). Nevertheless, the pattern of distribution changed only slightly as 7 of the sectors were within ±2.0 percentage points of the 1948 figure and 4 of the sectors were within ± 0.5 percent. The extremely high volume of trips made by residents of sector 3 can be attributed to the concentration of population in apartments, row houses, and boarding houses, and the relatively adequate transit service for this sector.

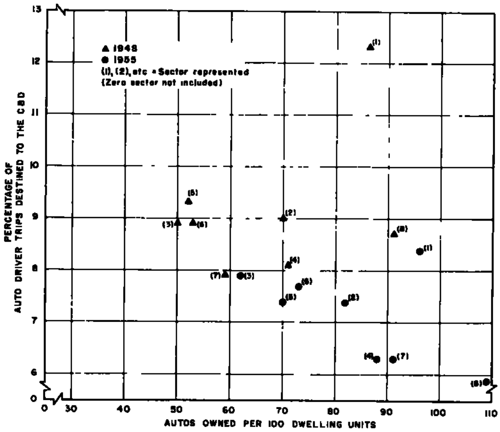


Figure 20. Relation of autos owned per 100 dwelling units to the percentage of auto driver trips destined to CBD, by sectors of residence-1948 and 1955.

Unlike other modes of travel to the CBD, the number of mass-transit passenger trips per dwelling unit decreased in each sector between 1948 and 1955 (Table 21). As a result, there was a growing similarity in the number of trips per dwelling unit in all sectors. The area in which the most important decrease took place occurred between sectors 2 through 6. In 1948, the range between the sector with the greatest and that with the fewest number of mass-transit passenger trips to the CBD per dwelling unit was 17.3 trips. By 1955 the range was only 7.5. If sector 3 is excluded in the comparison, the range is 11.5 trips in 1948 and 4.2 in 1955.

Of the percentage of intra-area mass-transit trips destined to the CBD, it was found that only residents of sector 1 maintained approximately the same percentage in 1955 as in 1948 (Table 19). The relative decreases that did take place in the other sectors, however, appeared to have a geographical relationship with the CBD. A comparison beginning with sector 2 and moving around the CBD through sector 8, with the exception of sector 6, would show that a progressive increase in the relative changes in orientation took place between 1948 and 1955 (Table 19).

Trips to work remained the principal purpose for which sector residents made mass-transit passenger trips to the CBE (Table 16). By 1955 residents of each sector, excluding sector zero, were making 60 percent of more of their CBD mass-transit passenger trips to work. Trips made by residents of sectors 7 and 8 are especially noteworthy. By 1955 these residents of Virginia were making approximately 4 out of 5 mass-transit passenger trips for the purpose of work, which indicated the very limited use of mass transit to the CBD for all the other purposes.

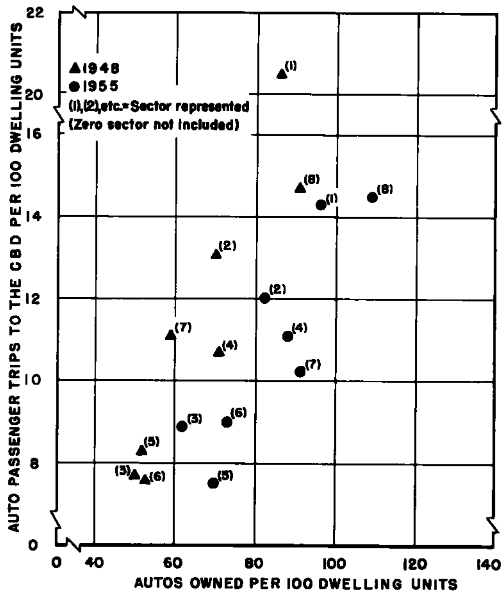


Figure 21. Relation of autos owned to the number of auto passenger trips to the CBD per 100 dwelling units, by sectors of residence-1948 and 1955.

Continuous Sampling Method of Conducting Origin-Destination Surveys

WARREN B. LOVEJOY, The Port of New York Authority

The Port of New York Authority is using a continuous sampling method in conducting origin-and-destination surveys at its bridges and tunnels in the New York Metropolitan area. This paper is a discussion of the results of the first year's experience in the actual operation of this new type of survey.

The paper briefly summarizes the statistical rationale underlying the continuous sampling method, describes the various steps necessary in planning a survey of this type, the operating procedures which have been developed for the field work, and the new methods employed in processing the data. The various advantages which this type of survey provides over previous "one-shot" surveys conducted by the Authority are discussed, and an appraisal is provided of the results of the first year of the survey operation in the light of these expected advantages.

●REASONABLY ACCURATE and up-to-date origin-and-destination information is one of the primary tools used in the planning of vehicular facilities. Since 1935 the Port of New York Authority, in connection with its planning for future vehicular facilities across the Hudson River in the Metropolitan New Jersey-New York area, has conducted periodic roadside surveys of origins and destinations of vehicles using its tunnels and bridges. In the past, because of the expense of conducting these surveys, reliance has had to be placed on so-called "one-shot" surveys, taken approximately every three years, in which one to three days of traffic have been surveyed as representative of the entire year's traffic.

Although this method of conducting surveys has given over the years a substantial body of origin-destination information, the method has some serious drawbacks. The surveys have generally been conducted in October because observation has seemed to indicate that October traffic patterns are fairly representative of a yearly average traffic pattern. Actually, although volumewise this is true, it may well be that because of seasonal variations October is not typical of an annual traffic pattern at all. Furthermore, much of the work concerns peak-hour analysis and inasmuch as the peaks are usually summer peaks, perhaps from this standpoint it would have been better to catalog the traffic flow in the summertime rather than an average annual flow, which it was thought was being obtained in October.

Another difficulty was that the day, or two, or three days, on which the survey was conducted might for some reason or another have been quite unrepresentative of the rest of the days of the year. For instance, on one Sunday there was an unusual amount of traffic going between New Jersey points and the Yankee Stadium, and a later check showed that there was a football game at the Yankee Stadium that day which was of particular interest to New Jersey residents. Certainly the information obtained on that day was not typical of all of the Sundays of the year. Similarly, there have been severe weather conditions on some of the survey days, and there is little reason to doubt that traffic flows are different in rainy weather than they are in good weather. Therefore, the pattern obtained in the survey taken on a rainy day may have been quite unrepresentative of the average day in the year.

Another difficulty in this so-called "one-shot" survey was the job of hiring and training the 200 to 300 interviewers required to do the job. No matter how carefully this problem was approached, there were numbers of men involved who had very little aptitude, training, or inclination for this type of work. As a result, the accuracy of the results secured were open to considerable question. This is true not only of the interview information obtained in the field, but also of the accuracy of the coding of the results, as selected numbers of these men also had to be used in coding.

Continuous Sampling Technique Provides Numerous Advantages

Recently, a new sampling technique called "continuous" sampling has been developed by statisticians and market researchers in other fields to a point where its use in the traffic field, and more specifically in O-D surveys, has become practical. Briefly, this new technique is based on a carefully designed and controlled probability sample which builds up the interviews obtained to the required number for any desired degree of reliability by sampling over a considerable length of time rather than by sampling heavily in a short period of several days. Thus, in the continuous survey, by obtaining a few hundred interviews each day a substantial number of interviews has been accumulated over the course of a year and these have been obtained under all of the varying conditions which exist in the field throughout the year.

There are a number of distinct advantages to be derived from use of this new technique. Among the more important of these, as they apply to the Authority origin-destination survey problem, are the following:

1. By spreading the sampling over a long period, this system avoids the great danger inherent in the previous "one-shot" surveys that seasonal variations or unpredictable variations of one kind or another might make the day or the few days surveyed quite unrepresentative of an average day or days. In continuous sampling, enough days and seasons of the year are covered so that it can be said with certainty that the survey results are representative of normal activity. By the same token, it is possible, by this new technique to measure seasonal variations in traffic patterns, about which there presently is no real information.
2. This new technique will provide up-to-date information on origin-destination patterns at all times. By summarizing the results of the survey quarterly, semi-annually, or annually, information on changes in the O-D patterns caused by the construction of new vehicular facilities in the metropolitan area, or by developments in other modes of transportation, will be provided almost as soon as the changes occur. This will enable isolation of the effect on the Authority's own facilities of each of these changes, thus greatly improving knowledge of traffic movements and ability to forecast the size and timing of future diversions. Current data will be available at all times for incorporation into studies and forecasts that are required almost continually in the course of the working year in connection with various planning studies that are undertaken by the Authority.
3. Building the size of the sample over a long period, rather than by intensive sampling during one day or several days, eliminates the necessity for hiring large numbers of unskilled, uninterested, temporary employees as interviewers and coders. Rather, use is now being made of a group of four interviewers who continuously sample throughout the year. These men are Port Authority career employees who are well trained in interviewing methods, have developed a thorough knowledge of the geography of the metropolitan area, and have become skilled coders of the interview data, thus producing more reliable and meaningful survey results than have been obtained in the past.
4. By spreading the sampling period over the course of a year, the office work load of coding, verifying, tabulating, etc., which used to be tremendous and require the hiring of numerous temporary personnel under the old "one-shot" system, is now spread evenly throughout the year, thus eliminating the uneven periods of activity of the past.
5. Because continuous sampling avoids intensive sampling at any facility at any one time, there is less chance of causing congestion at the facilities while obtaining the O-D information. Furthermore, skilled interviewers greatly reduce the time required for each interview. These features of the new type survey have appealed greatly to the operating personnel at the bridges and tunnels and have enabled getting more complete information on each interview than used to be possible under the old method, when it was often necessary to concentrate simply on the answers to one or two questions from each motorist in order to keep the traffic flowing.

DEVELOPMENT OF STATISTICAL SAMPLE DESIGN

Having decided that the advantages possible with this new survey technique were well worth investigating, the aid of S. T. Hitchcock, of the U. S. Bureau of Public Roads, and Leslie Kish, of the Survey Research Center, University of Michigan, was enlisted in developing a statistical sample design. Before any work could be done in the development of this design, certain preliminary information had to be provided. One of the advantages of a probability sample is that by adhering to the mathematical rules of probability, it is possible to estimate with considerable accuracy the precision that the survey results will attain. Before the sample size required and the detail of the construction of the sample could be determined, therefore, it was necessary for the Port Authority to decide what level of precision was required for its planning purposes. It was determined that it would be satisfactory to have a level of precision which would enable saying that 95 times out of 100 if the survey found that 10 percent of the vehicles had a certain origin-and-destination pattern, the actual percentage of vehicles with this origin-and-destination pattern would lie somewhere between 9 and 11 percent.

The second type of information to be provided before the sample could be designed concerned the characteristics of the population being measured. Fortunately, because all of the facilities involved are toll facilities, there exist very accurate measurements, volumewise, of the characteristics of the traffic over each of the facilities, thus, it was possible to provide the Bureau of Public Roads and Dr. Kish with data which showed seasonal, daily, and hourly variations in traffic volumes on each of the tunnels and bridges operated. In fact, for the three trans-Hudson facilities this same type of information was available for each toll lane. Information also had been developed which showed, for each of the facilities, the expected number of lanes that would be open at any hour of the day in which the interviewers would be there. Finally, there were forecasts of future annual, monthly, daily and hourly traffic volumes which could be expected at each of the facilities.

Inasmuch as statistical formulas are generally of interest only to statisticians, no attempt is made to specify the various statistical formulas which can be used to describe the sample design used. The design, however, can be described in more general terms. First, it is a self-weighting probability sample. That is, the sample is so designed that the number of interviews obtained is proportionate to the volume of vehicles moving through the facility at the time the interviews are being taken. Thus, there is no need to expand or weight the numbers of interviews in order to make them proportionate to traffic volumes. Although this feature of the design makes for somewhat more difficult and rigorous operation, it was decided to use it because of the great savings in time which could be achieved by eliminating the necessity for weighting of the interviews by hour, by lane, by direction, etc.

The sample can be described as a stratified multi-stage probability sample. This means that the entire amount of traffic is divided into several strata, which are felt to be as homogeneous as they can be made. Thus, the traffic has been divided into weekday, Saturday, and Sunday traffic, and within each of these day types has been split into 8-hr shifts running from 11 P. M. to 7 A. M., 7 A. M. to 3 P. M., and 3 P. M. to 11 P. M. These hourly groupings were selected after studying the hourly volume records that were available and analyzing the traffic in order to identify similar types of travel.

Perhaps the meaning of the word "multi-stage" can be explained by briefly citing the various stages through which the final selection of a vehicle to interview is carried. The first stage is selection of a shift at a facility in which, for instance, it is selected at random that on a certain day an interviewer will be at the George Washington Bridge on the 7 A. M. to 3 P. M. shift.

The next stage is selection of a location at the facility where the man will start his interviewing. This is necessary because there are several toll plaza locations at this facility and the man can not rotate from one location to another readily. Suppose, picking at random, it is determined that the interviewer will start at the westbound Main Plaza. This then is the second stage of selection.

There are a number of toll lanes at this location so that for the third stage of selection another random selection must be made as to the lane at which the interviewer will start to operate. The interviewer rotates from lane to lane each hour on a definite prearranged pattern, but selection of the lane in which he will start is based on a random procedure so that the laws of probability can be applied.

The fourth and final stage is selection of the specific car in the lane in which the interviewer is located. This is done by specifying for that lane, for that hour, for that location, and for that facility, the interviewing intensity the interviewer must attain. By interviewing intensity is meant that he will take every fourth car, or every sixth car, or whatever is indicated by the procedure.

At each of the four stages a random procedure is introduced so that the probability feature of the sample is maintained through each one of the stages. Furthermore, a known probability of selection is calculated for each stage of selection, and it is determined that the product of the probabilities of each one of the four stages will give the over-all probability it has been determined is necessary to obtain a sample of the required size by the end of the year.

PLANNING FOR OPERATION OF THE SURVEY

Once the sample design had been developed the next phase in planning the survey was to determine the various operating procedures and methods to be followed. A great deal of field testing and checking was done in order to arrive at the necessary methodology; as a matter of fact, the procedures are still being modified from time to time according to lessons learned from the day-to-day conduct of the survey. First it was necessary to determine how much interviewing time could be expected over long periods from each interviewer without loss of efficiency due to fatigue or lack of interest. After a good deal of experimentation it was decided to have the interviewers interviewing 44 min out of each hour during the 8-hr period of the shift. In each hour, 16 min were to be taken as a relief period and also as the time to rotate from one lane to another. In addition, the men are given sufficient time for their lunch period. It was found that a schedule of this type could be maintained by interviewers throughout the entire 8-hr period day after day without undue fatigue.

The second step was determination of the number of interviewers who would be needed for the conduct of the survey. This, or course, is proportional to the number of interviews required and the interviewing speed possible. Again, after a good deal of field work, it was determined that an average rate of 40 interviews an hour was possible. This does not mean that in very busy periods more than 40 interviews can not be secured. (As a matter of fact, close to 100 interviews have been obtained from one interviewer in an hour.) It does mean, however, that it was felt that throughout the conduct of the survey, on the average, a rate of about 40 interviews per hour was achievable. It was also felt that because of the repetitious nature of the interviewing job and the often difficult physical conditions surrounding it, much more efficiency would be obtained from the men if they also were used in the office for coding the material obtained from the interviews in the field. It was determined that in the annual distribution of the work approximately 60 percent of an interviewer's working days would be in the field and 40 percent would be in the office coding the interview material. Thus, four interviewers could obtain the requisite number of interviews and, at the same time, very nearly carry the entire load of coding the interviews.

Based on the sample design (which, incidentally, is developed in 13-week groups and therefore totals four seasonal groups during the year), working schedules had to be developed for both the interviewing time and office time of the interviewers. Interviews had to be obtained at all six of the Port Authority facilities at all hours and on all types of days. Therefore, it is necessary for the men to work around the clock, to work weekends as well as weekdays, and to rotate from one facility to another from day to day. As far as possible in working up these schedules an attempt was made to insure that the men would work five days and be off two regularly. In some cases these exact results could not be achieved, but over the 13-week basic period each man had the same number of working and off days. An endeavor also was made to have the men work the same hours for an entire week. Controlling on time this way, it was necessary to send the men to a different facility almost every day; therefore, use of a vehicle by each man was an absolute requisite for the job and the men receive extra compensation for the use of their private cars.

Field experience showed that uniformed interviewers achieve a better response from the public than non-uniformed men, so uniforms were provided for each of the interviewers. These uniforms consist of both summer-weight and winter-weight trousers, shirts, tunics, overcoats, and foul-weather gear. A complete set of the uniforms is provided each man to start, and he is given a specified annual allowance for maintenance and replacement of uniforms.

Because most of the equipment required for the successful conduct of this survey also is required in "one-shot" surveys as well, it is not covered here. It is sufficient to say that the interviewing sheets used are specially designed for ease in recording the information and also for ease in coding and then key-punching the information into IBM cards for processing later. Survey forms are shown in the Appendix. A good deal of safety equipment (cones, lights, etc.) has been assembled to safeguard the men when they are working on the plazas.

Finally, in hiring the interviewers success was achieved in obtaining men by promotion directly within the Port Authority staff. Thus, the interviewers are career employees who are interested in doing a good job in furthering their Port Authority careers. The salary classification of these men was set high enough to attract the kind of personnel needed, in spite of the known physical difficulties encountered by the men in periods of bad weather and the inconvenience of the shift work which the job entails. The men have to be responsible, as they are working on their own with only the over-all supervision that can be given from the office and by occasional spot checks. They also have to be in good shape physically and be able to stand a good deal of monotony without losing sight of the aim of collecting and coding accurate data. The performance of these men to date has been a revelation.

SURVEY EXPERIENCE TO DATE

How has the survey actually worked out? Operations were started on December 30, 1957, and so there has been a period of testing under all weather conditions and traffic conditions expected to be encountered throughout the survey period.

From both an operational and a statistical point of view the survey is turning out to be much as anticipated in the planning. The number of interviews secured during the first eleven months of 1958 was somewhat less than had been anticipated, primarily because the traffic itself was less than had been forecast. Even with the relatively slow start for the first six months of the year, however, it is expected to total within 6 or 7 percent of the 100,000 interviews it was planned to obtain during the first year of operation of the survey. A response rate of approximately 99 percent has been achieved. Of the 1 percent of refusals encountered, very few have engendered unpleasant situations, most of the refusals being because of lack of time.

In aiming at an average interviewing rate of 40 interviews per hour, different interviewing intensities had to be assigned for each hour in the day depending on anticipated hourly traffic volumes. The interviewers have been able to maintain the assigned rates virtually 100 percent of the time without causing traffic congestion. Furthermore, despite an extremely severe winter and very rainy conditions for most of the spring and summer, the survey has shown that although bad weather conditions certainly do not make life easy for the interviewers, they do not make it impossible to obtain the correct number of interviews.

The various precautions taken for the safety of the interviewers have proved to be effective. Working with the police forces at the bridges and tunnels in all cases, it has been found that strategic placing of traffic cones and the good lighting provided all of the plazas have been sufficient to protect the men under all conditions, even when the weather is bad at night. It is gratifying to say that there have been no injuries or "near misses" during the time that the survey has been in progress.

To determine whether the sample is really representative of the entire traffic flow, some careful auditing of the survey results has been done. Preliminary tabulations have been made for each of the first two 13-week periods in such a way that it has been possible to check survey coverage hourly by direction, by toll lane, by facility, by day of the week, and by license plates of the vehicles interviewed. As a result of this auditing, it was discovered that in the first quarter there had been oversampling of one of the locations at the George Washington Bridge, with a resultant undersampling of the other locations. This situation has now been adjusted. Except for this one error, the audit has shown that the correct proportionate distribution of traffic hour-by-hour at each facility has been obtained in the sample. Check has also shown that the procedure for rotation between the lanes has yielded the correct number of interviews from each lane. It also has been found that the proper directional distribution of the traffic has been achieved, not only on a daily basis but also in peak hours versus non-peak hours. All in all, the results of this auditing have confirmed the representativeness of the sample.

Origin-destination patterns as revealed by these preliminary tabulations have been compared with the results of the "one-shot" survey of October 1956. The results of the first 13-week period (roughly January through March) are quite similar to the 1956 results. However, the second 13-week period (April through June) has evidenced seasonal variations of sufficient magnitude to warrant a thorough investigation of the extent to which origin-destination patterns vary from one season of the year to the next. Analysis of the third and fourth 13-week periods is now proceeding with this purpose in mind.

As far as coding of the interviews is concerned, originally an average of 200 or less interviews was coded per day by the interviewers when they were working in the office. That has now been increased to an average of 450 interviews a day. By a process of verification it has been found that the accuracy of the coding has been extremely high. The method of coding verification used is modeled along the lines of statistical quality control procedures and it has been determined that original expectations of accuracy have been more than met. Less than one error is found in each 125 interviews coded; most of the errors that have been found have been extremely minor in nature.

The cost of conducting the continuous survey for a year is only two-thirds that of a "one-shot" survey covering a weekday, a Saturday, and a Sunday. The survey is currently being carried on with four interviewers and the equivalent of one man-year of statistician time and one man-year of clerical time. In addition, of course, there is the cost of tabulating the material. Here, too, it is felt that savings will be achieved by the orderly scheduling of the processing work load throughout the year, which is possible with the continuous survey.

FUTURE PLANS

Because this is such a new type of traffic survey and because it has been in operation for a relatively short time, little actually is known about the method and what it can produce. Undoubtedly many improvements in efficiency, accuracy, and other aspects can and will be made based on the experience being gathered now. For instance, it already has been determined that by slightly changing the intensity of interviewing on certain shifts, the same amount of information as is now being obtained can be gathered with approximately 50 fewer field shifts each year. This will allow use of more of the interviewers' time in coding and in keeping the various records that must be maintained in order to produce the accuracy desired.

There are many other ways in which improvements may be possible in the future. Detailed analysis of the variances obtained in the sampling for different hours of the day, for different types of days, or at different facilities, may well lead to changing the sample design in such a way as to obtain more efficient use of the interviewers or perhaps to get along with fewer interviews and still achieve the same level of accuracy as sought from the start. It may be found unnecessary to interview as often during non-peak hours as has been done so far. Once there has been accumulated over the course of a year or two a sufficient body of information to give reliable annual and seasonal relationships, the information thereafter may possibly be kept current by a much lighter sampling than was required to build up the information in the first place. It may be found that seasonal variations are at a minimum at certain times of the year and that, having a more or less homogeneous population during these periods, they need be sampled only sparsely. Also, peak-hour information possibly should be emphasized and there may, therefore, be need to change the survey from time to time in order to concentrate on peak periods rather than giving total over-all coverage such as is presently being obtained. In other words, the procedures and operating methods now being used really should be regarded as first steps in a new venture—steps that will eventually lead to a much more efficient way of accomplishing the desired end. It is intended to continue modifying the methods until it is felt that the maximum efficiency possible has been achieved.

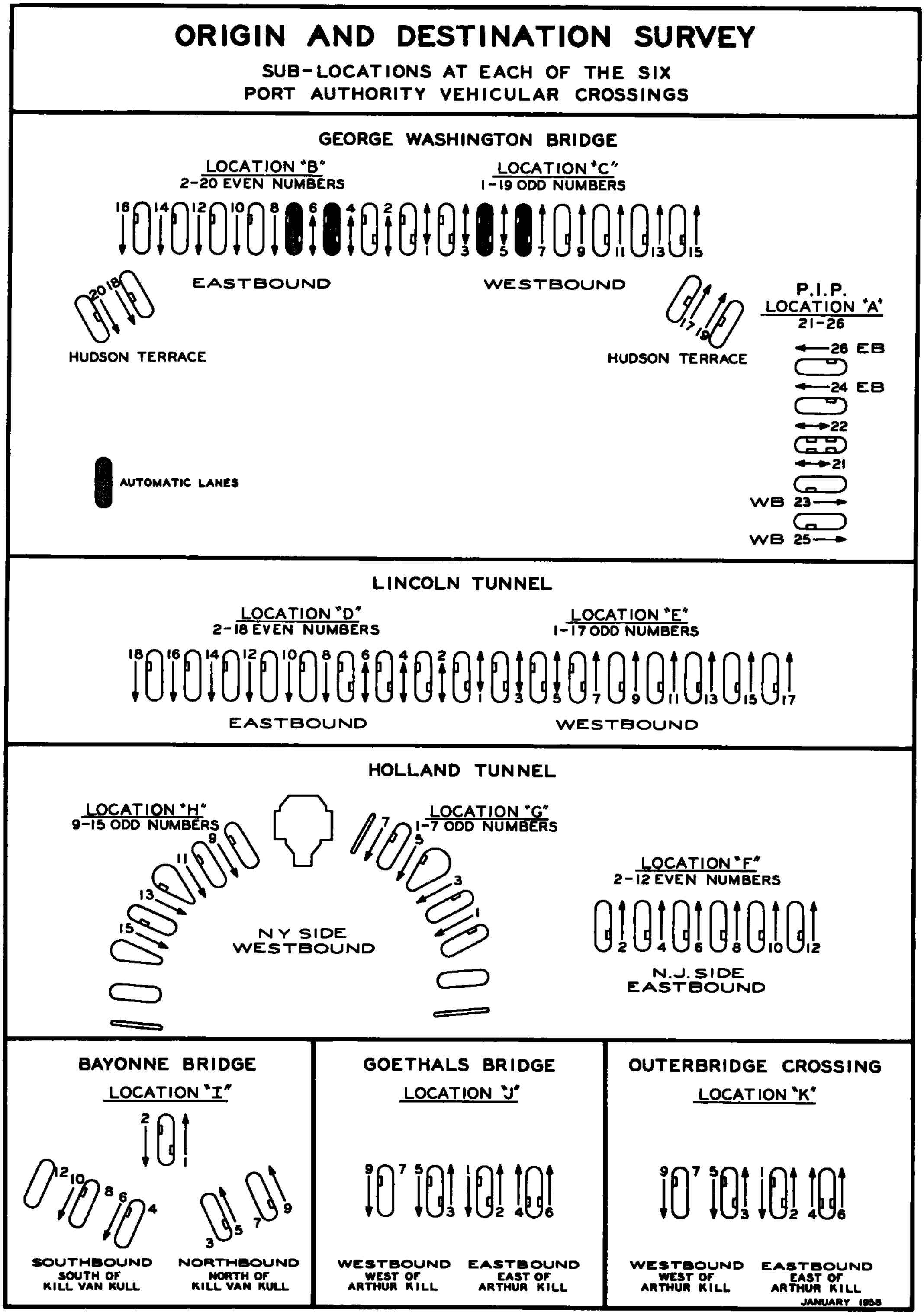
POSSIBLE APPLICATION TO NON-TOLL FACILITIES

Because all of the Port Authority facilities are toll facilities, they are made to order for the conduct of a continuous sampling survey. The vehicles all must slow down and funnel into separate lines as they approach the toll booths. Because they must stop to pay their tolls anyway, the drivers do not object to stopping for the few additional seconds required to answer the survey questions.

This does not mean, however, that this technique cannot be expanded to apply to freeways and other types of vehicular facilities where the situation is not so ideally suited to this type of survey work. For instance, a continuous sample design could be worked out for origin-destination survey work on other types of highways, whether of the controlled access type or not. Just as the reported survey is now rotating from one facility to another, and from one location to another at a facility, and from one lane to another at each location, so, on a freeway, the interviewers could rotate from one entrance or exit to another in a planned and controlled manner so as to obtain all the necessary origin-and-destination information covering the total traffic on the freeway without the necessity for blocking traffic on the freeway itself.

This same method could be applied to origin-and-destination surveys taken along cordon lines or rings around metropolitan areas, where a small team of interviewers would rotate from one point of access to another in a prearranged and carefully controlled method, interviewing vehicles either on stop signals or in some other way. In this way, a good picture of the total origin-and-destination pattern of all of the vehicles crossing a cordon line could be obtained over a period without seriously disrupting traffic, as so often must be done in the more conventional type of roadside O-D survey.

As a matter of fact, this same continuous sampling method can be applied to other types of information gathering than origin-destination information surveys. A classified count of traffic entering and leaving a city or crossing a cordon can be achieved in the same way by rotating a small force of enumerators from one point to another on a controlled basis, thus building up over a period of time the information required as to the average movement of vehicles over the given line. Just as it is felt that the Port Authority survey work has just begun to scratch the surface of the usefulness of this tool, so it is felt that for many other applications this continuous sampling method can be used to great advantage, and that its realm of usefulness and its different possible applications will continually expand as users come to understand more and more of the implications of the method.


ORIGIN AND DESTINATION SURVEY
SUB-LOCATIONS AT EACH OF THE SIX
PORT AUTHORITY VEHICULAR CROSSINGS
GEORGE WASHINGTON BRIDGE
LOCATION "B"
2-20 EVEN NUMBERS
LOCATION "C"
1-19 ODD NUMBERS
EASTBOUND
WESTBOUND
HUDSON TERRACE
HUDSON TERRACE
P.I.P.
LOCATION "A"
21-26
26 EB
24 EB
22
21
WB 23
WB 25
AUTOMATIC LANES
LINCOLN TUNNEL
LOCATION "D"
2-18 EVEN NUMBERS
LOCATION "E"
1-17 ODD NUMBERS
EASTBOUND
WESTBOUND
HOLLAND TUNNEL
LOCATION "H"
9-15 ODD NUMBERS
LOCATION "G"
1-7 ODD NUMBERS
N Y SIDE
WESTBOUND
LOCATION "F"
2-12 EVEN NUMBERS
N.J. SIDE
EASTBOUND
BAYONNE BRIDGE
LOCATION "I"
SOUTHBOUND
SOUTH OF
KILL VAN KULL
NORTHBOUND
NORTH OF
KILL VAN KULL
GOETHALS BRIDGE
LOCATION "J"
WESTBOUND
WEST OF
ARTHUR KILL
EASTBOUND
EAST OF
ARTHUR KILL
OUTERBRIDGE CROSSING
LOCATION "K"
WESTBOUND
WEST OF
ARTHUR KILL
EASTBOUND
EAST OF
ARTHUR KILL
JANUARY 1958

F 192
10-58

ORIGIN AND DESTINATION SURVEY
FACILITY AND SHIFT ASSIGNMENT

WEEK NO. ______________

WEEK BEGINNING ______________

DAY TYPE	DATE	INTERVIEWER NO.	FA-CILITY	SHIFT	SURVEY		SELEC. RATE	RANDOM	FACILITY LOCATION	LANE ROTATION	
					START	FINISH	1:	START		BEGIN	SEQUENCE

PA 2190-A
12-57

ORIGIN AND DESTINATION SURVEY

GEORGE WASHINGTON BRIDGE

Page

Fac.	Year	Month	Week	Day	Day Type	Shift	Hour	Dir.	Lane
0 1	5 8								

Type	Pass.	Lic.	Purpose		East of Hudson River	West of Hudson River
1. Auto 2. Truck 3. Tr-Trlr.	No. of people in vehicle	1. N.Y. 2. N.J. Others Abbrev.	1. Work 2. Shop 3. Recr. 4. Other		Street Address Borough or Town	City or Town
					0	5
					0	5

LANES OPEN

No.	Time

Remarks:
Weather ______________
Other ______________

____
Interviewer

PA 2202
10-58

ACCURACY CONTROL RECORD FOR O/D SURVEY

Facility ____________________ 195____

SEAS. (1)	DAY TYPE (2)	WK. (3)	DATE (4)	SHIFT (5)	HR. (6)	LANE (7)	NAME OF INTER. (8)	TIME FACTOR (9)	NO. OF INTERVIEWS				LANE FACTOR (14)			LANE ADJ. (B) (15)	ADJ. NO. OF INTER. (16) = (13) − (15)	REMARKS (17)
									SEC. (10)	REF. (11)	NON-RES. (12)	TOTAL (13)	Actual	Assum	(A)			

PA 2201
10-58

SUMMARY OF SHIFTS COVERED - O/D SURVEY

Month ____________________ 19____

DATE	FACILITY	SHIFT	INTERVIEWER	NUMBER OF INTERVIEWS				DATE CODED	CODER NO.	DATE VERIFIED	VERIFIER NO.
				SECURED	REFUSALS	NON-RESPONSE	TOTAL				

10-58

CODING VERIFICATION CONTROL RECORD FOR O/D SURVEY

VERIFIER	ORIG. CODER	DATE	FACILITY	SHIFT	POPULATION N	LOT n	TYPE OF ERROR				
							EHR (AK), SKVK	REJECT (R) or ACCEPT (A)	WHR (AK), NKVK	REJECT (R) or ACCEPT (A)	LIC. PLATE

Report on Analysis of Urban Work Trips

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Common to virtually all wage-earners and proprietors in cities is the daily journey from home to work and back again. An easily observable characteristic of this travel is that most of it occurs at virtually the same time: a morning period of maximum volume of travel occurs in most cities from 7 to 9, and in the evening another peak-period of traffic flow—in the opposite direction, away from the work places—occurs in the hours from 4:30 to 6:30. The massive flows to and from work places represent many vehicles which alternately speed, stop and crawl along, but more importantly, they represent thousands of people spending a considerable part of their days and of their lives in moving from one place of residence to another. These diurnal migrations are represented in the term, the "journey-to-work."

That most workers are employed away from their homes and travel between homes and work places at approximately the same times has considerable effect on capacity requirements of the circulation systems of cities. Further, the decisions made by workers and heads of families in selecting work places and in finding places to live, in the aggregate, have important effects upon the physical patterning of cities. Location decisions also influence labor force availability in various parts of the urban area. Not to overstate the case, it should be made clear that while the home-work-place relationship is clearly an operative factor at all times in providing limits for home-location decisions, it may seldom be the prime factor in location choice.

From a statistical viewpoint, trips to work constitute the largest single grouping of trips, by purpose, of all trips leaving urban residences. In metropolitan areas, trips from home to work and back again represent generally about one-third of all trips made, and up to half of the trips made to central business districts may be of work-purpose.

In a more important sense, it needs saying that for the people concerned, work-travel consumes much time and energy. The fact is that a large proportion of work-travel in metropolitan areas is arduous and long; many trips involve two or more changes of mode of travel. These two examples will help to give an idea of the scale of the journey-to-work and its costs. Estimates made for both the London Central Area and Lower Manhattan indicate that time spent in the journey-to-work lengthens the work-day by a gross amount of almost 20 percent. Thus, for the approximate figure of 3 million employed persons who travel into Lower Manhattan each weekday, over half a million man-days are consumed in travel en route.

Discernible trends in urban settlement appear to indicate, for future years, longer trips to work for many, and lengthy journies-to-work for increasing proportions of the dwellers in metropolitan areas. On the other hand, the longer trips to work mean wider areas from which employers may attract workers and a greater range of places and types of occupation for the individual wage-earners.

These considerations indicate the nature of the journey-to-work as a factor of connection between the utilization of land for circulation routes, and for residential, commercial, and industrial purposes. From this, it follows that understanding of urban life will be enhanced and planning for cities will be aided by further study of work-oriented travel (1).

Wider understanding of the relation of homes to work places will aid in decision-making processes concerning future organization of intividual metropolitan areas. With evident trends to decentralization of industry and growth of low-density residential suburbs, decisions for renewing the central areas or cities, or for developing outlying subcenters of residence and/or employment cannot be made without assumptions concerning the work-travel of individuals.

The purpose of this paper is to present some of the findings and conclusions made in studies of the journey-to-work conducted at the Institute for Urban Studies. The present paper does not present details of the analyses of patterns of trip generation and confluence. This paper briefly describes some aspects of work-trips as a part of urban traffic, and presents some general conclusions derived from the recent studies.

●EXTENSIVE information on the journey-to-work dates from at least as far back as 1896 in Europe, while systematic consideration of urban work travel and its effect in structuring of cities and their circulation facilities was substantially begun after World War II in the United States. Despite the late beginning, however, attention is now being increasingly focused upon this important aspect of travel in the United States.

European studies on "Pendelwanderung" or "le mouvement alternant" or Japanese studies on places of work in relation to residence may be found in virtually every decade of this century. Most of these studies were based upon official census surveys in the respective countries. Journey-to-work surveys at one or more points in time may be found in many countries, including such diverse locations as Australia, Belgium, Denmark, England, Holland, Sweden, and Venezuela.

In the United States, at present, a considerable body of information on the journey-to-work is being accumulated in the urban O-D surveys and in the state-wide motor-vehicle-use surveys. The United States Bureau of the Census has cooperated on a service-contract basis with the Bureau of Public Roads in the latter type of survey. In the future, it is to be hoped that the Bureau of the Census will find the time and financing, and see the value of including a few questions on the journey-to-work in the regular decennial national census of population.[1]

The information in the O-D surveys is so extensive that special runs of cards are likely to be required to yield information relevant in specific problem analyses.

As an example, where it is desired to learn the proportional distribution of distances traveled (by the various modes) between residences and work places, the work-purpose trip-cards must be run on an area-of-origin to area-of-destination basis, with a cross-tabulation by mode. This particular information, which is not presented in the usual reports on O-D surveys, may be found to be among the most valuable parts of a major traffic survey. From this type of run may be found typical distribution patterns of residences about the major work places, or the distribution patterns, of auto-driver work trips, for instance, may be found about new housing developments. This kind of information is most useful in the study of housing markets and availability of labor force for new industrial sites.

These two major types of surveys, especially the O-D, should be regarded as virtually mines of information. Unfortunately, it appears to be often the case that little

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[1] In 1957, a committee was formed by the Population Association of America to study this matter for the Bureau of the Census. The Committee reported favorably on journey-to-work questions for the decennial census, but no action will be taken on this in 1960. The committee was chaired by Gerald Breese, and Henry O. Sheldon of the Bureau of the Census served as liaison officer. Committee members included: Nathan Cherniack, William Grigsby, Howard S. Lapin, Harlin G. Loomer, Warren Lovejoy, Chester Rapkin and Arthur Row. Organizations represented by these members were the Port of New York Authority, City of Philadelphia, Princeton University, and the University of Pennsylvania.

use has been made of the thousands of interviews and the information taken from them.

WORK TRAVEL AS A COMPONENT OF URBAN TRAFFIC

Work travel takes place in an environment where trips are made for a great variety of purposes. It is the trips of all and various purposes which have until lately been studied en masse in terms of "desire-lines" in urban traffic surveys. The present study deals with the systems of work travel only, but it is nonetheless important to observe the relationships between work travel and the total urban travel. The concept of relationship is vital for qualitative and quantitative reasons: first, to give an idea of scale to the discussion of work travel, and second, to provide data from which multipliers might be derived to expand to a more complete basis the information derived solely from systems of work travel. The latter point applies particularly in those cities where, for budgetary reasons, only work travel has been found measurable (as in Los Angeles and Toronto), but possibly elsewhere, because of the greater completeness of the work-travel measurements as compared with trips of other purposes.

The discussion following concerns numbers of trips, modes of trips, lengths in time- and mile-distance, and daily time patterns.

Number of Trips

Trips of work purpose range from one-sixth to one-third of all vehicular trips recorded in internal area surveys (2). The average volume of work trips in the internal survey is about one-fourth of the total. The largest group of trips by objective are those made to home which for 15 cities, of from 75,000 to 1,500,000 population, ranged from 37 percent to 48 percent and averaged 43 percent. There was no correspondence in these sets of figures, for either work or for home trips, between the proportions of trips by purpose and population size of city.

The group of trips "to home" include those made from work to home, as well as trips made from the great variety of other possible activity areas.

The relative scale of work-travel, in the figures above, is described in terms of the total of two systems of trips from internal-area origins: the "home-work" trips, and the "other-work" trips. These are the two systems which comprise a tabulation of internal area work-purpose trips. The relative proportions of the two are not determinable without specific referencing in the sorting process.

From consideration of the systems of trips it may be seen that the "journey-to-work," "home-work" plus "work-home"[2] trips (in the internal area) represents something less than double the proportion of work-purpose trips. The amount by which it is "less" depends upon the volume of "other-work" trips.

One of the reasons for wide variations in the reported fraction of work-trips as a part of all internal trips is that trips to home are sometimes included in the denominator and sometimes omitted. Other groups of trips which are also dealt with in inconsistent fashion are the "change-travel-mode" and "serve passenger" trips. In addition, and confusing the picture by another degree, work trips are also reported in terms of their proportion of trips to ultimate, non-home destinations. Thus, for Philadelphia-area data there are three possible proportions, as shown in Table 1. In the table it is seen that work-trips represented 24.6 percent of all trips, 38.8 percent of all trips other than those "to home," and fully 55.6 percent of trips made to an ultimate purpose, other than getting home. Again, it should be noticed that all the above data pertain only to the internal survey.

Another generality may be stated about work trips in reference to central business districts. These trips, as measured by O-D studies, represent about 40 to 50 percent of trips made to destinations in the central areas. There is variation because of differences from city to city, in importance of the CBD. For Detroit (1953), for instance, trips of work-purpose represented fully 52 percent of all daily trips to the area (3).

For Philadelphia (1947), work-purpose trips represented 236,000 of the 545,000

[2] See Glossary for definitions.

internal area trips made to or within the CBD. This represented a proportion of 43.3 percent (4). It should be noticed that the trips described are those made "to or within" the CBD. A great many trips may be made to and through the CBD. So in order to make city-to-city comparison more meaningful, only those trips are considered which have goal activities, or purposes, within the CBD. For Philadelphia, it was found that the vehicular trips of all purposes into and to the central district comprised one-half of the total vehicular trips made into, to and through the district. The latter proportion represents a strong reason for the proposed CBD circumferential loop freeway design for the Quaker City.

TABLE 1

INTERNAL TRIPS BY PURPOSE, PHILADELPHIA AREA, 1947

	All Modes, 1000's of trips	Work-trip Percentage
All trips	3,548	24.6
To home	1,305	-
All trips, less "to home"	2,243	38.8
To change-travel mode	628	-
To serve passenger	47	-
To ultimate purpose (except to home)	1,568	55.6
Work	871	-
Business	83	-
Med.-dental and school	108	-
Social-rec. and eat-meal	323	-
Shopping	183	-

Source: "Philadelphia-Camden Area Traffic Survey," Pennsylvania Department of Highways, et al. 1950.

The care taken above in qualifying data as being applicable in either internal or external surveys may leave the reader with this question: if most of the proportions given for work trips relative to total trips are for the internal area only, to what extent are these proportions changed by including the external trips? Two factors condition the answer to the question:

(a) External survey trips bear no constant relationship to the total of internal and external, but in urban areas of over one hundred thousand population, the proportion in the past has been well under one-fourth of the total. (This proportion is of course dependent on criteria of location of the outer cordon.)

(b) Trips to and from work are counted as work trips in the external survey.

From the two factors above, it may be assumed that work trips in the total of internal plus external trips will be of a somewhat higher proportion than for the internal survey trips only. Little in representativeness of data is lost in inter-city comparisons of internal work-trips proportions only, but comparability is enhanced. Table 2 shows proportional distributions of external trips as measured in two major metropolitan areas.

Mode of Travel

The mode of travel selected by an individual is a personal decision made upon such bases as the condition of available facilities, the relative times and costs of travel by the various possible modes, relative convenience (including waiting times, connections, and walking distances) and possibly, prestige (5). For individuals, the choice is important but not crucial. For cities, the choices made by large numbers of people have become crucial in recent years. The long-term trend toward use of the personal, flexible automobile mode and away from use of public transit, for example, is directly related to the increasing demands placed upon the street, highway and parking facilities of the cities. This same trend has an effect, eventually, upon freedom of choice in sites for housing, commercial, and industrial purposes. Since capacity requirements of both highway and transit facilities are conditioned by peak-period demands, and thus by the demands of primarily work-trip traffic, the modes employed in work trips are of vital concern.

Table 3 indicates the way in which usage of the various modes is distributed in the journey-to-work as measured for a number of cities of varying size in 1951. The dominance of the automobile can be seen in these figures, though the proportion of auto usage is seen to decrease with increasing city population size (where public transit service is more widely available).

Spatial Pattern of Selection of Mode

The evidence available indicates that location within the metropolitan influence area

TABLE 2

PURPOSES OF EXTERNAL TRIPS BY AUTO

Purpose of Trip	Auto Occupants St. Paul-Minneapolis Number	Percent	Percent	Auto Drivers Philadelphia-Camden Number	Percent	Percent
Work	36,151	27.0	50.2	150,433	46.6	56.5
Business	31,036	23.2		32,075	9.9	
Social-recr.	48,626	36.4		95,186	29.5	
Shop	8,012	6.0		19,151	5.9	
Other	9,910	7.4		25,799	8.1	
Total	133,735	100.0		322,644	100.0	

Sources: "Saint Paul-Minneapolis Traffic Survey," Minnesota Department of Highways, 1949.
"Philadelphia Area Traffic Survey," Pennsylvania Department of Highways, 1955.

is a strong determinant of choice of mode used in urban travel. Similarly, the measurable factors which are functions of location (net residential density, distance from city center, income, and auto ownership) are to varying degrees associated with the numbers of daily trips generated from each dwelling unit.

In a study of Philadelphia data for trips to the Philadelphia CBD, it has been reported that specific area patterns in selection of mode tend to prevail throughout the range of trips of all purposes (6). Where a single mode was emphasized, or particularly characterized a section of the city, it was found that the mode tended to predominate throughout all of the trip-purpose categories.

Thus, the purpose of an urban person-trip does not appear as a primary factor in the selection of mode, since the area patterns of mode selected tend to prevail over a number of disparate purposes. Hence, the key to the study of mode selected for trips originating from home is more likely to be found on an area basis. Area characteristics considered to be relevant to some degree in study of modes selected are: auto ownership per capita, income levels, occupation of residents, net residential densities, and location of residence relative to the major centers of destination.

A Study of Spatial Pattern of Selection of Mode

A geographic pattern of selection of public transit for work trips was studied from the specially tabulated O-D data for Philadelphia (1947). The percent of workers selecting public transit was computed for each residence area, and contours of equal percentage were drawn.

All work-trips of origin within the Philadelphia transportation survey area (except for some districts in New Jersey) were grouped according to mode selected: that is, by private vehicle or by public transit. (Taxi trips were grouped with automobile trips.)

The data when plotted turned out to be surprisingly consistent—which indicates, in this instance, that the work trips from residence were either well-reported, or at least that any errors made have geographical uniformity. Thus, it is inferred, the spatial location of residence affects the numbers of trips made per dwelling place (as has been reported elsewhere) and the choice of mode for those trips.

In the study generally, it was found that residence areas of relatively high transit usage on work trips were located radially from the center city along old, well-established transit lines. Transit usage was found to "decay" regularly with decreasing density throughout the area, but along the radial high-speed lines were noted contour

TABLE 3

MODES USED IN TRAVELING FROM HOME TO WORK
SIX STATES, 1951

Mode	Population Size of City: 5,000 to 25,000	25,000 to 100,000	100,000 plus
Passenger Car	64.4	62.8	46.4
Public Transit	4.2	15.7	38.4
Pass. Car and Public Transit	0.9	0.9	2.2
Walk	24.2	17.2	9.9
All other means and not reported	6.3	3.4	3.1
Total	100.0	100.0	100.0

Source: Motor-vehicle-use studies. See footnote Table 4.

"fingers" of a slower rate of decay.[3] As was expected, it was found that high-transit riding for work trips occurred most often in middle- and low-income areas of quite high population density.

At present, the use of transit has declined considerably relative to private automobile transportation in the journey-to-work since the time of the Philadelphia area 1947 O-D survey. For this reason, the patterns described above have little value in terms of absolute numbers. Rather, the goals of analyzing "old" data are to provide a basis against which more recent data may be compared, and more importantly when possible, the finding of pattern and explanation of that pattern in terms of independently measured demographic, social or physical factors. Hence, the sifting and assay of 1947 data is presented with qualification but without apology.

Selection of Mode as a Function of City Size and Trip Length

Table 4 shows summary data derived from a distribution of gainfully employed workers traveling from home to work, with trips classified by mode of travel and by size of city. The original data were gathered by interview method in six states in connection with the Bureau of Public Roads motor-vehicle-use surveys. (The states were Arkansas, Louisiana, North Dakota, Oklahoma, South Dakota, and Wisconsin, and the surveys were made in the summer of 1951.) The full results of the study with data grouped by mile-distance class intervals, may be found in the source listed at the foot of Table 4.

As might be expected, the proportion of persons using transit on work-trips was found to increase with increasing size of city. But slightly surprising was the finding that the average length of transit trip was fully 1.5 miles longer for cities of 5,000 to 25,000 population than it was for cities in the next larger group, from 25,000 to 100,000 population, and one-third of a mile longer than the trips to work in the largest category of cities. Thus, of the relatively few who used transit to go to work in cities under 25,000 population there was a large proportion who took fairly long bus trips to work. The peculiar reversal in trend did not apply when the median lengths were considered. The medians, according to expectation, increased directly with city population size (or more correctly, with increasing extent of the urban area).

The reversal of trend in average trip length occurred also for the passenger automobile mode for work trips, and in the summary data for work trips of all modes. And as with the transit mode, median work-trip lengths increased regularly with city population

TABLE 4

LENGTH OF WORK TRIP AS A FUNCTION OF CITY SIZE SIX STATES[1]: SUMMER 1951

		Population Size of City		
		5,000 to 25,000	25,000 to 100,000	100,000 plus
Public Transportation	Percent of reporting workers	4.5	15.9	39.0
	Average length of trip, miles	4.45	2.93	4.12
	Median length of trip, miles	1.90	2.29	3.28
Passenger Automobiles	Percent of reporting workers	67.7	64.3	47.5
	Average length of trip, miles	4.30	3.66	5.44
	Median length of trip, miles	1.58	2.22	4.00
All Modes[2]	Percent of reporting workers[3]	100.00	100.00	100.00
	Average length of trip, miles	3.35	3.12	4.46
	Median length of trip, miles	1.20	1.89	3.31

[1] Arkansas, Louisiana, North Dakota, Oklahoma, South Dakota, Wisconsin.
[2] Includes the following mode categories: combination of auto and public transportation, walking, and "all other means and not reported."
[3] "Reporting workers" refers to those who reported length of trip. The total of "reporting workers" includes some who failed to report on modes used.
Source: Average and median data derived from information in article by T. A. Bostick, R. T. Messer, C. A. Steele. "Motor-Vehicle-Use Studies in Six States." Public Roads, Vol. 28, No. 5, December 1954. p. 111.

3 The term "decay" is used here to indicate the decrease in an ordinate value of a curve, with increasing abscissa value. The term derives from the physical science usage, for example, the "decay" of an existing electromotive force in a conductor, over time, after interruption of a previously closed circuit.

size for trips by automobile mode and those by all modes.

It might be noted that median transit trip length was less sensitive to variations in city size than was the median trip by auto. Thus, the median transit trip for the largest cities was 73 percent longer than for the smallest group (3.28 miles as compared with 1.9 miles). But the median auto work trip in the largest cities was 153 percent greater than for the smallest group (4.0 miles compared with 1.58 miles).

Amplification of these summary data is given in the original data distribution (see Source, footnote of Table 4). The distribution by distance class indicated that for the smaller cities (25,000 to 100,000 population) few persons selected transit mode for trips of over 5 miles in length. Conversely, for work-trips of over 5 miles in length in and to these cities, the auto and auto-plus-public-transit modes accounted for over 80 percent of the trips made.

The auto mode was not so popular in the larger cities. For trips of under 5 miles length in the cities of over 100,000 population (in the six-state survey), less than half of the workers utilized autos to get to work. For the work-trips of over 5 miles in these cities, the auto was selected by well over 60 percent of the work-travelers in each of the longer distance classes of trips.

Other than the reversals in average trip lengths noted above, the patterns by city size were as might be expected.

Time Characteristics

Considering that the validity of traffic surveys and projections rests wholly upon the repetitiveness of traffic patterns, very little is known of the time characteristics of traffic except for the hourly pattern throughout an "average" day. At least one study shows that the pattern of urban traffic is repetitive over a weekly cycle (7). Seasonal patterns or relation of a given survey period's figures to those for an annually averaged day are study areas requiring exploration. Perhaps even more important are changes in pattern on a long-run, yearly basis.

While not much may be known of traffic behavior over the longer time periods, the variation throughout the typical survey day are known to the point of notoriety. Work travelers themselves may be poor accountants of the time and costs of their trips on a cumulative basis, but they are all quite aware of the "crush hour."

Many are familiar with the two-peaked graph of the hourly distribution of traffic volumes passing a given point (such as a cordon station). These are the peaks which determine capacity requirements of facilities, and represent the time during the day of work-trip dominance. In Detroit, for example, it has been found (1953) that fully 90 percent of the morning peak-period traffic, and 78 percent of the evening peak-period traffic was composed of vehicles en route to or from work places (8).

The hourly peaking characteristic of work trips sets the tone of the interrelationship between vehicular traffic and the physical facilities employed. Trips between home and work in Sacramento, for instance, required 12 percent more time than trips of other purposes in traveling equal distances (1947, 9). This greater friction of peak-period congestion may be inferred from the sharply peaked hourly time distribution of the journey-to-work.

Similarly, traffic measurements made in St. Paul (September and October 1949) showed that 45 percent more distance was covered in the first 15 minutes of travel from the CBD in the off-peak as compared with the peak-period of traffic flow. The equivalent figure for Minneapolis was 18 percent (10). The retarding effect on traffic of the great volumes of workers who travel at the same time is evident in these figures.

Nature of the Data Presented

The description of this section is sparse. Omitted, for example, are discussions of time trends in selection of mode (the trend toward greater automobile usage is well known), effects of auto ownership, income, average rental, and net residential density in selection of mode. However, time and space for this presentation are limited, and materials selected for presentation here indicate some vital characteristics of the journey-to-work.

SOME CONCLUSIONS AND IMPLICATIONS

This section presents some general statements on the journey-to-work, on planning techniques, and some implications of the research study. Detailed studies from which these three topics were developed have been omitted by reason of space limitation. These studies will be available this year from the Institute for Urban Studies.

Perhaps the best general statement which has been made of the journey-to-work is the following:

"People tend to minimize their journies-to-work, maximize their employment benefits, and maximize their residential amenities" (11).

This description incorporates the Zipf concept of minimization of travel effort in regard to length of trip, and also states the operative factors which influence the specifics of home or work place selection within the distance limits imposed by the Zipf approach (12).

Again, as Renyak pointed out, the general statement above becomes an empirical theory to the extent that relationships among work place and residence areas are developed and hypothesized, and more specifically, that relationship is found among numbers of jobs in work place areas and the numbers of employed persons routinely traveling to those jobs from particular residence districts.

Generalizing about the journey-to-work is based upon assumptions concerning the statistical behavior of individuals. Considering such seemingly non-free-will behavior has a flavor of abhorrence to most people. But the probabilistic bases of generalizing about behavior assume essential freedom of choice of each individual. The financial health of the large insurance companies is a demonstration that the generalities work. That behavior is describable in this way need not be redemonstrated here. An abundant literature exists on the subject of patterns of human "interacting" over geographic space.

The literature contains several generalizations and summary statements about travel to work place destinations. Three are given below:

1. (a) "Total urban area population is residentially distributed about the central business district of the principal city. The residential distribution of persons employed in central districts tends to approximate that of the entire urban area population."

   (b) "Residences of persons employed in off-center work places are concentrated most heavily in the immediate vicinity of the place of work." J. Douglas Carroll, "The Relation of Homes to Work Places and the Spatial Pattern of Cities." "Social Forces," Vol. 30, No. 3, pp. 271-282, March (1952).

2. "Each (manufacturing) plant draws workers from each of the distance zones in accordance with the number it employs—the larger the plant the greater the distance from which it attracts workers." Leo F. Schnore, "The Separation of Home and Work in Flint," Institute for Human Adjustment, University of Michigan, (1954).

3. "The dominant role of zone 1 (CBD) as the employment centre for all of Metropolitan Toronto can be seen very clearly... (from the data). From all but one of the 10 significant zones and all but two of the 7 others more than one-third of all employed residents traveled to work in this centre... In seven of the ten significant zones, over one-half, and in three, over two-thirds of all (employed) residents commuted to the central zone. The percentage appears to depend partly on the distance from the centre... and partly on the excess of (employed) residents over jobs in each zone." H. Blumenfeld, "Memorandum Re Characteristics of Work Trips." Metropolitan Toronto Planning Board, (1957).

In the current studies being reported on, regular patterns were found for the proportional distributions by mile or time-distance rings of work place destinations about residence loci and conversely of residence origins of workers about work place centers of confluence. These were studies of the relationship between a trip-origin or trip-confluence center and its surrounding field of influence.

The studies were based largely upon graphical analyses and were of two general types: one gave a proportional distribution by distance rings of the total trips leaving or arriving at the locus of study; the second type considered the "per capita" proportion arriving at a destination from each distance ring. The first type is the easier to calculate, but is also of lesser significance. It is considered in the first four statements below. The second group of studies, employing the "per capita" approach, has meaning in terms of studies of "interacting" between centers of influence in a demographic gravity field (13, 14, 15, 16, 17). Tests of correlation and significance thereof for plotted data have not been applied in all instances. Still it is believed fair to make statement 5 below based upon partial testing and apparent uniformities in plotted data patterns.

Agreement is found between the data of the present studies and the three quoted statements above in these ways:

1. There is an apparent consistency in the decay of numbers of workers commuting to work places in a given city, with each mile-ring of increasing distance.
2. The volume scale of the work place dictates the absolute numbers of workers drawn from each distance ring, but the forms of the distribution curves in the same metropolitan area will be similar at a given point in time. Important factors affecting local variations in shapes of these curves include location of work place (central or outlying), and the consequent proportional use of transit by employees.
3. Because of the greater absolute numbers of workers drawn from each distance ring by places with large volumes of employment, the probability of drawing some workers from quite long distances increases with the volume-scale of the work place.
4. Measurable characteristics of the origin areas (net residential population density and distance from city center) relate roughly to work-trip percentile distribution patterns from origin areas.
5. Persistent patterns are discernible for the proportions of work trips bound to a particular destination of all work trips leaving origins in each mile-distance-ring about that center.[4]
6. Location of employment destinations in relation to city center and job density of destination area may be relevant to the form of the distribution function in statement 5, but neither factor has been adequately tested.

The first four statements hold interest for their descriptive value relative to housing and labor markets. They aid in description of the volumes of persons traveling varying distances between homes and work places in terms of percentile and median values.

The fifth statement has the greatest analytical value for its eventual applicability in describing the potentials for work-travel to destinations from a total residence "gravity field."

Thus, several of the statements immediately above are considered to agree with and amplify conclusions made in the past concerning patterns of distribution of residences in relation to work places, and therefore of patterns in trips between them.

Analysis and Planning Techniques

Consideration of three factors is basic to description and detailed analysis of urban transportation patterns.

1. Distribution of origin trip-ends.
2. Distribution of terminal trip-ends.
3. Distribution of trip among origins and destinations.

Until only recently, urban traffic analysis consisted primarily of study of the third item above, the distribution of trips only. Lately some attention has been focused upon

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[4] On log-log scale, distance as abscissa, curves which may be fitted to the data include straight lines, and parabolic arcs warped concave-downward. Statistically the "fit" is fair but significant for the straight-line examples tested. Curvilinear patterns appear quite consistent but are as yet untested. Data developed in this manner are for Philadelphia and Toronto.

the first aspect, origin of trips from residence areas. But consideration of special characteristics of terminal trip-ends has been given only sporadic attention, most notably in consideration of the special case of the central business district as a locus of terminal trip-ends.

As analysis techniques improve, fairly complete synthetic models of past and current systems of travel appear quite possible. Means are to be sought to explain changes between the older and the more current descriptive model. As such changes can be related to independent measures of social, economic, and urban structural change over the intervening years, means will be found for developing synthetic models of future transportation behavior. The work described in this report is largely concerned with useful description of transportation patterns at single points in recent time. From such description usable predictive techniques may be developed as travel data for more than a single point in time become available for individual cities.

A current practice in forecasting travel patterns is to multiply current trip-interchange data by various factors of expansion to obtain the relationships among future trip-origins and trip-terminations. This practice is expedient and probably necessary at present, but tends toward a perpetuation of existing travel patterns in future plans.

As more clear characteristic patterns can be found (and described) about the centers of dispersion and confluence, the possibility for a synthetic and, thus less biased, model of future travel will be increased. The most fertile field for seeking such patterns is in the journey-to-work, for reasons of scale and completeness.

A procedure may be roughly described to illustrate the application of the preceding ideas. The development of an analysis model of the future might be considered in these steps:

1. Prepare origin and terminal trip-end data for each area unit, based upon current information.
2. Develop inter-relationships of area-units through gravity formulations, utilizing varying constants, weights for individuals, and varying exponents for systems of trips, location of area units, etc. Where functions are excessively complex, apply graphical solutions.
3. Modify trip-end and trip-exchange data in terms of independent forecast measures.
4. Test work-trip production and interchange findings by means of graphical distribution analysis.
5. Test total trip-production and distribution findings by means of derived relationships between work-trip systems and other systems of travel.

In development of such tecnhiques, it is likely that graphical studies will provide the "bridge" to more detailed analyses. Graphical distribution studies have additional value in their greater likelihood of usage in local applications as compared with abstruse formulations to which research time but not applied field time can be given, other than in the exceptional examples of multi-million dollar survey and planning efforts. More importantly though, the graphical analyses can lead the way toward generalization in algebraic formulation. Where an indication of consistency of pattern can be found, and where a logical basis exists for selection of a particular type of equation, then further and more detailed study by researchers is probably warranted.

In the long-term development of this type of analysis, mathematical gravity concepts of trip interchange appear to hold the greatest promise for improving predictability of systems of urban travel. Problems in applying this formulation reside in determining multiplier constants, weights for individuals, and/or exponents. But whether or not a solution is sought in terms of varying negative exponents of distance[5] or of weights for individuals, the function of intervening distance, $f(d_{ij})$, is not to be interpreted as the same function throughout the metropolitan field. The function of distance is variable over the metropolitan field depending upon such factors as purpose of trip, and location of at least one of the two zones (origin and destination) in each combination (18).

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[5] "Journal of the American Institute of Planners, article by Carrothers (16).

Needed Data Accumulation and Research

A major need in origin-destination travel surveys is for separation among the systems of work travel in development and presentation of the data. This refinement among the three systems will aid trip-end analysis, and help in study of completeness of reporting by increasing the comparability of employment and residential labor force data with trip-production information.

Another helpful source of needed information would result from inclusion, within the decennial or special census surveys, questions concerning area of workplace, and time and mode of travel.

In cities where the building inspection program is maintained on a current basis by a consistent program of residential inspections and interviews, it may be found possible to include a question or two on work place of wage-earners to help in developing and maintaining a current file on journey-to-work patterns, and thereby indirectly cross-reference information which may aid in analyzing total travel patterns. The latter point would become more meaningful if the city area in mapped representation is divided into a number of planning analysis areas, with the boundaries of these to be regarded as cordon lines. Thus, with a continuous traffic-counting program, it could become possible, eventually, to relate current traffic counts to current trip-generation information. Given this degree of understanding of city-wide trip generation, planning for future anticipated needs could attain new levels of closeness to actuality. Similarly, better dealing with the problem situations in dense traffic areas might be made possible as control could be moved back closer to trip origins. (To get this point out of the "cloud level" of theorizing, the analogy might be made to the local check-dam approach to flood control as the sources of ground water in the water-shed areas become known, in contrast with expensive high-dam control at a point of great depth or density of flow.) Controlling traffic problems at point of maximum conflict is essentially an after-the-fact approach (19).

Careful studies of production of origin trip-ends in relation to residence indicate the present status of auto-ownership levels as the principal input data for explanation of variations in total trip generation per dwelling unit (20). In the immediate future, as suggested by authors of the HRB paper, it would appear highly desirable to improve the available information on auto ownership for travel forecasting purposes. This form of ownership is completely regulated by state governments. It should not be impossible to establish and maintain in local transportation planning offices, current information on total vehicle ownership ty type of vehicle, and by census tract of residence or place of business of the registered owner, or of registered user and partial owner (in the prevalent situation of installment purchasing). However, a very important question for transportation planning is how long the "prediction" value of auto ownership will continue into the future. As auto ownership levels become more nearly equal over time, as the physical character of cities change, it may be found that auto ownership will be relegated to the place of a transient factor in explaining trip production. The question then becomes: are auto ownership and trip production two effects of the same cause? Can one seek further into the propensity to travel in order to be prepared for saturation levels of auto ownership?

Not as a solution to the problem posed above, but as an independent consideration, another type of research is described here. It is believed to be of a lower priority as a problem than others named. The suggestion is toward development of an aid which could be helpful in improving predictability of peak-period travel. The point is that a number of indicators are available to show person-miles of travel by the several modes in all United States cities. Preliminary examination shows that variations in total urban person-miles of vehicular travel (auto, transit, taxi, railroad commutation) may be shown to be closely associated with variations in a series of annual indices of industrial production and of non-agricultural employment (21). Now in an expanding economy, some indices may be found which plot over time with startling appearances of correlation (aspirin production versus new housing starts, for instance). The point is that a logical basis must exist for a given relationship study. Nonetheless, it is reasonable to suppose that some part (at least) of urban vehicular travel, taken in summation as vehicle-miles and/or person-miles may relate over time closely to certain measures of the level of local economic activity. It is also reasonable to suppose that the components of urban travel which would have the greatest relevance in this relationship would be the systems of work-travel. What then appears as a possible form of urban research, is a time-series analysis of total work-travel and indices of urban or regional economic activity. From this might be developed a means of roughly estimating the total future peak-period demands for urban vehicular travel, in terms of street transit, taxi, and commuter-rail capacity.

The assumptions necessary in such an approach are at present gross and the refinement difficult. The possibilities of this research avenue, even if only to supplement other and (hopefully) independent forecasts, should not be discounted, even though it represents a different approach to anticipating urban circulation requirements.

Repetition will not be made in this summary of problems posed in the previous section concerning gravity formulations of urban travel. However, one additional question is raised: that of whether or not to seek relevant "weights" for individuals by purpose of trip and zone characteristics, or to continue to seek solely for gross multiplier constants and exponents of the population and distance measures.

CONCLUSIONS

The foregoing discussion of "systems" of work-trips and their analysis, it is hoped, has awakened in the reader a wider concept of how the "ore" of available traffic data may be further sifted and refined for information useful in understanding the workings of urban circulation and in planning for its improvement.

GLOSSARY

It has been found desirable to adapt terminology and to propose a few new terms in order to deal in detail with work travel as measured in O-D and motor-vehicle-use surveys. All trips referred to are those made by individuals (person-trips) rather than those made by the vehicles.

Work-trip: A work-purpose trip as defined in connection with Bureau of Public Roads format O-D surveys. This is a trip to location of place of gainful employment, or to locations which must be visited in the course of an ordinary day's work.

Home-work trip: A trip made from residence to a work place by a person going to perform gainful employment.

Work-home trip: A trip to a person's residence from a place where his gainful employment is pursued.

Other-work trip: A trip made from work or other non-home location in connection with regular activities of a person's gainful employment.

System of movement:[6] A broad pattern of movement that is functionally related to an organized activity of business or other social action.

Journey-to-work: The two systems of movement in a city or metropolitan area, comprising all "home-work" trips and all "work-home" trips.

Work-travel: The three systems of movement in a city or metropolitan area, comprising all "home-work," "work-home," and "other-work" trips.

Central business district:[7] A district which is arbitrarily determined for planning purposes as the locus of the greater part of commercial activities within a city and constitutes an area of very high land values. In it are located many stores, service establishments, offices, hotels, and theaters. It is an area of high daily accumulation of persons and vehicles.

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[6] From Mitchell and Rapkin, op. cit., p. 218.

[7] Definition is expanded from that given in a U.S. Department of Commerce publication: "Central Business Districts and their Metropolitan Areas...," Office of Area Development, November 1957.

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A Method of Traffic Assignment to an Urban Network

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● THE CHICAGO Area Transportation Study was given, as a prime objective, the task of developing a plan for new transportation facilities for the Chicago urban region. Since an unlimited number of plans or variations of plans is possible, the search clearly must be toward the one that is best or near-best.

Judgment of a plan involves many considerations but foremost is the measure of service the proposed new network of facilities will provide for future travelers. One of the tools for making such measures is traffic assignment. This involves the allocation of travelers moving between specified zones of an urban region onto particular travel routes. Having assigned every trip to a route, the level of service of the proposed network can be evaluated.

This allocation of trips is often a very complicated and time consuming task. In the Detroit Study it was possible to do this for a proposed expressway network in a period of from three to four weeks (1). This method gave useful information and did so within a reasonable time period, considering the magnitude of the task, but there were shortcomings. Only express routes received assigned volumes, whereas, in order to provide the greatest utility of the results, the loads on the surface arterial streets should have been known. Obviously, it would be questionable strategy to build an express route in a location where the surface streets could provide adequate service. A second shortcoming in the Detroit method was that it did not allow for assignment of travel to public transit routes.

In the planning of the Chicago Study, much effort was devoted to the development of a method which would rapidly assign travelers to the surface arterial streets as well as to express routes and also to rapid transit and surface transit routes. This was a particularly difficult problem because of sheer magnitude. The following measures will give some scale to the size of the problem:

(a) Six hundred thirty zones in a region of about 2,400 square miles and 396,000 interzonal traffic movements.

(b) A surface street network of 2,500 miles of route with 2,500 intersections.

(c) About 350 miles of proposed new express facilities.

(d) A rapid transit, suburban rail, and bus service network made up of nearly 2,500 route miles.

(e) A 1956 weekday total of over 6,500,000 vehicle trips and nearly 2,500,000 transit trips.

(f) If every possible route between every possible pair of zones were considered, the number of combinations would be greater than the number of atoms in the world.

The method of allocation had to be such that judgment was not involved in the process (that is, anyone using the same assumptions would obtain identical answers) and that the results would be unique for a specified network and a specified population of trips. Above all, it had to be fast for clearly it is desirable to be able to test many different possible plans.

The method selected, after much research, represented a consolidation of ideas from many sources. The beginnings came in a proposal made by Armour Research Foundation staff, working under contract to the State of Illinois on the development of network assignment methods. Their report pointed up the work of Moore (2) who had proposed a systematic and economical method for finding the shortest path through a maze. They also developed a computational program which would accomplish this work on a digital computer (3).

It was obvious that the computer program, as they developed it, could not handle a network of the size specified because the internal storage limits of any known machine were too small and the computational time would have been prohibitive.

Mr. Morton Schneider, Chief Computer Program Planner of the Chicago Area Transportation Study staff, developed an ingenious modification of this minimum path program to bring the traffic assignment within the range of computational feasibility. The elements of Mr. Schneider's method are outlined below, using the highway network as an example.[1]

First, he considers how to represent the street network to the computer. To do this, the key properties of the network were identified:

(a) The network of streets and highways consists of intersections and route sections between intersections.

(b) This network can be mapped so that each intersection is placed at a point in an oblong matrix of points measuring 55 x 95. This allows a maximum of 5,225 intersections.

The following examples illustrate the method of representing the actual street network. Figure 1, shows a portion of the existing street system from the basic network map.

In Figure 2, one can see the drafted form of the same map, converted to a form for

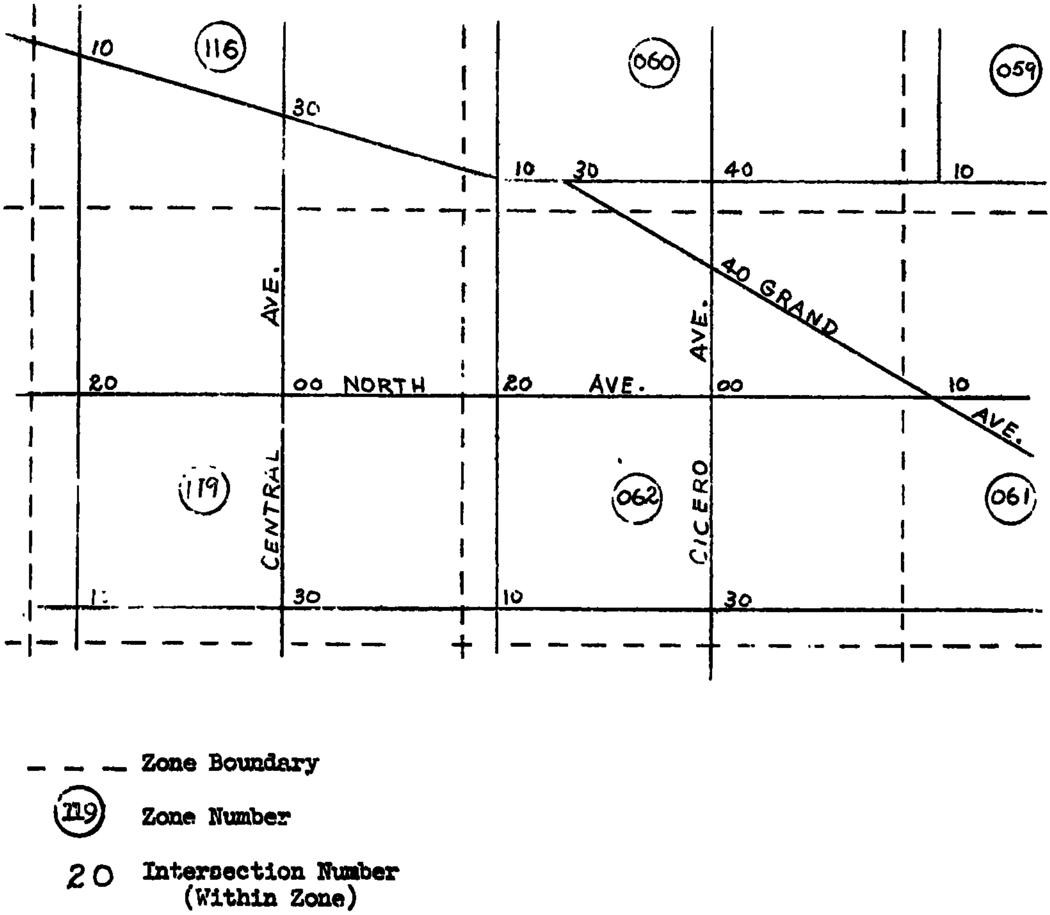

Figure 1. Section of Chicago area arterial street network.

[1] Credit should be given to CATS staff members, E. W. Campbell, E. L. Gardner, L. E. Keefer and P. J. Caswell, who helped to solve technical problems.

coding for representation in the memory of the computer.

Each intersection is given a number representing its location in machine memory and for each such location or intersection it is possible to code to four route sections. This is shown in Figure 3. In this fashion, all intersections have the possibility of interconnecting with their neighbors.

Figure 4 illustrates an eight legged intersection case and shows that with four route sections coded to each intersection, all possible connections in the network are allowed for, that is, any intersection may have as many as eight connecting route legs if it is possible to go from that intersection to each next adjacent one, although obviously the typical intersection will have only four connecting route sections. Now the simplicity of the system appears—the intersection requires no code number. It is simply at a location in the machine, that is, an address, so no use of numbers is required.

The same is true of a route section. At each memory location there is a word. Depending upon the computer used, this "word" consists of a number of possible digits. Assuming ten digits, the first two digits of each word may be used to represent the route

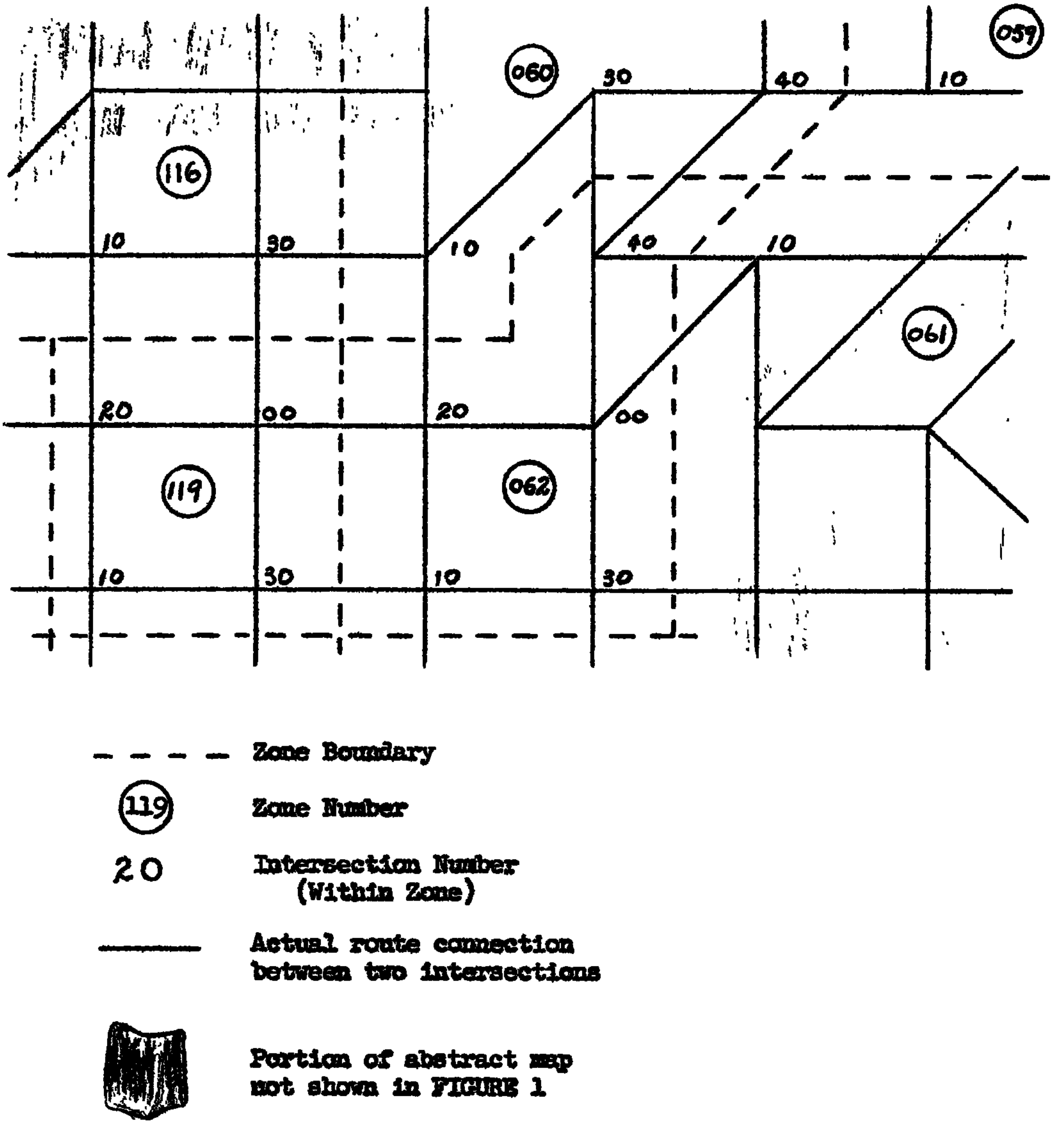

Figure 2. Abstract street network of Figure 1.

section in Direction 1, the next two a connection in Direction 2 and so on. In this fashion a space in a word, in memory, identifies a particular route section of the network.

In the appropriate section of each word, it is possible to code in the unit resistance which represents that piece of the network. In this case, one is concerned with minimizing journey time. (Clearly, cost, distance, or any other measurable factor could be used.) Thus time of travel to the nearest $1/10$ of a minute required to traverse each route section can be read from the coded map and stored in computer "memory." As an example, consider the true intersection, A, which appears in Figure 5. In the word, significant digits are had in the first two locations which indicate to the machine that there is a road leaving the "home" intersection and going to the one stored immediately above. And it shows that 0.4 minutes are required to traverse this route section and reach the next intersection. No road is indicated in Direction 2, a 1.5 minute route section lies in Direction 3 and none in Direction 4. Note that the other two connecting routes are referenced at other intersection addresses. The last two digits of the "word" may be used to mark which route section is part of the "minimum path tree" being computed.

What the machine program does, then is to begin at an intersection which corresponds to a zone center. From this beginning point (Zone 1) the program, using a system of address modification, carries

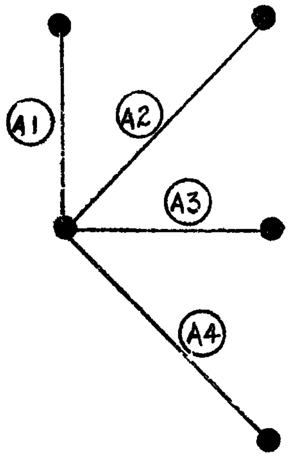

Figure 3. System of route leg identification.

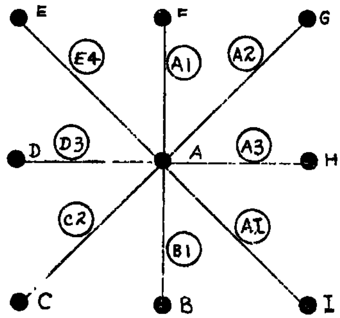

Figure 4. Diagrammatic representation of possible interconnection of one intersection with eight adjacent ones.

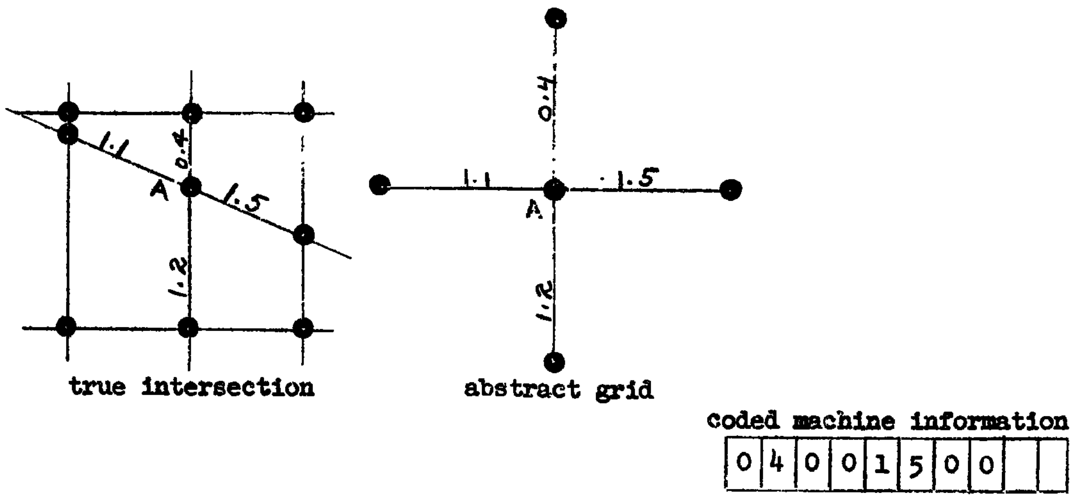

Figure 5. Example of network coding.

out a search of the network proceeding systematically outward from Zone 1 to every other intersection and identifies that route which requires the least travel time. One of the very great time saving devices is the economy of search as Mr. Schneider has designed it. This program insures that the shortest travel route in terms of the measure used—in this case travel time—is shown. Basically, the machine is programmed to search outward from an origin zone identifying minimum path routes successively until the most distant zones have been reached. This is known as building a "minimum path tree." The descriptive term "tree" is used because, starting from one center intersection of a zone, there is one and only one path from that beginning point to each next zone reached. As successively more distant intersections are found, more branches are developed, so that the entire trace of minimum paths identified would seem like a tree with the trunk at the origin zone and with ever increasing numbers of branches leading to the outermost zones.

After the minimum path from one origin zone to all others (that is, a "copy") is complete, the trips from the origin zone to all destination zones can be loaded onto the network routes that have been identified. Each zone thus is taken in sequence and the process is repeated until all zones have been treated and all trips have been loaded onto the network.

This is an over-simplified description of techniques. Detailed coding and machine procedures will be written up in a separate publication. This degree of detail has been used to illustrate the principal elements of coding and logic in using a digital computer for traffic assignment.

It is possible, under this system, to add new routes or to subtract others with a minimum of re-coding. Other features allow the storing of turning movements where these are of significance, or of restricting turns where this is a characteristic of the network (that is, limited access highways or toll roads).

All of the properties of the highway network can be applied to a transit network excepting that many bus routes run on the same street. It seems reasonable, however, to generalize bus service so that it is analogous to arterial streets and to code rapid transit and railroad routes like separate expressways. In this fashion, special assignments can be made to a large and complex network of transit routes.

Criticism of Method of Highway Assignment

A number of significant questions have been raised about this system of traffic assignment. The two principal ones are: (a) that this is simply the old "all or nothing" method which was displaced by the diversion curve and (b) that this will give highly artificial or unrealistic results.

Critics of this approach as being only the old "all or nothing" method point out that empirical research has shown that travelers between a pair of zones will split in their selections of route so that assigning an entire zone-to-zone movement to a single route is false.

There are a number of facets in the reply to this criticism. First, there is the simple matter of scale. In the Chicago area there are 630 zones and an average weekday travel volume of about 6,500,000 vehicle trips in 1956. Since there are 396,000 directional pairs of unique zones possible, the average movement will be about 16 trips and since sample data are used, this is less than one sample per zonal pair. It, therefore, seems ridiculous to split each transfer onto alternate routes.

Historically, the proportional allocation of zonal transfers came about because large zones—both geographically and in terms of trip volumes—have been used. Clearly, for example, if one is assigning a single driver to a network for one trip, he must take one, and only one, path. It can easily be shown that the more detailed geographic dispersion of zones will produce a substantial distribution of loads between the various competing routes.

On the other hand, tests have shown that some routes, because they do not connect directly to zone centers and/or because they have been given somewhat lower levels of speed than alternate streets, do actually come up with no trips allocated. This may indicate a more complex network than is justified in terms of the number of zones and more work is needed to evaluate the appropriate balance between network complexity and zone size. But it is also likely that streets with no assigned volumes represent a significant result and should be there to illustrate particular weaknesses in the network or in the value of speed given to those sections of route.

Those who have advocated diversion curves for use in traffic assignment have done so to meet the requirements of designers who ask the traffic engineer to tell them how many vehicles will use a ramp or a facility in the peak hour. The use of these empirical curves may be useful for such assignments to an already determined line.

But it is also possible that diversion curves are wrong. They have been established by making observation of an existing system's usage. Naturally, such systems tend to be in traffic equilibrium —that is, "traffic seeks its own level." It follows, therefore, that diversion rates are a function of the capacities and traffic pressures in the region being examined. If the expressway being measured for diversion had either fewer or more lanes, it seems quite clear that correspondingly greater or less traffic would use it and, therefore, diversion rates would change. For example, if the Shirley Highway (5, 6) had been built with six instead of four lanes, is it not possible that a different diversion rate would occur? The same comment would hold true for the competing surface route which is used to calibrate expressway diversion rates. Therefore, it is quite likely that route choices are very heavily influenced by the precise situation being observed. If this is so—and it must be true in some degree— then where is the value of using a diversion curve for assignment and which of many different curves should be used.

If it is argued simply, that travelers are non-rational in route choice and, therefore, it is better to use a diversion curve to estimate these non-rationalities, that again makes little sense. It suggests that there is a feeling that accuracy is increased simply by using a device to disperse groups of events about a mean or average answer. This certainly is not calculated to increase accuracy in such cases. Referral, incidentally, to most diversion curves shows that where journey times on two competing routes approach equality, the diversion rates approach 50 percent—that is, half of the trips use each facility. This appears to lend support to the "all or nothing" approach which merely says to use whichever route is superior. Final results from this "all or nothing" method would be very similar to those obtained by using a diversion curve which indicated a 50 percent split of traffic when the two competing routes used were equal in respect to the determining criterion.

In sum, there are quite apparent and inherent weaknesses in diversion curves as they are developed and used today. One of the greatest is that such curves provide an answer which is unrealistic by definition and yet is assumed to be correct. Therefore, the analyst does not truly know what he has obtained because the elaborate construction of the diversion curve merely produces an answer.

The second major criticism of this proposed method is that the results are "unrealistic." In other words, critics say that certain sections of the network will have no traffic while others can achieve loads well above their "capacity."

This raises the significant question of the true purpose of traffic assignment. To answer this criticism, it is necessary to distinguish between the simulation of traffic flow and traffic assignment.

A simulation of traffic flow would, if properly done, produce a result identical with the current usage of the urban network. In other words, the result of accurate flow simulation would be a current traffic flow map. Since drivers will seek to find the best travel path to their destination, congestion will be avoided and no single route in the urban system is likely to be severely congested while adjacent routes are free. There is very strong evidence that journey time is inversely related to rates of flow and travel times vary with changes in volume. Thus most urban systems appear to have a kind of equilibrium of flow as of any one time. It is likely that the destination and route of travel are both determined by the network and its level of usage.

To the planner, then, the extent of driver diversion is not visible on a traffic flow map and it is quite difficult to read the need for improved routes where the overloads are evenly distributed throughout the system. In short, needs cannot be determined by reading a traffic flow map. It is precisely for this reason that origin-destination data were collected.

It is possible to confuse a request for realism with traffic assignment as it can be of use to the planner. The planner needs to know where an improvement in capacity will do the most good. This method of traffic assignment by being "unrealistic" is able to magnify the points of great system stress and thus insure most judicious placement of improvements.

Also, when a plan is finalized, this method can be modified so that capacity restraints are introduced to the network and trips are diverted from congested to alternate routes, thus more realistically simulating predicted usage. In this fashion, capacities can be dealt with explicitly and the extend of diversion caused by capacity constraints can be measured. It is of substantial interest to note that this cannot be achieved by diversion curves. They are not sensitive to capacity constraints excepting those which were in effect when these curves were empirically established.

There are some other unique features possible with this system. Since the machine program computes the journey times from a single zone to every other one (that is, a "copy"), the elapsed travel times between that zone and the others are on hand in the computer memory, available for instant use. Knowing that trips are made from any zone to possible destination zones, in ascending amounts as the number of trip destinations at the receiving zone increases and in descending amounts as the time or distance of travel increases, (6) it is possible by stating such relationships mathematically to compute zonal interchange volumes as they are needed to allocate trips to the network. This eliminates the great problem of storing data for some 396,000 possible zonal pairs and greatly speeds up the entire process of assignment. This is especially useful for future traffic assignments because zonel interchanges are calculated as needed and reflect and space time system created by the new network. While much work can be done on the question of the appropriate method of computing zonal interchanges, this system has the advantage of allowing the changes in the network of streets to be used in calculating new travel interchange. Thus, wherever street improvements change the relative nearness of any pair of zones, it is possible to adjust travel frequencies in the direction indicated by present behavior patterns. This could be called "generated" traffic, although in this system it would be re-directed or diverted. It is believed that this is, in the long run, a more sensible way of computing future zonal interchanges than the current iterative methods in use.

Results of Tests Using This Method.

It was found that 6,500,000 auto trips could be assigned to the complete express and arterial network of the greater Chicago region in about 11 hours, using an IBM 704 computer with 32,000 words of core memory. The input to the machine consisted of 5,225 data cards to represent the existing network, 630 cards representing zone totals, and the program deck.

One copy (that is, the computation and identification of the shortest path from one zone to all others) requires about 30 seconds, the calculation of the interzonal transfers requires about four seconds, and the loading of the interzonal trips onto all route sections used requires from 10-80 seconds. Altogether, one complete copy which calculates and assigns all trips from one zone to all others is accomplished in an average of about one minute. By hand, this would require about five man-weeks, require extensive mapping and be subject to human error. Thus, a conservative cost for a man to do one copy by hand would be about $450. One copy on the machine costs about $10.

The output of the machine is a fully loaded network punched out on 5,225 cards or less. In addition, the total vehicle miles of travel are known and the total trips generated for each copy reported. All turning movements into, out of, and through the expressway network, are separately tallied. The entire assignment for the Chicago region was accomplished in one day. Future assignments can be completed in somewhat less time.

There are still many possible refinements in technique, but this particular system seems to go in the direction wanted—that is, rapid assignments at reasonable cost so that continuing tests can be made of route modifications.

One last point is of great significance. It has been customary to make traffic assignments to a single route. This is known to be inaccurate because the change of one route will create echoing changes in travel volumes throughout the entire network. It follows, then, that any traffic assignment to a single route would best be made if the entire network were treated and there were some adjustment in zonal interchange volumes. The speed and the methods outlined do go in this direction.

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Land Use Projections For Predicting Future Traffic

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● FORECAST is a fearsome word. Some soften it by referring to the process as estimation; others provide a wide range of conditions and then refrain from choosing a "best" or "most probable" condition. The very brave simply decide on the future and require no graphs or charts to bolster their choice.

Regardless of the name or process, anticipation of future events, and planning for them, is necessarily and regularly practiced by people and organizations.

There is no shortage of brave men in the field of transportation planning, but courage alone will not provide adequate forecasts of future traffic against which proposed facilities can be tested. Ideally, one should know all of the factors which are related to traffic, understand how these factors have been changing through time, and anticipate technological changes which will be significant.

The outlook for achieving the ideal is not too bright; one may never expect to know the future so precisely and must concentrate on approaches and techniques which temper boldness with caution and attempt to scale problems, set limits, and avoid gross errors that result from the extrapolation of imperfectly understood relationships.

Although knowledge of traffic is far from ideal, a strong case has been made for examining traffic in terms of land use. The order of presentation is as follows:

(a) To describe the relationships between land use and traffic which indicate that land use forecasting is a logical basis for estimating future traffic.

(b) To describe the land use survey which is essential to develop the relationships necessary for forecasting.

(c) To describe land use forecasting techniques.

LAND USE - A BASIC MEASURE OF TRAFFIC

Land use is the name given to the activity taking place on a site. There are the factories, stores, schools, homes, etc. Taken collectively, these activities or land uses form the structure of the community.

Each site is characterized by the kind of activity or land use, the intensity of use, and a location with respect to all other sites. These characteristics largely govern traffic within the community.

The kind of land use determines the kind of people or materials which will go to a specific site. Steel manufacturing sites will attract steel workers. A shopping center will generate shopping and work trips. The intensity of land use and the number of persons it will attract are also highly related. A multi-story department store will experience heavier traffic than a single story store. Dense residential neighborhoods will generate a greater number of trips per acre than will low density suburbs.

The location of a site with respect to all other sites describes the distances which must be traveled by trip makers coming from other sites. Given the transportation channels, the location of the interacting sites will also determine, to a larger degree, the volume of traffic on the streets.

If the various activities of the community are thought of as competitors for the available sites, the most desirable sites should receive the highest bid. But the higher the cost of the site, the more intensively the successful bidder must use his site, generally resulting in multi-story structures.

The most desirable sites, typically, are those which are most accessible to other sites. In a hypothetical city with flat terrain, the central point is the most accessible to all others. If movement is restricted to roadways, and these focus on the central business district, the advantage of centrality for accessibility is increased.

Peripheral sites lacking in access to all others fall at the other end of the bidding distribution and typically are developed at lower intensities which, for residential uses, means lower densities.

There are advantages in locating centrally but the costs are higher. Certain land uses, typically, seem to be able to afford these costs better than others because of a higher return from the location.

There is a balancing of advantages derived from central siting against the lower site costs but higher movement costs. The actual factors may be numerous and complicated but, most simply stated, the process is one of competition relative for centrality in sites which by definition are limited in number. This competition results in the selection of the kind of activity which can locate profitably in a given location and it determines the intensity of use at that location.

The process also has a time dimension. All of the parameters governing the siting process may be changing in accessibility which has resulted from improvements in transportation technology. The flexibility provided by the automobile has brought a tremendous number of potential sites within easy travel range of the community. This has been associated with development of low density suburbs and the so-called "scatteration" of urban activities.

Developed sites, however, are resistant to changes in accessibility and change only gradually through time. The extremes of central land use intensity found in cities like New York and Chicago have withstood the decentralizing effects of transportation advances, but their recent suburban growth is more typical of the low density developments characteristic of such cities as Detroit and Los Angeles.

In summary, forecasting future traffic is necessary to transportation planning. While there are a variety of ways which could be and have been used to forecast traffic, the most reasonable basis is a land use forecast because traffic is movement between different land uses and land use is relatively stable through time.

In approaching the problem of forecasting the future land use distribution, it is necessary to consider the interplay of the factors of kind of land use, intensity of land use, location with respect to other land uses, and the impact of possible further reduction in the friction of movement within the structure.

A complete and accurate land use inventory is necessary to measure the current distribution of land uses, the intensity of use, and to establish the relationship of traffic to the land use structure. To fulfill these requirements the classification system, unit of measurement, collection units, and identification and processing must be considered carefully.

MEASURING THE LAND USE STRUCTURE

The two basic uses of the land use survey in transportation planning are to provide data for analysis of traffic generation and to establish a base from which to estimate the future land use structure of the area. To fulfill these requirements the following factors must be considered:

1. Classification System. The land use data should have sufficient detail to distinguish between extremes in terms of traffic generation and still be suitable for forecasting purposes. A minimum classification should include residential, manufacturing, public building, public open space, commercial transportation and utilities, streets and alleys, and vacant land. Additional detail in commercial and manufacturing is desirable.
2. Scaling Land Use. Possible measures of land use are dollar sales, employment, population location and density, land area, and floor area. Of these, net acres in use is most appropriate except in the CBD and possibly some additional commercial centers, where, because of the prevalence of multi-storied structures, floor area measurements should also be collected. Land area measures are particularly significant for the vacant land where the bulk of the future growth in activities will take place.
3. Geographic Units of Collection. The land use must be collected in the same areal

unit or units which are reconciliable with the traffic analysis zones. In addition, the O-D survey should also identify the land use of trips at the origin and destination, using the same classification scheme as the land use survey, so that trips and land use may be compared directly.

4. Identification and Processing. A field inspection generally will provide the most precise identification, but can be expensive. If a field listing operation is required to obtain the O and D samples, the land use survey may be incorporated into this operation (this is being done in Pittsburgh). The Chicago survey obtained highly satisfactory data using secondary sources such as Sanborn maps, utility meter cards, telephone criss-cross directories, etc.

For those portions of the area covered by zoning ordinances, the zoning classification of vacant land should be recorded for use in estimating future potential use.

The use of punch card techniques is essential to processing and manipulating the inventoried land use excepting in smaller communities.

The use of a coordinate system of geographic coding will permit very flexible manipulation including mechanical mapping and calculation of distances.

RESULTS OF THE LAND USE SURVEY

The conception of the organizing influence of central location on kind of land use and intensity of land use can be examined empirically using the land use data collected for the Chicago Area. One would expect non-residential activities, and especially commercial land, to be concentrated in the CBD, with residential land occupying a greater proportion of all land as distance from the center increases.

The proportion of each of six land uses of all land in use—excluding vacant and public open space—by 2-mile rings from the center are shown in Figure 1.

The conception of a central core of specialized, non-residential activities is confirmed by the distribution of land use. The commercial category is heavily packed in the CBD, and declines rapidly to ten miles where it levels off at about 3.5 percent of the land.

Residential land is practically excluded from the central area but increases rapidly just outside the core to about eight miles from where it fluctuates around an average of 41 percent.

Another way of observing the distribution of land uses from the city center is shown in Figure 2. Here the land use data are presented in the form of ogives which give the cumulative percentage of distribution of land use, by distance. Fifty percent of the total land area of the Chicago Area Transportation Study falls within a radius of 19 miles and 50 percent beyond. In contrast, 90 percent of the manufacturing land, 85 percent of the commercial and transportation land, 75 percent of the residential land, 70 percent of the streets, 60 percent of the public open space, 66 percent of the public buildings, and only 26 percent of the vacant land are located within a radius of 19 miles.

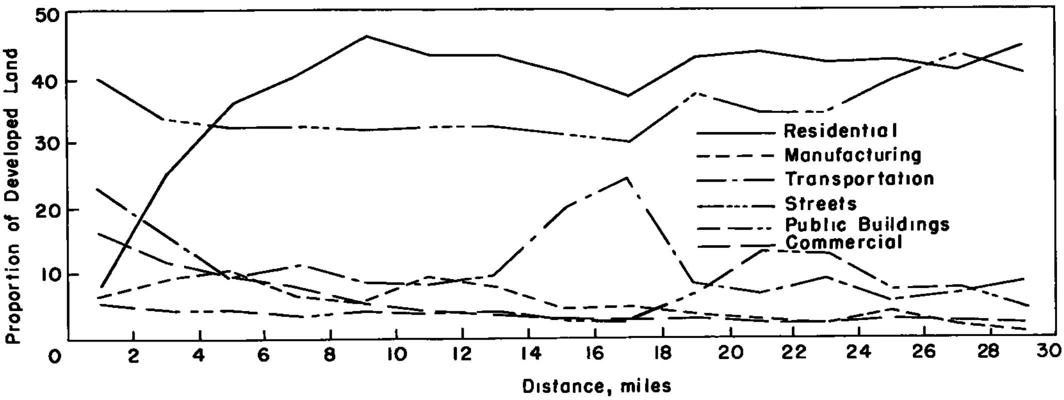

Figure 1. Land use proportions by distance from the CBD-1956.

These measures of land use proportions confirm the expected pattern of an orderly array about the city center with the non-residential uses preempting the central sites. The element of intensity of land use, however, has not been considered. Intensity is particularly important for anticipating future land use; the amount of land required by a given activity can vary significantly from place to place within the urban structure. In certain parts of Chicago a square mile of land devoted entirely to residential use will house up to 100,000 people while in other locations this figure may drop to as low as 10,000. By combining population data with the amount of residential land by

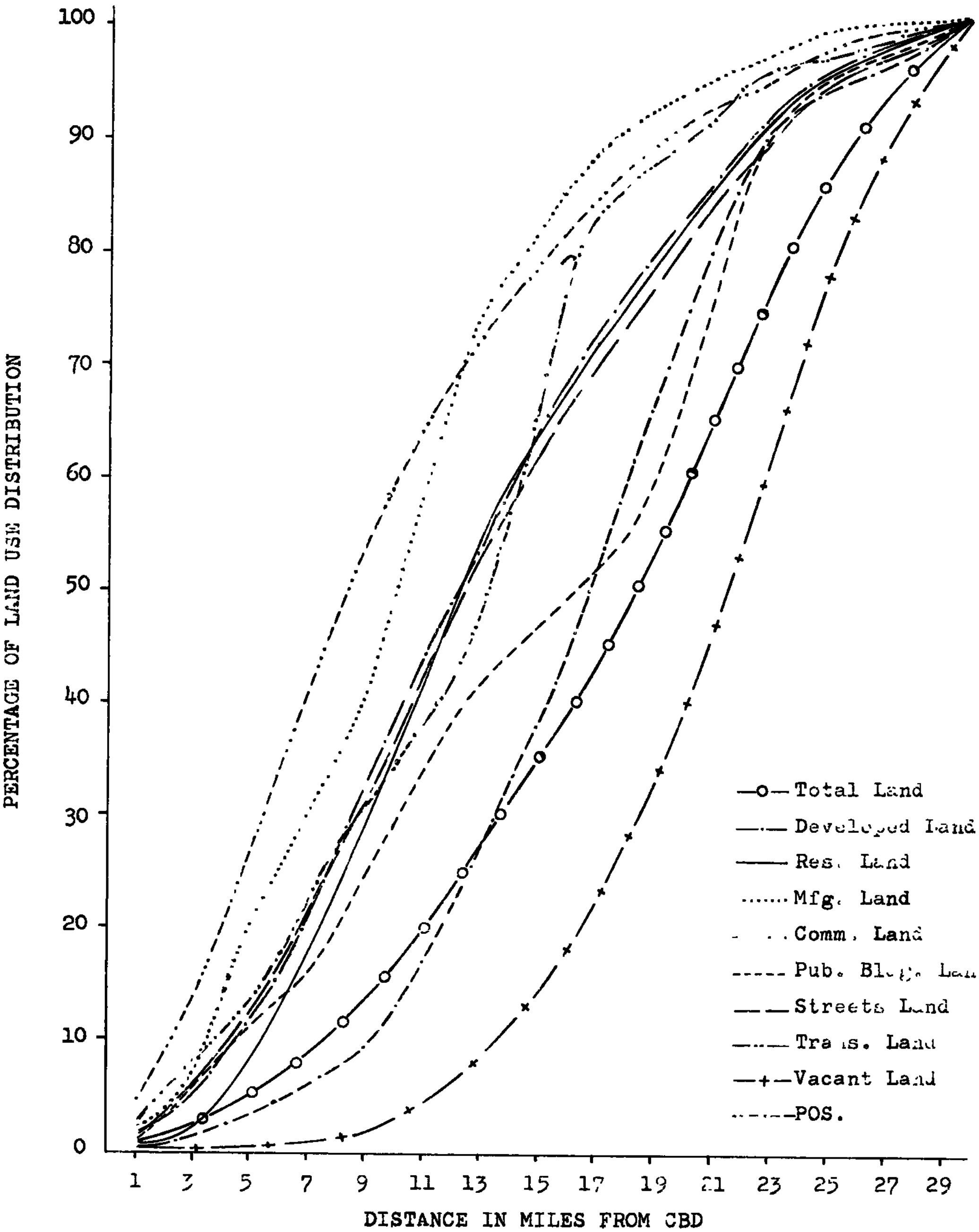

Figure 2. Cumulative percentage of distribution of land use by distance from the CBD.

successive 2-mile rings from the CBD measures of residential land use intensity are obtained (see Fig. 3). The distribution indicates that population densities decrease sharply to about nine miles from the CBD. A more gentle slope is observed from 9-18 miles with a flattening of the curve from about 18 miles continued to the edge of the survey area. The density curve exhibits striking regularity and graphically illustrates the extreme intensity of use of central land while the flattening of the curve at 18 miles to about 10,000 persons per square mile of net residential land represents about four to five dwelling units per net acre of land which is characteristic of suburban residential densities.

Figure 4 shows the gradient of industrial worker density and workers per acre of industrial land by distance rings. There is a marked similarity in the shape of this curve to the population density curve. The relationship of distance and relative intensity of land use is clearly defined and the tendency to flatten out at about 16-18 miles is present in both the worker density distribution as well as the population density distribution.

These data substantiate empirically the systematic variation of the land use distribution and land use intensity with distance from the CBD. But are these relationships a real basis for a land use forecast?

To answer this, it must be realized that distance is really a substitute measure for accessibility, and that accessibility has been changing through time.

Consider the simple example of a hypothetical city with a limited number of radial

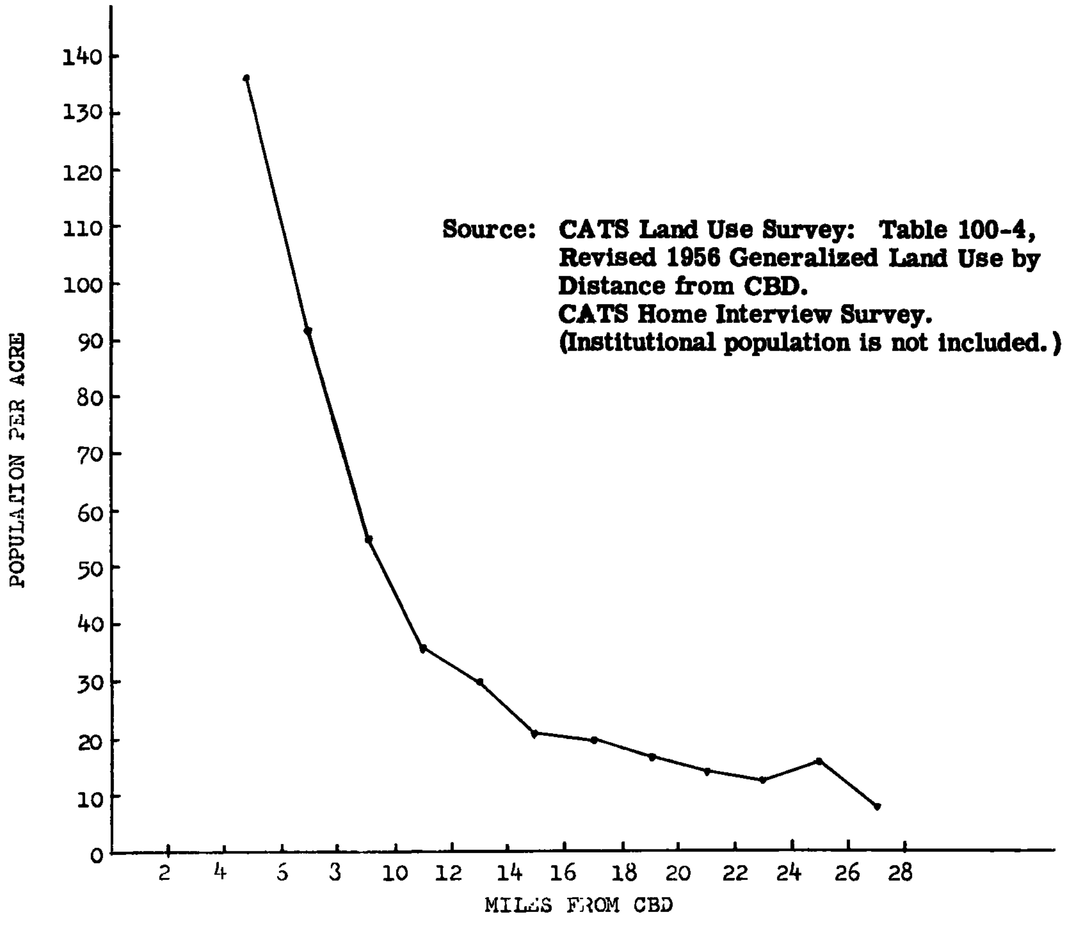

Figure 3. 1956 Chicago area population densities by 2-mile distance rings from the CBD.

transportation routes to the center with equal speed, Sr, on all sections of the routes. Consider also that non-radial movement travels at a speed So. Accessibility in terms of time to the CBD could be computed as the sum of the time required to reach the radial or the CBD plus the time traveled on the radial, if used.

$$\text{Time} = \frac{Do}{So} + \frac{Dr}{Sr}$$

Where: D = Distance
S = Speed

Assuming that the settlement pattern is a function of the time distance from the city center as the speed of travel on non radial routes approaches pedestrian speeds or slower, a stellate pattern of development would emerge. If the two speeds are equal, all other things assumed equal, a concentric ring growth shape would result.

The evidence on land use displayed a fairly smooth gradient with distance. But radial distance from the CBD averages the characteristics of developed corridors along major transportation routes with those of the largely vacant interstitial areas. The actual pattern is star shaped.

Super highways might therefore be expected to continue the star shaped pattern of settlement found in the Chicago area. Actually a system of expressways and rapid transit facilities, combined with rising rates of car ownership, could increase interstitial area accessibility relative to more distant sites, provided that feeder roads and ramps are made available.

The settlement pattern, in any case, will result partly from the very transportation facilities which are to be planned on the basis of the land use projection. The circular effect is minimized to the extent that the future facilities do not create severe sectoral distortions in accessibility at given distances from the center.

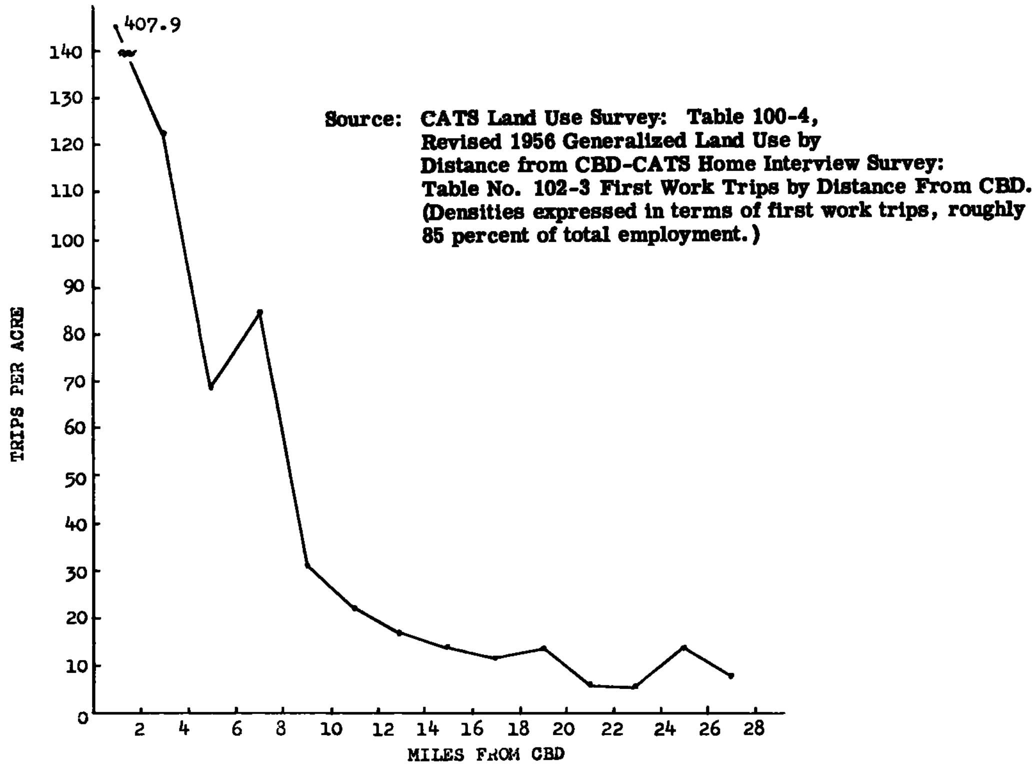

Figure 4. 1956 Chicago area manufacturing worker densities by 2-mile distance rings from the CBD.

Another difficult problem involves the effect that increases in speed of travel will have on intensity of land use. While time series data on land use are not available, the density patterns by distance are a kind of crosscut through time since the central areas are oldest and the peripheral development is most recent. These gradients have been assumed to flatten out at about 18 miles for the forecast period.

A further difficulty involves the fact that as speed of travel, or more accurately as the cost of travel declines, development may become discontinuous and developments can jump over large tracts of land. This effect is expected to be cancelled out as the skipped areas would eventually be filled in unless cost of travel approaches zero, at which time all concepts of locational advantage lose meaning.

FORECASTING THE FUTURE LAND USE

The forecasting of future land use is treated as a distributional problem in which aggregate population and worker forecasts are distributed spatially to small areas. Most simply, upper limits to population and industrial workers are set by small areas, these areas are rated in terms of desirability, and aggregate forecasts of total population and workers are assigned to each zone.

The procedure for estimating future land use by analysis zone required the following:

1. A complete inventory of current land use by zone.
2. Estimation of the future population density and worker density by zone.
3. Plans for redevelopment projects, the CBD, and other local plans.
4. Estimation of the future use of land in each zone assuming no land to be vacant.
5. Development of population and worker holding capacities by zone. Calculation of the ratio of 1956 population to the capacity population and 1956 workers to the capacity workers by zone.
6. Estimation of aggregate population and worker increase for the study area by 1980.
7. Distribute the forecast increases in population and workers to zones on the basis of holding capacity and relative accessibility.
8. Estimation of remaining land uses by zone on basis of predicted future population.
9. Review for reasonableness.

THE CENTRAL AREA AND REDEVELOPMENT PROJECTS

Local agencies were contacted and their plans for redevelopment were obtained. A clipping file of planned shopping centers was also maintained.

The recent plan for the central area of Chicago was scaled in terms of proposed added floor area and activities, and is currently being reviewed.

SETTING FUTURE POPULATION AND WORKER DENSITIES

The 1956 inventory of land use has been described. Analysis of population density patterns indicated that there was a systematic decline in net residential density as distance or place of residence from the CBD increased. This pattern was regular enough to suggest the use of norms based on location with respect to the CBD. In order to decide which zones would be set at the norms and which zones would continue at their current density, and 582 CATS analysis zones were grouped according to the percent of current used land to total usable land. This procedure resulted in three basic groupings:

1. Zones which were over 75 percent developed in 1956 continued at the same residential density as in 1956. The majority of these high developed zones (256) were in the city of Chicago.
2. For zones which were between 75 percent and 50 percent developed, a normative density was estimated by using the appropriate sector regression curve of density on distance. This estimated density was compared to the current density and if there was less than ten percent difference, the existing density was continued. Careful inspection

of the aerial photography and existing development were the basic references for setting the future densities for the remaining zones.

3. For the 90 zones which had less than 10 percent of their land developed, the sector distance norms were used to estimate future densities. In the main, these zones had densities which varied between 8 and 10,000 persons to the square mile of residential land.

The estimation of the future worker densities by zone was less precise than the estimation of the population densities. The regular declines which have already been examined served as the base for the estimation of future worker densities.

The bulk of all future industrial expansion is expected to fall beyond a radius of nine miles from the CBD. Worker densities for zones between 9 and 12 miles were set at 29 workers per net acre of manufacturing land. For zones between 12 and 18 miles, densities were set at 20 workers to the acre and for zones beyond 18 miles, the density assumed was 17.5 workers to the acre.

DESIGNATION OF LAND USE

With future densities estimated, the question of the rate of utilization land use for population and workers is resolved. Next, the problem of how much land is available for different activities by zone must be answered. It was assumed that currently developed land would continue in that use until the target year 1980, except for planned redevelopment projects, the CBD, and committed demolitions for highway construction. Zoning regulations were used to divide vacant land into residential, industrial, and commercial.

Additions to the major park system were estimated after contacting the Forest Preserve officials and reviewing the current ratios of open space and population in the study area. This land was subtracted from vacant zoned residential land by zone.

Records of industrial land on the market but not currently zoned for industrial land are maintained by the Commonwealth Edison Company. These sites were obtained, reviewed and in some cases added to vacant industrial land and then subtracted from vacant residentially zoned land.

Street area was considered constant for zones with less than ten percent of their total area vacant in 1956. For zones having a large amount of vacant unplatted land, streets were added at a variable rate according to the distance from the CBD.

Potential increase in public building land was obtained by multiplying the vacant residentially zoned land by .06, which amount was deducted from vacant residential.

Commercial land was obtained by multiplying the remaining vacant residential land by the estimated future residential density to obtain the additional population which could be absorbed by the zone. This population was added to the current population to obtain the zone's population holding capacity. If the sum of the current commercial and zoned commercial land fell below the ratio of two acres per thousand population, the commercial acreage was increased to meet this minimum and the residential area adjusted accordingly.

Vacant residential land is thus a residual of the above operations. These operations resulted in estimates of potential land by land use type and permitted the calculation of population and manufacturing-worker capacities by zone.

CATS AREA POPULATION CAPACITY

Population holding capacity by zone is obtained by multiplying the designated residential land by the estimated residential density for each zone and adding this to current population. On the basis of these calculations, if all of the vacant land in the CATS Study Area were developed, the area could accommodate about 9,200,000 persons. The 1956 population was 5,200,000 or 57 percent of the capacity.

Figure 5 illustrates the distribution of "percent population capacity" by 2-mile rings from the CBD. The percent of population capacity declines shartly from nine to 19 miles and then less rapidly to ten percent at 29 miles distance from the CBD.

Figure 6 shows the comparable gradient for manufacturing workers. Here again the sharp decline with a flattening at the edges of the study is apparent.

Both of these distributions illustrate the tremendous organizing impact of the central area on the distribution of population and workers and hence, the development of land. While there are sectoral effects present, these are thought simply to be the distortions of a purely concentric ring growth based on equal distances instead of equal times. If adequate measures of the friction of travel during the time these sectors were experiencing their heavy growth were available, sectoral variations might be largely explained.

FORECAST OF 1980 POPULATION AND WORKERS

For the CATS study area, the 1980 population estimate was 7,752,000. This would be an increase of about 48 percent and is well within the estimated population capacity of the area (see Table 1). The 1980 estimated population amounts to 84 percent of the estimated capacity which leaves room for about 1.5 million persons or about 16 percent of the area's holding capacity.

The forecast of manufacturing workers was obtained from an economic analysis using an "input-output" technique. The 1980 forecast of manufacturing workers was 1,098,000 as compared to 857, 000 in 1956. This is an increase of 28 percent compared to a 48 percent increase in population (over-all increase in employment was 52 percent). The lower rate for manufacturing results from a relatively greater increase in productivity (1). The relation to capacity is shown in Table 1, which indicates that on aggregate basis, there is ample manufacturing land in the study area.

POPULATION AND WORKER DISTRIBUTION

The spatial distribution of 1956 percent of population capacity displayed a distinct pattern of gradual build up to a peak of 96 percent at seven miles with a sharp decline

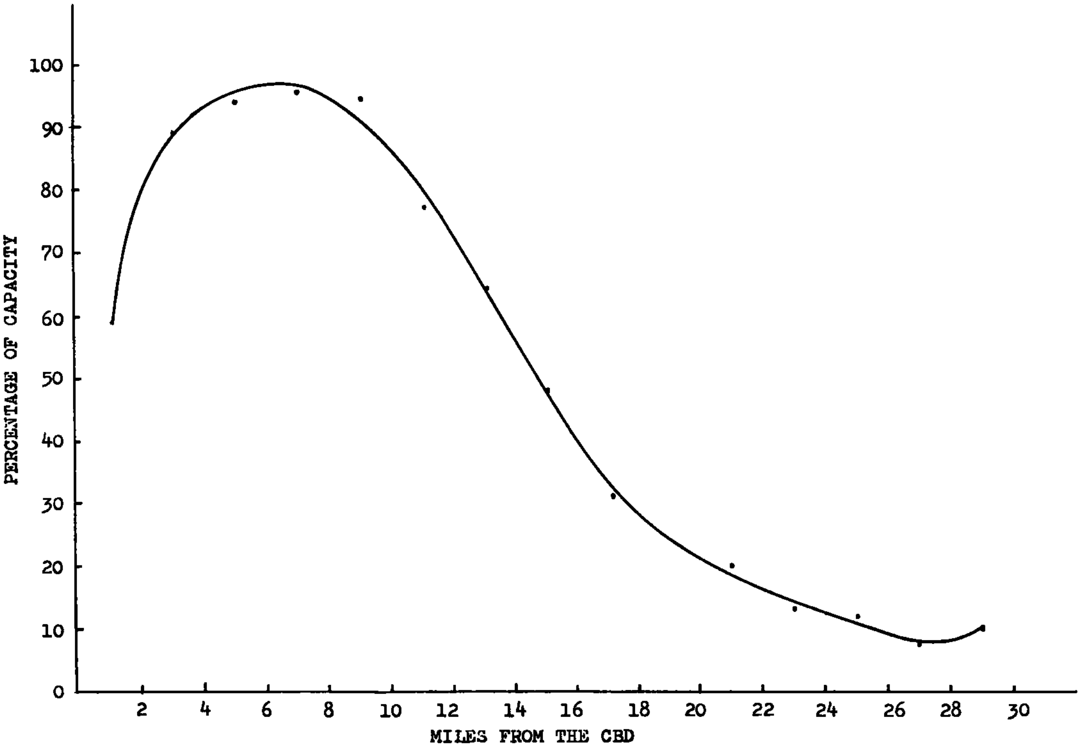

Figure 5. Percentage of population capacity by distance from the CBD-1956.

TABLE 1
COMPARISON OF 1956, 1980, AND CAPACITY POPULATION

Year	Population	Percent Capacity	Mfg Workers	Percent Capacity
1956	5,201,000	57	857	54.9
1980	7,752,000	84	1,098	70.4
Capacity	9,188,000	100	1,560	100.0

to 19 miles and then a gradual decline to the edge of the study area. Analysis of trends for the city of Chicago based on census tract data revealed much the same pattern. Successive time cuts show that the ring with the highest percent population capacity to be moving slowly outward and the inner rings, which were previous highs, to be declining.

The procedure for estimating the 1980 distribution of percent of population capacity by distance ring from the CBD centered on estimating (a) the 1980 peak, (b) the amount of decline for the rings closer to the CBD and (c) the slope of the curve from the peak to the edge of the study area. The curve resulting from these components must also satisfy the aggregate population estimate for the target year.

The 1980 peak population capacity was set at 11 miles from the CBD which represents a rate of movement of 1.6 miles per decade. This is the approximate rate of movement which was experienced from 1920 to 1956.

Very slight decreases were forecast for rings within ten miles with the exception of a 0-2 mile ring.

For distance rings beyond the 10-12 mile ring, a semi-logarithmitic relation between

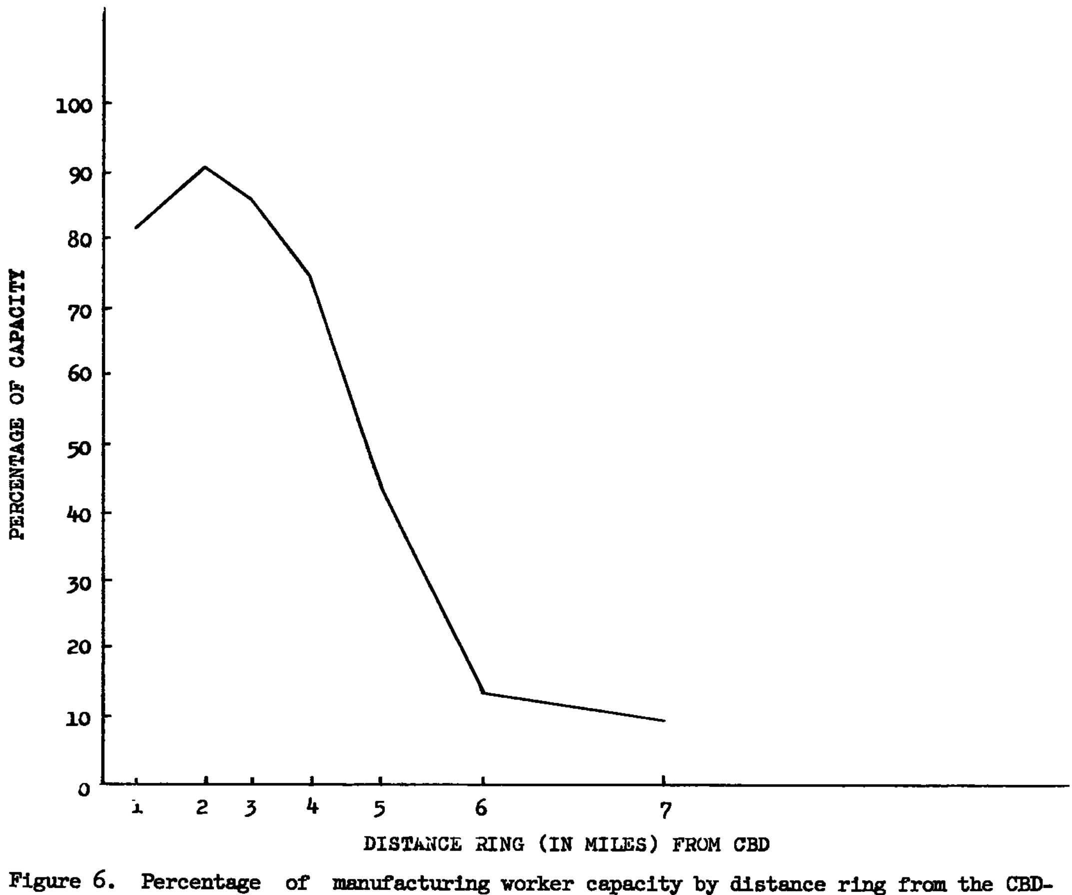

Figure 6. Percentage of manufacturing worker capacity by distance ring from the CBD-1956.

distance and percent capacity was assumed and the slope adjusted so that the over-all shape of curve of percent population capacity for 1980 resulted in a total area population of 7,752,000 persons. The resulting distribution by distance is shown in Figure 7.

Within this major control of distance on the distribution of future 1980 population, sector and then zonal estimates were made on the basis of the present capacity, the proximity of each zone to an expressway and/or to an incorporated area which could provide needed services. The results were then mapped and reviewed on the basis of reasonableness.

Over all, the population forecast recognizes a tendency for close in areas to develop sooner than more distant areas. At the same time, on a small area basis, individual variations reflecting transportation facilities and past trends are allowed. Within the limits of present knowledge, this appears to be a most reasonable estimate of the future population distribution.

MANUFACTURING WORKER DISTRIBUTION

The manufacturing worker distribution procedure parallels the distribution of population in many respects. An over-all estimate of future manufacturing workers was obtained, the land available for future industrial growth was inventoried and reviewed, the present distribution including worker densities was examined, and finally, a successive distribution of growth by major geographic units, down to traffic analysis zones, was prepared.

ZONAL ESTIMATION OF LAND USE FOR 1980

With the zonal estimates of manufacturing workers and resident population and their respective densities, the amount of land devoted to residential and manufacturing

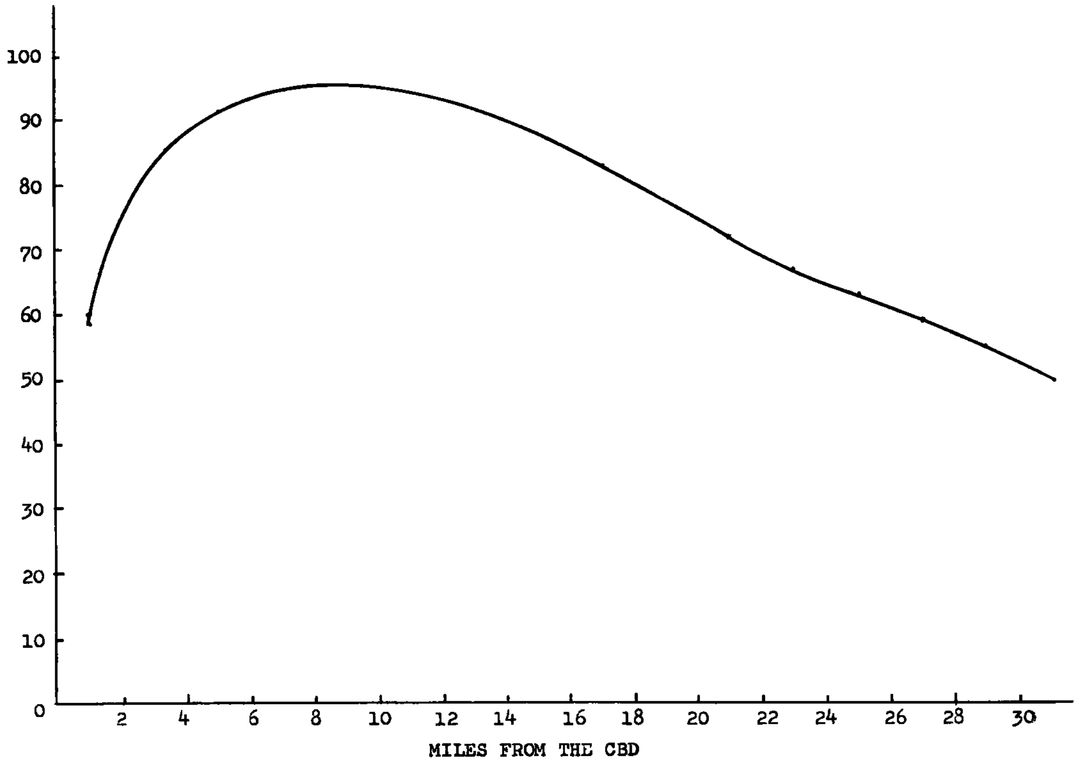

Figure 7. Estimated percentage of population capacity by distance from the CBD-1980.

activities is set. The exact amount of the remaining land uses has still to be estimated although the "capacity" has been designated.

For commercial, and public building uses, the amount estimated to be in use as of 1980 derived population and residential land norms. Planned regional shopping centers can be inserted into the forecast.

CONVERSION TO TRAFFIC

The land use projection provides estimates of the amount and kind of land use in each traffic analysis zone for the forecast year. The land use has been tied directly to forecasts of workers and population so that the estimation of residential and manufacturing destinations is a relatively easy conversion.

The calculation of trips to commercial and public buildings employs the generation rates of these land uses as measured by the 1956 surveys of land use and traffic.

By estimating the total traffic which the forecast population would be expected to make and estimating the distribution of that traffic by land use of destination, excellent checks are available for reviewing the traffic estimates made directly from the land use.

SUMMARY

The estimation of future land use by geographic location is a prerequisite to planning future transportation facilities because traffic results from the interaction of spatially separate specialized land uses.

A detailed land use survey provides the basic data from which current patterns emerge and also gives measures of the location of present vacant land and current zoning.

Analysis of the present distribution of activities and intensity of land use reveals a pattern which is heavily organized around the CBD.

Land use holding capacities can be estimated by setting the future land use intensity by zone and multiplying by the probable amount of land that could be in that use if all land in a zone were used.

A population forecast and an economic forecasting model are used to obtain the future aggregate population and manufacturing workers. Knowing the holding capacity of each zone, and the aggregate number of persons estimated to be living in the area by 1980, the zonal forecast becomes a distributional problem. Modification of the current pattern of percent population capacity on a distance gradient provides basic controls within which reasonable sectoral variations can be continued. The future manufacturing workers can be distributed in an analogous way.

Land to serve the population and workers is reserved on a normative basis. The entire land use pattern is then reviewed to insure that a reasonable pattern has resulted.

With future land estimated, the number of trip destinations to any zone can be estimated by using traffic generation rates by land use type and the amount of land for the corresponding use. An independent estimate of the total trips which the future population would make can be made and compared to the estimate based on land use and traffic generation.

The kind of forecasting procedure herein described should not be confused with a typical "master plan." While known planning projects have been incorporated, the forecast represents an attempt to anticipate the pattern of future land use if current trends are continued. It is an attempt to scale the dimensions of future land use rather than to say what future land use "ought" to be.

The projections should be considered as a basic framework within which detailed local land use plans and exceptions—where local considerations indicate deviations are in order—should be worked out.

Some of the areas in which further research should be very rewarding would be in developing better measures of accessibility, land use classifications and, most important, review and reformulation of theory relative to the spatial characteristics of growth of population and non-residential activities in regions.

In spite of the many shortcomings, land use projections should provide a basis for integrating land use planning and transportation planning which should result in a more nearly balanced relation between urban growth and construction of transportation facilities.

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Home-Interview Surveys and Related Research Activities

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Division of Highway Planning, Bureau of Public Roads

●IT HAS now been 15 years since the home-interview method of making origin and destination surveys in urban areas was developed. The first surveys by this method were made during the war, when conditions were quite abnormal. The method has now been used in 126 urban areas and additional repeat surveys have been made or started in 10 of these. During 1958, surveys were started in the following areas:

Vallejo, Calif.
Champaign-Urbana, Ill.
Topeka, Kans.
Minneapolis-St. Paul, Minn. (repeat)
Charlotte, N.C. (repeat)
Pittsburgh, Pa.
Reading, Pa. (repeat)
El Paso, Tex.

In addition, repeat studies were being organized for Denver, Philadelphia-Camden, and Nashville, and were under consideration for Atlanta, New Orleans, Tucson, and Honolulu.

The field methods and the information obtained have been changed very little since the earliest surveys. A few items have been added or altered, however, to aid in the study of trip projection. Present emphasis is on the improvement of analysis methods.

It was recognized in the beginning that the most difficult problem was to find a satisfactory method of forecasting future travel. It was thought that fundamental relations could be established which would permit the determination of the future travel pattern from projections of land use, population, and economic factors. For this reason information was obtained in the interview on such items as size of family, number of cars owned, occupation and industry, mode of travel, and purpose of trip.

One important addition that has been made in the present practice is the determination of land use or the character of establishment, at the beginning and the end of each trip. This is done in considerable detail; for example, a shopping trip made to a food store is differentiated from one made to a clothing store, and a social trip made to a residence is recorded differently from a recreational trip made to a theater. Such detail requires in the neighborhood of 60 land-use classifications. This detailed classification of land use at trip ends was made first in the Chicago study, which is nearing completion, and is being made in most of the surveys that have been started during the past year.

The purpose of the detailed land-use information is twofold. First, the number of trips attracted to each class of development or establishment can be determined and related to some measurable factor such as population, automobile ownership, employment, dollar sales or area; second, the effect of distance or travel time on trip attraction for each class can be studied. These are the important factors which enter into any interarea travel formula such as the so-called "gravity model".

Of course, it will not be practicable to forecast future land use in any such detail. However, analysis of the data will permit the evaluation of the variability of the trip attraction and distance factors for different land uses, the testing of the form and possible accuracy of an interarea travel formula, improvement of the zoning by grouping land uses of similar trip attraction characteristics to the extent practicable, and the estimation of the factors for zones on the basis of approximate anticipated distribution of land uses within the zone.

Throughout the past 10 years, much research has been conducted on trip production and trip attraction in relation to land use. The results of many such studies have been presented to the HRB in numerous papers (1 through 8). Difficulties have been encountered because of mixed land uses within zones and lack of precise knowledge as to the character of establishment at the ends of each trip. Progress has been slow because of the mass of detailed data to be analyzed and the shortage of personnel. However, some fairly reliable factors have been developed for trip production by purpose for residential zones, and for the effect of distance on shopping trips. What remains to be done is to test and evaluate various interarea travel formulae that have been proposed and to develop, if possible, statistically reliable factors for use in these formulae. Because of the availability of electronic computers, considerable progress is being made in this direction.

The interarea travel formula which is being evaluated is in general form, as follows:

$$T_{ij} = (P_i \frac{A_j}{\Sigma A} + P_j \frac{A_i}{\Sigma A}) \frac{K}{D_{ij}{}^n} \quad ,$$

in which

T_{ij} is the number of primary trips between zones i and j, that is trips with one end at home;

P_i and P_j are the number of primary trips produced in zones i and j respectively by residents of those zones;

A_i and A_j are the number of primary trips attracted to zones i and j respectively by nonresidents plus intrazone trips by residents of those zones;

ΣA is the number of primary trips attracted to all zones;

D_{ij} is the distance between zones i and j, generally expressed in terms of travel time; and

K is a constant and n an exponent, both to be determined empirically from the analysis.

After K and n have been calculated, the application of the formula will probably result in a different number of trips attracted to, and trips produced in each of the zones than was originally estimated from the land-use data. A series of successive approximations or some other method will then have to be used to make the number of trips in and out of each zone, calculated from the formula, agree with the original estimates of trip ends.

This formula and a similar one for secondary, or nonhome-based trips, are being evaluated by the Bureau of Public Roads, and with the aid of a 650 IBM computer, using data from the Washington metropolitan area 1948 and 1955 O-D surveys. For trips produced and trips attracted (the P and A factors) actual survey values are used, and the test is to determine whether a formula of this general form will produce reliable results, and if so, what values of K and n are applicable to different situations.

The test is being made by trip purpose, as it is expected that the value of the time exponent n will vary for different purposes. It is thought for example, that travel time will be more of a deterrent for shopping trips than for work trips. Also, it is expected that n will be smaller for trips to the central business district than for other trips.

In this test, the travel times reported in the interviews are being used. This part of the program has been completed and some preliminary runs have been made. The travel times appear to be reasonably consistent; the relation between peak hour and offpeak hour times for example, being about as would be expected. It is necessary, however, to smooth out the reported times because of the small number of reported trips between some pairs of zones and also because of the tendency to report times in even 5- or 10-min intervals. This is being done through a study of time-distance relationships for pairs of zones similarly situated

Data from the 1955 survey are being analyzed first. Subsequently, it is planned to use the data from the 1948 survey to see whether the values of K and n change over a period of time.

A similar test of this formula is being made by the Ohio Department of Highways using data from the Dayton and Toledo surveys. These were controlled post-card surveys, and neither trip purpose nor travel time were obtained. It will be necessary, therefore, to confine the analysis to the total number of trips for all purposes, and to determine travel time from time runs. The survey will have special value, however, in permitting a comparison of the results for the two cities, as well as with those for Washington.

A program is being developed by Public Roads for testing the application of an interarea travel formula to travel between cities or counties. The states have supplied a large amount of data for this from external surveys around urban areas throughout the country. Factors currently being considered are population, median income, automobile registrations, and persons employed in eating and drinking establishments and in hotels and other places of lodging. The last named factor is thought to be of special importance in connection with recreational travel. Trip production by residents, and trip attraction for nonresidents will be considered separately as in the case of the formula that has been described. An adjustment of airline distance to highway distance will probably be used instead of travel time.

Last year Messrs. Brokke and Mertz reported on a test of the Fratar, average-factor and Detroit growth formulae for projecting the future urban traffic pattern from the present one (9). They found that the three formulae gave results of equal accuracy, but that the Fratar required fewer iterations than the others. The standard errors for zone-to-zone movements were naturally high because of the very small numbers of trips between many pairs of zones. Zones were grouped, therefore, to give substantial trip volumes between each of the groups. When this was done, the standard errors were not unreasonably high. Since the grouped zones are much larger than would be used in practice, a different kind of test is thought to be necessary. What we actually wish to know, is how accurate the results will be when a large number of zone-to-zone movements are accumulated on a freeway. It is planned therefore, to accumulate the trips across grid lines and to determine the standard errors for sections of the grid crossed by substantial volumes of trips. This project is still in the planning stage, but it is hoped that it can be carried out during the coming year.

A program to apply the Fratarformula has been written for a 705 IMB computer by the Bureau of Public Roads with the assistance of the National Bureau of Standards. This program has been used to project the future zonal traffic interchange from the 1955 data for the Washington area.

The Chicago area transportation study has developed a program for the IBM 704 computer for assigning zone-to-zone traffic movements to a complete urban highway network, based on a minimum travel time concept. This program is being described by Dr. Carroll in a paper to be presented at this meeting of the HRB (10). The Detroit area traffic study is developing a similar program based on somewhat different concepts.

A program to accomplish the same purpose has been written for the IBM 704 computer by the General Electric Computer Division for the Regional Highway Planning Committee of the Washington metropolitan area with the assistance of Bureau of Public Roads personnel. This is based on a time ratio rather than on a minimum travel time concept. It is being described at this committee session by Mr. Brokke.

One of the most important accomplishments of the past year is the development and testing of what seems to be a satisfactory formula for estimating proportionate mass-transit usage. There has been a lack of knowledge in this field that would permit the determination of future trips between mass transit and private automobile with any degree of assurance. The formula involves a number of factors and is based on data obtained in part from the O-D surveys, in part from the transit companies, and in part from planning commissions. Full cooperation of such agencies in more than 20 cities has made the accomplishment possible.

The formula, as so far developed and tested, seems to predict the proportion of the trips made by mass transit in different cities with a surprising degree of accuracy. Preliminary tests indicate that it is also applicable to the prediction of mass transit usage in different sections of the same city but this will be further tested during the coming year as additional information becomes available. Mr. Warren Adams is reporting on this study at this meeting of the HRB (11).

In some of the O-D studies now being started, provision is being made to obtain information on availability and cost of parking and on walking time between place of parking or transit and origin or destination. It is thought that factors may be developed from such information that will improve the transit usage formula.

On the whole, the prospects for important research accomplishments during the next year in the field of O-D studies seem bright. The personnel engaged on such research in the Bureau of Public Roads remains small, but the availability of electronic computers is speeding up the work. Furthermore, with greatly increased highway planning survey funds, the States are showing increased willingness and desire to engage in research that will aid them in forecasting future traffic volumes and patterns. In the St. Paul-Minneapolis study, for example, $75,000 has been programed for research. The Ohio Department of Highways, in addition to the interarea travel formula test that has been mentioned, is planning to undertake some research on the diversion, generation and growth of traffic following the construction of rural freeway sections. Highway impact studies are under way in many States, in some cases with State personnel and in others through universities. The North Carolina State Highway Commission is conducting several traffic research studies, both through their highway planning division, and with university cooperation.

In most of the current urban O-D studies continuing organizations are being set up or planned. These organizations will, in many cases, carry out continuing research. In Detroit, for example, continuing research is being planned through an agreement with Wayne University.

Considering all of these factors, it is not unreasonable to hope that, within a few years, the analysis and projection of traffic patterns will be placed on a sound scientific basis.

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Program for Assigning Traffic to a Highway Network

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●FOR MANY YEARS highway engineers have been faced with the problem of estimating the volume of traffic that would use a proposed new facility. In addition, they would like to know how well this facility will continue to serve traffic in the future.

A realistic solution to this problem is not simple. All zones in an entire area have the potential of affecting any highway facility. The degree of this effect is governed by the location and design standards of the highway system as it now exists or as it may be subsequently improved. Thus, individual highway improvements can cause a realinement of traffic throughout the area.

Much research work has been done to provide a method of solving these problems. Although the future will probably bring added refinements, and even major changes in concepts, present knowledge is sufficient to warrant establishing at least an interim procedure for assigning present and future traffic.

A characteristic of traffic problems is the necessity of handling a mass of information in the relatively simple but coherent manner. To process these data in a reasonable time, it has usually been necessary to use a series of short cuts, approximations, or judgment estimates, each exacting its toll in deviation from accuracy. It now seems possible to employ electronic computers to provide a consistent solution subject only to the limitation of knowledge of the behavior of traffic.

The use of computers does involve the time consuming operation of preparing a program. Although it is desirable to allow flexibility in the program, this is not easily accomplished. Thus, to use an existing program it is necessary to have access to the machine for which the program is written, to furnish input data in precisely the correct form, to be willing to accept the logic that is incorporated in the program, and to accept the results in predetermined format.

The U.S. Bureau of Public Roads has written, tested, and used an IBM 705 program to predict the future distribution of trips. The input required is the number of existing zone-to-zone trips and the growth factor for each zone. The program logic follows the Fratar formula. The output is the estimated number of future zone-to-zone trips. Either three different modes of travel or one mode to three different future periods can be processed simultaneously. For a city the size of Washington, D.C., with 500 zones, about one-half hour of IBM 705 time is required for each iteration. Two or three iterations are usually sufficient, thereby making the cost of obtaining future zone-to-zone trips somewhat less than $600 for a city the size of Washington.

With the present and future zone-to-zone trips available, the next problem is to estimate the loading of these trips on a highway network. To do this, some method of predicting the distribution of traffic between routes is required.

Three types of diversion curves are in current use—the time-ratio curve as attached to the Bureau's "Guide for Forecasting Traffic on the Interstate System," dated October 15, 1956; the distance-ratio and speed-ratio curves as used in Detroit; and the time-and-distance differential curve as used in California.

The Bureau's time-ratio curve relates the percentage of trips using a freeway facility based on the ratio of the travel time via the freeway to the travel time via the best alternate route. The percentage of trips using the freeway varies as an S-shaped curve from 100 percent at a time ratio of 0.5 or less to 0 percent at a time ratio of 1.5 or more. If the travel time via the freeway is equal to the travel time via the alternate route (time ratio = 1.0), approximately 42 percent of the trips are assigned to the freeway.

The speed-ratio curves developed for the Detroit Area Transportation Study consist of a family of curves where the percentage of freeway use is related to speed ratio and distance ratio. These curves are also S-shaped for normal conditions, and with a speed ratio of 1.0 and a distance ratio of 1.0 assign approximately 45 percent of the trips to the freeway. Because these curves represent a three-dimensional surface with an undefined mathematical relationship, they are difficult to use in a computer application.

The California time-and-distance curve consists of a family of hyperbolas where equal time and distance on the freeway as compared to the best alternate route will assign 50 percent of the traffic to the freeway. These curves can be expressed by

$$P = 50 + 50\,(d + \tfrac{1}{2}t)\left[(d - \tfrac{1}{2}t)^2 + 4.5\right]^{-\frac{1}{2}} \qquad (1)$$

in which

P = percentage using the freeway;
d = distance saved, in miles, via the freeway; and
t = time saved, in minutes, via the freeway.

The development of an assignment procedure has two major difficulties, as follows:

1. Measurement of the minimum travel time between each pair of zones over the arterial network and then over the entire highway network, including the contemplated freeways.
2. Accumulation of the assigned volumes on the various segments of the highway system.

The Washington, D.C., Regional Highway Planning Committee, having recently completed an origin-destination study and having predicted the zone-to-zone movements to 1980, desired to assign this traffic to a highway network using the Bureau's time-ratio diversion curve. The labor involved in accomplishing this task for an area the size of Washington was clearly beyond the range of practicability unless an electronic computer could be used for a major portion of the work. The Bureau of Public Roads offered technical assistance.

It was established, almost immediately, that no program was available which would handle the complexities of Washington in a reasonable manner. Hence, it became necessary to develop a Washington assignment program.

At about this time it became known that the staff of the Chicago Area Transportation Study had discovered a method of determining the minimum path through a highway network. It was also known that the staff of the Detroit Area Transportation Study had carried this minimum path principle along somewhat different lines toward an assignment procedure. Both organizations were visited and each was entirely cooperative and responsive in outlining its procedures and ideas on the problem.

Because all diversion curves being considered are based on the relationship between the travel time (and distance) on the most favorable freeway route and the travel time (and distance) on the most favorable alternate route, the initial problem is to determine which of the freeway routes and which of the alternate routes are truly the most favorable.

The difficulty of this problem can be appreciated most easily if a rectangular street network is considered. To arrive at a point four blocks east and four blocks south of an origin, there are more than 40 different routes or paths that appear approximately equal to the eye as far as travel time (or distance) is concerned. However, by accurately adding the time (or distance) values on each of the segments involved for each route, the route with the least over-all travel time can be selected. This selected route is the minimum travel time route, or minimum path.

It is true, and probably apparent, that the longer the trip, the more alternate routes there are available between two points. For travel across an entire city, there may be literally thousands of alternate paths or routes and the initial problem of determining which path is the minimum appears rather difficult.

Fortunately, the staff of the Chicago Area Transportation Study were able to use a procedure developed by Moore (1). The same basic method is used in this program and essentially consists of accumulating the minimum time and path from a central point to an ever-increasing circle of points surrounding this central point.

The value of the use of the minimum path principle can hardly be overestimated in the solution of the assignment problem. The distance and travel time on each segment of the highway network are determined and fed into the computer. These initial time and distance measurements are required for any of the methods being used and are neither easier nor more difficult to obtain for the minimum path procedure. Once the travel times are in the computer, however, very substantial advantages begin to accrue.

The most obvious advantage is the saving in man-hours. On the optimistic basis that the best route of travel between a pair of zones can be located and measured in three minutes by manual methods, approximately two man-years of labor would be required to find the travel time via the arterial network and via the freeway network for the 40,000 zone-to-zone volumes occurring in the Washington area. The computer can absorb all of this manual work at the rate of about two computer-hours being equivalent to one man-year of manual computation.

A second advantage is the increase in accuracy and consistency. A manual determination of the best route has two sources of frequent errors. The routing selected as the minimum path may actually be longer than some other path. Secondly, an error may be made in adding the time intervals that make up the selected path. The minimum path program, however, tests all possible paths, selects the minimum and adds the time intervals unerringly.

A third advantage, somewhat more obscure, is the ability of the computer to take additional factors into account. For example, the computer can be rather easily instructed to test a routing and insert a turn penalty whenever a right- or left-hand turn occurs. To add this or a similar complication into a manual procedure would be entirely impractical.

The Washington traffic assignment program is in reality a library of programs that can be called upon in any desired order through the use of a master control program. To use this library of programs certain conventions must be observed, and to understand these conventions a few definitions are required, as follows:

Node—A node is any specific point on the highway system that is needed for identification purposes. Primarily, nodes are used to designate zone centroids and highway intersections. They are identified by number.

Link—The portion of the highway system between two nodes is a link. To avoid needless complication only the "through" or more important highways are identified by actual location. Links are identified by the two node numbers which terminate the link.

Route—A group of connecting links between a pair of zones is the route of travel between these zones. If a particular route has a shorter travel time than any other route, it is called the minimum time path. If distance instead of time were the criterion, a minimum distance path could be similarly described.

Tree—All minimum path routes from one particular node to all other nodes in the system constitute the tree for that particular node. In practice, trees need to be built only for the zone centroid nodes.

PROGRAM CONVENTIONS AND LIMITATIONS

The following program conventions and limitations are observed:

1. No more than four links may meet at any node. To accommodate five or more links which would otherwise intersect at a single node, it is necessary to separate the one node into two (or more) nodes with zero time and distance between them.
2. No node may be numbered more than 4,000.
3. The node numbers must be arranged in sequence in four separate groups in the following order:

Group A—Zone centroids starting with number 1.
Group B—Four-way arterial nodes.
Group C—Two- or 3-way arterial nodes.
Group D—Freeway nodes.

4. From each 4-way node there must be at least one link to a numerically larger node number.

5. The zone-to-zone trip cards must be in major sort by the first zone and in minor sort by the second zone before being placed on tape.

6. To be able to insert a turn penalty for right and left turns, it is necessary to designate each link as positive or negative. Movements between links of the same sign involve no turn. To accommodate diagonal or curving streets a flag position is also available to change signs as needed.

The Washington traffic assignment program library consists of the following individual programs:

Program No.	Title
0	Master control.
1	Build trees.
2	Load arterial network (all or nothing).
3	Load entire network (time-ratio curve).
4	Sum vehicle-miles and vehicle-hours.
5	Convert link data from decimal to binary.
6	Make freeway corrections to link data.
7	Convert trip volumes from decimal to binary.
8	Correct trip data.
9	Prepare time-ratio diversion table.

These programs are on tape and can be called in any desired order through the master control program.

INPUT DATA REQUIREMENTS

Zone-to-Zone Trips

Each of the zone-to-zone trip volumes must be represented by a trip card identifying the two zones (or stations) involved and the number of trips between them. Zero volumes need not be represented by a card except that each zone other than the last one must be represented by at least one card (zero volume if necessary) when arranged in major sort by the first identifying zone number. If not already accomplished in a previous stage, the zones and stations must be renumbered to form an unbroken sequence starting with number 1. When placed on tape the zone-to-zone cards must be in major sort by the first identifying zone number and in minor sort by the second identifying zone number.

Highway Link Data

The highway network must be described in a manner that the computer can understand. This is done by listing each link of the highway network on a coding sheet. The listing consists of the two identifying nodes, together with the sign, a flag if needed, the travel time in minutes and hundredths, and the distance in miles and hundredths. These data are then key punched with one link to a card. The cards are then duplicated, reversing the two identifying nodes, so that in the final deck each link is actually listed on two cards. The data on the cards are then transferred to magnetic tape.

PROGRAM OPERATION

Program 0—Master Control

Program 0 sets the program for the specific area in which traffic is being assigned and permits the choice of any of the programs included in the program library. As input it requires the number of zone centroids, the number of 4-way intersections, the number of 2- or 3-way intersections, the number of freeway intersections, and the amount of turn penalty in minutes and hundredths.

In addition it has been necessary to scale the time and distance values into units which will economically use the memory availability of the computer. Therefore, the maximum travel time on any link plus the turn penalty is equated to 63. The time values on all other links are converted to 63d's of this maximum travel-time link. For the same reason the maximum distance link is likewise equated to 63 and all distances converted to 63d's of this maximum distance link. It should be noted that the maximum travel-time link and the maximum distance link need not be the same link.

The maximum travel-time link and the maximum distance link are also necessary inputs to the master control program.

All of the other programs are then set with the specific characteristics entered through this master control program.

Program 5—Convert Link Data from Decimal to Binary

In program 5 the computer edits the link data for impossible codes, scales the time and distance values to appropriate units, converts all data from decimal into binary, and pecks the information to fit exactly into a block of computer memory. The output is a binary coded tape containing this large block of information.

Program 6—Make Freeway Corrections to Link Data

The most difficult problem in determining the freeway route was to arrive at some method which would compute a minimum freeway path even though it was longer than an arterial street path. This was necessary because some diversion to a freeway exists even if the time ratio is more than 1.0.

To retain the advantage of the minimum path method and still obtain a freeway time longer than arterial time, it was decided to temporarily halve the time on the freeway links. Once the tree has been established, the time values are corrected.

By this program the previous arterial links are modified as needed by the addition of the freeway nodes, the freeway links are inserted in the system with their time values cut in half, the information is converted to binary and packed into a block of memory. The memory is then written out on tape in binary code.

Program 7—Convert Trip Volumes from Decimal to Binary

The tape containing the zone-to-zone trip volumes is edited in Program 7. The numbers are converted from decimal into binary and all of the trips from the first listed (or origin) zone to all other zones are packed into one record block, which is written out on tape. There must be a trip record block for each zone except for the last (highest numbered) zone.

Program 8—Correct Trip Data

If in the process of editing or through subsequent checking it is found that some of the zone-to-zone trips are in error, the values may be corrected by Program 8 without rerunning the entire program.

Program 9—Prepare Time-Ratio Diversion Table

Program 9 builds the diversion curve table for converting time ratio to percent diversion. At present the traffic diversion curve attached to a BPR circular memorandum to division engineers (dated October 15, 1956) is incorporated in the program.

Program 1—Build Trees

Program 1 determines the minimum path from each zone to all other nodes in the highway network. If only the arterial links are used, the program builds arterial trees. If the freeway links are also included, the program builds freeway trees. Thus, the previously prepared link data are the input for this program.

The program then instructs the computer to set aside a block of memory for the tree, with each memory word of the block corresponding to an actual node on the highway system. The memory words in the block are in the same sequence as the node numbers. Thus, the position of the memory word identifies the node number.

In addition each word in the tree memory block will contain two major items of information, as follows:

1. The preceding node through which the route has passed in building the tree (back node).
2. The total elapsed time from the tree centroid to the node represented by this memory word.

Each memory word is initially set to the largest possible value. The computer then starts building the tree from zone centroid 1 in the following manner:

1. Because the tree is being built from node 1, the first step is to set the back node and the elapsed time in memory word No. 1 to zero. At the same time this node is listed in an elapsed time sequence table in the zero time slot.
2. The computer then takes the miminum entry in the elapsed time table, erases this entry, and from the link memory block, finds all links that emanate from this node, which can be called node A.
3. At the end of each of these links there is a second node, which can be called node B. The link time from node A to node B, plus a turn penalty if required, is added to the total elapsed time at node A to give the total elapsed time from the tree centroid to node B. The machine compares the computed elapsed time at node B with the previously established elapsed time stored in the word represented by node B in the tree memory. If the new time is less than the stored time, it replaces the stored time and node A replaces the previously stored back node. At the same time this node B is stored in the elapsed time sequence table in the appropriate time slot. If, however, the new time is equal to or greater than the previously stored elapsed time, the route is not a minimum path and the computer discards this value.
4. When all of the links emanating from node A have been completed in this manner, the computer again selects the minimum entry in the elapsed time sequence table and repeats the process.
5. When all values in the elapsed time sequence table have been used, the tree from zone centroid 1 has been completed and the tree memory is written out on tape.
6. The computer then proceeds to zone 2 and builds the tree from this zone in exactly the same manner.
7. When trees have been built from all zone centroids, the arterial tree routine has been completed. For the Washington, D.C., area, about 450 trees will be needed.

Freeway Tree Routine. —The program has been written so that any freeway pattern may be superimposed on the arterial street network without destroying the arterial trees already completed.

The freeway trees are built in exactly the same manner as the arterial trees except that the freeway links as well as the arterial links are included in the input data.

Program 3—Load Entire Network (Time-Ratio Curve)

The previously completed freeway and arterial tree tapes and the zone-to-zone trip tape become input for Program 3. In addition, the relationship between time ratio and percent diversion is placed in the computer memory. The program then performs the following operations:

1. The arterial tree for node 1 (also zone centroid 1) is read into a block of memory.
2. The freeway tree for node 1 is read into a separate block of memory.
3. The zone-to-zone trips from zone 1 are read into a third block of memory.
4. The trips between the first pair of zones initiates the following action:
(a) The destination zone of the trip becomes the first entry in the arterial route.

(b) From the arterial tree, the back node of the destination zones becomes the second entry in the arterial route.
(c) The back node of the second entry becomes the third entry for the route, and so on, until the route reaches zone centroid 1.
(d) The freeway route is established in same manner with the corrections to travel time on the freeway links being made.
(e) The arterial route is compared with the freeway route:

(1) If the routes are identical, all of the trips are accumulated on the arterial routing in a block of memory where each word represents a corresponding highway link.
(2) If the routes are different, the two points of choice are determined.

(f) The travel time via the freeway and via the arterial system between points of choice is computed and converted to time ratio and then to percent diversion.
(g) The freeway traffic is accumulated in memory via the freeway route and the arterial traffic is accumulated in memory via the arterial route.
(h) At all 4-way intersections two of the turning movements are recorded separately in a turn table so that in the final analysis all turning movements are available.

5. The remaining trips from zone 1 are handled in the same manner, after which the trees and trips from zone 2 replace those of zone 1 and the process is repeated.

6. This process is continued until all zone-to-zone trips have been processed, at which time the accumulated volumes are written on tape in decimal form. The decimal tape is printed on peripheral equipment. The printed output is the traffic load on all segments of the entire network, including all turning movements.

Program 2—Load Arterial Network (All or Nothing)

The library also includes a program for loading all trips on the shortest route. This is accomplished by reading only the arterial trees into memory and loading all trips on the routing established by these trees.

Program 4—Sum Vehicle-Miles and Vehicle-Hours

The vehicle-miles and vehicle-hours on the freeway network on the arterial system, and on the local system, are then computed and printed.

COMPUTER RUNNING TIME

The entire program library has been completed and a major portion tested on the Virginia portion of the Washington metropolitan area. This area consists of 102 zones, 543 nodes, and 3,488 zone-to-zone movements. The time required to run through the various programs in the library was as follows:

Program	Units	Computer time (sec)	Rate
Convert links to binary	543 nodes	25	¾ min per 1,000 nodes
Convert volumes to binary	3,488 z-z cards	60	3 min per 10,000 z-z cards
Build trees	102 zones 543 nodes	280	8½ min per 100 zones per 1,000 nodes
Load network (time ratio)	3,488 z-z cards	275	13 min per 10,000 z-z cards
Load network (all or nothing)	3,488 z-z cards	97	4⅔ min per 10,000 z-z cards $\times\left(\frac{\text{No. of nodes}}{500}\right)^{1/4}$
Compute vehicle-miles and vehicle-hours[1]	543 nodes	35	1 min per 1,000 nodes

[1] Includes conversion of link volumes and turning movements from binary back to decimal, written out on tape in an appropriate format.

Using these rates it is possible to estimate the computer time required for one complete assignment for any area. For example, it is expected that the Washington, D. C., metropolitan area will consist of about 450 zones, 3,100 nodes, and 40,000 zone-to-zone trip cards. The estimated computer time for this area would be as follows:

Program	Units	Rate	Total Time
Convert arterial links to binary	3,100 nodes	$\frac{3}{4}$ min per 1,000 nodes	3 min
Convert freeway links to binary	3,100 nodes	$\frac{3}{4}$ min per 1,000 nodes	3 min
Convert volumes to binary	40,000 cards	3 min per 10,000 cards	12 min
Build arterial trees	450 zones, 3,100 nodes	$8\frac{1}{2}$ min /100/1,000	120 min
Build freeway trees	450 zones, 3,100 nodes	$8\frac{1}{2}$ min /100/1,000	120 min
Load network (time ratio)	40,000 cards	13 min per 10,000 $\times \left(\frac{\text{No. of nodes}}{500}\right)^{1/4}$	90 min
Compute veh-mi and veh-hr	3,000 nodes	1 min per 1,000 nodes	3 min
Total			5 hr 51 min
Set up and control time			10 min
Contingency time	(10%)		34 min
Grand total			6 hr 35 min

An IBM 704 computer with 32,000 words of memory will cost from $350 to $400 per hour. Thus, the machine cost for one assignment for the Washington area will be about $2,200 to $2,600.

ACCURACY OF ASSIGNMENT PROGRAM

The accuracy of the assignment program rests basically with the accuracy of the assumption that traffic divides between routes in accordance with the time-ratio diversion curve. In any particular city, the accuracy of this assumption can be checked by assigning present trips to the existing highway system and checking against current traffic counts. If better criteria are subsequently developed which improve the distribution of traffic among routes, they will be incorporated into the program.

The program as written has considerable flexibility. Changes in the extent or location of the proposed freeways can be tested by merely altering the freeway network and rerunning the program. If any of the proposed highway segments are loaded beyond capacity, the travel times on these sections can be adjusted and the program rerun until there is a balance between capacity and travel time on each segment.

If directional zone-to-zone trips are available, the program can give directional assignments. Thus, traffic on one-way streets or ramps can be directly computed.

It is likely that the future use of the program will develop additional subroutines which will be useful in designing highways. By way of illustration, consider the case of a ramp connection immediately before an interchange between freeways. If the predominant flow of traffic from the ramp turns left at the freeway interchange, it may be advantageous to bring the ramp into the freeway from the left to avoid the confusion of weaving this traffic across the freeway. By suitable instructions, the computer can develop these or similar data.

The program is written for an IBM 704 computer with 32,000 words of memory. If there are less than 900 nodes in the highway system, an 8,000-word memory will be sufficient. In addition to memory capacity, it is essential that the computer have extremely fast access time to all memory positions. This consideration, at least for the present, precludes the use of computers which rely on a magnetic drum memory.

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REFERENCE

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Use of IBM Port-a-Punch in Origin-Destination Surveys

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●THE Port-a-Punch was developed by IBM primarily as a means of simplifying documentation of data. Its use eliminates the need for key-punching. In many respects, the Port-a-Punch card is similar to "mark sensing," which has been used for a number of years and is probably familiar to most people.

The cards used are standard-size IBM cards with up to 40 perforated columns of 12 punch positions each. The 40 columns correspond to even-numbered columns on the regular IBM cards. The cards are inserted in a plastic board with slots under the columns (Fig. 1). A pencil-like stylus punch then easily removes the perforations corresponding to desired information.

The principal reason for experimenting with the Port-a-Punch in New York was to obtain finished data faster and more economically, if possible, than with previously used methods. In today's traffic little delay can be tolerated; therefore, a faster method of interviewing than the conventional method was sought and the Port-a-Punch device was tried out in 1958 O-D surveys for the cities of Yonkers and Canandaigua and the Village of Brewster.

The cards were set up so that hourly volumes of about 600 vehicles per lane could be handled with a 90 percent or better interview sample. This was thought possible because all of the O-D information could be recorded in as few as five punches on the card. Under these conditions, vehicles could be stopped in the travel lane for not more than 10 seconds. As a matter of fact, many of the locations in Yonkers were on single-lane curbed parkway ramps. At those locations there was no alternative other than to interview traffic in the travel lane.

APPLICATION

The Yonkers cards were set up with 12 pre-coded origins and destinations, three within the city and nine outside. The places within the city were Otis Elevator, the city's only major factory; Getty Square, the downtown central business, shopping, and city government area; and the Cross-County Shopping Center, one of the largest of its kind in the state. The nine pre-coded places outside the city were names of cities and villages nearby.

Both Brewster and Canadaigua had 24 pre-coded origins and destinations. These pre-coded places could be punched as either origin or destination, but interviewers were cautioned that a single place should not be punched as both.

The coding for vehicle type and trip purpose were memorized for Yonkers by the interviewer, but abbreviations for those items were printed directly on the cards for the subsequent O-D studies in Brewster and Canadaigua. It was found that the pre-coded origins and destinations for the 154 survey sites in Yonkers accounted for 31 percent of all the interview information. It appears that the statistics for the Brewster and Canandaigua surveys will show about the same proportion of information documented by the system.

It must be considered that conditions imposed by the Yonkers survey required exact addresses for all trips terminating either in Yorkers, Mt. Vernon, or the five buroughs of New York City. New Jersey and the counties of Westchester, Rockland and Nassau were divided into zones, so that named places were required for trips terminating in those areas.

Thus, with the foregoing limitations, it is of interest to note that the cards accounted for such a sizeable percentage of the total trips. The Canandaigua survey was similar to Yonkers in that all trips terminating within the city were required to be pin-pointed by exact addresses. The Brewster survey had no street address areas.

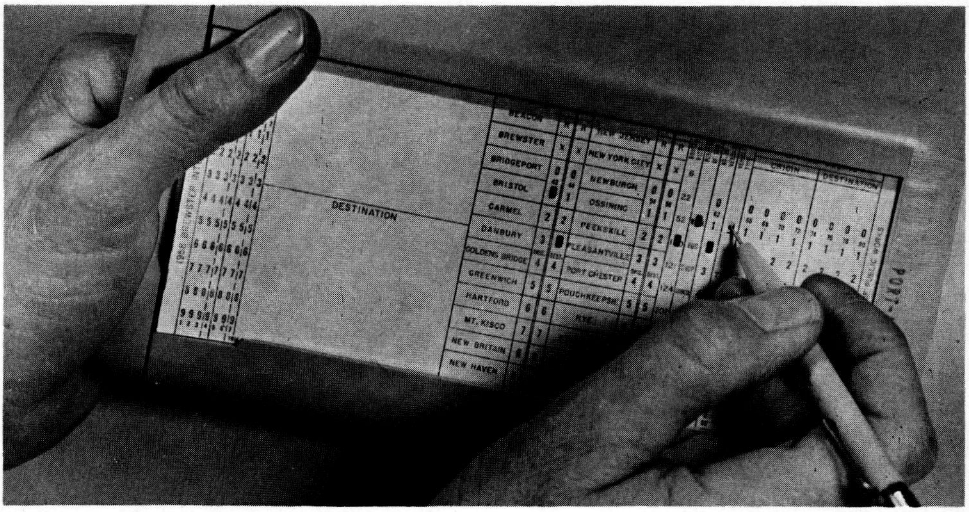

Figure 1. Completing normal field punching operations for the origins and destinations printed on card.

The cards for Yonkers were ordered with a colored stripe throughout the length of the card with the stripe position indicating hour and the color indicating AM or PM. These cards were gang-punched with station, direction, and hour identification in estimated quantities for each site as determined by one-day machine counts. This preparation involved a considerable amount of hand work, traffic counter machine, and IBM work, but this work was still less than for previous interview surveys. Card needs by hour could not be estimated by hour for Brewster, so the color stripes were used to denote AM and PM only. Canandaigua cards were not color-striped or identified at all prior to field use.

Observations on the color stripes and pre-punching for interpretation are as follows:

1. Liberal estimates should be made for the number of pre-punched cards needed by hour at each site. In Yonkers, blank cards were used to fill out when pre-punched cards were exhausted because of greater-than-anticipated interview rate. These cards had no identification and had to be handled carefully to avoid errors. On the normal cards, the pre-punched and interpreted data were intended to keep them in proper order for machine processing. However, after coding and editing, practically every hour had a number of "extra" cards that had to be machine punched for proper identification. In the Canandaigua survey, a number of blank "extra" cards were gang-punched with the interview cards after the field work was completed. The identification was done both before and after in Yonkers, and only after in Brewster and Canandaigua.

2. In Brewster, color stripes were used to separate AM and PM hours. There were only eight sites for Brewster, so no pre-punching was done for that survey. Under these conditions the color stripes served as an excellent way to keep hours in order. However, it is planned to use color stripes in addition to different background card color to separate directions on future two-way interview areas.

From experience with the above variations, it appears that:

1. Inbound and outbound cards should have different background colors.
2. Inbound and outbound cards should have different make-up regarding pre-coded information so as to better utilize geographical features.
3. Color stripes should be used to designate hours.
4. The cards should be pre-punched and interpreted with identification.
5. The "spare" or "extra" cards should be identified by field punching.

FIELD EXPERIENCE

The field work for all three surveys was similar. Roadblocks at the survey sites were set up and nearly every vehicle was interviewed. The pre-punched cards were stored in their original cardboard boxes (approximately 2,000 per box) by sites. Morning-shift cards were separated from afternoon-shift cards as interviewers operated from 7:00 a.m. to 2:00 p.m. and 2:00 p.m. to 9:00 p.m. A panel station wagon was used as an office and supply truck. Morning-shift crew chiefs were contacted at the end of shift, the used cards collected and cards to begin operation the following morning supplied. The same procedure was used with afternoon crew chiefs. Each weekend (Friday night concluded week) the completed cards were taken to the main office for coding and editing. Some 250,000 Yonkers cards were handled.

If both origin and destination were on the card as pre-coded places, interviews were finished in less than 10 seconds. If both origin and destination were write-ins, the interview took up to 30 seconds. The pre-coding speeded up interviewing on an average of 2½ times over the 100 percent write-in method. This speed-up enabled the interviewers to obtain a 90 percent sample or better of trips without seriously affecting traffic.

The interviewers were local people hired for the purpose and paid on an hourly basis. They were given six hours of classroom instruction before field operations were begun. The Yonkers survey was scheduled to use 100 interviewers working 13 days. As the job progressed, a maximum of only 80 interviewers were obtained at any one time and the Brewster survey (being relatively close) was operated with the same people. Combined, the two surveys took approximately a month.

Canandaigua, being far removed from Yonkers, was run on a single Thursday using six experienced main office employees as crew chiefs. Training was accomplished on the day prior to the survey, by setting up a site on a local highway and training "on the job." Five permanent people from the office took groups of ten interviewers, and instructed them on an actual contact basis, operating for a period of 4 hours until all persons were thoroughly indoctrinated. This proved more effective than the method used in Yonkers, which was principally "classroom" instruction.

Some of the findings on the field work are as follows:

1. Crew chiefs need to be trained prior to the interviewers.
2. Using the Port-a-Punch, traffic could be stopped in the travel lanes.
3. A minimum of police direction was required.
4. There were 168,327 codeable trips produced in Yonkers. Of these, there were 55,767 pre-coded destinations and 49,115 pre-coded origins representing 31 percent of the total trip terminations. (Comparable data for the Brewster and Canandaigua surveys were not available when this paper was written, but it appears that the proportion of total trip terminations will be somewhat higher than for the Yonkers survey.)

CODING

The coding was similar to previous studies; however, the coders punched the numeric information in the interview card rather than writing on the interview sheet. Little difference in coding production was found using Port-a-Punch or sheet methods, because reading the generally poor penmanship and looking up appropriate codes for exact street addresses of origins and destinations took the major portion of the time.

Coding was finished, except for editing, about two months after the interviews were started.

It will be noted that in the coding of Port-a-Punch information, key punching is entirely eliminated. As to accuracy, it was learned that machine editing as well as spot checking proved advantageous.

MACHINE WORK

By machine work, three sets of tabulations were obtained, as follows:

1. Origin to destination by station.
2. Station to destination.

3. Origin to destination for groups of stations (city line).

After hourly and 24-hr expansion factors were calculated and gang-punched, the Port-a-Punch cards were sorted on ten columns; that is, origin to destination by station. A listing and summary cards also were made from the original cards. This listing showed station, direction, card count, hourly expanded total, and 24-hr expanded total for passenger vehicles, commercial vehicles, and the sum of the two types. The summary cards were then used for the station-to-destination tables and station-group tables.

The Port-a-Punch cards eliminated key punching, which would have been a momentous "one-shot" overload on the existing key punch staff. The field survey cards were used in various IBM machines a number of times (that is, reproducer, interpreter, sorter-one pass, reproducer, sorter-twelve passes, and tabulator-one pass) without difficulty. If duplicate cards are to be supplied to the Bureau of Public Roads, the original cards can be reproduced as a first-machine operation.

CONCLUSIONS

Conclusions on use of the Port-a-Punch system for O-D surveys are as follows:

1. The Port-a-Punch system enabled interviewers to produce more useable interviews faster with a minimum of traffic delays and motorist irritation.
2. The pre-coding reduced office coding by about 31 percent.
3. Key punching was entirely eliminated.
4. Intermediate paper work was eliminated.
5. Tabulated results were delivered to analysts within five months from start of survey.
6. It is anticipated that for future studies, the tabulated results can be obtained in five weeks or less after completion of field work.

Novel Traffic Survey Method Utilizes Vehicle Lights

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New York State Department of Public Works

● DURING the week of October 6, 1958, a unique traffic survey was conducted in Rochester, N. Y., by the New York State Department of Public Works. The method eliminated severe congestion problems that would have occurred if any of the conventional methods requiring the traffic to stop had been used.

The facility under study was the Memorial Bridge Traffic Circle not far from the principal Eastman Kodak plant and other large industries in the northern part of the city. With peak-hour traffic volumes as large as 1,400 per lane entering the circle and six connecting streets, it was obvious from the first that a considerable operation was involved.

Several possible methods of making the survey had been considered, including the conventional roadside interview, the license plate survey, numbered stickers or colored facial tissues, and 10-sec motion pictures. All of these methods were discarded for

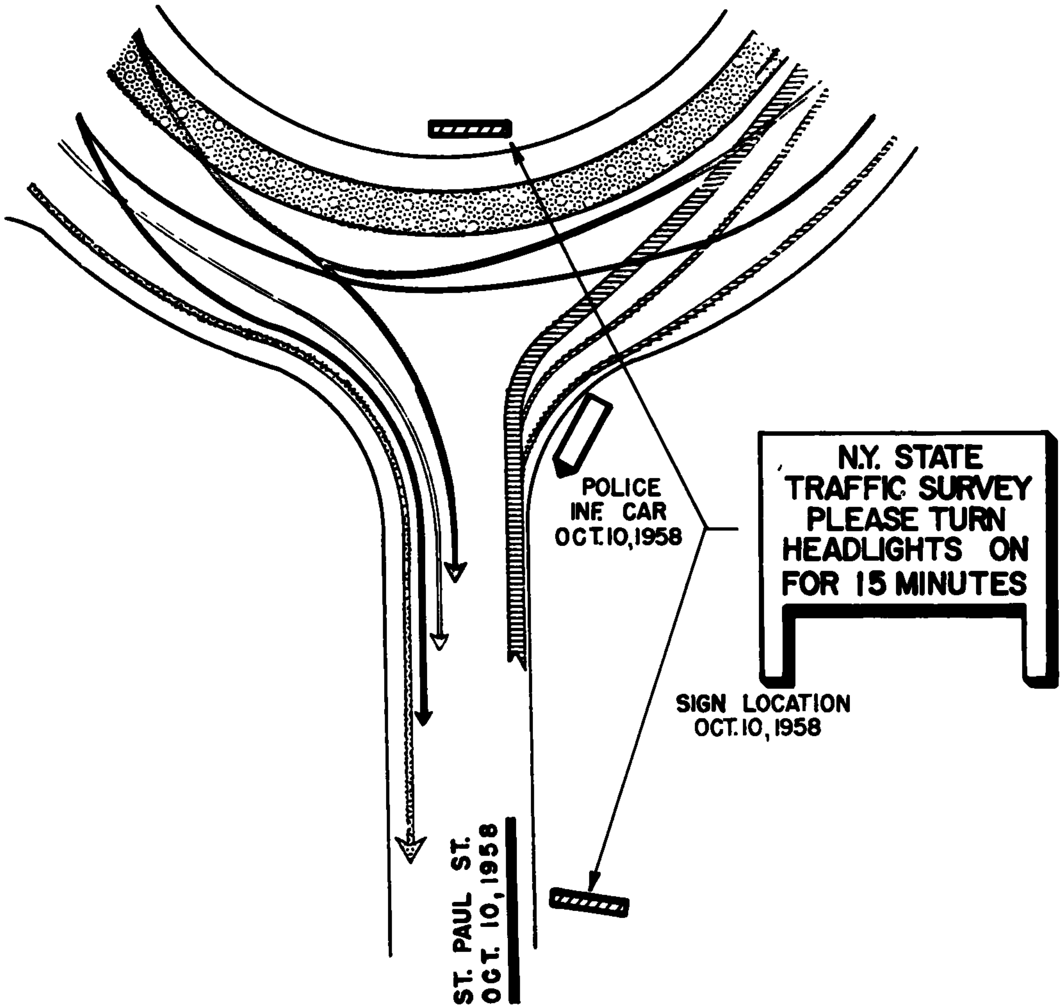

Figure 1.

various reasons. It remained for a clerk, who was concerned with the administrative details of the survey and not with procedures, to make the novel suggestion that one approach be studied each day during the afternoon peak hours and that the motorists be simply requested to turn their lights on so their cars could be counted at the five exits.

GOOD PUBLICITY PAYS OFF

The press, radio, and television were quite enthusiastic about this approach and provided the very best of publicity. Their emphasis was on motorist participation. One paper stated: "Motorists will be asked to use their automobile headlights to shed some light on one of the city's traffic mysteries."

The operation became known as " Lights On. " In addition to the excellent publicity, there was exceptional cooperation from all concerned, including the motorists. The police furnished a sound truck as each approach was studied. The position of the truck and the type and location of information signs are shown in Figure 1. A composite of the results is shown in Figure 2.

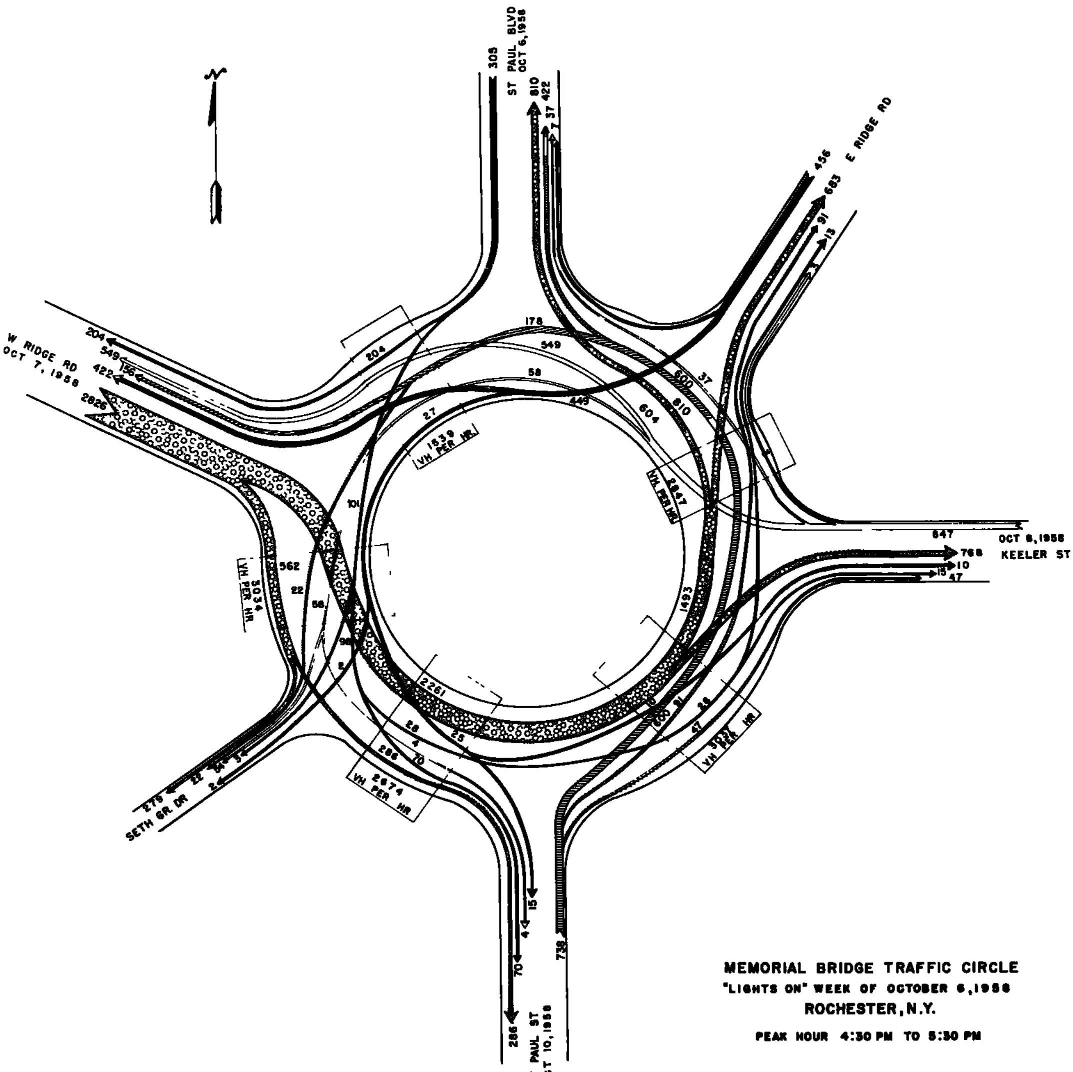

Figure 2.

In conclusion, it should be pointed out that this simplified type of survey is applicable to many spot studies and that the method might introduce a whole new area of study, involving motorist participation.

Estimating and Forecasting Travel for Baltimore by Use of a Mathematical Model

ALAN M. VOORHEES, Traffic Planning Engineer, Automotive Safety Foundation, and ROBERT MORRIS, Traffic Planning Engineer, Department of Transit and Traffic, Baltimore, Maryland

Based on such factors as the number of people living and working in various zones and car ownership and the travel time between zones, a mathematical model was used to estimate the origin and destination of travel in the Baltimore area. The model was used to predict the future traffic volumes of proposed highways and the volumes which could be expected if specific mass transit improvements were made. Numerous tests of the model have indicated its reliability and versatility. It proved an economical method of conducting a comprehensive transportation study for the region.

●THE BALTIMORE Regional Planning Council, in 1957, began to examine the numerous methods of evaluating the urban transportation needs of their region. Because of limited time and funds, the Council sought a quick, inexpensive, although comprehensive, method of evaluating Baltimore's transportation deficiencies.

After analyzing the available research on urban travel that had been done by the Bureau of Public Roads and others, it was believed that traffic movement could be synthesized from known land use factors. In other words, if certain factors were known about a community, such as the number of people who lived and worked in various zones as well as the car ownership in these zones, it would be possible to estimate the origin and destination of urban travel.

The method that was finally selected was, in effect, an application of a mathematical model. A model, in a descriptive sense, utilizes certain mathematical techniques which involve various steps and equations. More simply, it can be defined as a mathematical statement of observed relationships. For example, surveys of shopping habits have revealed that shoppers follow certain patterns that can be predicted mathematically. With such mathematical procedure and facts on individual residence, travel time to shopping centers, and their size, it becomes possible to estimate or forecast where people will shop. Since these techniques deal with travel habits, they are known as traffic models.

The traffic model used in Baltimore was founded on two simple premises:

1. Frequency of individual trips depends on desires and needs of individuals.
2. Modes of travel and trip destinations reflect personal transportation alternatives and land use distribution.

For instance, an insurance salesman undoubtedly travels more each day than does a mother with three or four small children. The mode of travel either party chooses will depend on the availability of an automobile and/or the adequacy of public transportation services. The destinations of their individual trips will depend on the distribution of land uses—the location of shopping centers, industrial and commercial areas, and residential neighborhoods. In a way, these principles might be summed up as a "theory of opportunity."

Trip Frequency

The techniques devised in Baltimore relied first on the establishment of trip frequency. Numerous O-D studies indicated that work trips are the most common type in metropolitan areas and total about 40 percent of all trips during an average day. This percentage is higher—often 60 or 70 percent—during peak hours (1).

Another category of trips, those linked to commercial areas, include trips for personal business, shopping, and dining or entertaining. Most of the commercial trips occur in off-peak hours; but 20 percent of peak-hour travel is comprised of non-work trips linked to commercial areas.

Trips for the purpose of visiting friends have been identified as social trips. Although not very important in the whole picture, social trips have a unique characteristic in that their destination is influenced by distribution of population. These trips account for 10 percent of the peak-hour travel and about 20 percent of off-peak travel.

Non-home-based trips consist, for example, of salesmen in door-to-door traveling, or housewives shopping from store to store. These trips represent about 15 percent of the travel in off-peak hours, and 5 percent of the travel during the peak hour.

In arriving at trip frequency in Baltimore, certain modifications within these known percentage ranges were made. The commercial and social trip frequency was based on car ownership. For every 1,000 cars garaged in a residential area, 900 commercial and 700 social auto trips commenced daily. Forty commercial and 15 social started at the peak hour. (The Washington, D. C. Transportation Study revealed about the same number trips return during the peak hour.)

Calculating work-trip frequency involved a more complicated procedure, since the number of work trips is related to employment rather than to car ownership. First,

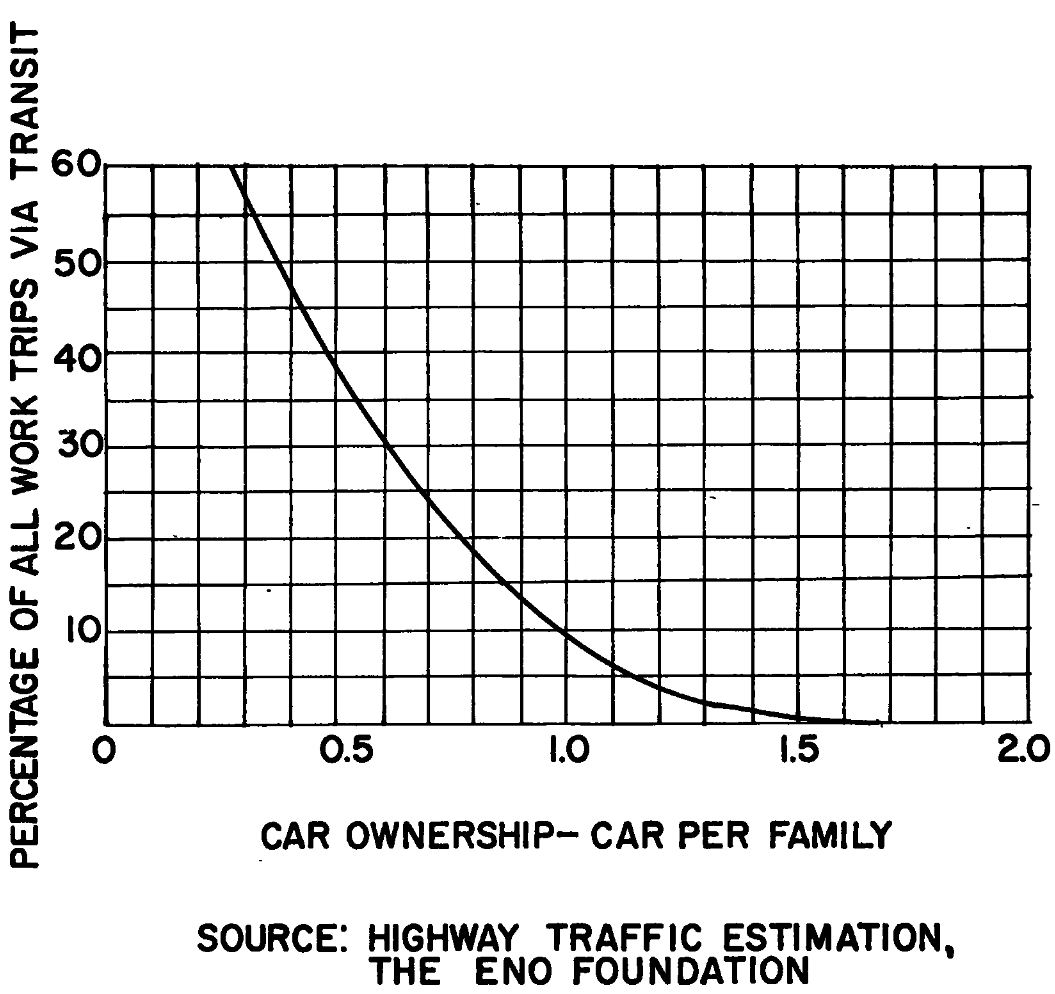

Figure 1. Relationship between transit usage and car ownership.

the number of transit work trips in residential areas was estimated by using the curve illustrated in Figure 1, which was based upon an analysis of 32 different O-D studies by the Eno Foundation. This estimate was then subtracted from the number of workers usually departing daily from a residential district by some form of transportation (85 percent of labor force) indicating the total number of persons traveling by private automobile. Using Figure 2, the number of persons per car was ascertained for each residential area. From these data, it was possible to compile the number of auto work trips starting from each residential area. To simplify computation, it was assumed all work trips would be returning home during the evening peak hour.

To keep the technique simple, only two types of transit trips were considered—work trips and miscellaneous trips. Since frequency of miscellaneous transit trips was assumed to be equal to that of work trips, it was possible to estimate all transit trips from Figure 1. The total number of transit travelers was calculated on this basis and was compared with the known number of transit trips for the area. (The estimate was within 10 percent of the actual, therefore no modifications were made.)

The foregoing steps established the mode of travel and the frequency of work, commercial, and social trips starting from a residential area. Non-home-based-trip frequency was developed in later stages of the procedure.

Trip Destination

To evaluate destinations of residentially based trips, a gravitational principle was applied. Essentially, this principle states that all trips emanating from residential areas are attracted or "pulled" to various land uses. The strength of this pull is associated directly with the size of land use development and indirectly associated with the distance (or travel time) between the land use and the residential area (2).

Utilizing this concept for transit travel, transit time between zones was used; while auto-travel time between zones was applied for private-vehicle trips.

Transit users, of course, tend to adjust their traveling habits to accord with mass public transportation service. Travel time between zones depends upon transit service. The auto user, being more versatile, however, is influenced by the travel time

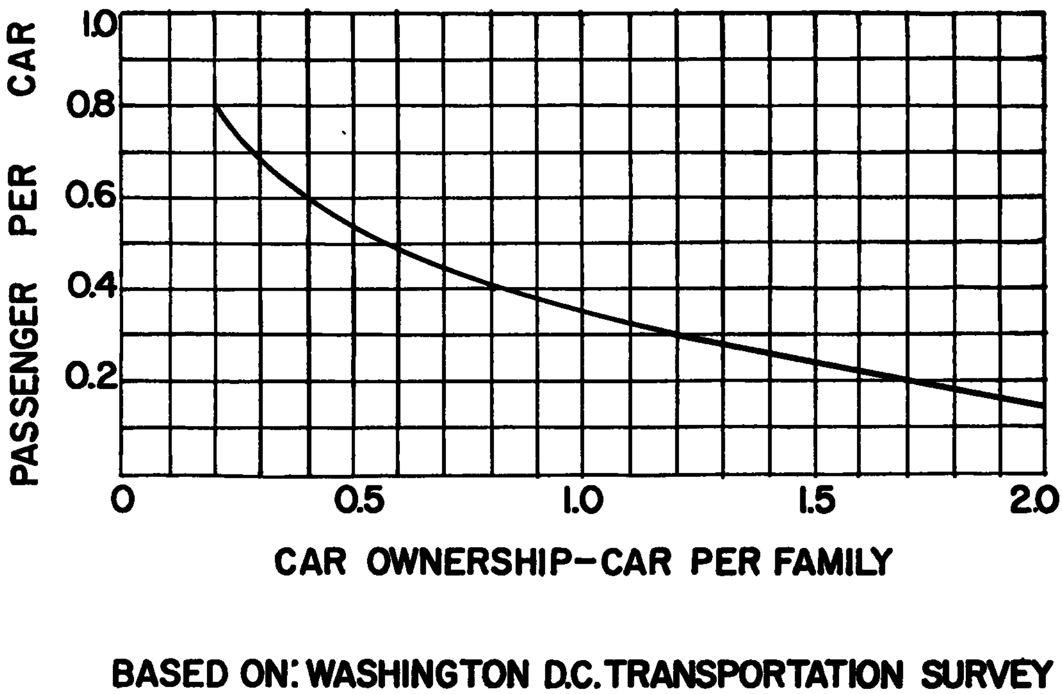

Figure 2. Relationship between passenger per car and car ownership.

permitted by the highway network. And, because most auto and transit travel occurs in the off-peak hours, midday hours were studied.

In selecting suitable factors to express the "size" of the attracting land use for work trips, the total number of people employed in each area was analyzed. For commercial trips, retail employment for each zone was examined to reflect the size of the attractor. This index was selected primarily as a matter of convenience, because the city planners had estimated retail employment in determining the number of workers employed in each zone. For social trips the number of people living in each area was chosen to indicate attractor size.

Working with employment statistics and population figures, it was easier to link the survey with the economic-base data for the area. From experience gained in Baltimore, it was judged that it is more effective to express the size of the attractor in terms of employment and population rather than in acreage of various land uses.

The influence of travel time on trip destination was measured by a series of factors shown in Table 1. (These travel-time factors are based on research that has shown that different factors are necessary for various trip types.)

The values of these factors reflects the best available data but certain judgment decisions had to be made to fill in gaps in available information (3). Such factors indicate the effect that travel time has on the frequency of trips between areas.

To illustrate the significance of these factors: an industrial zone two minutes from a residential area attracts four times as many work trips as a comparable industrial zone ten minutes distant (see Table 1).

Thus, to figure the destination of work trips starting in a residential zone, the appropriate time factor is multiplied by the number of people employed in various zones. Work trips are subsequently distributed to each employment zone in proportion to that zone's product and the sum of the product for all zones. (An example of this process is included at the end of this paper.)

The number of non-home-based trips beginning in each zone was computed by totaling social and commercial trips attracted to a zone after employing the gravity model. In figuring non-home-based trips over a 24-hour period, the number of trips attracted to a zone for commercial and social purposes was divided by three to conform to the frequency pattern already discussed. The number of peak-hour trips attracted to a zone was divided by eight. The resulting compilation indicates the number of non-home-based trips starting from each area. In estimating the destination of these trips, the proportion of trips attracted to each zone for commercial or social purposes

TABLE 1

TRAVEL-TIME FACTORS

Travel Time in minutes	Travel-Time Factors by Trip Purpose			
	Work	Social	Commercial	Non-Home-Based
2	4.00	5.00	8.0	8.0
3	2.86	3.33	7.0	7.0
4	2.28	2.50	6.0	6.0
5	1 90	2.00	4.0	4 0
6	1.60	1.62	2.7	2.7
7	1.40	1 42	2.0	2.0
8	1.21	1.25	1.5	1.5
9	1.11	1.11	1.2	1.2
10	1.00	1.00	1.0	1.0
11	.93	.91	.80	.80
12	86	.83	.68	.68
13	.80	.77	57	.57
14	.75	.71	.50	.44
15	.70	.67	.44	.40
16	.66	.62	.40	.35
17	.62	.59	.35	32
18	.59	.55	.32	.28
19	.56	52	.28	.25
20	.53	.50	.25	.22
21	.50	.46	.23	.19
22	.47	.43	.21	.16
23	.44	.40	.20	13
24	.41	.37	.18	.10
25	39	.34	.16	.08
26	.36	32	.15	.06
27	.33	.30	.14	.04
28	.31	.28	.13	.02
29	.27	.26	12	.01
30	.25	.25	.11	
31	.23	.23	.10	
32	.21	.21	.10	
33	.19	.19	.09	
34	.18	.18	.08	
35	.17	.17	.08	
36	.16	.16	.07	
37	.15	.15	.07	
38	.14	.14	.07	
39	.13	.13	.07	
40	.12	.12	.07	
41	.11	.11	.07	
42	.10	10	.06	
43	.09	.09	.06	
44	.08	.08	.06	
45	.07	.07	.05	
46	06	.06	.05	
47	.05	.05	.04	
48	.05	.05	.04	
49	.04	.04	.04	
50	.04	.04	.03	
51	.03	.03	.03	
52	.03	.03	.03	
53	.02	.02	.02	
54	.02	.02	.02	
55	.02	.02	.02	
56-60	.01	.01	.01	

was used to indicate the size of the attractor. The time factors applied are shown on Table 1.

The same general technique may be used in studying truck travel in an urban area. Other studies have shown that the non-home-based-trip pattern is fairly comparable to truck movement patterns in urban areas.

Work trips were brought into balance when the gravity model was put to use. If, in its application, too many trips were allocated to a particular employment center, they were adjusted to conform to the estimated number of auto and transit trips destined to a center. This was achieved by multiplying the trips to the center by an appropriate adjustment factor similar to that done in the growth factor technique. These corrective measures were applicable to work trips only.

To estimate the work trips destined to an area, it was assumed that transit usage, in an employment area of low car-ownership, would be high. On the other hand, in an area of high car-ownership transit travel would be low. Trip destination was estimated using this assumption. Therefore, without empirical evidence to the contrary, it was decided that Figure 1 could be used to reflect this relationship, and it was used as the basis for the necessary calculations.

The model was modified also for trips to the downtown area. It was adjusted for the difference in relationships between homes and employment of different occupational classes. From experience in other cities it would appear that this correction is necessary only for trips to the downtown area (1).

The correction for downtown trips was quite simple. It involved an investigation of the model's degree of error regarding downtown trips. (This was achieved by analyzing a previous transportation study for the CBD.)

Checks

Though the techniques used in Baltimore were based on considerable research, it was considered prudent to make certain checks on the resulting estimates. The question was asked, "Is the traffic movement synthesized through this technique an authentic picture of the traffic actually developing on Baltimore's streets?" To answer this, four screen lines were created which divided the metropolitan area into large segments. Traffic was counted as it crossed these lines and compared with the traffic estimates obtained by using the model. As indicated in Table 2, the screen-line checks were usually within ten percent of the actual traffic counts. Moreover, similar checks were carried out for mass transit and the results indicate a comparable degree of accuracy.

In addition to screen-line checks, information was amassed on place of residence of employees in several industrial plants. This information was checked against estimates developed by the gravity model. As indicated by Table 3, the technique accurately portrays the proportion of trips within specific travel times of the employment area. In making this comparison on a zone-to-zone basis there was a greater deviation between the actual and theoretical estimate. For example, when zone-to-zone volumes were 100, the root-mean square error was around 50 percent; for volumes of 1,000, the error was about 20 percent; for volumes of 10,000, the error was in the neighborhood of 10 percent.[1] This series of checks indicated that the Baltimore traffic model error was about comparable to the statistical error that would result from a five percent home-interview study.

An interesting historical check was based on data from 1926, 1946, and 1958 studies which revealed home-work relationships. For this time span the gravity model was applicable if the appropriate travel time for each era was used, an especially extraordinary finding since travel times have changed drastically over the years.

Projections

When it was agreed that this method could adequately synthesize existing travel,

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[1] Root-mean square error means that two thirds of the time this error will be less than specified.

TABLE 2

SCREEN LINE CHECKS OF THE BALTIMORE 1958 TRAFFIC ESTIMATES

	24 Hours			Peak Hour		
Screen Line	Actual	Estimate	Estimate As Per Cent of Actual	Actual	Estimate	Estimate As Per Cent of Actual
A	487,500	457,200	94	40,100	40,300	100
B	384,900	399,100	102	35,400	32,900	93
C	323,200	365,700	112	30,200	33,700	111
D	254,400	280,900	110	23,000	24,100	105

TABLE 3

COMPARISON OF ACTUAL AND ESTIMATED NUMBERS OF TRIPS, BY TRAVEL TIME FROM THREE MANUFACTURING PLANTS, BALTIMORE—1958

	Percentages of Trips Within Time Periods					
Time of Trip	Westinghouse		Bendix		Glenn L. Martin	
in Minutes	Actual	Estimate	Actual	Estimate	Actual	Estimate
0-10	42	37	32	29	-	-
0-20	64	60	74	76	24	17
0-30	82	78	94	94	71	64
0-40	97	98	100	100	93	94
Over 0	100	100	100	100	100	100

the same general technique was used to project future travel. But in projecting future travel it was recognized that traffic patterns depend upon the transportation alternatives that are offered the public. Therefore, two general projections were made for 1980. The first was based upon a plan that called for extensive highway improvement with few transit changes; the second was derived from a plan that comtemplated several rapid transit lines and the completion of only the interstate highway systems.

The traffic projections for the first plan were based on the Regional Council's forecast of population and employment distribution. Car-ownership forecasting was carried out in several ways for comparative purposes. The method finally selected was based on a Bureau of Public Roads study. It showed that income of household and type of residential area had a direct bearing on the number of cars per household. The study also revealed an increase in car ownership for specific residential areas until the income level reached a range of from $8,000 to $10,000 per year. Beyond this range car ownership leveled off. This means that, in effect, there was a ceiling for car ownership for various types of residential areas (see Table 4). The number of cars expected to be garaged in each residential zone was estimated on the basis of trends of existing car-ownership patterns and anticipated income levels for various zones.

The existing travel times between zones were not used in projecting travel for the first plan; instead, travel times resulting

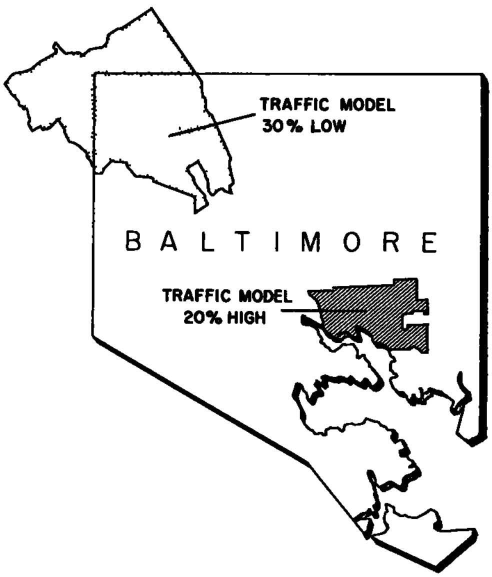


Figure 3. Residential areas where observed travel to downtown Baltimore varied from traffic model.

TABLE 4

CEILING FOR CAR OWNERSHIP PER HOUSEHOLD

Residence Type	Autos Per Household
Single Family	
new area	1.6
old area	1.0
Two Family	
new area	1.2
old area	0.9
Row House	
good transit and poor parking	0.4
good transit and good parking	0.6
poor transit and good parking	1.0
High Rise	
good transit and poor parking	0.2
good transit and good parking	0.4
poor transit and good parking	0.6

from the development of an extensive freeway system were employed. This was done to reflect the fact that improved highway facilities tend to increase travel length. In essence the traffic forecasts considered the effects of anticipated increases in population and employment, car ownership, and expected increases in auto speeds.

The traffic projection for the transit plan was accomplished on a somewhat similar basis. Car-ownership patterns in the vicinity of proposed rapid transit lines were adjusted in accordance with Table 4. The auto-travel times between zones reflected a more limited freeway system. Certain changes were made in the land use forecasts, specifically, a 20 percent increase in employment in the CBD.

By using these criteria, a new set of auto and transit patterns was formulated. However, it was recognized that a certain portion of the population would shift from auto to transit travel in the event rapid transit lines became a reality. The estimate of the volume of this shift to rapid transit was calculated with the aid of the curve in Figure 4. The curve was applied to only 75 percent of auto trips, that percentage of trips for which autos were not essential. Completing this step, it was possible to forecast the traffic and auto patterns for the second plan.

Example

To help understand the gravity model and to see how it can be employed to estimate traffic volume, the following example is given.

In Figure 5 the residential area designated R has 1,000 families within its limits. Each family has one car. There are three commercial areas in the vicinity C_1, a mile distant or 5 minutes away by auto with 100 employed in retailing activities; C_2 two miles away, or about 10 minutes away by car, with 200 retail employees and C_3 four miles away, or 20 minutes away by car, with 400 employees in retailing.

In line with previous discussion on commercial trip frequency, this would mean that 900 trips each day would start from the residential area R. On the basis of calculations shown in Figure 5, 360 trips would be made to C_1, 360 trips to C_2 and 180 trips to C_3.

Imagine, now, a new expressway that would enable residents to travel to C_3 in half the time, or 10 minutes. From the calculations shown, the 900 trips would be reoriented in the following manner: 225 to C_1, 225 to C_2 and 450 to C_3 resulting in 675 more vehicle miles or approximately a 40 percent increase. Furthermore, the new expressway would accommodate 270 additional vehicles and would increase traffic by nearly 150 percent.

Similar reorientation in traffic movement would be observed if a new shopping center or another type of land use were established in the vicinity.

Benefits

As in a conventional type interview of O-D study, this study permits the analysis of several transportation alternatives. The use of a model allows more flexibility and greater opportunity to evaluate these alternatives.

The role of mass transit transportation was clearly defined by studying the two

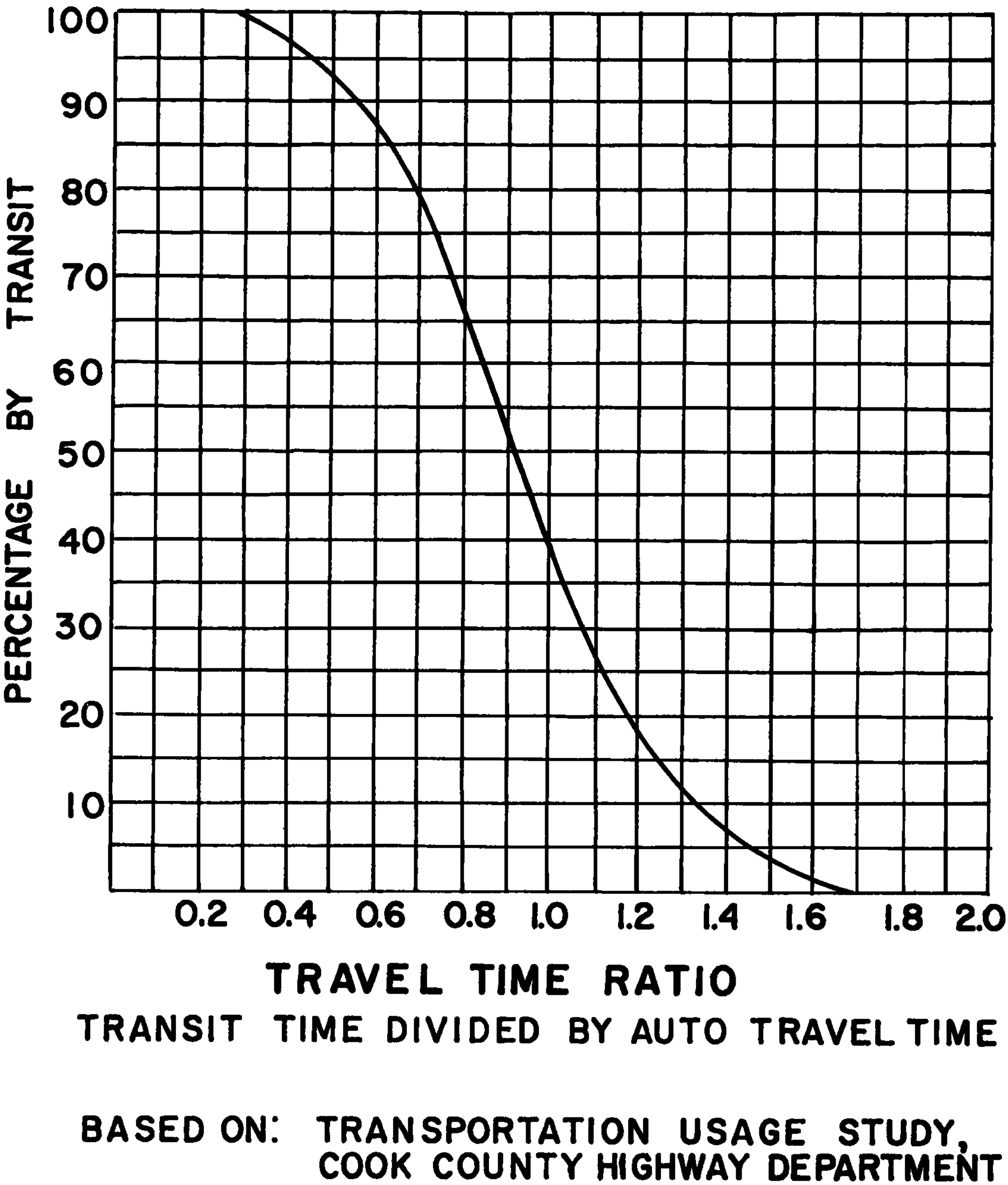
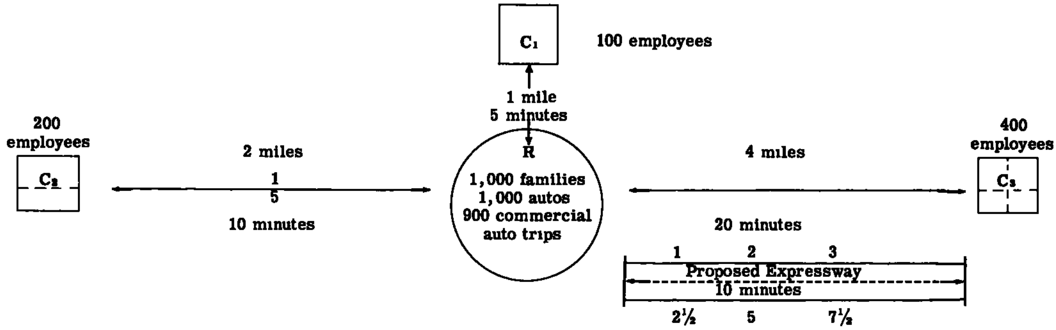


Figure 4. Transit assignment curve.



Existing "Pull"	Travel Friction	% of Total "Pull"	No. of Trips	Vehicle Miles
from C_1 = 100	2.00 = 200	40	360	360
from C_2 = 200	1.00 = 200	40	360	720
from C_3 = 400	0.25 = 100	20	180	720
Total "Pull"	= 500	100	900	1,800
"Pull" after Expressway is Built				
from C_1 = 100	2.00 = 200	25	225	225
from C_2 = 200	1.00 = 200	25	225	450
from C_3 = 400	1.00 = 400	50	450	1,800
Total "Pull"	= 800	100	900	2,475

Figure 5.

alternatives mentioned previously. The survey revealed that Baltimore transit services, no matter how extensive, cannot be considered a substitute for highway improvements. Nor will they drastically reduce highway building requirements. These conclusions could not have been drawn without the use of a traffic model.

This mathematical model has provided Baltimore's planning staff with a clearer conception of the city's traffic problems and, further, has helped it to envisage the effect that land use arrangements have on traffic patterns. Factually, any type of land use plan can be evaluated with such a model, and it is possible to investigate many transportation alternatives and to decide on the one making most "transportation sense."

SUMMARY

The use of mathematical models in highway planning work offers many advantages:

1. It assures better understanding of the factors that influence traffic patterns.
2. It also provides a better factual basis for plans, and permits more thorough testing and evaluation of alternatives.
3. By proper use of models, more realistic plans can be developed since it will permit one to analyze more effectively factors that influence traffic patterns.
4. Traffic models are low-cost (approximately $25,000 for the Baltimore study), technically simple and require only a limited staff.

The benefits that can accrue from application of mathematical models of this type certainly justify more exploration of these techniques. With the achievement of more effective mathematical models, urban highway planning will become a more exacting science.

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Application of O-D Data in the Baltimore Region

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In seeking a quick and inexpensive way to locate an efficient freeway system for the Baltimore area, a comparison was made of the existing street capacity with the travel desires over a series of screen lines. The origin and destination of traffic desiring to cross at the points of capacity deficiency were examined to give clues as to the type of freeway pattern required. The freeway system delineated by this technique stood up under various traffic assignments. Tests indicate that the method was sound. In addition, a method was developed that was helpful in locating and designing arterial streets.

●USE OF origin and destination data to determine highway needs and design factors presented some unique problems in the Baltimore transportation study. First, the study was under the general auspices of the Baltimore Regional Planning Council, a purely advisory group of officials from the various jurisdictions concerned. Therefore, the freeway plan had to be developed on a cooperative basis. Second, the local jurisdictions wanted the information prepared in such a manner that it would be helpful to them in determining their arterial and local street needs. Consequently, the program was developed into two phases, the first dealing with the delineation of the basic freeway system and the second being concerned with local street needs.

DETERMINING FREEWAY NEEDS

To eliminate the need of testing many freeway systems to find one with adequate capacity, it was felt that by properly analyzing the O-D data and available capacity information it should be possible to select a system initially that would not have bottlenecks. In attempting to do this, the following program was set up:

1. Scaling the problem.
2. Screen line analysis.
3. Delineating the plan.

Once these steps were completed the freeways were located more specifically and traffic assigned to them.

Scaling the Problem

The Baltimore Regional Planning Council had forecast a population growth of more than 800,000 in the Baltimore Region by 1980. Analyses of automobile ownership trends reveal that by 1980 the motoring population should be approximately 850,000. Both of these factors, when combined, would naturally bring about a rapid increase in vehicle travel. As indicated by Table 1, in 1957 more than 12,000,000 vehicle-miles were driven each day in the Baltimore Region.

It is estimated that by 1980 more than 20,000,000 vehicle-miles will be driven daily. This is an increase of nearly 70 percent and represents an additional 8,000,000 vehicle-miles. Inasmuch as most of the streets in the region are operating at capacity, this means that about 8,000,000 vehicle-miles of capacity must be added to the highway system by 1980.

Analysis of the Interstate Highway System programmed for the area showed that it would provide about half of this required highway capacity and that programmed arterial street improvements will provide a capacity of about 2,000,000 vehicle-miles. This means that more than 2,000,000 vehicle-miles of highway capacity will have to be added to accommodate the traffic adequately in 1980. The latter figure might be thought of as representing 50 miles of 4-lane freeways. In other words, at least 50 miles of freeways other than the Interstate System will be required by 1980 in addition to those now programmed.

Screen Line Analysis

This quick appraisal gave the scale of the problem. However, it did not indicate where these freeways will be needed. Figure 1 depicts the desire lines of traffic

TABLE 1

AVERAGE DAILY VEHICLE MILEAGE IN THE BALTIMORE REGION, 1957-1980

Item	Volume (veh-mi)
Avg daily driving, 1957	12,100,000
Avg daily driving, 1980	20,300,000
Increase, 1957-1980	8,200,000
Capacity provided by 1980:	
Program freeways	4,000,000
Arterial streets	2,000,000
Total	6,000,000
Addl capacity needed	2,200,000

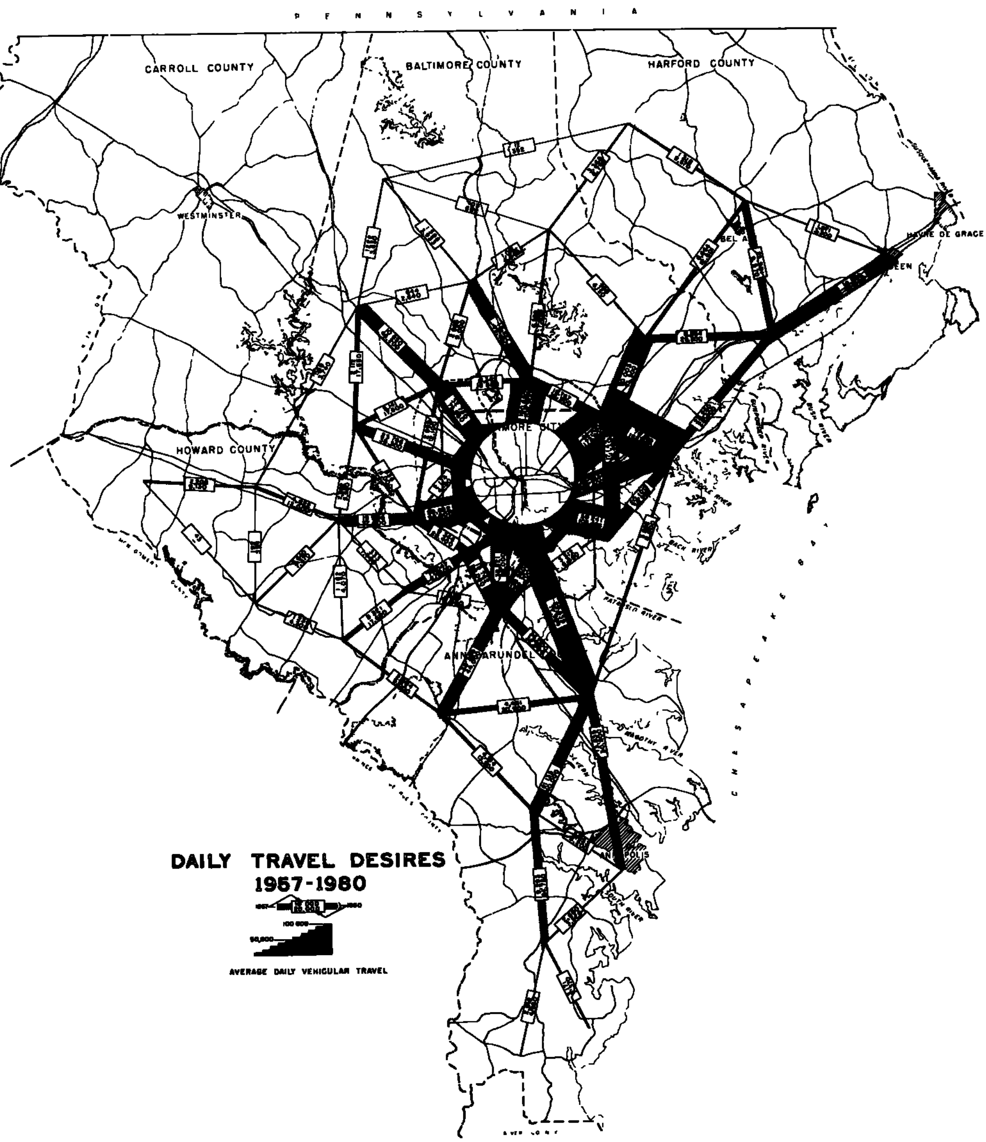


Figure 1. Desire line chart of 1957 and 1980 daily traffic.

throughout the counties of the region in 1957 as well as in 1980. Another one was prepared for the city of Baltimore.

These desire line charts indicate by the thickness of the band the estimated number of trips that desire to go through certain areas of the region. To make this presentation as simple as possible, all desire lines have been considered as passing through the centers of the transportation zones.

It was readily apparent from these charts that most of the increases in traffic would occur in the outlying areas, the largest portion occurring between the industrial areas in the northeast and the residential areas in the northwest. Another marked increase is in the traffic south of the city, primarily in the Baltimore-Washington area. These projections are reflected in the land use forecast prepared by the Baltimore Regional Planning Council.

Another factor of prime importance in designing highways is the directional aspect of the traffic flow. The gravity model technique used made it possible to forecast for

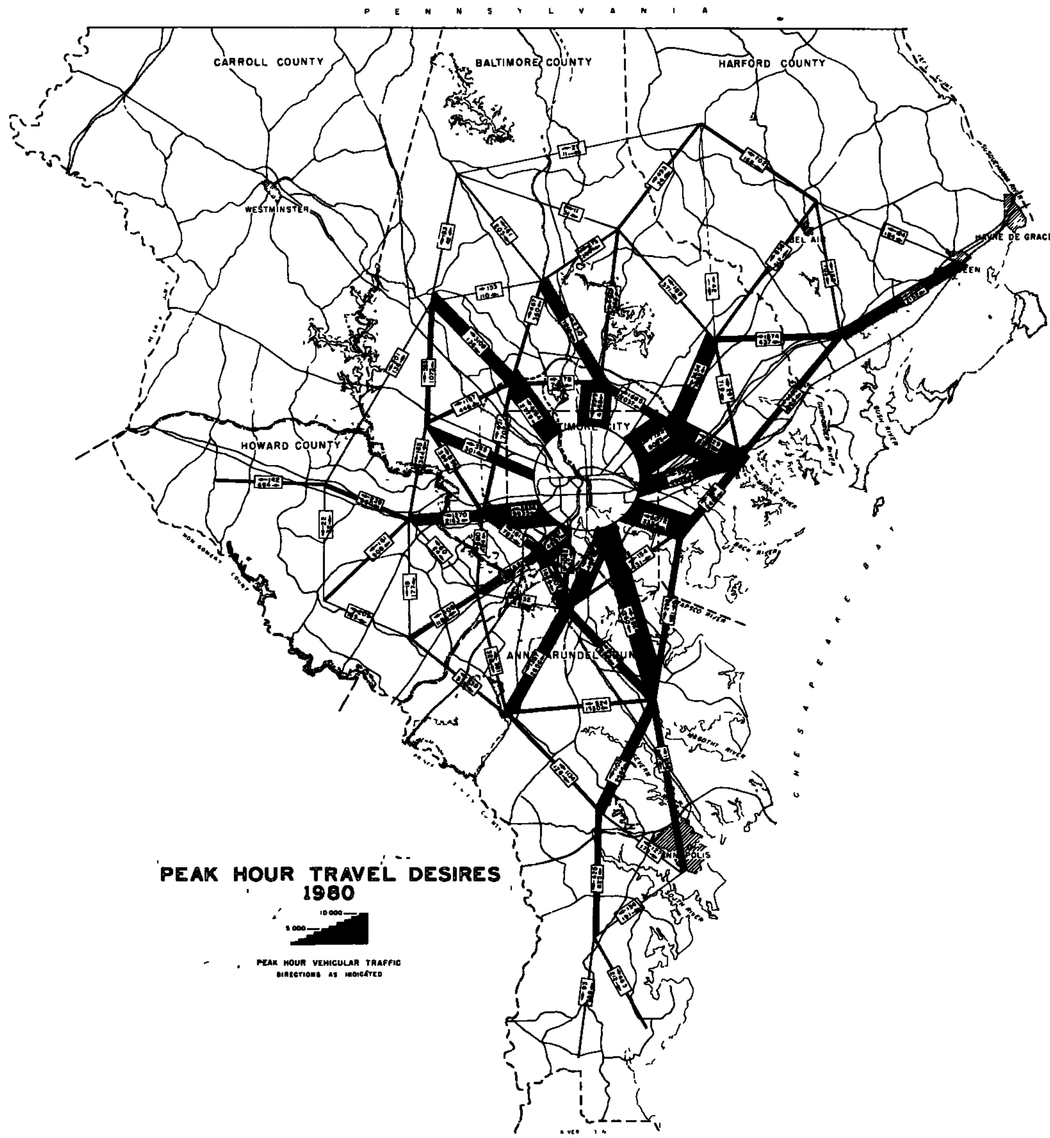


Figure 2. Desire line chart showing directional characteristics of 1980 peak hour traffic.

such movement in 1980 (Fig. 2). This forecast indicated that the traffic in and out of coastal industrial areas in the Baltimore County area show a marked imbalance and raised some question about the desirability of the projected land use pattern. It indicated the need for establishing ample employment opportunities in all suburban areas.

One of the principal advantages of using such origin and destination desire line charts is that it helps to delineate the highway network that will be required. By analyzing the 1980 desire lines crossing predetermined screen lines, the adequacy of the highway system, or any proposed system, can be readily determined by comparing desire lines with existing or proposed street capacity across these screen lines. For example, there is an anticipated volume of 61,000 vehicles per hour across the Jones Falls screen line in both directions by 1980 (see Table 2). The present street capacity across this line is about 41,000 vehicles, so that without improvements in the highway system, there would exist a capacity shortage of 20,000 vehicles per hour, about the capacity of 20 freeway lanes. (One thousand vehicles per hour were used in this analysis to reflect unbalanced flow conditions, as well as the fact that, if a freeway system is built, some of the arterial streets will not be used to their full capacity.)

Planned freeway construction, supplemented by possible improvements in mass transit and new arterial streets, could reduce the needs by 16 lanes, thus indicating a deficiency of four lanes across this particular screen line by 1980. A comparison of existing and proposed street capacity across this line with the desire line for 1980 gave a clue to the location of the principal deficiency (about half way between downtown and the Baltimore Beltway, in the vicinity of Cold Spring Lane Fig. 3).

Delineating the System

A closer look at the nature of the travel desiring to pass through this critical area revealed more specific information as to the origins and destinations involved (Fig. 4). Close inspection revealed that the bulk of traffic desire moved from the west and northwest to the east and southeast. Therefore, the apparent solution here would seem to be a cross-town freeway connecting the residential areas between the Baltimore Beltway and proposed east-west radial, and the industrial area east of the city. This need reflects the predictions of planners that a very substantial residential growth in the Baltimore Region will take place in the northwest section, whereas the industrial growth will be concentrated primarily along the coastal areas in both Baltimore and Anne Arundel Counties.

Similar analyses of other trouble spots on the screen lines helped to delineate the over-all plan for the area. In the case of the southwest screen line the analysis showed two critical areas, one on the eastern portion of the line and the other south of the CBD. The Gwynns Falls screen line showed no particular deficiency, whereas the Canton-White March screen line revealed two critical areas, one near the CBD and the other at the eastern end of the area. The Beltway screen line analysis indicated a major deficiency due south of the CBD, one northwest, and another northeast of the CBD.

On the basis of the deficiencies previously noted and a thorough investigation of the travel desires of traffic related to these critical areas, as was done for the Jones Falls screen line, it was possible to delineate the basic freeway needs for the area (Fig. 5). This figure indicates only the approximate location of the deficiency and how it is related to the existing freeway interstate system.

Once the freeway roots had been generally located, an attempt was made to determine

TABLE 2

CAPACITY DEFICIENCIES ACROSS SCREEN LINES BY 1980 IN TERMS OF FREEWAY LANES

Screen lines	Traffic		Capacity deficiency	Need Reduction			Additional need
	1957	1980	1980	Transit	Arterial	Freeway	
Jones Falls	40,000	61,000	20 lanes	2	2	12	4
South-West	30,000	53,000	24 lanes	4	2	10	8
Gwynns Falls	36,600	49,500	12 lanes	-	-	12	-
Canton-White Marsh	23,000	32,500	10 lanes	-	-	-	10
Beltway	51,500	83,500	32 lanes	-	-	24	8

their more specific location. In doing this, the following objectives were followed:

1. To reduce to the minimum the need for and the time required for vehicular travel.
2. To provide good access to all regional activities.
3. To enhance the accessibility of the CBD.
4. To encourage and foster industrial and commercial development in the Region.
5. To minimize the taking of productive property for right-of-way.
6. To provide maximum highway service with minimum disturbance to existing residential areas.

Testing the Plan

The soundness of any particular plan developed for a region depends largely on

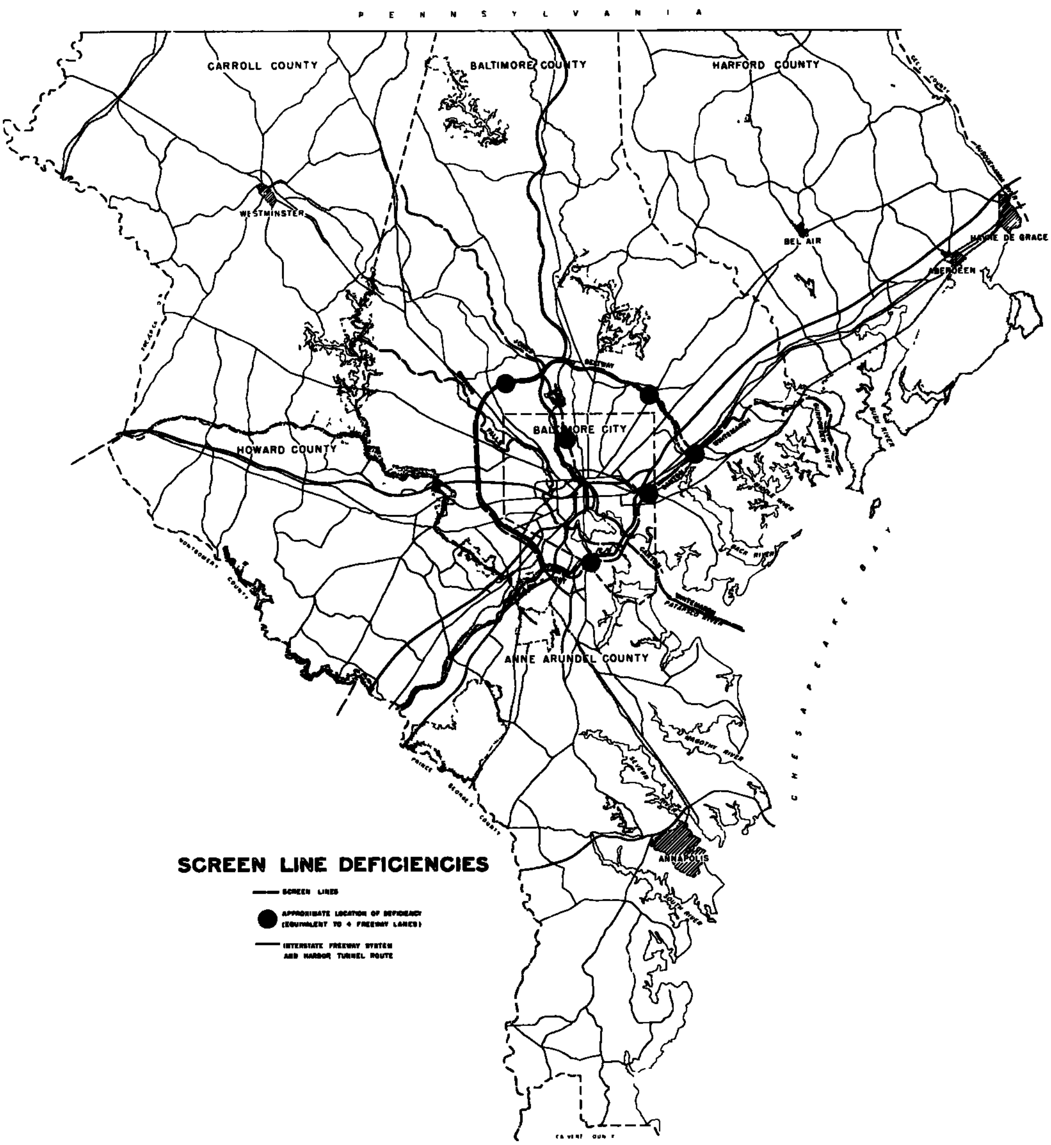


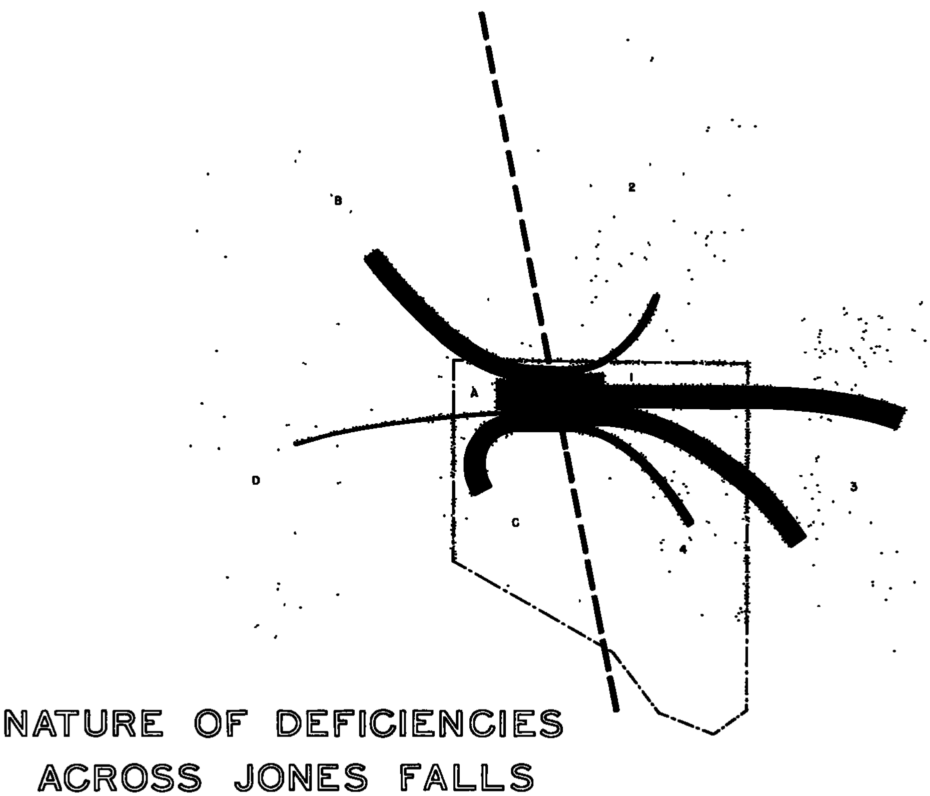
Figure 3. Map that depicts the location of screen line deficiencies.

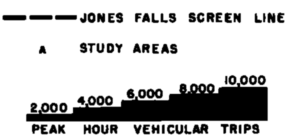
whether the proposed improvements will be able to handle the anticipated traffic in accordance with speed and safety standards. To ascertain this fact, an estimate was made of the number of vehicles that will use the freeway system when fully improved. In doing this, the projection of the origin and destination data must be used. On the basis of established relationships between travel time on alternate routes, trips estimated for 1980 were assigned to the proposed plan. This was achieved by following a procedure developed by the U. S. Bureau of Public Roads.

With the trips allocated to the freeway system, it is quite apparent that the freeway plan as proposed (Fig. 5) would be adequate in most respects for 1980 traffic.

The fact that the first plan tested by means of traffic assignments proved to be adequate indicated that the steps followed in delineating the plan were sound. Many other transportation studies have had to test numerous plans to find a system free of capacity problems. By the analysis made of the screen lines, it apparently was possible to develop an adequate system on the first try (Fig. 6).

It is recognized, of course, that the exact location of these freeways certainly will have to be determined by the local jurisdictions. To do this, transportation planning teams consisting of city planner, traffic engineer, and public works director, as well as the state highway representative, are being created in the various jurisdictions. In pinpointing the freeway locations, these teams not only will use the O-D data, but also





PEAK HOUR VEHICULAR TRIPS BETWEEN AREAS

AREAS	A	B	C	D	TOTAL
1	1200	685	1455	262	3,602
2	1083	—	421	205	1,709
3	5000	3840	4749	288	13,877
4	2516	295	—	—	2,871
TOTAL	9859	4820	6625	755	22,059

Figure 4. Special analysis of O-D of traffic desiring to pass through critical area on the Jones Falls screen line.

will evaluate the advantages various alternate locations will have on community development. They plan to analyze the O-D of the traffic assigned to each segment of the freeway system to determine if there would be any advantage to moving the freeway one way or another.

DETERMINING LOCAL STREET NEEDS

Once the general freeway pattern was determined the various jurisdictions began to analyze their arterial street needs, ramp locations, and local street requirements. This was done by indicating the amount of traffic that would desire to enter or leave any freeway segment and the amount of traffic that would be left on the local street system. The latter was shown on desire line charts similar to Figure 1. In undertaking this analysis most of the work was done for areas bounded by freeways, such as the downtown area surrounded by the downtown loop. Such information was extremely valuable in

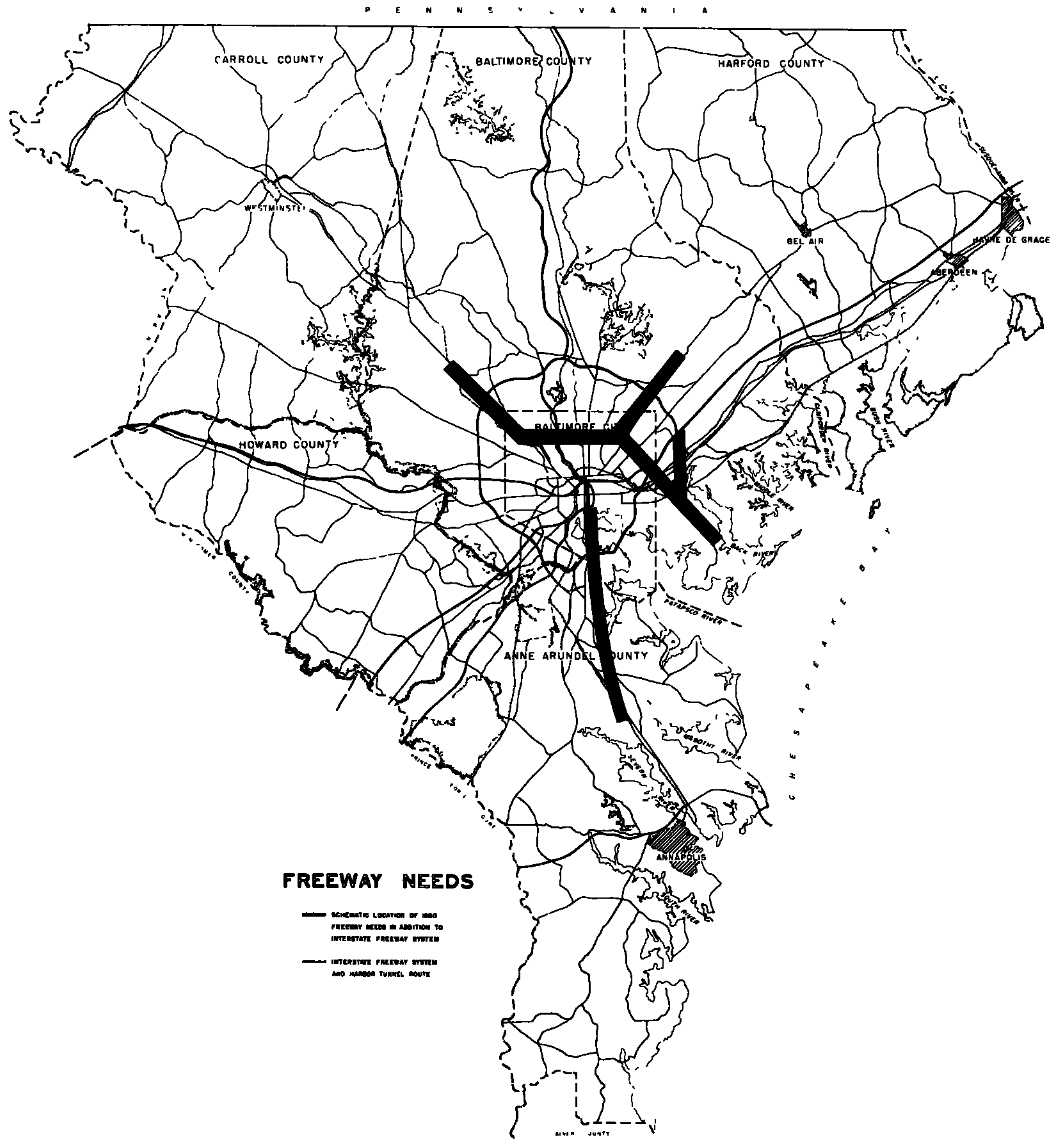


Figure 5. Appropriate location of the freeways needed in 1980 in addition to the Interstate System.

determining plans for the downtown area of Baltimore. It clearly indicated the capacity requirements that would have to be met by the local street system. It also showed the streets that would be most important for downtown circulation.

The analysis in the downtown area of Baltimore indicated that few streets could be closed in connection with the redevelopment of the downtown area unless new surface streets were provided. It is anticipated that similar studies will be made by all the jurisdictions in the area so that a complete arterial street and freeway plan can be developed for the metropolitan region.

ADVANTAGE OF USING LOCAL JURISDICTIONS

In summary, the general procedure described herein works out very well where it is desired that the local jurisdictions carry out a great deal of the work. However, it does have limitations in that such an arrangement usually brings about many delays

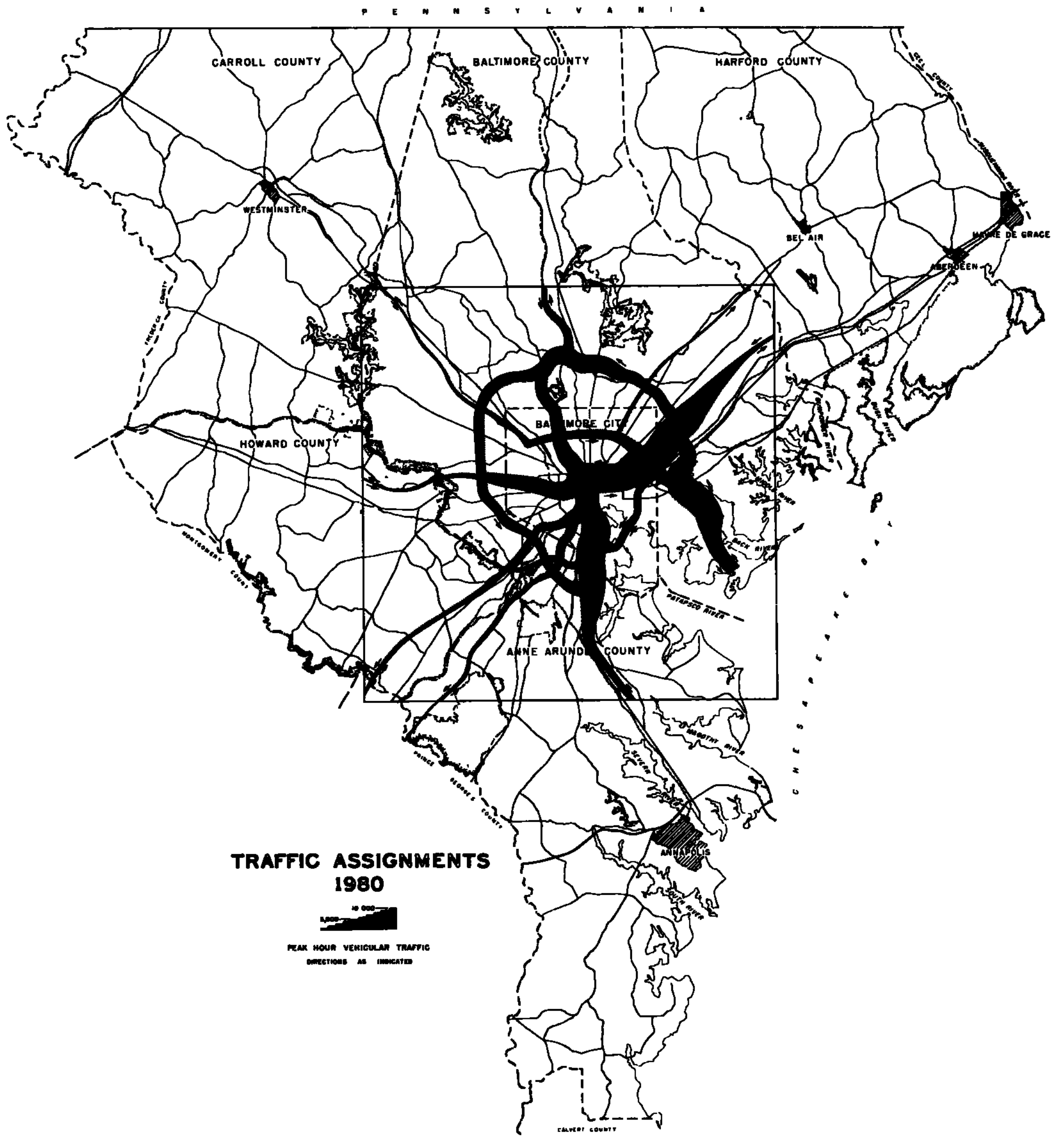


Figure 6. Traffic was assigned to the freeway system delineated by the screen line analysis.

because these local jurisdictions are burdened with so many other problems that consume their time. However, the end product of such an arrangement probably will have better local acceptance and, therefore, will have a greater chance of being completed.

Median Strip Mass Transit and Related Traffic Characteristics on Congress Expressway

ANDREW V. PLUMMER, Assistant to the Superintendent,
LEO G. WILKIE, Traffic Engineer, and
ROBERT F. GRAN, Statistician, Cook County Highway Department, Cook County, Illinois

The new Chicago Transit Authority rapid transit service operating in the median strip of Congress Expressway was opened to the public on June 22, 1958. This service is a replacement of the Garfield Park rapid transit line. The Congress CTA line runs in the median of the Congress Expressway from Halsted Street to Laramie Avenue, a distance of about six miles. West of Laramie the service is the same as the old Garfield Park line.

The Cook County Highway Department has maintained traffic counts on Congress Expressway for several years. There has been considerable speculation as to what effect, if any, the opening of the new CTA facility would have upon traffic patterns and characteristics on Congress Expressway. To determine these effects the Cook County Highway Department conducted a post card survey several weeks after the opening of the new facility.

This survey was accomplished by distributing almost 10,000 post card questionnaires to persons entering the Congress CTA between the Des Plaines Avenue station on the west and the Medical Center station on the east during the hours from 6:00 A.M. to 1:00 P.M. on July 17, 1958 (see Fig. 1).

Congress Expressway is not a continuous facility. The portion of the expressway between Laramie Avenue and First Avenue is under construction. Figure 2 illustrates the Congress Expressway and the route of the Congress CTA.

When Congress Expressway is completed the median strip CTA rapid transit facility will extend all the way to the Des Plaines Avenue terminal. The full impack of this service may not be realized until such time as the facility has been completed.

THE SURVEY yielded over 3,700 completed post cards, and the results of these returns are tabulated and evaluated in the following sections of this report.

Table 1 shows the distribution by station, of the cards given out and the cards received. The percentage of return varies quite markedly among the several stations. The stations at the west end of the facility showed the highest return and those at the east end the lowest. The highest single rate was from the Ridgeland Avenue station with a 49.6 percent return, and the lowest was from the California Avenue station with an 18.2 percent return. In actual number the Des Plaines Avenue station produced the largest return of 991 cards.

Previous Modes of Travel

One of the questions on the post card inquired as to the mode of transportation used prior to the opening of the Congress CTA facility. The answers to this question are shown in Figure 3 and Table 2. This table shows the distribution by previous mode of travel for both loop destined and non-loop trips.

Of the total returns, 74.2 percent indicated elevated rapid transit as the mode of travel used prior to the opening of the Congress median strip rapid transit facility. This is not at all surprising since this new facility replaces the Garfield Park rapid transit line. Of the total users 8.6 percent switched from various CTA surface lines.

Those previously using automobile accounted for 12.5 percent of the patrons, 9.2 percent from Congress Expressway and 3.3 percent from other routes. Of the CTA patrons 2.6 percent were drawn from the railroads, and the balance from all other modes. From the percentage of patrons who previously used automobile travel it is apparent

DEPARTMENT OF HIGHWAYS

COOK COUNTY ILLINOIS

DANIEL RYAN

PRESIDENT BOARD OF COUNTY COMMISSIONERS

WILLIAM J. MORTIMER
SUPERINTENDENT

Dear Patron:

This survey is being conducted by the Cook County Highway Department as a part of the tremendous program in the evaluation of transportation problems for this area. Your cooperation is greatly needed and will be sincerely appreciated.

Please answer all questions, and then mail lower portion of card as soon as possible.

All information obtained will be accorded confidential treatment and will be used in statistical tabulation only.

Thank you!

(Detach Here)

---

1. What was the starting time for this trip? ________AM, PM
2. What was the origin of this trip?

   ____
   address city
3. What is the destination of this trip?

   ____
   address city
4. What is the purpose of this trip?
   work______, shopping______, personal business______, recreational ____________.
5. At what station will you leave this branch of the CTA?

   ____
6. How many times per month do you make this trip? ____________________Times
7. Is a transfer required for this trip? Yes______, No__________.
8. What mode of transportation did you use for this trip before the Congress Street CTA began operations?
   - Train (specify line) ____________________________
   - Elevated Garfield Pk______, Lake St______, Douglas Pk__________,
   - CTA surface line__________,
   - Automobile; via Congress Expressway__________, via other route____________,
   - Other (specify) ....

90951

Figure 1. Post card questionaire-Congress Expressway, median strip, rapid transit.

that improved service such as this can have a significant influence on the choice of mode of travel. Since cost factors have remained constant, the influencing factor is most likely the one involving time required for the trip.

Loop and Non-Loop Trips

It can be seen that the percentage of trips previously made by elevated is less for

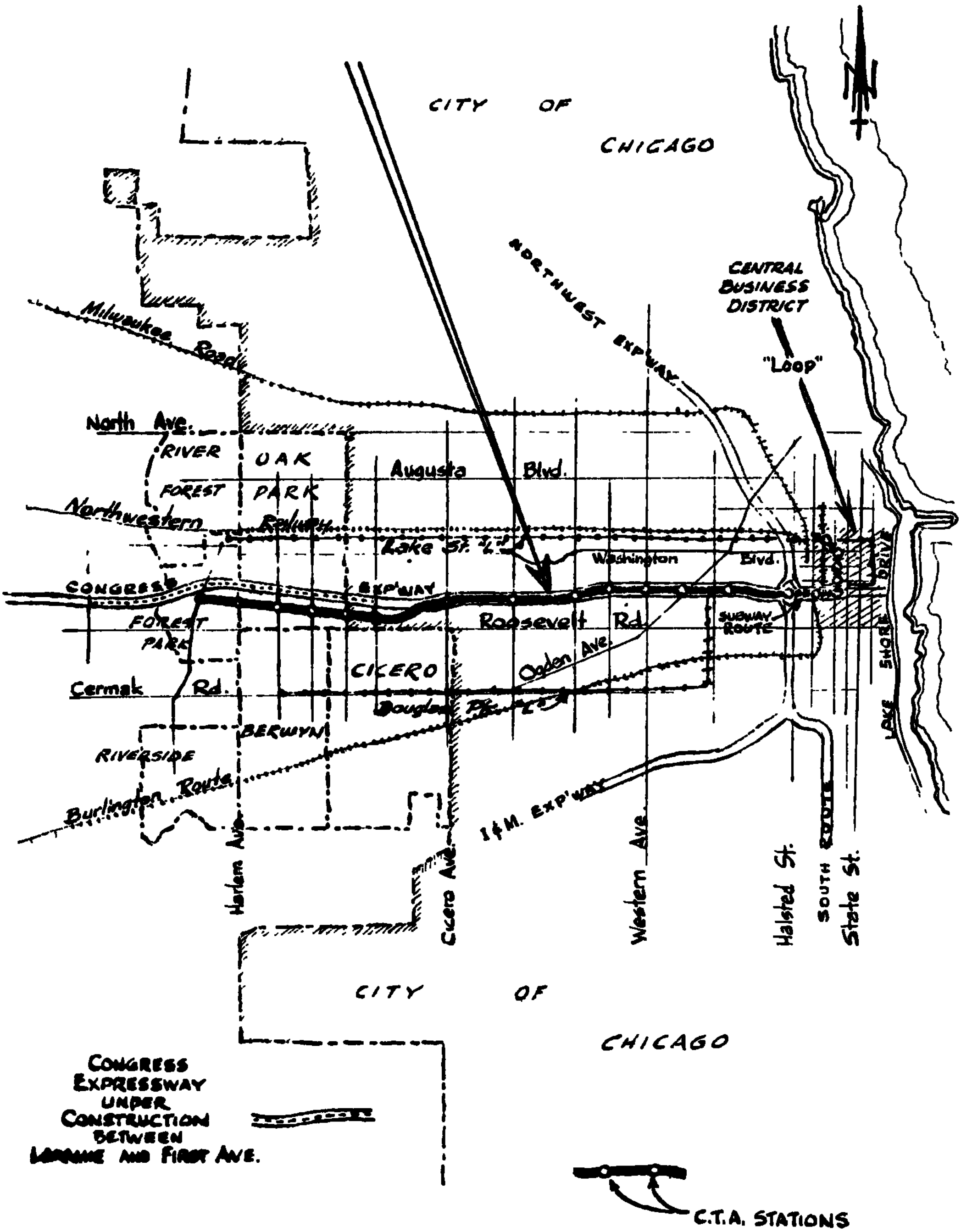


Figure 2. Route of the Congress Expressway rapid transit line.

non-loop trips than for loop trips. Also the percentage of trips previously made by CTA bus as well as that for those made by automobile is considerably greater for non-loop trips than it is for loop trips. This observation could very well lead to some pertinent hypotheses regarding the relative attractiveness of this facility for loop as opposed to non-loop trips. The scope of this survey does not permit the evaluation of such hypotheses.

Transfer and No Transfer

Table 3 shows, by previous mode, the percentage of persons who presently must make a transfer for their trips. Of all trips accounted for, 49 percent require transfers and 51 percent do not require transfers. These percentages vary markedly between previous modes. The average person who previously used automobile or railroad for his trip is significantly less apt to presently make a transfer than the over-all average rider, and persons previously using the surface lines are much more apt to make transfers than the average rider. Tables 4 and 5 indicate that this tendency was present for both loop and non-loop trips. The inference to be drawn is that persons using either automobile or railroad travel tend not to switch to a mode of travel that will require a transfer for their trips. A new mass transit facility must be highly competitive with automobile travel before it will attract a substantial volume of traffic from that mode.

STATION DISTANCE AND TRIP DISTANCE

Figure 4 shows the cumulative percentage of trips by distance to the CTA station for each of the previous modes of travel. The over-all average distance to the station is 2.2 miles. For trips previously made by the surface lines the average distance to the station is presently 1.2 miles; for trips previously made by elevated the average distance is 2.1 miles; for trips previously made by automobile on Congress Expressway the average station distance is 2.7 miles; for automobile by other routes the average station distance is 4.0 miles; and for all other previous modes the station distance averages 5.0 miles.

These averages indicate that persons who previously used automobile for their

TABLE 1

POST CARD RETURNS

Origin Station	Cards Given Out	Cards Returned	Percentage Returned
Des Plaines Ave	2,217	991	44.7
Harlem Ave	787	383	48.7
Oak Park Ave	982	475	48.4
Ridgeland Ave	700	347	49.6
Austin Ave	917	363	39.6
Central Ave	209	84	40.2
Cicero Ave	945	335	35.4
Pulaski Rd	1,236	291	23.5
Kedzie Ave	1,112	248	22.3
California Ave	231	42	18.2
Western Ave	301	70	23.3
Medical Center	300	87	29.0
Total	9,937	3,716	37.4

TABLE 2

MODE OF TRAVEL PRIOR TO CONGRESS STREET RAPID TRANSIT

Previous Mode	Loop Trips	% Loop Trips	Non-Loop Trips	% Non-Loop Trips	Total	% Total
Elevated						
Garfield Pk	1,829	61.6	415	55.6	2,244	60.4
Lake St	381	12.8	60	8.0	441	11.9
Douglas Pk	63	2.1	11	1.5	74	2.0
Total Elevated	2,273	76.5	486	65.1	2,759	74.2
CTA Bus	209	7.0	111	14.8	320	8.6
Automobile						
Via Congress	266	9.0	76	10.2	342	9.2
Other Routes	85	2.9	38	5.1	123	3.3
Total Automobile	351	11.9	114	15.3	465	12.5
Railroad	79	2.7	16	2.1	95	2.6
Other Modes	57	1.9	20	2.7	77	2.1
Total	2,969	100.0	747	100.0	3,716	100.0

trips travel substantially farther to the rapid transit stations than do the average riders. This definitely points to the competitive qualities of rapid transit service as opposed to automobile travel. If the service is improved substantially, a certain portion of those persons using automobile for their trips will change to the improved facility even though the change requires a greater than average journey to the station.

Figure 5 shows the cumulative percentage curves for all modes combined for both station distance and trip distance. As was already indicated the average station distance was found to be 2.2 miles, and this Figure shows the average trip distance to be 9.5 miles.

TRIP PURPOSE AND FREQUENCY

Because this survey was taken between the hours of 6:00 A.M. and 1:00 P.M. the trips were primarily for work purposes. The following table shows the frequency and percentage of trips for the various purposes.

Purpose	Frequency	Percent
Work	3,357	90.3
Shopping	83	2.2
Personal Business	140	3.8
Recreation	68	1.8
School	69	1.9
Total	3,717	100.0

The average monthly trip frequency was computed for each of the previous modes of travel, and it was found that these frequencies did not differ significantly between

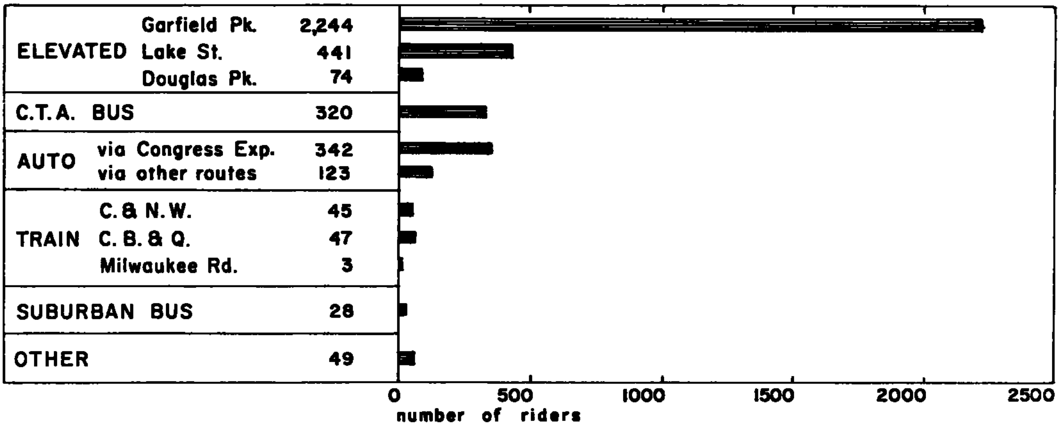


Figure 3. Previous mode of travel for congress rapid transit riders.

TABLE 3

PRESENT TRANSFER REQUIREMENTS DISTRIBUTED BY PREVIOUS MODE OF TRAVEL

Previous Mode	Make Transfer	Percent Transfer	Do Not Make Transfer	Percent Non-Transfer	Total
Elevated	1,307	47.4	1,452	52.6	2,759
CTA Bus	227	70.9	93	29.1	320
Automobile	197	42.4	268	57.6	465
Railroad	39	41.1	56	58.9	95
Other Modes	50	64.9	27	35.1	77
Total	1,820	49.0	1,896	51.0	3,716

modes. For all modes combined, the average frequency was about 20 trips per month. It is likely that variation, by previous mode, would have been found in these frequency comparisons if the survey had included all hours of the day, as well as Saturday and Sunday travel. Since work was so predominantly the trip purpose found in this survey, the 20 trip monthly average is entirely reasonable.

CONGRESS EXPRESSWAY TRAFFIC VOLUME COUNTS

Continuous machine volume counts were maintained on Congress Expressway before and after the opening of the new CTA rapid transit line. An analysis of these counts revealed no significant changes in total traffic volume characteristics on Congress Expressway. This analysis included hourly comparisons for average weekdays, Saturdays, and Sundays. It is likely that a certain amount of shifting has taken place, traffic removed from Congress by a shift to the CTA being replaced by traffic from parallel routes. This type of shifting is usually experienced when a new or improved facility is opened.

Lane Usage

A somewhat more qualitative approach to the study of traffic characteristics was obtained by manual counts of traffic by lanes as well as by direction of travel. The eastbound direction (inbound to the Chicago central business district) did not indicate any significant differences in lane usage in the before and after comparisons. The westbound direction (outbound) showed highly significant differences in lane usage. Figure 6 shows the percentage of total traffic using the median lane of the expressway before and after the opening of CTA. The Pulaski Road location is adjacent to a CTA station, while the Independence Avenue location is several blocks from the nearest station. In both cases there is considerably less traffic using the median lane after the opening of CTA than prior to its opening. The third portion of this Figure compares Independence Avenue to Pulaski Road after the CTA opening. This comparison shows that less traffic uses the median lane adjacent to the station than some distance away from one. These charts indicate that when traffic is relatively light there is a tendency to avoid the lane adjacent to the CTA facility, particularly in the vicinity of a station. When

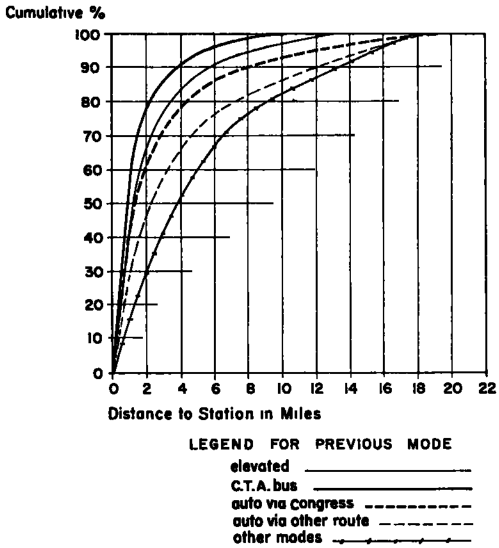


Figure 4. Cumulative percentage of trips by distance to the C.T.A. Station for each of the previous modes of travel.

TABLE 4

PRESENT TRANSFER REQUIREMENTS FOR LOOP TRIPS DISTRIBUTED BY PREVIOUS MODE OF TRAVEL

Previous Mode	Make Transfer	Percent Transfer	Do Not Make Transfer	Percent Non-Transfer	Total
Elevated	914	40.2	1,359	59.8	2,273
CTA Bus	133	63.6	76	36.4	209
Automobile	119	33.9	232	66.1	351
Railroad	27	34.2	52	65.8	79
Other Modes	31	54.4	26	45.6	57
Total	1,224	41.2	1,745	58.8	2,969

the traffic is heavy (as in the eastbound direction of this study) this tendency is apparently overcome by other factors. The lane usage at the Pulaski Road location for the westbound direction was rechecked four months later and the same tendency prevailed as is shown in the after portion of the chart. The purpose of this recheck was to determine if the advoidance of the median lane was a condition which would diminish with the passage of time.

CONCLUSIONS

1. One out of eight of the present Congress CTA patrons previously used automobile transportation for trips; about three out of four previously used some form of rapid transit; and the balance used surface lines, railroad, and miscellaneous other modes.
2. Of those trips previously made by automobile or by railroad there are significantly fewer transfers presently being made than there are for those trips previously made by rapid transit or surface lines.
3. For trips previously made by automobile or by railroad the average distance presently traveled to the CTA station is considerably greater than for those trips previously made by rapid transit or by the surface lines. This is indicative of the extended zone of influence of an improved mass transit facility.
4. No significant changes in the total traffic volume were observed on Congress Expressway following the opening of the new CTA rapid transit facility.

TABLE 5

PRESENT TRANSFER REQUIREMENTS FOR NON-LOOP TRIPS DISTRIBUTED BY PREVIOUS MODE OF TRAVEL

Previous Mode	Make Transfer	Percent Transfer	Do Not Make Transfer	Percent Non-Transfer	Total
Elevated	393	80.9	93	19.1	486
CTA Bus	94	84.7	17	15.3	111
Automobile	78	68.4	36	31.6	114
Railroad	12	75.0	4	25.0	16
Other Modes	19	95.0	1	5.0	20
Total	596	79.8	151	20.2	747

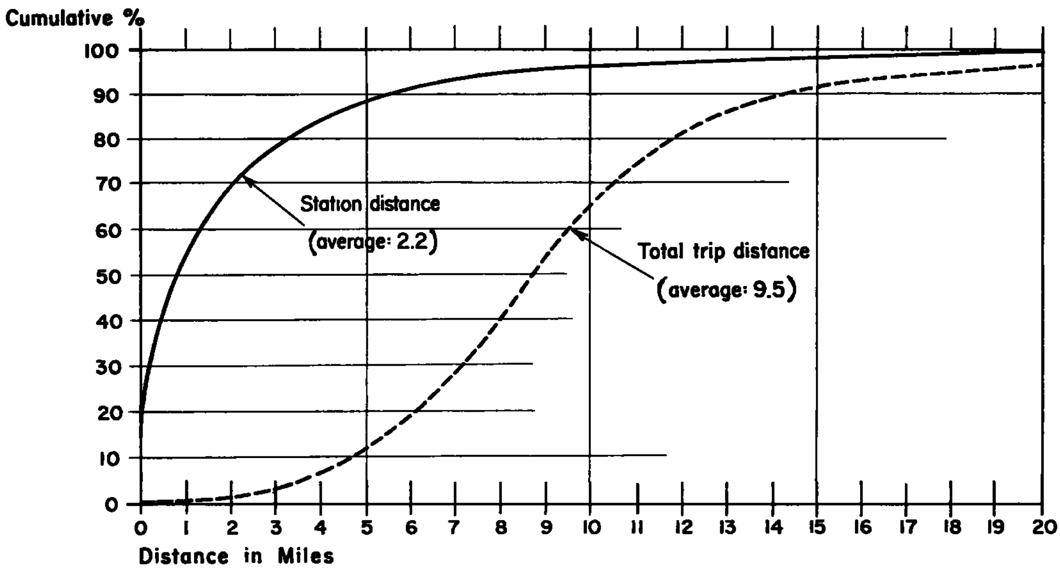


Figure 5. Cumulative percentage of trips by distance to the CTA station and by total trip distance for all combined previous modes.

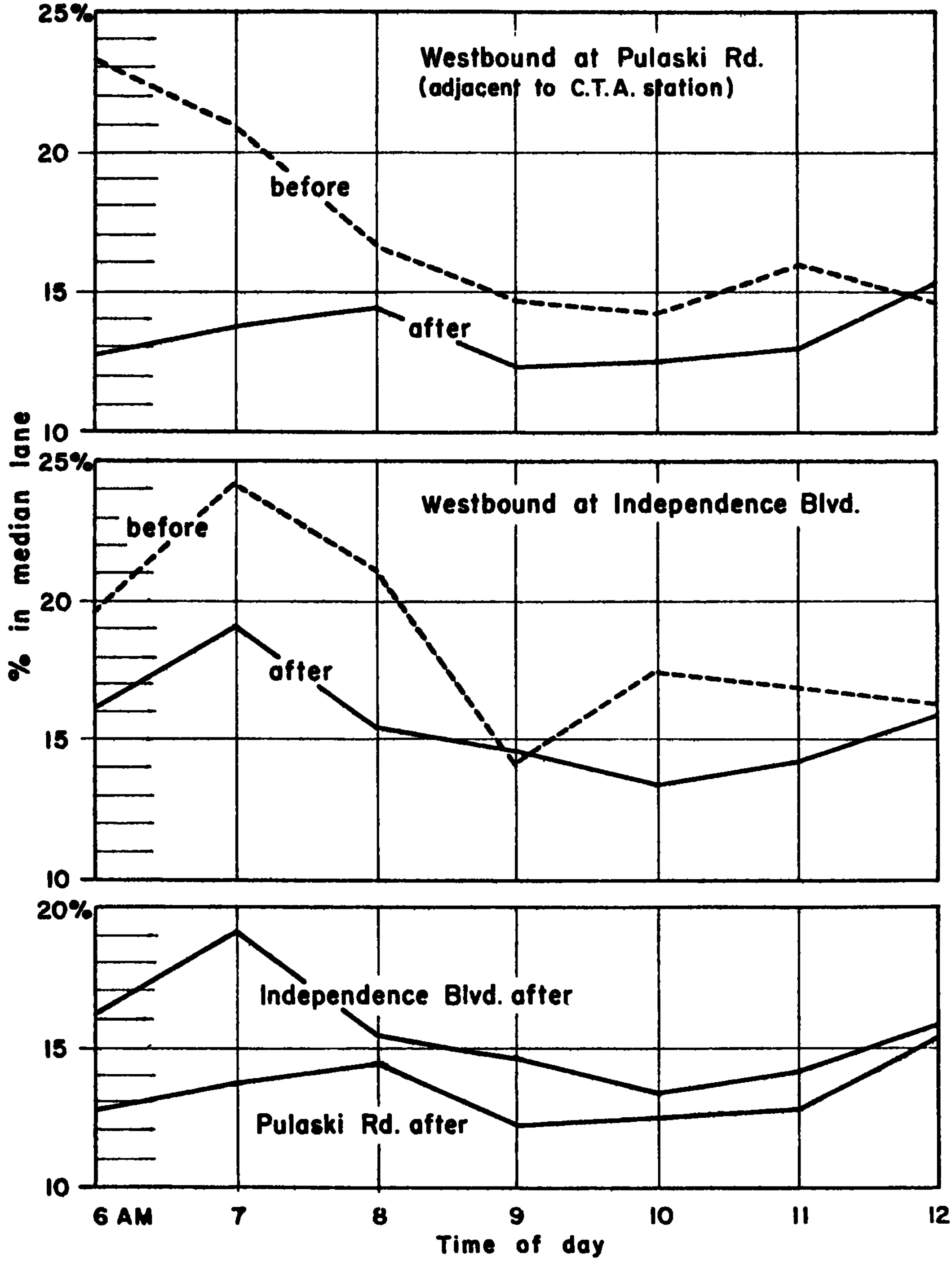


Figure 6. Lane usage on Congress Expressway before and after the CTA opening.

5. A pronounced tendency to avoid the median lane was found after the opening of the Congress CTA. This tendency was greater for the section adjacent to a CTA station than it was for the section some distance from a station. Indications of this tendency disappeared completely during periods of near capacity traffic volumes.

Land Use in Traffic Generation

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● THE QUICKENED pace of urban highway construction, culminating in the Highway Act of 1956, has intensified the demand for adequate urban land use and traffic forecasting. Large scale research has been initiated and various hypotheses and statistics have poured forth. Nevertheless, no final answers as to how land use and traffic generation are or will be related has come forth, and it is very unlikely—in the tabulated, handbook sense—that they will be forthcoming in the near future.

It has become evident that no community can sit back and ignore the problem. The city traffic engineer and the city planner must work together and establish the best traffic facility location and design and relate it to local land use plans. The City of New Haven is attempting to accomplish this objective. The Departments of City Planning, Traffic and Parking, and Redevelopment, and the Planning Consultant all function under one Development Administrator to the end that they coordinate their plans and are advisors one to the other in all related activities.

New Haven has under way a comprehensive redevelopment and renewal program. It coordinates its renewal progress with State Highway Department expressway planning and construction through the city. The over-all program is of such magnitude that virtually every major travel pattern in the city will be altered. Increased industrialization in the metropolitan area is planned, in addition to the suburbanization of the metropolitan area typical of so many cities. A city the size of New Haven, with 167,800 population in a metropolitan area of 350,000, cannot launch itself into an extensive research program designed solely for the production of basic data. It is not engaged in a research project and does not pretend to be. It must, and it has, attacked its study program with the tools at hand and put its best thought into the proper use of these tools in the local situation. It has taken on the task of supplying immediately the best information it can to state and local agencies that are now building new traffic facilities and changing land uses.

New Haven has six redevelopment and renewal projects in execution or planning, all related to highway plans. In every instance, the first item of study has been the expressway system, its relation to a new street system and to new land uses. Initially, broad objectives have been established showing areas to be connected and served by a new arterial system. Later, using origin and destination survey data, plans have been examined for general adequacy in serving major movements. Next they have been studied specifically for adequacy of connection with the street systems being planned in and through the various projects. Finally, as each project approaches reality and specific new generators to be constructed are known, adjustments have been made in the general anticipated traffic pattern in recognition of these generators.

In New Haven, this effort has been continuous, with re-study, revaluation, and revision. No final "frozen in place" report has been issued. No flat declaration by the traffic engineer that "this and this alone is the expressway and arterial system which must be," and no flat declaration by the city planner that "this and this alone is what the land use will be," is considered to be in order here. This type of decision is reserved for the moment of construction of specific projects, at which time full consideration and proper weight may be given to all that has gone before and all that is planned ahead.

In late 1957, it became necessary to move into a specific phase of program planning in reference to land use and highway location both in and outside the city. This came about by the reason of the creation of the Quinnipiac Valley Development Corporation whose area of concern lay in the City of New Haven and three towns immediately north. This corporation has the task of studying its allotted area for industrial development and making plans related thereto. In addition, it was instructed to present its views to the State Highway Commissioner on the proper location and design of an important segment of the Interstate Highway System which would pass in or through its area. To accomplish this purpose the four towns undertook, under the auspices of the Regional Planning Authority, a local agency which encompasses the four towns involved, a land use planning study which would contain the analyses and recommendations of the planning units of each of the towns. At the same time, the New Haven staff, with the co-operation and aid of the agencies of the surrounding towns, undertook a traffic analysis study of the proposed Interstate route. This latter study led the staff to the development of a method of relating land use to traffic generation which is discussed herein.

The study method contains no principles not heretofore considered, discussed, and published by planners and traffic engineers. It is based on assumptions and factors which are currently the subject of intensive study and which will, undoubtedly, be considerably refined as more facts become available. Its value lies in being a relatively straightforward procedure which can be repeated or updated whenever desired. It is an approach which can be undertaken by the traffic and planning staffs of virtually any community regardless of size. It combines judgment with numerical analyses in each step. It provides safeguards and methods of comparison with known data which protect it from becoming a completely untried hypothesis.

The basic premise of the New Haven study may be stated simply as follows: "If the specific land use which will exist throughout an area in some future year could be known and the traffic generation characteristics of these land uses and the way in which this generated traffic would distribute itself between those land uses were also known, then the origin and destination pattern of that future year would be established and traffic could be assigned to the traffic facilities to be in existence at that time." This is certainly not a new idea and surely there can be no argument with the logic of it. The problem lies in the doing, for there are many ways in which the specifics called for in the premise can be developed. There are many unknowns or factors which, to date, have only been partially explored. The New Haven staff considers that this premise is evolving as the most straightforward and practical approach to estimating future traffic generation and has accepted it as an instruction to simply carry out the required estimations with the best data it now has available.

In the long run, the adequacy and accuracy of the land use forecast is the most important feature of the method because all of the rest hinges on it and all the rest can be adjusted when the factors of relationship are refined. The objective is to produce practical analyses of what can and might be located in each study zone in the target year. Insofar as possible, the approach attempts to predict the cumulative effect of the actions which will be taken by various public and private interests that might consider construction in the zone under question. The net result should be a realistic preview of what the land use of the zone might look like in the target year. The method of land use estimation employed was as follows:

1. Obtain statistics concerning land use for each zone. Specifically, population, vehicle registration, and area devoted to residential, commercial, industrial, and open space was recorded.
2. Become personally acquainted with the nature of each zone in its relationship to the rest of the area, its street pattern and relationship to generalized arterial plans, its terrain, its soil conditions, its existing structure conditions and the existing kinds of industrial and commercial establishments.
3. Take into consideration present zoning and probable changes, its effectiveness and its reasonableness.
4. Estimate specifically what might be constructed on any remaining open area in the zone and in any area which might be replaced due to obsolescence or changes in land use.

As a check against this method, the over-all estimate of population and industrial and commercial concentration in the metropolitan area resulting from the summation of the specific zonal estimates was compared with generalized forecasts developed for the metropolitan area and the region from general trend statistics. Discrepancies were reconciled by re-examination of both the specific and the generalized forecast. This consideration provided a check on the reasonableness of the specific estimates.

Traffic generation was considered to be a direct function of land use and vehicle availability. For each zone, vehicle ownership was projected on the basis of general vehicle ownership trends with consideration given to the likely variation in ownership due to type of residential land use existing in the various zones. The summation of these specific estimates were checked against over-all estimates based on vehicle ownership trends in the area.

Trip generation was considered to be a function of the land use at each terminus of each particular trip. For purposes of establishing a distribution, it was considered that one trip end is the basic source and such sources were titled "trip production." (It was assumed that 50 percent of all trips would actually be return trips from a point of attraction to a point of production.) The factor utilized in determining the number of trip ends of each type to be generated in each traffic zone is shown below.

Trip Production

1. Three trip ends per passenger car in zone of registration.
2. Four trip ends per truck in proportion to effective industrial and commercial acreage of the zone as a part of the total effective industrial and commercial acreage of the survey area.

Trip Attraction

1. One hundred trips per effective industrial acre.
2. Two hundred trips per effective commercial acre.
3. One-half trip per passenger car in zone of registration.

The term effective industrial or commercial acre refers to an intensity factor developed in the course of study. It was found that a simple factor of 100 trips per industrial acre or 200 trips per commercial acre could not be applied directly to such acreage. By subjective judgment, a zone of average commercial activity and a zone of average industrial activity were selected as standard, or 100 percent intensity, and the activity of every other zone graded upward or downward on a percentage basis in relation to them. For this procedure, the detailed personal knowledge of the various zones gained in the land use estimation study was utilized. The intensity factor was applied to the actual acreage devoted to these purposes to produce effective acreage. The necessity of subjective development of this factor could undoubtedly be avoided by relating generation to other measure of commercial and industrial activity, such as gross sales, floor area, number of employees or other more definitive measurable quantities.

Having established an estimate of the total trip ends to be produced or attracted to each zone, it became necessary to estimate zone to zone distribution. The "gravity model" system, with modifications, was adopted. The hypothesis of the gravity model states simply that, "The total trip production of any zone will be attracted to each other zone in the same proportion that the attraction of the latter zone bears to the total attraction in the area, but will be modified by the effect of travel distance." The basic modification of this hypothesis adopted in the study consisted of utilizing controls which required the resultant distribution to produce known total movements between towns in the survey area and between towns and external areas. For the target year distribution pattern, estimates of the same control movements were used. Control movements were estimated by applying growth factors of total production and attraction for each town and growth factors of the external areas to the initially known control movements and balancing by the average factor method. The significance of this modification is that it insures the reasonablemess of the over-all distribution pattern established and effectively takes into account the unknown factors which limit or induce travel between major sectors of the survey area.

The method required an estimate of the effect of distance on the distribution pattern. Local data were used to establish this effect so that it might reflect conditions in the local area. Origin and destination data from a recent screenline survey were used. Scatter charts of the ratio of actual zone to zone movements to theoretical zone to zone movements were plotted against the distance between zones. A curvilinear relationship similar to that developed in other studies of this phenomenon, and of the form $y = \frac{K}{X^n}$, was obtained.

The logical check of any estimation method is comparison of its predictive results against a known pattern. Existing origin and destination survey data made such checks possible to a limited extend in this study. It provided information concerning trips between one northernmost town and the three southernmost towns. A complete distribution pattern, based on current land use and the derived factors, was produced and compared with the field survey data.

This check on adequacy involved 7,028 trips distributed among 748 zone interchanges. For analysis, trip interchanges were divided into two groups, those involving 10 or less trips in either the survey or the estimate and those involving more than 10 trips in both the survey and the estimate.

The comparison of relative agreement between the minor survey trips and estimated trips is shown below:

Survey		Estimate		
Trips	0	1-5	6-10	over 10
			Number of Zones	
0	106	149	14	4
1-5	8	117	46	10
6-10		33	37	33
over 10		9	28	

The results of this examination led to the conclusion that the minor trip movements were sufficiently accurate.

Trip interchanges over ten were plotted in a scatter chart. There were 154 such interchanges, varying from 11 to 210 trips daily. The material was plotted in log-log form so that the line of perfect agreement would be a 45 deg straight line and the scatter would be on a proportional or percentage basis. It was found that 68 percent of the trip estimates fell within $\pm$ 44 percent of the line of agreement. It was noted that the estimates were approximately as likely to fall above the line as below the line (with slight bias toward under estimation, attributed to the fact that the method produces fewer zeros in the minor interchanges than the survey results—leaving fewer total trips to be distributed among major interchanges).

From these checks and considering the fact that the survey results themselves are sample expansions and therefore subject to sampling error, it was concluded that the estimates were adequate for the purpose of the study.

The method of analysis used in New Haven is not offered as basic research on the most difficult question of the relationship between land use and traffic generation. It is presented instead as a practical method of deriving answers sufficiently accurate to permit the continuation of this work. It has been described in detail because the New Haven staff firmly believes that it is a proper study approach that can be refined as new data become available from the many research projects now under way. Most significant, is the relationship between city planner and traffic engineer which is expressed in the study method. In retrospect, one finds it most difficult to know where the work of one leaves off and the other begins.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.