Studies of Trip Generation in the Nation's Capital, 1956-58

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●DURING the past twenty years the Washington, D. C. area has experienced very rapid growth, both in population and the extension of urbanization into adjacent portions of Virginia and Maryland. With the new growth have come heavy demands on the transportation facilities which serve Washington and the National Capital Region. These demands continue to increase, with every indication that the future will see a steady growth in travel throughout the area.

In 1955 a Mass Transportation Survey of the Washington area was authorized by Act of Congress, to be conducted jointly by the National Capital Planning Commission and the National Capital Regional Planning Council. Studies were organized and work begun by the traffic engineering consultants in 1956 (1).

A principal phase of the traffic study was concerned with evaluation of past and present travel characteristics in the metropolitan area and derivation of techniques or formulae which would relate trip volumes and modes of travel to the numbers, wealth, and geographic distribution of populations. These studies are reported in this paper. The application of the trip estimating formulae to future urban population and the assignment of future travel to proposed systems of highways and transit were other principal aspects of traffic analysis for the Mass Transportation Survey which have not been described here.

The National Capital Region

The National Capital Region includes the District of Columbia; the counties of Montgomery and Prince Georges in Maryland; the cities of Alexandria and Falls Church, and the counties of Arlington, Fairfax, Loudoun, and Prince William in Virginia.

The most important sources of detailed travel information for the National Capital Region are the Washington Metropolitan Area Transportation Studies of 1948 and 1955 which were prepared by the Regional Highway Planning Committee for the Maryland State Roads Commission and the highway departments of Virginia and the District of Columbia, in cooperation with the Bureau of Public Roads. The 1948 and 1955 surveys were metropolitan area interview studies which did not include residents in Loudoun and Prince William counties nor those in the outer portions of Montgomery, Prince Georges, and Fairfax counties.

Both 1948 and 1955 transportation studies were of the home-interview type, designed to collect data on the many aspects of traffic behavior within the urbanized community. Despite very large increases in the urban population between 1948 and 1955, only slight adjustments of the 1948 survey boundary lines were necessary to define limits of the 1955 study. The physical areas incoporated in both origin-destination surveys are thus almost directly comparable.

Organization of Study Area—1948 and 1955

Both origin-destination surveys followed similar ground rules. The external boundary line constituted a traffic cordon and careful records were kept of all vehicles crossing this cordon during the periods of study. In the course of each survey many of the vehicles crossing the cordon were stopped and drivers questioned as to origin, destination, and purpose of trip.

Within the external cordon, a cross-section of urban dwellings was carefully selected and the residents interviewed in their homes. Special samples of truck and taxi drivers were also interviewed.

Sectors. In both surveys the area within the external cordon was divided into 9 sectors, including a sector for the central business district (Sector Zero) from which all other sectors radiate. The 1955 definition of Sector Zero includes a much larger area

than was identified with the sector in 1948. In both studies the Zero Sector included much more area than that which is generally considered to be the central business district.

District. Each sector was further subdivided into 9, or fewer, districts. The 1948 study area contained 65 districts. In the 1955 study 68 districts were defined. Most of the districts for the 1955 study retained the boundaries and numbering of the 1948 survey. Principal exceptions occurred in and adjacent to Sector Zero and in areas near the external cordon where rapid population growth required re-definition of the 1948 districts.

Zones and Sub-Zones. Each of the origin-destination districts was further sub-divided into zones and sub-zones to be used in very detailed analysis of trip data. The area-wide analyses described here were not made at the zone or sub-zone level.

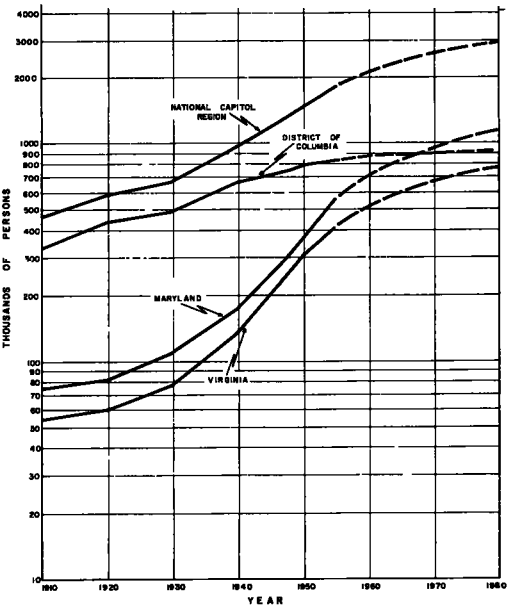

Figure 1. Population trends—National Capital Region, 1910-1980.

External Zones. Trips which entered or left the study area were also coded to points of origin and destination. The trip ends which fell outside the cordon were identified by external zone numbers. The external zone system was designed to identify trips which ended any place on the North American continent. Long trips were coded to state of origin or destination. Nearby trips were coded to counties, or to subdivisions of counties.

Stations. Since the principal uses of the origin-destination data are to describe and analyze urban traffic, for most purposes the identification of external origins and destinations need be carried no farther than the external cordon line. Each roadway was given a station number at the point where it crossed the cordon and the external terminus of each trip through the station was identified with both station number and external zone code.

Characteristics of Study Area—1948 and 1955

Several series of statistical data were prepared for each of the coded areas in the National Capital Region. The 1948 and 1955 field surveys furnished detailed information about the number of persons, cars, and dwelling units inside their external cordons. To these have been added data prepared by the National Capital Planning Commission and National Capital Regional Planning Council concerning the number of persons in the labor force, the number employed, the dollar volume of retail sales, and the median income of families resident in each district and zone. Similar estimates were made for each zone or planning area in those parts of the National Capital Region which lie outside the respective cordons (2).

Population. Figure 1 shows the history of population growth in the National Capital Region and the estimated increase to 1980. Most of the regional population is within the traffic study area. In 1948, 82 percent of the region's 1,362,000 residents lived within the cordon surrounding the study area. In 1955, 1,568,000 persons, or 84 percent of the region's 1,892,500 population lived within the cordon.

Employment. Work trips accounted for nearly half the travel reported in the 1948 and 1955 surveys. Employment inside the cordon numbered 614,435 in 1948. Another 48,648 persons were employed throughout the rest of the Region. In 1955 approximately 736,000 were employed within the cordon and 80,000 in the remaining portions of the Region.

Retail Sales. Business and shopping (commercial trips) motivated a large proportion of all non-work travel in both transportation surveys. The volume of retail sales in each district in 1948 and 1955 was established to help interpret the generation of commercial trips. In 1948 retail sales within the area bounded by the external cordon accounted for 94.64 percent of all sales in the National Capital Region. In 1955, 93.24 percent of the Regional retail transactions took place within the cordon.

Car Ownership. Trip frequency and mode of travel are closely related to car ownership. Information on the number of cars owned by urban residents was obtained in the course of the home-interview studies. In 1948 urban residents owned 203,460 cars, a ratio of one car for every 5.46 persons living within the cordon. In 1955 the residents reported 418,500 cars, an ownership ratio of one car for every 3.75 persons. Trends in automobile and truck registration are shown in Figure 2.

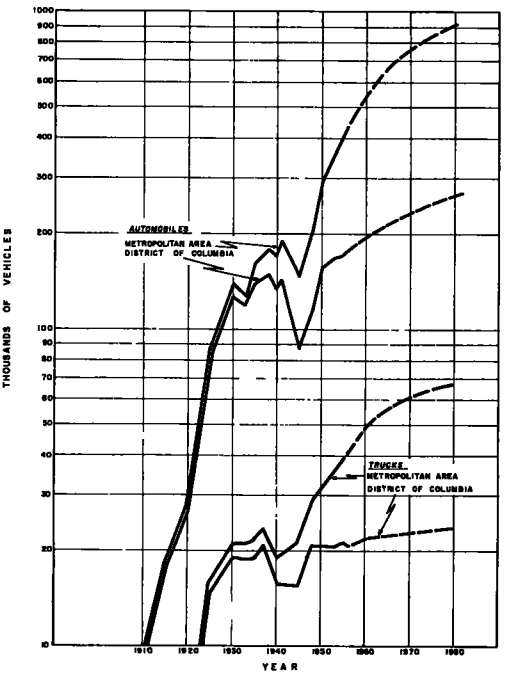

Figure 2. Estimated automobile ownership and truck registration, 1910-1980.

Transportation Facilities

The Washington metropolitan area is provided with an extensive network of streets and highways which provide access to every residence and place of business, trade or employment in the community. These public ways are traveled by people on foot, in private cars and taxis, and in streetcars and buses. They also accommodate the trucks and emergency vehicles which transport goods and perform services.

Traffic is discharged into this network of streets and highways from every occupied dwelling and from offices, factories and retail establishments. Traffic is also generated by the parks and playgrounds and at the railroad, air, and water terminals through which pass many of the non-resident visitors of the Capital City.

The major thoroughfares plan for Washington, prepared by L'Enfant in 1791, provides for a system of radial boulevards focused on the Capital and White House. These boulevards today are the principal routes of access to the centers of government and commerce in the District of Columbia. Except for the boulevards laid down in L'Enfant's plans and some of the recent parkways and freeways, very few of the traffic ways were built in anticipation of constantly increasing traffic demands.

Transit System. The D. C. Transit System[1] is the principal local transit operator, carrying about 80 percent of the Region's transit passengers. The firm serves nearly all of the District of Columbia, provides most of the Maryland-District of Columbia interstate service, and provides a bus line over Key Bridge to Virginia at Rosslyn Circle. The firm's wholly-owned subsidiary, Montgomery Bus Lines, Inc., provides a small amount of service from central Montgomery County into the District of Columbia. Nearly all operations are on the surface in public streets. D. C. Transit owns approximately 500 PCC street cars which operate over about 70 miles of track. The company also owns about 900 buses which are routed over approximately 330 miles of street. Street car operation is being curtailed and it is intended to terminate all street car service about 1963.

[1]In August 1956, the Capital Transit Company was purchased by the D. C. Transit System, Inc. References to either service appear in the name of D. C. Transit System in this report.

Other Maryland service is rendered by WMA Transit Company[2] operating interstate between southeastern Washington and Prince Georges County and intrastate within each jurisdiction. Another Maryland firm, Suburban Transit, operates intrastate in the Bethesda-Silver Spring areas.

Transit service within Virginia, and into the District of Columbia from Virginia, is provided by the AB&W[3] and WV&M[4] lines. Interstate service into the District of Columbia is limited in nature and the Virginia carriers do not hold operating rights over the District portion of their routes. The two firms own a total of approximately 350 buses.

Average weekday transit use reported in the 1948 origin-destination survey numbered 677,960 trips, while the equivalent figures from the 1955 study found 639,413 daily transit riders, a decrease of about 5.5 percent from the 1948 levels. Both origin-destination surveys were of excellent quality and provide reliable estimates of transit use.

The fact that transit use decreased in the face of rapid population growth, as shown by the origin-destination data, is very significant; and the relatively modest decline in transit use, over-all, may be construed as an indication of a basic, minimum demand for public transportation in the National Capital Region.

Travel Time. Detailed studies of travel time between places within the survey area were made in both 1948 and 1955. Travel times between outlying districts and Sector Zero increased appreciably in some areas during the 7-yr interval between studies. Most increases occurred in areas of changing land-use densities. Suburban speeds were affected by parking and other roadside encroachments in newly developed areas, and by the addition of stop signs and traffic signals which impede the free flow of traffic. At peak hours, traffic congestion also became a factor in some areas. Parkways (Mount Vernon Memorial Parkway, Suitland Parkway) and freeways (Shirley Highway, Pentagon Network) were feeling the effects of traffic congestion in 1955.

Estimates of travel time on public transit were developed from published schedules for all transit lines, 1948 and 1955. Walking time, headway time (frequency of service) and transfer time were items included with time spent in transit vehicles. The travel times computed were "portal-to-portal" times, rather than time spent in the transit vehicle. Similar portal-to-portal times were developed for auto travel between districts in order to compare the time requirements of trips made by different modes. In correlating trip generation with population, employment and the other measures of trip attraction, auto travel time was found to be an effective measure of time-distance for either transit or auto trips.

Origin-Destination Surveys

A little over two million trips, exclusive of travel by truck, were made in the National Capital Region each day, according to the 1948 origin-destination survey. Nearly 40 percent of them (774,000) were performed by auto drivers. The 1955 survey reported 3,140,000 person trips each day, about 50 percent (1,556,000) by drivers.

The origin-destination surveys produced trip information in very detailed form, related to the area subdivisions described above. Four separate surveys were organized to obtain information from all segments of the traveling public:

1. Home-Interviews. In 1948 interviewers called on the residents of every 20th dwelling in the survey area and recorded all of the trips performed by them. In 1955, every 30th dwelling within the District of Columbia and every 10th dwelling in the Maryland and Virginia portions of the study area was visited by interviewers.

2. Taxi Interviews. The trips performed by 10 percent of the licensed taxi cabs were transcribed from trip manifests, or were obtained from personal interviews of cab drivers in 1948. The 1955 taxi information consisted of a basic 10 percent sample of taxi cabs licensed in the District of Columbia and a 20 percent sample of cabs li-

[2]WMA Transit Co. formerly (1953) Washington-Marlboro and Annapolis Motor Lines.
[3]Alexandria, Barcroft and Washington Transit Co.
[4]Washington-Virginia-Maryland Coach Co. (Arnold Lines).

censed in Maryland and Virginia.

3. Truck Interviews. Ten percent of all trucks registered in the metropolitan area were interviewed in the 1948 survey. The 1955 truck sample also included 10 percent of the registered vehicles.

4. External Interviews. Trips to, from, or through the Washington area were intercepted at roadside stations located on the external cordon line. In 1948 the external survey was made concurrently with internal interview surveys. External data were collected again in 1953 and adjusted to 1955 levels for use with the 1955 internal interviews.

TABLE 1

TRIPS REPORTED IN HOME INTERVIEWS, 1948 AND 1955

Mode of Travel	1948 No.	1948 %	1955 No.	1955 %
Internal trips by residents				
Auto driver trips, 1948	631,533	36.7	1,278,352	48.7
Auto, truck, taxi passengers	414,377	24.0	708,767	27.0
Public transit passengers	677,960	39.3	639,413	24.3
Total internal trips	1,723,870	100.0	2,626,532	100.0
External trips by residents[a]	113,464		131,481	
All trips by residents	1,837,334		2,758,013	

[a]Some of the trips reported in home interviews began or ended outside the survey area. These are labeled "external" trips and represent travel by auto drivers and passengers.

Reliability of Interview Surveys. Expanded trip reports obtained in the interview surveys were thoroughly checked for completeness. Screen lines were established at the Potomac and Anacostia Rivers, and a careful count was made of all vehicles using the river crossings.

In 1948 about 87 percent of the automobiles crossing the Potomac River on an average weekday were accounted for in the interview surveys. These results were considered satisfactory. The 1955 interviews accounted for nearly 97 percent of all automobiles at the Potomac River screen line, an excellent agreement. Expanded trip reports at the Anacostia River accounted for a slightly smaller percentage of the ground count in each year.

Home Interviews

The home interviews accounted for most of the travel performed in the metropolitan area. Except for work trips made by truck and taxi drivers, all information on non-pedestrian travel by urban residents came from the home interviews. The trips made by each person were identified by purpose, mode of travel and time of day.

Table 1 summarizes trips by mode for the two surveys. In 1948 a little less than 40 percent of all internal trips were made by bus or street car. Almost as many were made by auto drivers. The rest of the trips were made by passengers in cars, trucks, and taxis.

Although the number of internal trips reported in the 1955 survey increased by more than 50 percent over 1948 travel, the number of transit trips declined by about 5.5 per-

TABLE 2

TRIPS REPORTED IN HOME INTERVIEWS - BY MODE - 1948
TRIP PURPOSES OTHER THAN HOME

Purpose to or from	Auto Drivers	Auto and Truck Pass.	Taxi Pass.	Transit Riders	All Modes
Work	268,788	110,740	14,889	388,758	783,175
Business	45,297	15,708	4,975	40,577	106,557
Medical and dental	6,725	5,989	3,294	11,962	27,970
School	9,501	16,578	583	48,652	75,314
Social and recreational	104,123	153,546	15,080	92,762	365,511
Change mode	4,068	10,247	2,764	15,704	32,783
Eat meal	16,695	10,810	1,723	10,718	39,946
Shopping	80,508	40,026	3,809	68,158	192,501
Serve passenger	95,828	3,464	152	669	100,113
Total	631,533	367,108	47,269	677,960	1,723,870

Note: Trip information from "Washington Metropolitan Area Transportation Study, 1950."

cent. More than twice as many internal auto driver trips were made in 1955 as in 1948. Auto drivers accounted for almost half of all trips made in the Region.

Purpose of Trip. Trip reports obtained in the home interview survey were carefully catalogued by purpose or motive. Ten purpose classifications were recognized, although these varied slightly in the two surveys. Tables 2 and 3 show the number of trips made for each purpose by each of the principal modes of travel.

Transit trips reflected the greatest changes in trip purpose between 1948 and 1955. About 7.5 percent (48, 652) of all transit trips reported in 1948 were made by children going from home to school, or from school to home. By 1955, 20 percent (123, 586) of a slightly smaller total volume of transit trips were made by school children.

The reverse condition occurred in trips made for social and recreational purposes. In 1948 this travel accounted for about 14 percent of all transit trips (92, 762) but dropped to around 6 percent (37, 704) in 1955. Trips in other categories were more stable, with work travel accounting for about 57 percent of non-school transit trips in 1948 and 66 percent in 1955.

Trips "to home" have been eliminated from Tables 2 and 3 by sorting them on purpose at origin. Thus, "work" trips consist of all trips "to work" plus all trips "from work to home." Work is assumed to be the motivating purpose of all of these trips.

Population in the metropolitan area increased 41 percent from 1948 to 1955 and over-all work travel increased in direct proportion. Shopping trips almost doubled, due, in part, to decentralized growth in areas from which few walking trips were made. Trips for personal business were also reported at about twice the 1948 volume. The medical-dental-eat-meal category increased considerably, from 67, 916 to 82, 798.

Trips reported as travel to school almost tripled, indicating that fewer students walked to school in the new suburbs. Social-recreational trips actually decreased in relative number. The drop in social-recreational travel is unexpected. Increased car ownership has usually been found to result in more recreational travel, but car ownership doubled from 1948 to 1955, while driver trips in the social category increased by only 12 percent. The significance of this is discussed later in this paper.

Of the remaining purposes, "change-of-mode" travel represents trips which are made in two stages, usually by car and transit. This indicates an incidental stop rather than a trip purpose. Most of the "serve-passenger" trips are also incidental to other purposes. The number of "serve-passenger" trips more than tripled between 1948 and 1955. Most were made by drivers who picked up passengers before proceeding to a common terminus for some specified purpose. Some, however, represent travel which had no other purpose than to serve the passenger carried. Such

TABLE 3

TRIPS REPORTED IN HOME INTERVIEWS - BY MODE - 1955
TRIP PURPOSES OTHER THAN HOME

Purpose to or from	Auto Drivers	Auto and Truck Pass.	Taxi Pass.	Transit Riders	All Modes
Work	500,287	213,311	20,524	341,565	1,075,687
Business	103,987	43,901	7,533	44,292	199,713
Serve passenger	260,494	24,360	448	689	285,991
Change mode	14,493	18,161	2,886	19,986	55,526
Social and recreation	127,892	153,615	11,800	37,704	331,011
Shopping (grocery-drug)	127,301	53,778	1,757	8,547	191,383
Shopping (other)	90,139	48,900	5,312	46,175	190,526
School	23,224	66,307	780	123,586	213,897
Medical, dental, eat	30,535	27,496	7,898	16,869	82,798
Total	1,278,352	649,829	58,938	639,413	2,626,532

Note: Trips from final tabulations prepared by Regional Highway Planning Committee.

TABLE 4

HOME INTERVIEW STUDY—INTERNAL TRIPS BY PRINCIPAL PURPOSE CATEGORIES

Travel	1948 Work	Com'l	Social	Misc.	Total	1955 Work	Com'l	Social	Misc.	Total
Auto driver	233,214	125,408	110,479	76,961	546,062	469,508	310,458	144,318	124,466	1,043,750
Auto pass.	110,441	66,050	163,730	17,045	357,266	212,391	152,474	210,198	43,284	618,347
Transit	383,262	112,411	133,629	38,049	667,351	348,540	97,860	156,554	28,403	631,357
Total	726,917	303,869	407,838	132,055	1,570,679	1,030,439	560,792	511,070	196,153	2,298,454

Note: Totals are less than those in Tables 2 and 3 due to deletion of change-of-mode trips and serve passenger trips. Other minor irregularities in data processing also contribute to differences.

trips are those by wives who chauffeur husbands to work or to the bus, and mothers taking children to and from school.

Combined Purposes. The ten purpose categories (9 purposes exluding "home") and nearly one hundred possible combinations of purposes "to" and "from" pose a complex problem of analysis which can be greatly simplified by grouping purposes in logical combinations. The combinations defined in this study were based on the categories of land use described earlier—employment, retail sales, and population—so that relationships between land use and trip production could be found and used to relate future travel to predictions of future land use. Trips combined combined by purpose are shown in Table 4.

All trips have been grouped into four main purpose categories for each of the three principal modes of travel. All trips in the three most significant classes have either origin or destination at place of residence. These "home-based" trips are classed as "work" trips, "commercial" trips (business, shopping, medical-dental and eat-meal trips) and "social" trips (social-recreation and school trips). The fourth, or "miscellaneous" class of trips is made up of "work" and "commercial" travel which does not begin or end at home.

The "change-of-mode" trips have been eliminated from trip purposes since they merely represent parts of other trips. "Serve-passenger" trips that were made for passenger pick-up or delivery have also been discarded because they usually represent incidental stops by a driver traveling between his home and another trip-motivating origin or destination.

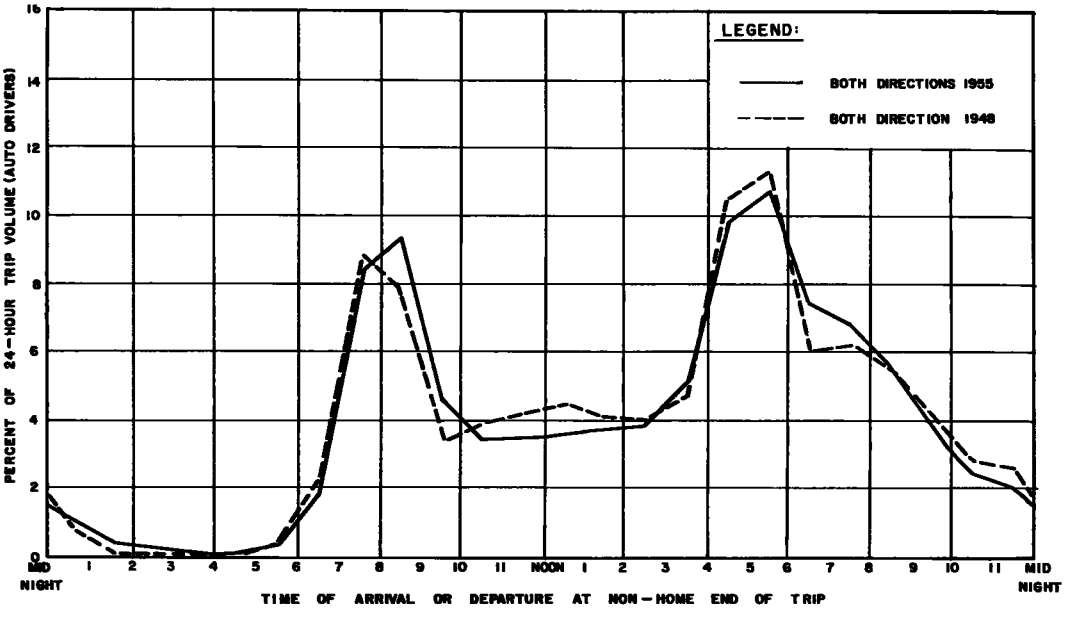

Figure 3. Hourly distribution of trips made by residents of area, 1948 & 1955; auto drivers (all purposes).

Many of the inbound passenger pickups (driver traveling from home to some other purpose) and outbound passenger deliveries (driver going home) take place in the "home" district of the driver. The origin or destination coded to the "serve-passenger" end of the trip has, therefore, been identified as the "home" district. An equivalent number of trips between "home" end and "serve-passenger" have been cancelled. Similar assumptions have been made for "change-of-mode" trips, relating the "home" end of each trip to the "change-of-mode" location. Most of these trips are performed partly by car and partly by transit. Since use of the car is usually associated with the "home" end of the trip, the majority of these trips have been classified as transit travel. This broad treatment of change-of-mode trips is not entirely accurate, but they are relatively few in number and elimination of the category results in a more precise representation of travel motives.

TABLE 5

SUMMARY OF EXTERNAL PERSON TRIPS
1948 AND 1955

Type of Trip	1948	1955
Auto driver trips at cordon	142,856	278,050
Through trips (counted once)	6,818	9,845
"Local-external" trips	136,038	268,205
Internal auto driver trips	631,533	1,278,352
Total driver trips	774,389	1,556,402
Percent external	18.4	17.9
Person trips at cordon	298,618	534,018
Through trips (counted once)	16,510	21,243
"Local-external" trips	282,108	512,775
Internal person trips	1,723,870	2,626,532
Total person trips	2,022,488	3,139,307
Percent external	13.9	16.4
Trips from home interviews	1,837,334	2,758,013
Internal trips by residents	1,723,870	2,626,532
External trips by residents[1]	113,464	131,481
Average car occupancy	2.00	1.57
External driver trips[2]	56,600	78,475
Percent of local-external drivers	41.7	29.3

[1]For 1948 the difference between internal trip summary tables and total trips from home interviews. For 1955 tabulation of home-interview trips with external origin or destination.

[2]For 1948, 16-hr total vehicles garaged in area = 49,217. Sixteen-hr traffic is approximately 87 percent of 24-hr ADT. Expanded trips by residents = 56,600. For 1955, 24-hr total as obtained in home-interviews, (probably under-reported 25-30 percent).

The re-definition of serve-passenger and change-of-mode trips has reduced the number left in those categories from 97,350 trips per day, all modes (about 5.8 percent of total) to 46,701 driver trips per day (about 2.8 percent of all trips or 7.4 percent of driver trips) in the 1948 study. The remaining trips represent the chauffeured travel of passengers in cases where the driver had no purpose other than to serve passengers.

In the 1955 study these trips were reduced from about 245,000 (9.5 percent of total) by all modes to 115,000 driver trips (about 4.5 percent of all trips, or 9.0 percent of

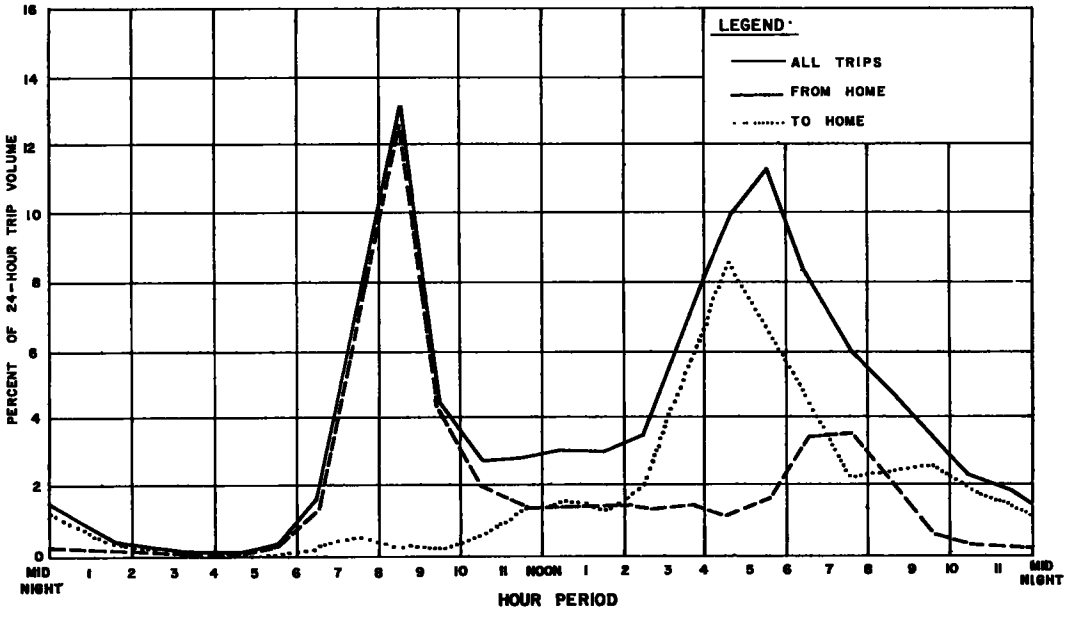

Figure 4. Hourly distribution of trips made by residents of area, 1955; all modes and purposes.

driver trips), thus eliminating stops which merely represent interrupted travel rather than a trip-motivating purpose.

Hourly Distribution by Mode and Purpose

The principal purpose-of-trip categories described above have distinctive patterns of time distribution throughout the day. Since traffic congestion problems tend to be concentrated into a very few hours of the day, the significance of trip purpose and peak-hour travel can hardly be over-emphasized. The hourly patterns of travel in 1948 and 1955 provide the only available background for predicting the hourly distribution of work, commercial, and social trips in future years.

Mode of travel is also of much concern in this study. The proportion of trips made by transit can be correlated with trends, purposes, trip lengths, income levels, and other factors. For non-transit trips, it is necessary to develop occupancy factors in order to estimate the number of cars that will be needed to accommodate any predicted number of trips.

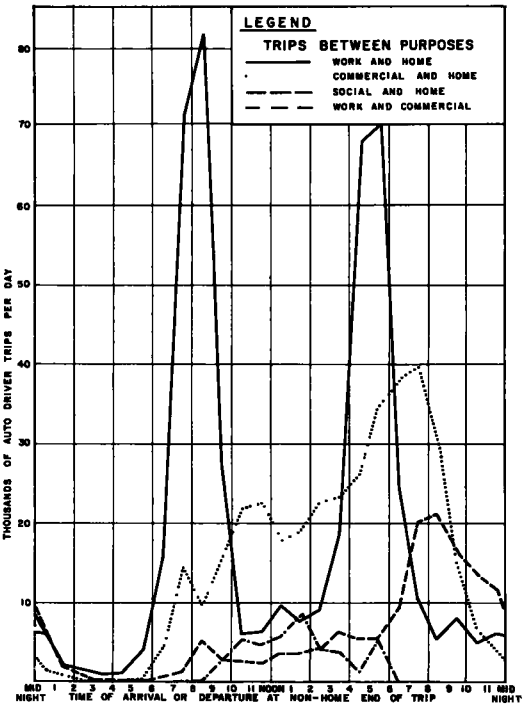

Figure 5. Hourly distribution of trips made by residents in 1955; auto drivers by purpose of trip.

Figure 3 illustrates the hourly distribution of automobile driver trips for all purposes in the years 1948 and 1955. The volume of trips made during each hour is expressed as a percentage of the 24-hr total so that the two curves are directly comparable.

The hourly distribution of auto trips was very similar in both years. In 1948 the morning peak occurred in the hour 7:00 to 8:00 a. m. The hour 8:00 to 9:00 a. m. was also very heavily traveled, but the volume was a little less. In 1955 the reverse was true, with the morning peak hour coming at 8:00 to 9:00 a. m. and also representing a higher proportion of the day's travel than did the 1948 peak.

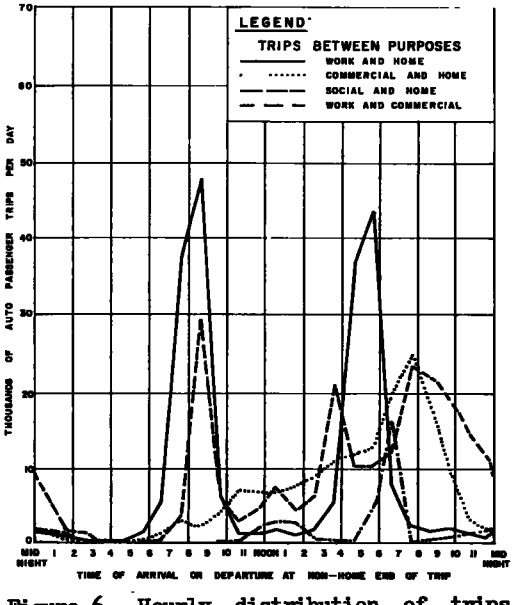

Figure 6. Hourly distribution of trips made by residents in 1955; auto passengers by purpose of trip.

The evening peak occurs in the hour 5:00 to 6:00 p. m. in both years, the 1955 peak again representing a higher share of the 24-hr volume. Midday travel is a smaller proportion of daily traffic in 1955, balancing the increased sharpness of the peaks.

Figure 4 shows the 1955 hourly distribution of trips by all modes, segregated into trips "from home" and "to home." The hourly distribution of trips is expressed as a percentage of the 24-hr travel. Trips from home were "inbound" to work at the morning peak hours. After 10:00 a.m. trips from home became a low but constant volume of travel until 6:00 to 8:00 p. m.

when they picked up sharply (evening shopping and recreation). Homebound trips balanced trips from home during the midday hours, 10:00 a. m. to 3:00 p. m., and dominated travel the rest of the afternoon and evening. They were heavily represented in travel after 3:00 p. m. and accounted for most of the evening rush between 4:00 and 6:00 p. m.

Figure 4 is especially interesting because it shows more travel at the morning peak hour than in the evening, with the evening peak spread over more hours.

The general pattern of trips from home and to home was found to apply to each mode. Transit peaks represented a higher proportion of the day's travel than trips by drivers and passengers.

Auto Driver Trips

Figure 8 illustrates 1948 auto driver trips by purpose and is comparable with Figure 7 for 1955. (Figure 3 indicates that the 24-hr distribution of driver trips, disregarding purpose, was about the same in both years.) The 1948 data were based on the time of arrival at destination. For 1955, the hour of trip performance was

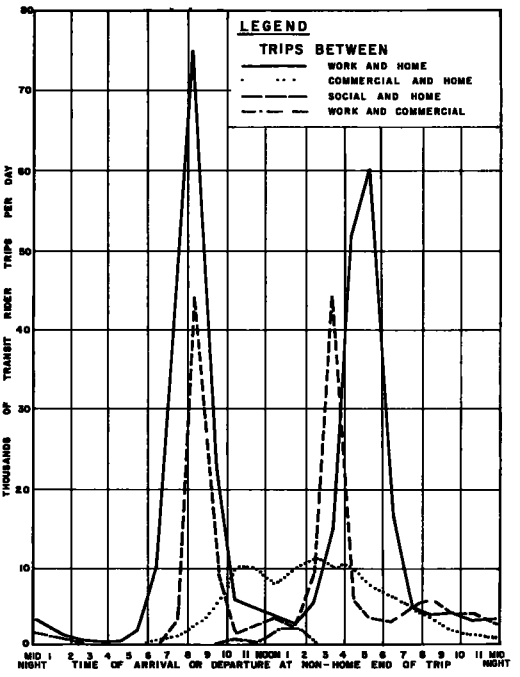

Figure 7. Hourly distribution of trips made by residents in 1955; transit riders by purpose of trip.

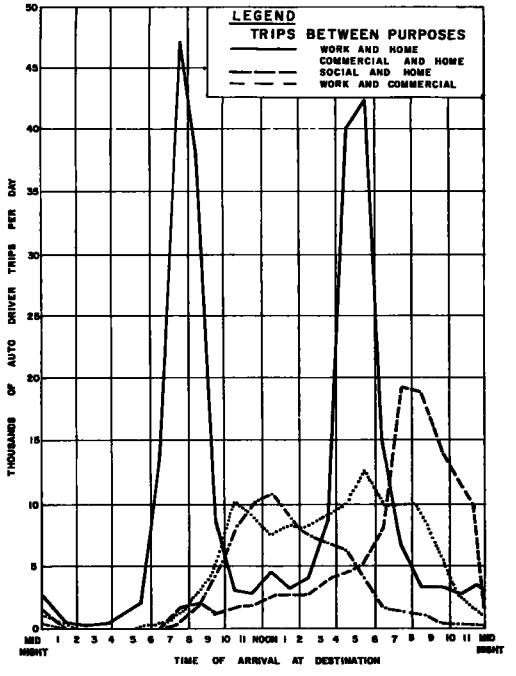

Figure 8. Hourly distribution of trips made by residents in 1948; auto drivers by purpose of trip.

related to time of arrival or departure at the non-home terminus of trip. Trips "to home" have been tabulated according to the time that the trip began rather than by time of arrival. This was done to relate trip purposes to hours of occurrence at the controlling end of the trip where traffic congestion is often a problem. Work trips, for instance, are timed to bring the worker to his place of employment at scheduled hours. The simultaneous arrival or dismissal of large numbers of employees in the central city, at the Pentagon, and at other large employment centers creates the periods of peak traffic demand. These peak demands are reflected in the hourly distributions shown in Figures 5 and 8.

Work Trips. The work-trip pattern dominates both of these drawings because of the large volumes of movement which take place at morning and evening peak hours. Off-peak work travel is very small compared to peak demands and the contrast developed in these illustrations is impressive.

Although the vertical scale for 1955 work trips represents larger volumes per inch of height than the 1948 drawing, the shape

of the two curves in much alike. There has been a slight shift in hours of arrival during the morning peak, but afternoon peak and off-peak work patterns are almost identical for both years.

TABLE 6

AVERAGE CAR OCCUPANCY AT EXTERNAL CORDON

Type of Trip	1948	1955
All cars at cordon	2.09	1.92
Through trips	2.42	2.16
Local trips	2.07	1.91
Trips by residents[1]	-	1.57
Trips by non-residents	-	2.05
All internal cars (for comparison)	1.62	1.53

[1]Determined from tabulation of external trips, by mode, obtained from home interviews.

Commercial and Social Trips. In the other purpose categories there have been marked changes. Although these changes have little effect on the over-all hourly distribution patterns of automobile trips (Fig. 3), they are of concern in developing travel characteristics discussed in this study.

The most important changes in the hourly distribution of auto trips have taken place in "commercial" (business, shop, medical-dental) and "social" categories (social, recreational, school). Table 4, summarizing data by purpose and mode for both 1948 and 1955, shows that twice as many auto driver trips were reported for commercial purposes in 1955 as in 1948. On the other hand, "social" driver trips increased less than one-third during these years even though car ownership doubled.

The hourly distribution curve for commercial driver trips showed a maximum trip rate in the hour 7:00 to 8:00 p. m. in 1955. In 1948 the commercial movement was most intense in the hour 5:00 to 6:00 p. m., and declined somewhat in the evening hours. This change may be due to the postwar trend to "shopper's nights" in retail centers.

The small increase in social driver trips from 1948 to 1955 appears, at first, to be in error. However, social-recreational trips were defined exactly alike in the two surveys and trips reported in this class in 1948 were identified in the same category in 1955. There are several reasons why social-recreational travel decreased in the interval between surveys.

First, an increase in evening commercial trips replaced some of the recreational travel which took place in those hours. The suburban shopping centers contain many recreational facilities—bowling alleys, motion picture theaters and such; the trips motivated primarily by a shopping purpose may also have included incidental recreational functions not reported as the motivating trip purpose.

Probably more important has been the change in recreational habits occasioned by the growth of television viewing in the years 1948 to 1955. Television made its debut in 1946. Relatively few homes were equipped with TV sets as early as 1948 but by 1955 almost 80 percent of all homes in the National Capital Region contained one or more television receivers, according to a Sales Management study (3). This means that nearly everyone in the area had access to a TV set in 1955. The effect of TV viewing on movie attendance has been pronounced, and it can be assumed that other forms of recreation have likewise felt the impact.

Miscellaneous Trips. The number of driver trips, performed for work or commercial purposes, which do not have a terminus at home appears to have increased in direct proportion to automobile registration, which doubled from 1948 to 1955. The hourly pattern of occurrence is more pronounced for the evening in 1955, reflecting the increased commercial travel at those hours.

Auto Passengers and Transit Riders

The hourly distribution of auto driver trips shows that significant changes have taken place in the non-work travel patterns of Washington residents. The use of transit has decreased sharply; shopping patterns have shifted towards the evening hours; recreational habits have experienced a marked change, probably related to "at home" entertainment provided by television.

Figures 6 and 7 show the 1955 hourly distributions of auto passenger and transit rider trips by purpose. The work curve for auto passengers is similar to that for drivers, but of smaller magnitude. The morning peak hour coincides with chauffeured

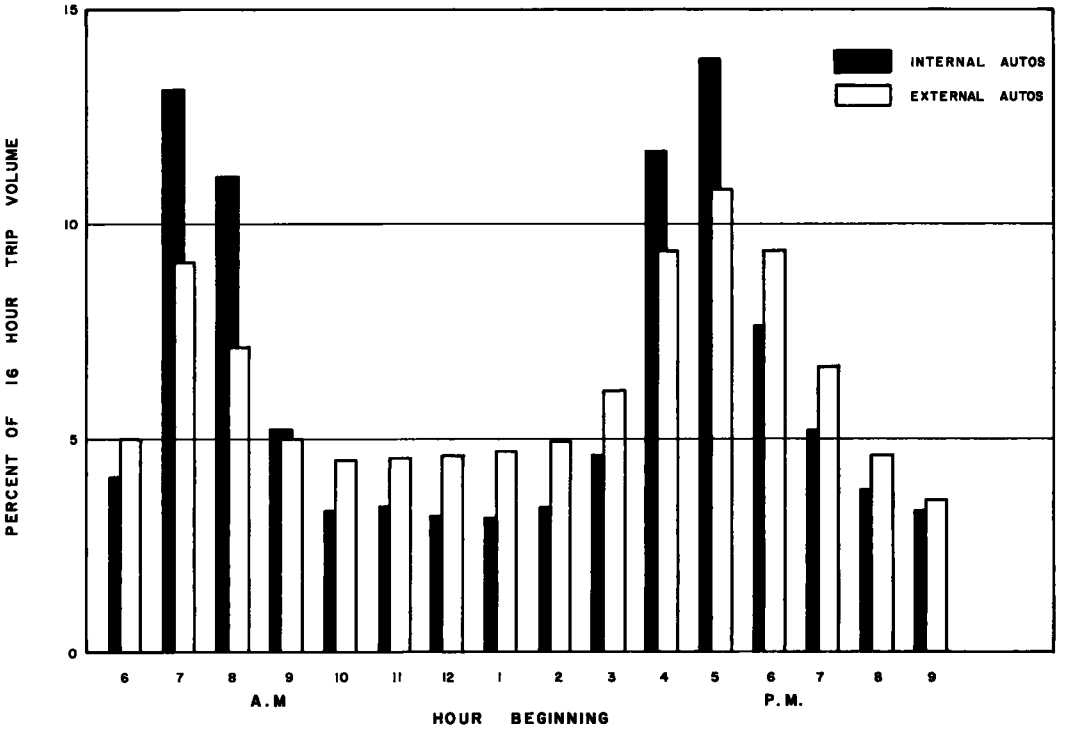

Figure 9. Comparison of internal and external auto driver trips, 1955; hourly distribution at Potomac River screenline.

trips to school (social category) which are nearly 40 percent of the auto passenger load during the hour 8:00 to 9:00 a. m.

Shopping trips by passengers repeat the evening build-up shown for drivers. High occupancy of auto trips for social purposes is indicated. "Miscellaneous" travel is not an important generator of auto passengers, but evening shopping travel is reflected here as in the auto trips.

It is interesting to note that commercial trips by transit (Fig. 7) follow the conven-

TABLE 7

EXTERNAL AUTO DRIVER TRIPS AT PEAK HOURS—1953

Hour	Outbound Trips No.	%	Inbound Trips No.	%	Both Directions No.	%	% In-bound
7-8 a. m.	1,651		2,547		4,198		
8-9 a. m.	1,223		1,697		2,920		
a. m. peak hours	2,874	4.9	4,244	7.3	7,118	12.2	60
4-5 p. m.	2,448		1,734		4,182		
5-6 p. m.	3,040		1,965		5,005		
p. m. peak hours	5,488	9.4	3,699	6.3	9,187	15.7	40
4 hours	8,362	14.3	7,943	13.6	16,305	27.9	
24 hours	29,451	50.3	29,000	49.7	58,451	100.0	

Note: Data from 2-way roadside interview stations No. 22, 41, 51, 73 and 84.

tional downtown patterns of concentrated midday travel. Shopper and business travel by transit is associated most closely with the central areas which it best serves. Evening shopping appears to be a phenomenon peculiar to the motorist, strongly related to suburban shopping centers with ample parking space.

External Driver and Passenger Trips

Traffic to and from the Washington Metropolitan Area was interviewed at 34 roadside stations in 1948 and 37 stations in 1953. External auto drivers crossing the cordon averaged 142,856 per day during the period of the 1948 survey. The 1953 interviews were expanded to match an average 1955 daily volume of 278,050 passenger cars.

The external trips were an important part of the Region's traffic. Table 5 shows that external cars transported 282,108 persons to and from Washington on the average day in 1948, or nearly 14 percent of all trips made within the study area. In 1955 more than half a million persons crossed the cordon on an average day, accounting for almost one-sixth (16.4 percent) of all metropolitan area travel.

A good deal of this external traffic was generated by residents of the internal study area. In 1948, 143,464 trips reported in home interviews were not included in tabulations of internal trips. Most of these represented external travel by residents. At the cordon, cars "garaged in area" numbered 49,217 in the 16 hr from 6:00 a. m. to 10:00 p. m., vs 32,608 reported in home interviews, indicating that only two-thirds of the residents' external travel was reported to interviewers.

Since 16-hr traffic accounts for about 87 percent of the 24-hr volume at the cordon, estimates of external driver trips by residents have been adjusted upwards by the appropriate amount. Residents were thus found to make nearly 42 percent of 1948 external driver trips.

External trips reported in 1955 home interviews were also tabulated. Residents

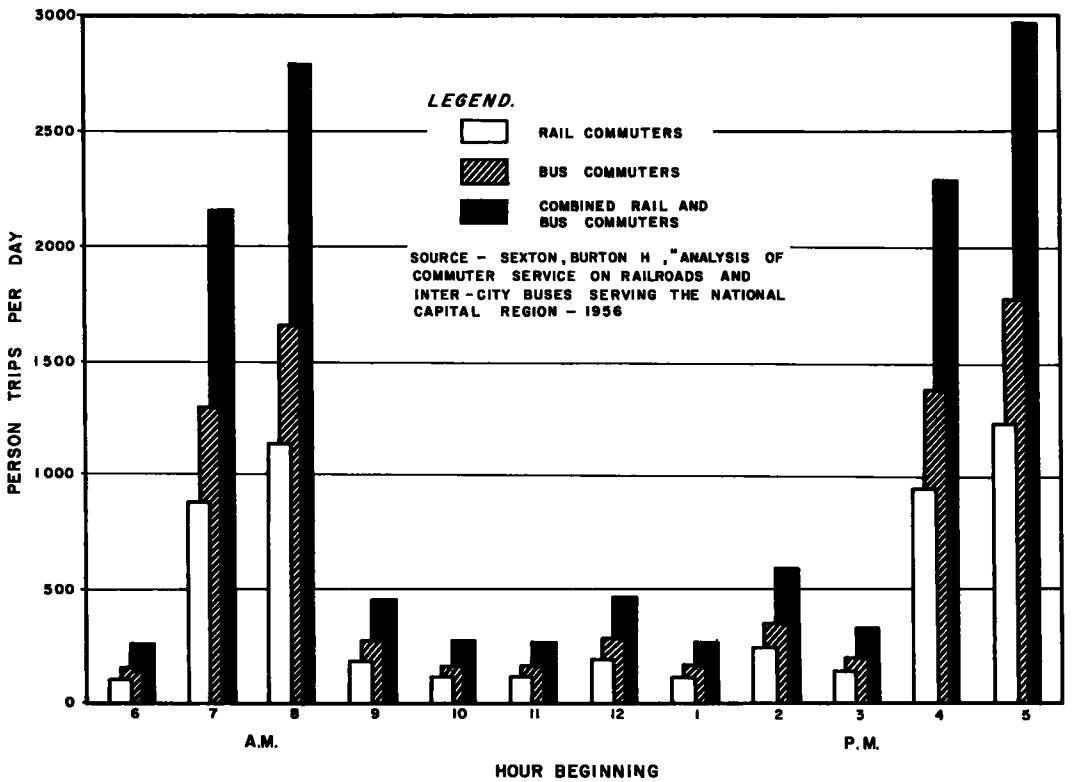

Figure 10. Hourly distribution of bus and rail commuters to and from the National Capital Region, 1956.

who reported that they drove across the cordon numbered 78,475 and total persons (drivers and passengers) amounted to 131,481. About 8,000 of these person trips were reported as made by bus. External trips reported in the home interviews thus accounted for 29.3 percent of all external travel at the cordon in 1953. Like the 1948 interviews, these trips were probably under-reported by 25 to 30 percent. It seems likely that area residents accounted for about 40 percent of auto travel at the cordon in 1953.

TABLE 8

VEHICLE TRIPS IN STUDY AREA—1948 AND 1955

Type of Vehicle	1948 No.	1948 %	1955 No.	1955 %
Auto drivers	779,646	66 2	1,556,402	74 1
Taxi drivers	247,924	21.1	266,654	12.7
Truck drivers	149,570	12.7	277,028	13 2
Total	1,177,140	100.0	2,100,084	100.0

TABLE 9

TAXICABS "ON STREET"[1]—1948 AND 1955

Area	1948	1955
District of Columbia	7,920	8,872
Alexandria	108	136
Arlington Co., Virginia (includes Airport)	51	147
Fairfax Co., Virginia (includes Falls Church)	7	24
Montgomery Co., Maryland	137	259
Prince Georges Co., Maryland	56	127
Total	8,279	9,565

Source: National Capital Planning Commission
[1]Average number of taxicabs in service in a 24-hr average weekday at time origin-destination surveys were made.

Car Occupancy. Local-external autos at the 1948 cordon contained an average of 2.07 persons per car. In 1953 average occupancy had decreased to 1.91 per car, reflecting increased car ownership, with fewer persons dependent on each vehicle.

Cars in through traffic contained more persons than local cars in both years as shown in Table 6. Data from 1955 home interviews showed that external trips by residents maintained occupancies consistent with internal auto trips. Auto, truck, and taxi passengers reported to cross the cordon were 57 percent the number of persons who drove across, representing an average occupancy of 1.57 for all internal trips by car. When non-resident auto occupancies were adjusted for trips by residents, an average of 2.05 persons per car was developed—not much less than through-trip occupancy. This conforms to studies which have found that non-resident autos usually contain more passengers than cars driven by residents. In this survey, many of the non-resident trips represent family visits to the Nation's Capital.

Time of Day. External trips were not found to be so concentrated into peak hours as were the internal trips in 1948 and 1955. The relative hourly distribution of internal and external auto driver trips in 1955 is shown graphically in Figure 9. The hour of occurrence reported in home-interviews is shown for auto driver trips which crossed the Potomac River screenline. A similar distribution of external trips at the screenline was obtained from interviews and observed time of passage at external stations. Morning and evening peak hours each contained 13 to 14 percent of the 16-hr internal movement, while midday hours averaged about 3 percent. External trips peaked at about 10 percent of the daily total and midday volumes averaged about 4.5 percent. Screenline data for 1948 showed a very similar picture.

The time distribution of external auto drivers at the cordon in 1953 was analyzed for the 4 hr of heaviest travel in the city (7:00 to 9:00 a. m. and 4:00 to 6:00 p. m.). The data analyzed represent travel which was intercepted in both directions at five heavily traveled locations in 1953—Stations 22, 41, 51, 73 and 84. About 28 percent of the external driver trips crossed the cordon in the four peak hours. The number of inbound trips nearly balanced outbound trips during the four hours. In the morning hours, trips were split approximately 60 percent inbound and 40 percent outbound. In the afternoon this condition was reversed (Table 7).

Bus and Rail Commuters

A special study of commuter travel in the National Capital Region was made to supplement the origin-destination surveys (4). This study found that a small number of persons commute several times a week to and from Washington by rail and inter-city bus. About 2,750 commuters arrive each day in Union Station and equal numbers depart. About half of these (45 percent) originate in Baltimore; about one-sixth (17 percent) originate beyond Baltimore in Wilmington, Philadelphia, or New York metropolitan areas.

About 4,000 persons commute to Washington by inter-city bus, via two downtown bus terminals,[5] and account for some 8,000 commuter trips each day. Most bus commuters originate in nearby Virginia and Maryland communities which lie just beyond the limits of local bus service. These trips average less than 20 miles in length.

Time of Day. Most of the commuter activity at bus and rail terminals occurred during the four hours of peak travel within the study area. The time-distribution of commuter trips is illustrated in Figure 10. The majority of inbound trips arrived between 7:00 and 9:00 a. m. Outbound trips were concentrated into the period between 4:00 and 6:00 p. m.

Purpose. Over two-thirds of the commuters were traveling to and from places of work. About half of the remainder were engaged in business or shopping trips and the others had social or recreational motives or were going to and from school. Peak-hour movements were mostly work trips.

Downtown Distribution. More than three-fourths of the bus commuters walked to or from their downtown employment. Most of the remainder transferred to local transit in order to reach final destination.

Less than a fourth of the rail commuters walked between the Union Station and places of employment. The rail station is located well beyond convenient walking distance to most downtown employment. About 20 percent of the rail commuters rode to Washington destinations by taxi. Most of the others used local transit.

Mode to Transit Terminal. The mode of travel used by non-resident commuters between places of residence and the nearest bus or rail station was of special interest to the Mass Transportation Survey. More than half (53 percent) reported that they walked to the station; about a third (34 percent) drove to the station (22 percent drivers, 12 percent passengers); and the remainder used local transit. Most of the drivers parked near the terminal.

Taxi Driver Trips

Taxicabs were responsible for a large number of trips in the Washington area. In 1948 taxis made nearly one-fourth of the daily trips performed by automobiles in the study area (Table 8). Taxis accounted for a slightly larger number of trips in 1955, but a smaller share of the total. Although taxi trips were usually of short average length and accounted for fewer vehicle miles per trip than private cars, they contributed heavily to street congestion because most of them were concentrated in the central city.

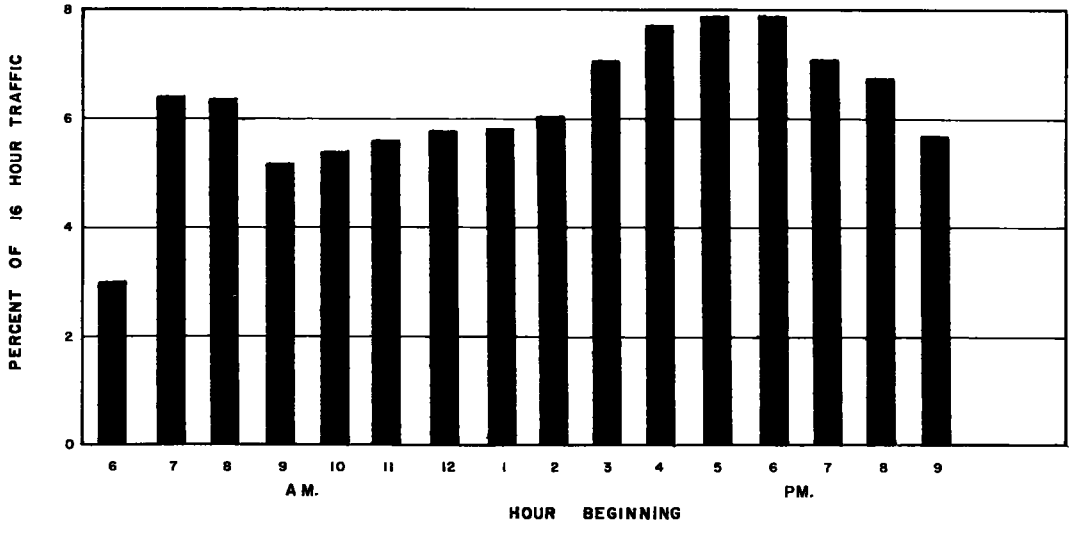

Figure 11. Hourly distribution of taxi trips—groundcounts at screenlines, 1948.

[5]The Trailways and Greyhound Terminals at 12th Street and New York Avenue.

Passenger Occupancy. The home interview studies did not produce complete reports on taxi passengers. In 1948, taxi drivers' trip manifests were analyzed to determine the number and destination of taxi trips. Some 8,279 taxicabs (Table 9) averaged about 30 trips per day. Passenger trips reported in home interviews amounted to only 47,227 trips, an average of 5.7 daily trips per vehicle. The 1955 study reported 266,656 taxi driver trips and 58,938 taxi passenger trips, a little higher proportion of passengers to drivers than was found in 1948.

Probably the majority of taxi riders are persons who do not live in Washington and are without a car for personal tranportation. The taxicab affords great personal convenience and flexibility, yet costs only a small premium over the street car or bus on short runs. Since many passengers are unfamiliar with the city, the cab driver also performs the duties of a guide at no extra cost.

A special study of taxicab occupancy was made by the Planning Commission staff in April, 1957. It was found that the trip reports furnished by drivers for the taxicab surveys (266,654 trips) did not all represent revenue travel. It was estimated that about 20 percent were non-revenue movements. Revenue trips thus averaged about 213,350 per day.

Based on taxi data from various sources, and especially on information reported to the Public Utilities Commission in a Formal Case Hearing in 1951, an average passenger load of 1.35 persons was established for revenue trips in the Washington area. This passenger occupancy figure applied to revenue trips indicates that taxi passengers totaled 288,000 persons per day in 1955. Only 20.5 percent of these trips were reported in the home interviews, permitting the conclusion that most of them were made by non-residents.

The number of taxi passengers carried each day is especially significant when compared to the daily volume of patronage on mass transit. In 1955, transit averaged 631,357 trips per day (Table 4). The estimated number of taxi drivers amounted to about 45 percent of this value. If taxi and transit passengers were combined, taxi riders would represent approximately 31 percent of some 919,350 trips. There was little similarity in the travel patterns and hourly distributions of transit and taxi passengers, however. Although taxis are a specialized form of public transportation, they do not compete with transit for the heavy peak-hour movements.

Special tabulations of 1955 taxi passenger travel were prepared by applying a factor to taxi driver trips to raise the number of passengers to the revised estimate. Average passenger occupancy per taxi driver trip, including non-revenue movements, worked out to about 1.08 persons, not including drivers.

Hourly Distribution of Taxi Trips. Taxicabs are especially well suited to off-peak service at hours when other forms of public transportation are least efficient. The supply of taxicabs was not large in terms of total vehicles in traffic (8,279 "on-street" in 1948; 9,565 in 1955—Table 9). Demand quickly exceeded supply at peak hours. Relatively few of the rush hour travelers were accommodated in cabs.

In 1948 a total volume of 18,771 taxicabs was recorded in the 16-hr ground count of vehicles at the Potomac and Anacostia River screenlines. Figure 11 illustrates the proportion of these trips which passed during each of the 16 hr. Between the hours 7:00 a. m. and 10:00 p. m. no single hour accounted for more than 8 percent of the day's traffic, nor less than 5 percent. This contrasted sharply with travel by private automobile (Fig. 9).

The four peak hours (7:00 to 9:00 a. m. and 4:00 to 6:00 p. m.) accounted for 28.4 percent of taxi trips at combined screenlines in 1948 (16-hr total). Analysis of 1955 data found 29.8 percent of the 16-hr taxi trip volume in those four peak hours.

Adjustments for taxi travel during the entire 24 hr of the day reduces these values to about one-fourth of the day's travel, in contrast to the 40 percent of trips by other modes during the four peak hours.

Truck Driver Trips

About a sixth of all vehicle trips in the study area were made by trucks in 1948 and 1955 (Table 8). Many of these were made by heavy trucks which had much more pro-

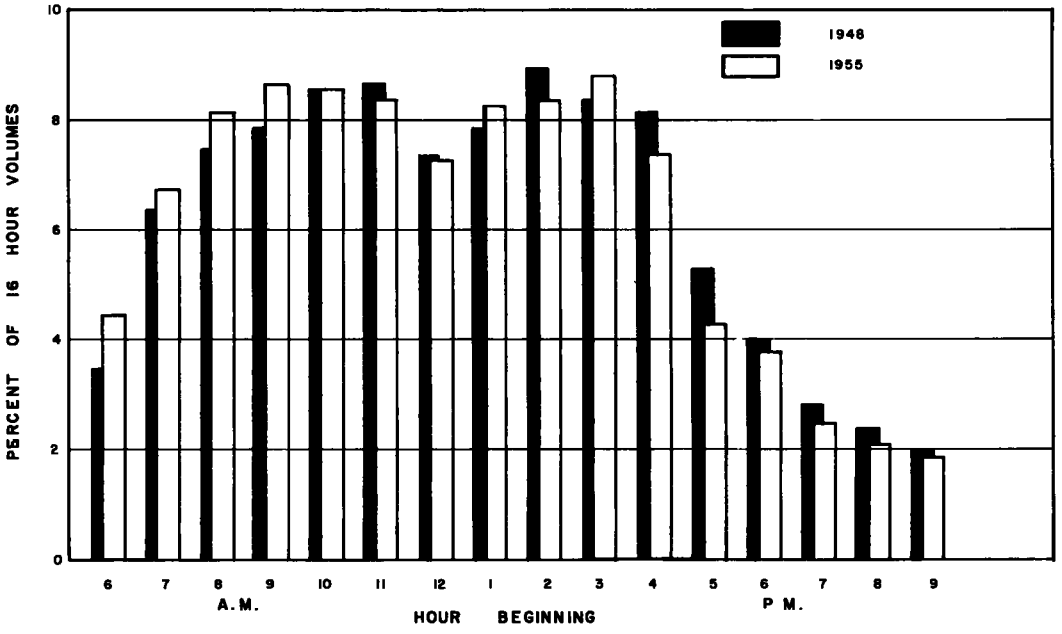

Figure 12. Hourly distribution of truck trips at combined Potomac and Anacostia River screenlines, 1948-1955.

nounced effect on street traffic operations than an equivalent number of passenger cars.

Truck trips increased more rapidly than personal travel between 1948 and 1955. Person trips performed in the study area (internal plus external) increased about 55 percent between surveys (Table 5). Truck travel grew about 85 percent in the same period. The increase in truck trips was somewhat less than that of auto driver trips. Car driver trips increased 100 percent from 1948 to 1955.

Time Distributions. Truck trips were not concentrated so heavily into the morning and evening peak hours as passenger car trips. The working hours of most truck drivers were about the same as those of other employed persons and the truck drivers were engaged with their trucks during 8 or 9 hr in the middle of the day. Truck travel reached its heaviest volumes in the midday hours and decreased during the usual traffic peaks, especially in the afternoon. Figure 12 illustrates the daily (6:00 a.m. to 10:00 p.m.) distribution of truck driver trips across the Potomac and Anacostia Rivers in 1948 and 1955. The hourly patterns of travel were virtually the same during both years. Traffic at the four peak hours (7:00 to 9:00 a.m. and 4:00 to 6:00 p.m.) amounted to about 27 percent of the 16-hr total each year, or, adjusted for trips which passed during the remaining night hours, accounted for about one-fourth of the average 24-hr truck traffic.

External Truck Trips. Table 10 shows

TABLE 10

TRUCK TRIPS IN WASHINGTON AREA—1948 AND 1955

Type of Trip	1948	1955
Sector Zero trips		
External	1,032	5,674
Internal		
Inter-district	12,346	34,445
Intra-sector	2,018	25,913
Other than Sector Zero		
External	23,547	40,627
Internal	104,851	159,044
Total trucks	149,570[2]	277,028
Internal	119,215	219,402[3]
External	30,355	57,626
Local	24,579	46,301[4]
Thru	5,776[1]	11,325[4]

[1]From Table H-I Vehicle Trips - Station to Station - Vol. III, 1948 O-D Report.
[2]From Table XXX - Summary of Origins and Destinations - Vol. 1, 1948 O-D Report.
[3]From Summary Table "Total Trip Ends for Trips Originating in Each District," March 1957.
[4]From Station - District Trip Tabulations, March 1957
Note: A much larger area was defined for Sector Zero in 1955 than in 1948. The volume of truck trips reported for Sector Zero in 1948 is not comparable with 1955 data for this reason.

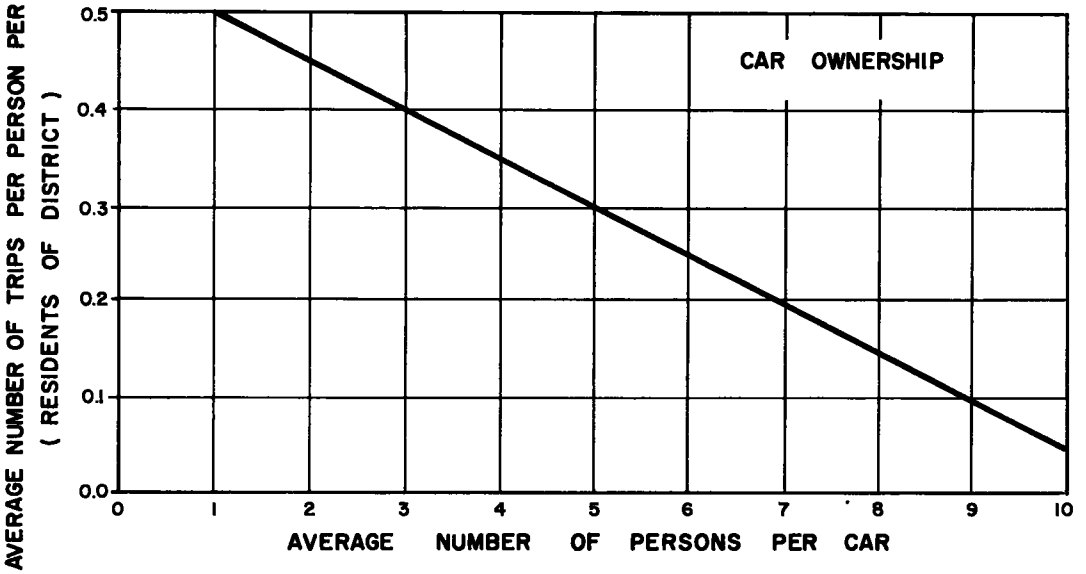

Figure 13. Trips made by residents of metropolitan area.

that more than a fifth of the truck trips in the study area began or ended outside the external cordon. As with auto drivers, many of the external trips were made by trucks that were owned and/or garaged in the city. A cordon line study made in 1948 found that 11,900 of the trucks at the cordon during the hours 6:00 a. m. to 10:00 p. m. were local vehicles—about 40 percent of all trips, a value similar to the proportion of local cars found at the cordon.

The hourly distribution of external truck trips differed from that of internal travel. The midday concentration of internal trips was more pronounced than external trips. Internal trips decreased very rapidly after 4:00 p. m., while external trips maintained considerable volume.

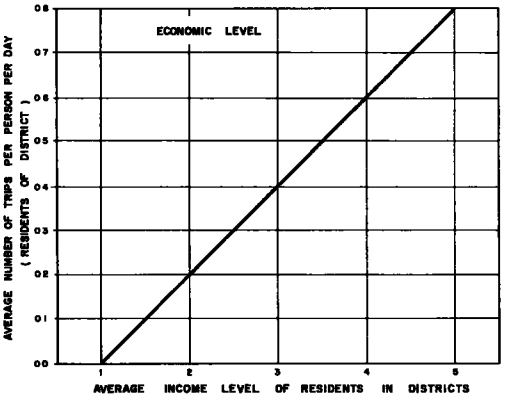

Figure 14. Trips made by residents of metropolitan area.

Studies of Trip Generation (9)

The origin-destination surveys and statistical data described above have been compared and studied for relationships which are clear enough and consistent enough so that they may be considered characteristic of travel in this particular community. This phase of the study has two principal goals:

1. To develop methods for measuring or predicting the number of trips of all kinds which begin or end in each district in the study area.
2. To find principles which govern the distribution of trips between districts.

The origin-destination studies found that fewer than nine percent of all trips made by respondents to the home-interview surveys did not begin or end at home (the

"miscellaneous" trips listed in Table 4).[6] Since most of the trips made by residents of the region are related directly to their homes, the analysis of trip generation logically begins at the place of residence.

Several of the statistical series derived from the origin-destination surveys or prepared by the National Capital Planning Commission and National Capital Regional Planning Council are directly related to the home. These include the number of dwellings in each district, the number of persons living there, the number of residents in the labor force, the number of cars that residents own, and the median level of family income in each district.

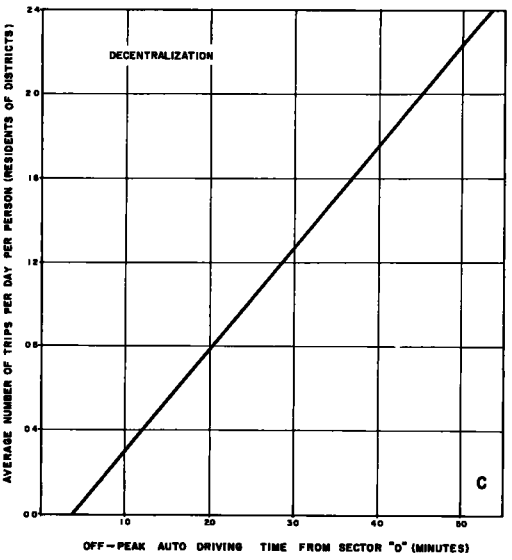

Figure 15. Trips by residents of metropolitan area.

Trips made by people who live in each district have been related to income level, car ownership and degree of decentralizations (distance from the center of the metropolitan area) modified by the relative "isolation" of districts in the outer fringe of urban development. Various other factors were considered and discarded in preliminary stages of investigation. Correlations have been developed, using graphic techniques adapted from Ezekiel (5), with which to predict the average volume of trips made by residents of the districts for both 1948 and 1955 conditions. Two-thirds of the predictions thus made were found to fall within 10 percent of the trip volumes reported in each of the surveys. The estimating formula is composed of the following elements:

Income. Average level of family income is an important component of the estimating formula. Low income families produce far fewer trips per person than high income families. Most of this is deficiency in the number of non-work trips, but at the lowest income level families also make fewer work trips. Figure 17 illustrates the importance of income on the average daily trip production by each resident of a district. Families in the lowest income class produce about 1.35 trips per person per day on the average, with trip production ranging below one trip per person in some instances. Upper income families may produce nearly twice as many trips.

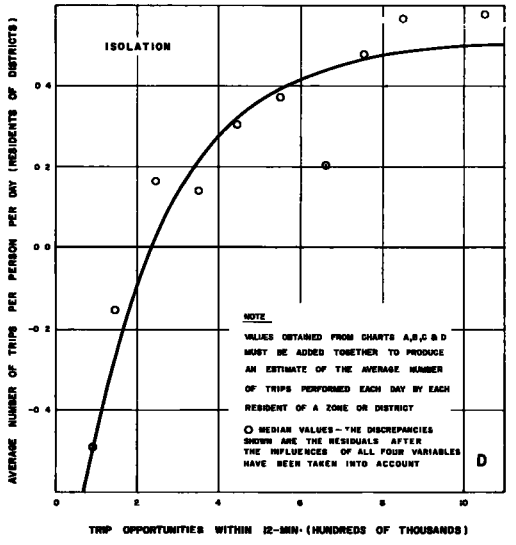

Figure 16. Trips by residents of metropolitan area.

Car Ownership. The number of cars that people own is also an indication of trip generation. In both 1948 and 1955 persons living in the districts of high car ownership produced trips at high average rates per person, and the opposite was true in districts where car ownership was low. In 1948, income level was also reflected to some extent by car ownership, but by 1955 the number of cars owned in the three highest income groups was virtually the same and ownership did not seem

[6] After adjustment for "interrupted" trips with origins or destinations at "change-of-mode" and "serve passenger" purposes.

to be an adequate measure of relative wealth (Fig. 18).

Car ownership and income level have been introduced jointly into a formula for estimating the over-all production of trips by the resident population of a district. Car ownership as used here (Fig. 13) is much less significant than level of income (Fig. 14) because, as the range of car ownership narrows, the effect of ownership tends to become constant. Between 1948 and 1955 car ownership increased rapidly in the low income districts, as shown in Figure 18. In future years the range of car ownership is expected to decrease still more.

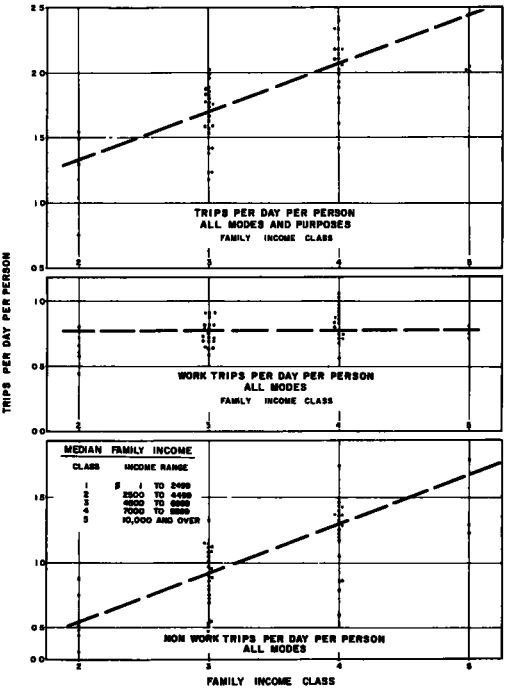

Figure 17. Trips by residents, 1955.

Decentralization. The number of trips produced by district residents tends to increase with distance outward from the center of the city. This comes about, in part, because population densities decrease with distance from city center and there are fewer trip destinations within walking distance. The distance factor is also interrelated with income levels which are usually high in the newest areas of development at the city's edge. The decentralization factor is one of the most important of the variables studied in measuring the rate of trip production in each district (Fig. 17).

Isolation. The fourth variable is significant only in the outer suburban areas. There

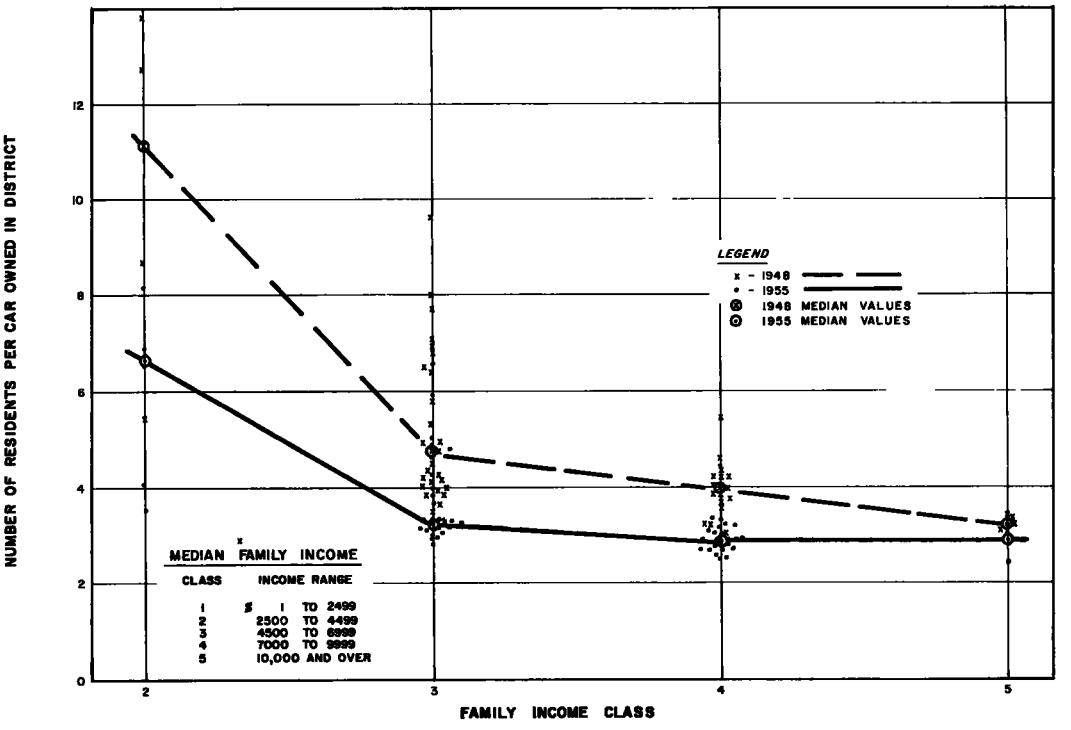

Figure 18. Car ownership related to family income, 1948 & 1955.

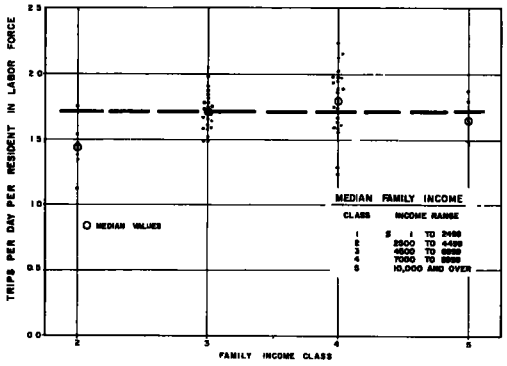

Figure 19. Work trips by labor force vs family income, 1955.

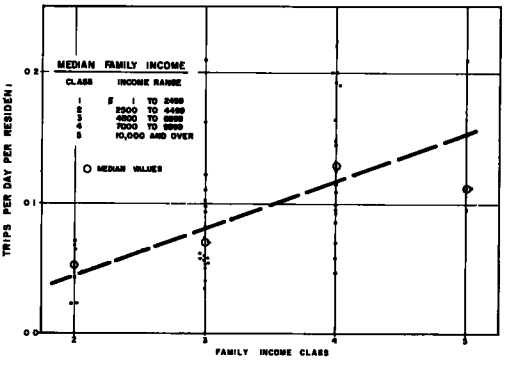

Figure 20. Miscellaneous trips (work-commercial) by residents, 1955.

the intensity of land use becomes very low. The average distance between residences and other trip generators is much greater than in more densely settled areas. Since a large proportion of the trips that people make are only a mile or two in length, the limited number of trip attractions at short range has an inhibiting effect on the number of trips produced. The isolation factor, as shown in Figure 16, has a negative effect on trip production in the outer districts. As such, it also corrects for over-statements of trip production which result from application of the decentralization curve to outlying districts.

In the analysis of 1948 and 1955 data the isolation effect was measured in terms of "trip attractions" within 12 min driving time of each district. The "attraction unit" in each case was one trip-end at the "purpose" which created the trip. These were the work, commercial, and social trips at the non-home end. A 12-min time interval was selected because it encompassed a wide range of trip attractions when centered on different districts. When applied to peripheral districts, fewer than 10 percent of all trip attractions in the study area may be within 12 min driving time. When applied to a district in Sector Zero, more than 70 percent of all trip attractions may be within that distance. The effect of isolation disappeared when approximately one million trip attractions were located within 12 min of of residential district.

The variables just described relate to the total volume of trips produced by the residents of any district. These include trips made to all internal points of interest, including the miscellaneous trips which neither begin nor end at the place of residence. They also include external trips by residents—trips which begin or end at the home, but have their other terminals beyond the external cordon.

Purpose of Trip

The origin-destination surveys found that work trips were the largest purpose category in most districts except those which contained the upper income families. In high-income areas both social and commercial categories sometimes exceeded work trips in number. Estimating formulae for each of the principal purposes were developed as follows:

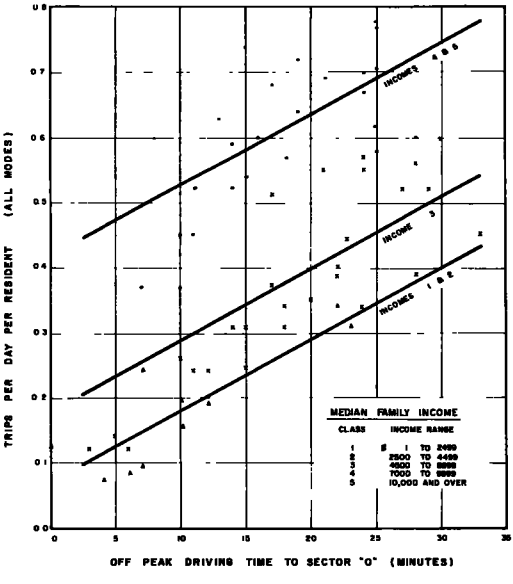

Figure 21. Work trips by labor force vs. family income, 1955.

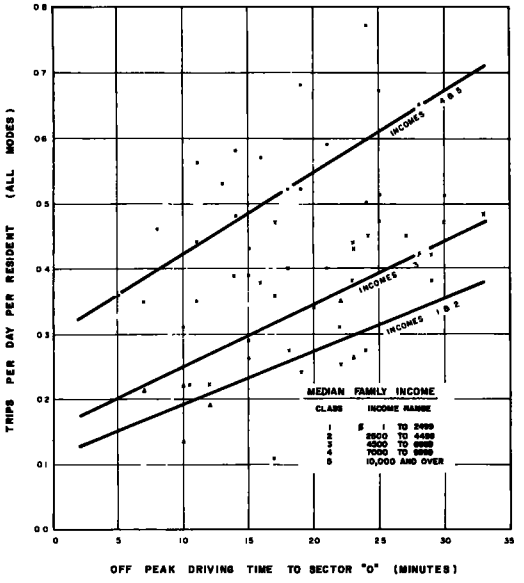

Figure 22. Social trips by residents, 1955.

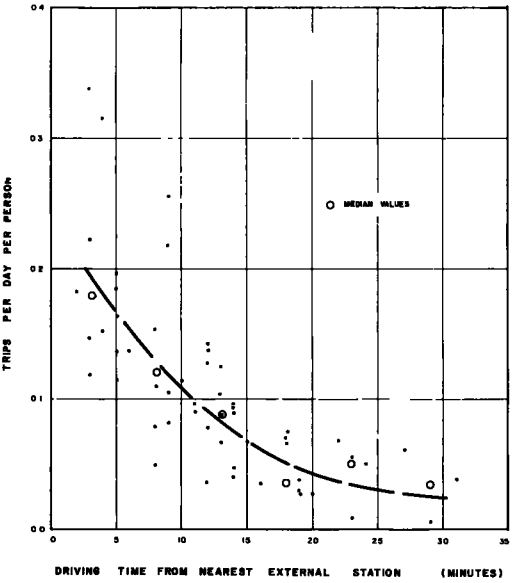

Figure 23. External trips by residents, 1955.

Work Trips. Work trips were first summarized by district of residence. Trips were then related to the labor force residing in each district since that was the population most consistent with work trip purpose. It was necessary to distinguish between labor force and total population because the proportion of residents who were in the working population varied from district to district.

The number of work trips made by each worker in different districts ranged for the most part between 1.5 and 2.0 trips per day, averaging 1.7 to 1.8 trips per day in the three highest income groups. Only in the lowest income families was trip production found to be substantially below this range. Their average rate was about 1.45 trips per worker per day (Fig. 19).

Work trips were also explored for correlation with other variables, but the range of average trip production was not great and deviations did not relate well to any of the other conditions studied.

Commercial Trips. Commercial trips were a relatively small proportion of travel in centrally located districts, especially among the lower income families. They became an important segment of travel in districts farther out. Many commercial trips were purely local in nature—errands to purchase convenience goods, cash a check or post mail—purposes which could often be accomplished on foot in the densely settled areas, but which were less likely to be within walking distance in more remote areas. Thus, decentralization was found to be an important element in the description of commercial trips.

Income level was also very significant. The number of commercial trips increased markedly in the upper incomes. A good correlation was achieved relating commercial trips to income and decentralization (Fig. 21).

Social Trips. Correlations with economic level and decentralization were also found for social trips (Fig. 22). Social trips were a less predictable component of all travel than the commercial trips, partly due to inclusion of trips to and from school in the social category. School trips were an important portion of all social trips in some districts; they amounted to very few in others.

Miscellaneous Trips. Some of the trips which had neither origin nor destination at home were labeled "miscellaneous" travel. As defined for this study, these were work-commercial trips which began or ended at work and/or commercial terminals. Trips without a home end which began or ended at social purposes were considered to

be home-based because most social trips were completed within residential areas.

Miscellaneous trips were relatively few in number. For this reason it was not surprising to find that they did not correlate well with income level, car ownership, or decentralization. In general, low-income families accounted for the fewest miscellaneous trips and high-income families produced the most, as shown in Figure 20. Miscellaneous trips were produced at low rates if car ownership was very low, but rate of trip production in high-ownership districts spread over the entire range so that this variable was found to lack significance. Driving time from Sector Zero appeared to have no significance other than that which might be attributable to level of income.

Miscellaneous trip production ranged from about one-fifth trip per person per day in districts of highest production to less than one-twentieth trip per person per day in districts of low trip generation. The total number of trips produced in most districts was not large and the apparent rate of trip production was doubtless influenced by sample variability.

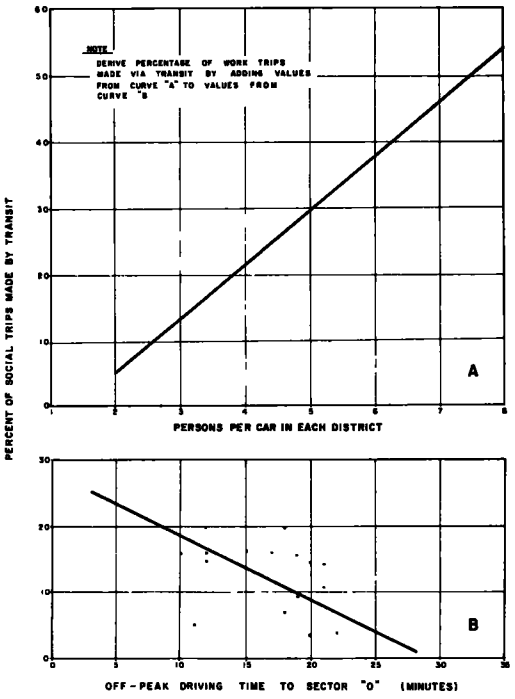

Figure 24. Internal social transit trips as percent of all social trips by District of Columbia residents, 1955.

External Trips. External trips were reported with all other travel in the home interviews. In districts adjacent to the cordon, located on high volume highways, 10 percent or more of the trips by residents were made to and from areas outside the cordon. The proportion of external trips to all trips made by residents decreased steadily as distance from the cordon increased. Persons living in or near Sector Zero made very few trips outside the study area.

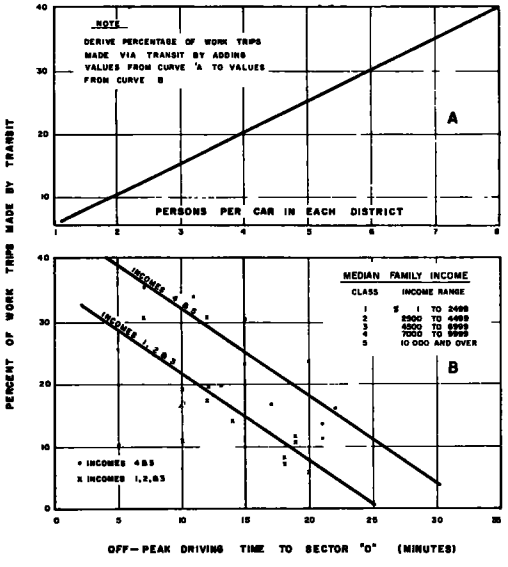

Figure 25. Internal transit trips for work as percent of all work trips by District of Columbia residents, 1955.

Figure 23 illustrates the significance of external travel in peripheral districts. The average number of external trips per person per day was plotted against travel time from district centroid to the nearest important cordon station. A free-hand curve illustrates the average effect of travel time to cordon. Variations from the curve were largely due to variations in population densities in nearby areas beyond the cordon and to sampling variability in the selection of homes interviewed.

Mode of Travel

The number of trips produced in households was influenced to some degree by the form of transportation that was readily available. The fact that the majority of families in most districts owned one or more cars was significant indication of the

flexibility with which residents were able to move about the city and accounted for the high and relatively uniform rate of trip production by families throughout much of the study area. Towards the center of the city transit facilities provide an efficient mode of travel which was used most extensively by lower income families who live in the areas best served by transit and who own relatively few cars.

Transit Riders. The proportion of travel generated by transit was found to be related directly to the quality of transit service (frequency of service, directness of route) and inversely to the level of car ownership and family income. Because the principal transit lines radiate from Sector Zero, transit provided its best service to the Central Business District and immediately adjacent areas. Public transportation in the National Capital Region, in its existing form, was most attractive for relatively short trips (less than half-hour duration) which terminated in Sector Zero. For longer trips, or circumferential trips served indirectly by transit, travel time was so much longer on transit than by car that transit got little use.

Political boundaries also distorted transit use in the Region. Within the District of Columbia the D. C. Transit System provided comprehensive coverage and frequent service. This service extended across the Potomac River into Virginia only to Rosslyn Circle via the Key Bridge. Interstate service between the District of Columbia and Maryland was provided mostly by D. C. Transit, supplemented by Montgomery Bus Lines and the WMA Transit Co. Transit service within Virginia and between Virginia and the District of Columbia was performed by the AB & W Transit Co. and WV & M Coach Co.

Due to the discontinuous pattern of transit service across the District of Columbia boundary, there was a sharp drop in transit use at the District line. Analysis of the trips performed by residents of each district, as reported in the 1955 origin-destination survey, found that the proportion of transit travel for each of the major purposes was related to the number of cars that people owned, their average level of income, and the distance between the district in which they lived and the center of Sector Zero (decentralization). Figures 24 to 28 illustrate these relationships. [7]

Transit riding accounted for a much larger proportion of the travel by persons living within the District of Columbia than by those living outside (Table 11). The interruption of transit service at the District line had much to do with this, of course, but decentralization may have been even more important. Suburban populations owned automobiles to near-saturation levels in many parts of the community and this seriously curtailed use of public transportation.

As shown in Table 11, nearly 80 percent of all transit work trips were made by residents of the District of Columbia. More than 80 percent of all transit commercial trips were made by District of Columbia families, and over half of the social trips. Social trips, as reported in this analysis , were mostly student trips to and from school.

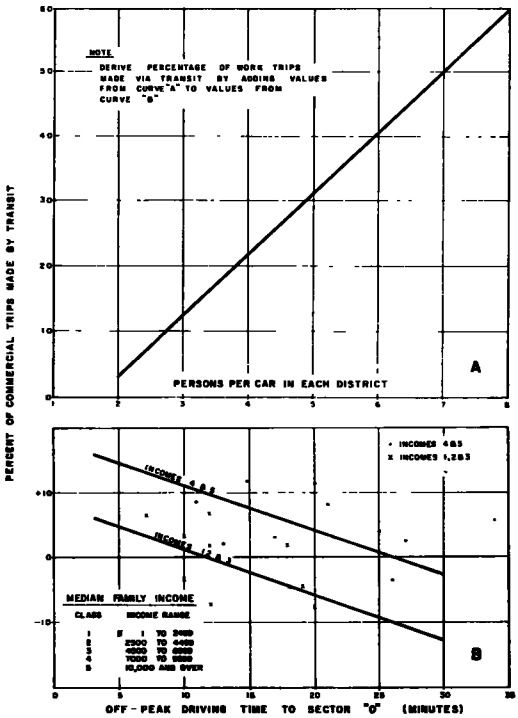

Figure 26. Internal commercial transit trips as percent of all commercial trips by District of Columbia residents, 1955.

[7]The plot of points on the "B" portions of these charts represent data after they have been adjusted for the relationships shown on part "A". Deviations from the curves in part "B" are residuals from the combined effects of curves "A" and "B."

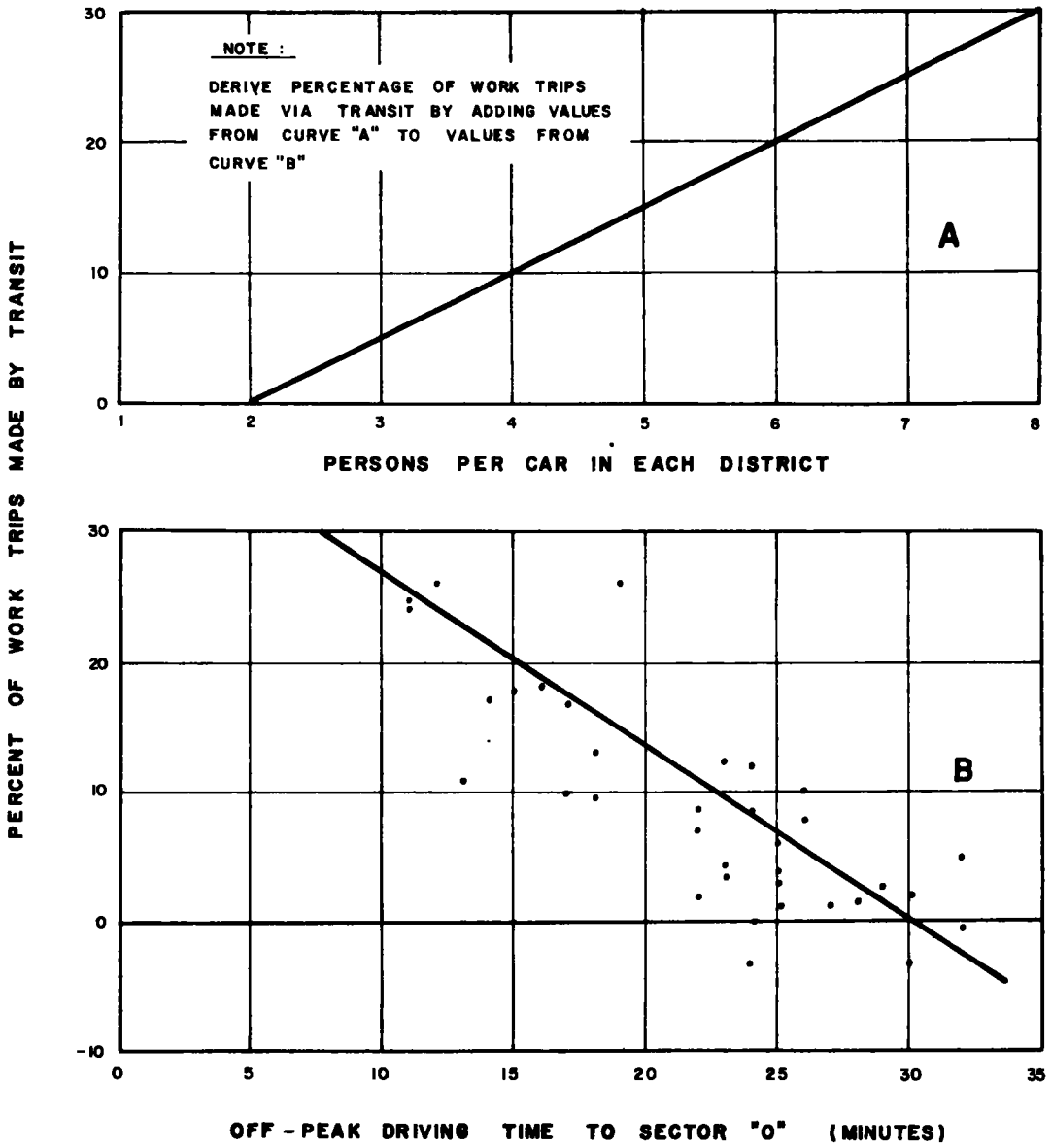

Figure 27. Internal transit trips for work as percent of all work trips by Maryland and Virginia residents, 1955.

Two sets of curves were prepared to show how transit level related to the condition of car ownership, income level and decentralization mentioned above. One set, Figures 24 to 26, pertain to travel by persons who lived within the District of Columbia. Graphic correlation methods were used to find the combined significance of these variables.

The average proportion of transit work trips made by residents of a district can be found from Figure 25 by combining the percentage values obtained from two curves. Car ownership was very significant within the District of Columbia. Several low-income districts reported very low car ownership, while upper-income families all reported high ownership. Two income levels have been recognized in preparing the figure.

Transit trips for commercial purposes (Fig. 26) developed similar relationships

TABLE 11

TRANSIT TRIPS BY PLACE OF RESIDENCE AND PRINCIPAL PURPOSE, 1955

Area		Work Trips			Commercial Trips			Social Trips		
		All Modes	Transit Trips No.	Transit Trips %	All Modes	Transit Trips No.	Transit Trips %	All Modes	Transit Trips No.	Transit Trips %
District of Columbia	No. of trips	598,237	272,541	45.5	248,735	80,051	31.2	234,832	85,688	36.5
	% of total	54.5	79.3		38.8	83.8		41.3	54.3	
Maryland and Virginia	No. of trips	497,520	71,140	14.3	393,027	15,465	3.9	333,701	72,177	21.4
	% of total	45.5	20.7		61.2	16.2		58.7	45.7	
Survey Area	Total trips	1,095,757	343,681	31.4	641,762	95,516	14.9	568,533	157,865	27.8

in which car ownership was even more significant. Transit social trips were also influenced by cars owned, but family income did not appear to be a factor, possibly because most were school trips(Fig. 24).

Curves were also prepared to show proportions of transit riding by residents of the National Capital Region living in Maryland and Virginia (Figs. 27 and 28). Work trips by transit were again related to car ownership and decentralization. Car ownership was found to be at uniformly high levels throughout much of the suburban community so that most of the signficance of Figure 27 attaches to the decentralization curve. Income level was of little significance since the lowest incomes were found within the District of Columbia.

Commercial trips by transit were, again, related most importantly to decretralization (Fig. 28). Income levels were also significant, with few upper income families using transit for commercial travel.

Social trips on transit did not correlate with any of these variables, doubtless because nearly all were school trips which followed no over-all pattern.

Auto Occupancy. Most of the travel performed in the Washington study area in 1955 consisted of trips in private automobiles. About 70 percent of the work and social trips and 85 percent of all commercial trips were made by automobile drivers and passengers.

Analysis of automobile travel for each of the principal purposes found the average number of persons riding in cars to be related to the level of car ownership (work trips) or related jointly to car ownership and decentralization (commercial and social trips).

Figure 29 illustrates the way car ownership affected the occupancy of autos driven to and from work. High-ownership areas (2.5 to 3.0 persons per car) averaged about 1.35 passengers per car, including drivers. Average occupancy rates were higher in cars from districts of low car ownership.

Figure 30 shows that average occupancy of commercial trips was affected by both ownership and decentralization. Commercial auto trips generated in suburban districts carried more persons, on the average, than did trips made by persons living closer to the center of town. The B curve for commercial trip occupancies was fitted to average rates in all districts in each successive increment of travel time from Sector Zero.

Figure 31, for social trips, shows decentralization to be a major factor in group riding. The B curve was fitted to average occupancies in successive increments of travel time from Sector Zero.

Miscellaneous auto trips maintained average occupancies of about 1.25 persons per vehicle. These trips neither began nor ended at home and average occupancy appeared to bear no relation to the places of residence of persons making the trips.

Peak Hour Travel

Washington, like most cities, experienced a few hours of heavy traffic demand each day. During other daylight hours, most streets outside Sector Zero were used by a moderate number of vehicles. During many of the night hours all streets were virtually empty.

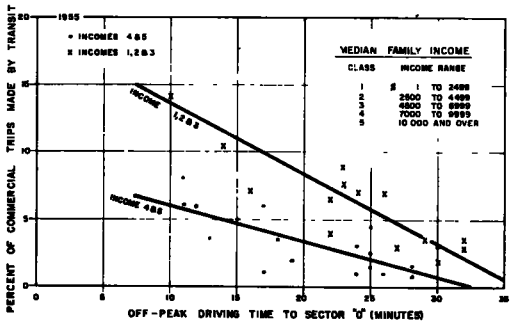

Figure 28. Internal commercial transit trips as percent of all commercial trips by Maryland and Virginia residents.

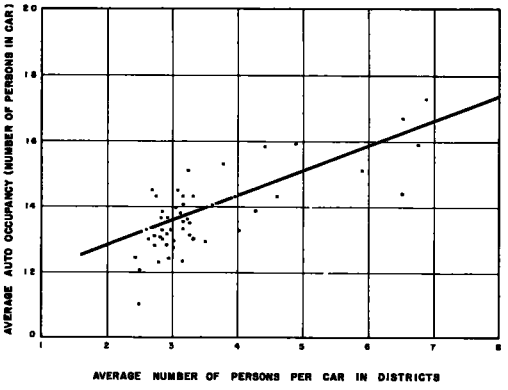

Figure 29. Average occupancy of automobile trips for work, 1955.

These familiar patterns repeated each weekday throughout the year. Figures 3 and 4 illustrate the magnitude of hourly variations for trips performed by auto drivers. Figures 5 to 8 show how hourly demands fluctuate by trip purpose and mode.

These drawings show that traffic demands were very heavy during the two hours 7:00 to 9:00 in the morning and again at the hours 4:00 to 6:00 in the afternoon. Trip demand for morning hours was based on time of arrival at trip destinations and defines the hours of heavy demand in Sector Zero and other principal places of employment. Trip demand during evening hours was compiled on time of departure from trip origin in order to again define hours of heavy demand at principal traffic generators.

Heaviest auto travel occurred during the afternoon peak. The purpose-of-trip drawings show that the morning peak was composed almost entirely of work trips. The number of work trips was somewhat less at the afternoon peak but many commercial, social, and miscellaneous trips occurred at those hours, which increased traffic demand on the streets over that in the morning.

Transit use reached its maximum in the morning. Heavy transit travel appeared to be spread over four hours in the afternoon. The reason for this is shown in Figure 7 which indicates that social trips (travel to and from school) coincided with work trips

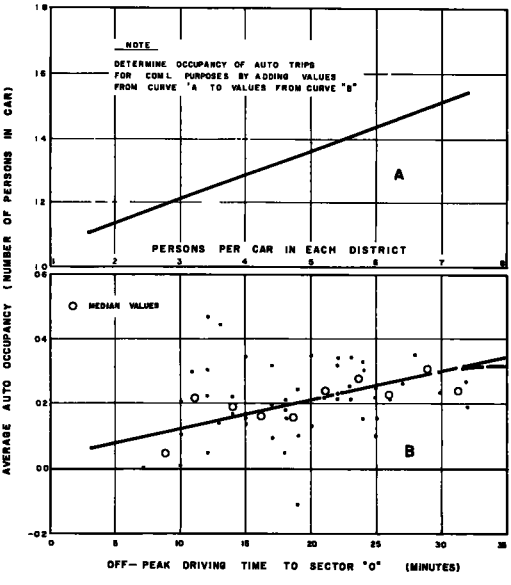

Figure 30. Average occupancy of automobile trips for commercial purposes, 1955.

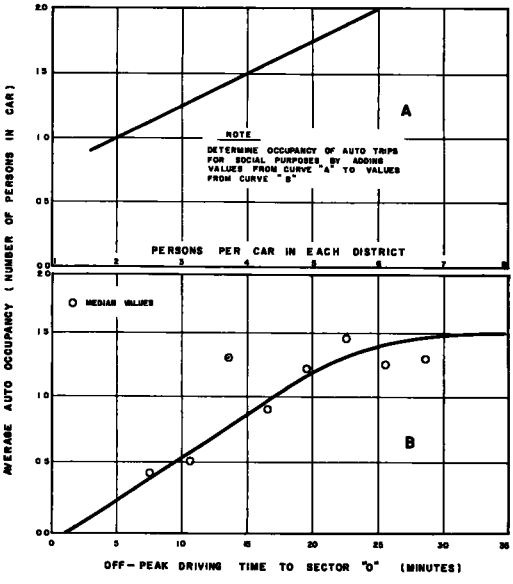

Figure 31. Average occupancy of automobile trips for social purposes, 1955.

in the morning but reached an afternoon peak at an earlier hour. Transit work trips, like auto driver work trips, were more heavily concentrated in the morning than in the afternoon.

Table 12 shows the composition of trips by mode and purpose during the 4 hr of heaviest demand. Nearly 40 percent of auto trips and almost half of all transit trips were performed during peak hours. About two-thirds of all work trips were accounted for during these hours, which confirms the general belief that peak-hour traffic problems are created by travel between home and work.

The single hour of heaviest traffic demand, as shown in Table 12, occurred between 8:00 and 9:00 a. m. However, many school trips were made at this hour (social trips by auto passengers and transit riders). Most of these trips were short, local movements which did not seriously congest the radial flow of traffic. The evening hour, 5:00 to 6:00 p. m. contained very few social trips and therefore was most representative of peak traffic. About 28 percent of all trips during the 4 hr of heaviest travel were made during the evening hour 5:00 to 6:00. Discounting school trips, the afternoon peak represented 30 percent or more of non-school travel during the hours of heavy street use, or about 12.5 percent of 24-hr average daily travel.

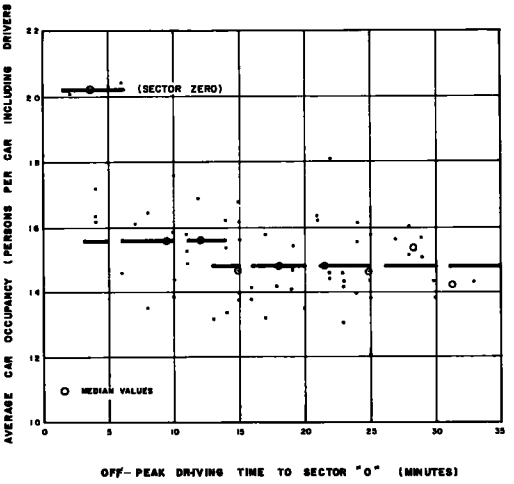

Figure 32. Average car occupancy—commercial trips to and from retail centers.

Correlation Studies—Person Trips at Non-Residence End

The trips made by residents of each district usually terminated at work, or at places of commercial or social purposes. Some trips ended within the district where they were generated, but most of them ended in some other part of the community. The number of trips by residents for work was the same as the number of trips generated at places of employment. Home-based commercial trips all had one end at a place of business or trade. Trips at social termini were, of course, equal to the number of social trips made by residents.

Studies were made to find relationships which reflect the trip-generating potential of employment and retail trade. Work trips to employment in any district came from all over the metropolitan area and were made by all modes of travel. As a result, the rate of trip production in each district tended to represent the average condition. The number of auto and transit trips that the jobs in an area produced was related to the type of work, the working hours, proximity to dwelling places from which workers could walk, and similar conditions. The trip data, as tabulated, did not supply information of this kind. The estimates of employment in each district were not derived from the survey, but were arrived at independently[8] and were subject to estimating errors other than those that affected sample selection and sample size and which influenced the trip reports.

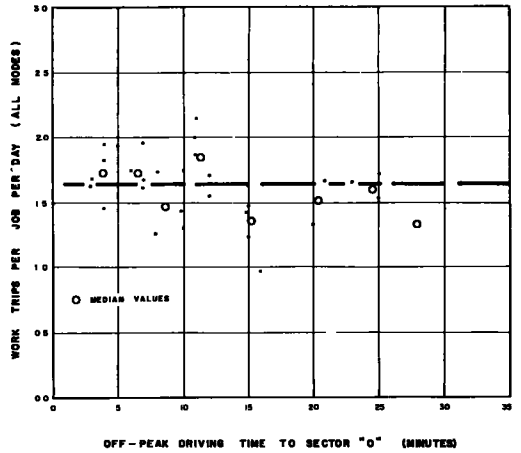

Figure 33. Work trips generated by employment.

[8]Prepared by National Capital Planning Commission from census data and other sources.

TABLE 12

PERCENTAGE OF 24-HR TRAFFIC AT PEAK HOURS, 1955
by Purpose and Mode

Mode and Purpose	Percent of All Trips a. m. 7-8	a. m. 8-9	p. m. 4-5	p. m. 5-6	Total
Auto drivers					
Work	15.08	17.65	14.63	15.09	62.45
Commercial	3.89	2.57	7.11	9.46	23.03
Social	1.04	3.52	4.00	4.03	12.59
Miscellaneous	-	0.48	2.65	-	3.13
Total	8.42	9.48	9.91	10.86	38.67
Auto passengers					
Work	17.98	22.71	17.11	20.56	78.36
Commercial	1.65	1.42	7.30	7.91	18.28
Social	1.52	14.02	3.71	4.71	24.99
Miscellaneous	-	-	-	11.68	11.68
Total	7.18	12.99	9.38	11.37	40.87
Transit riders					
Work	12.99	21.81	14.89	17.56	67.25
Commercial	1.08	2.21	9.31	7.10	19.70
Social	1.90	28.63	3.85	2.22	36.60
Miscellaneous	-	-	-	15.79	15.79
Total	7.51	18.72	10.27	12.16	48.66
Grand Total	9.23	12.69	9.87	11.37	41.16

Note: Trips to home have been tabulated on time of departure from origin. All others have been tabulated on time of arrival at destination. The hourly accumulations thus reflect the concentration of trips at places of work, business, and retailing and indicate travel in Sector Zero at the hours of congestion. The peculiar distribution of miscellaneous trips by mode is due to sample variance.

Figure 33 shows the effect of decentralization on the average number of trips produced by jobs in each district where employment exeeded 8,000 persons. There was a wide range in rate of trip production, some of which may be attributed to decentralization. The average number of trips per job in the metropolitan area was about 1.65 trips per day. Districts in Sector Zero, or adjacent to it, produced slightly higher average rates of travel than did outlying districts. Further analysis did not produce better estimates of trips per job than did the average value shown.

A similar study was made of trips generated in commercial areas. Trip data from districts which contained more than 1 percent of the Metropolitan Area's retail trade in 1955 were plotted in Figure 33. An average rate of trip production of about 6,000 trips per day per one percent retail sales was found for all districts. Near the center of the city the trip rate averaged a little less than this. Decentralization beyond 15 min driving time appeared to affect trip generation, indicating larger number of trips per dollar of

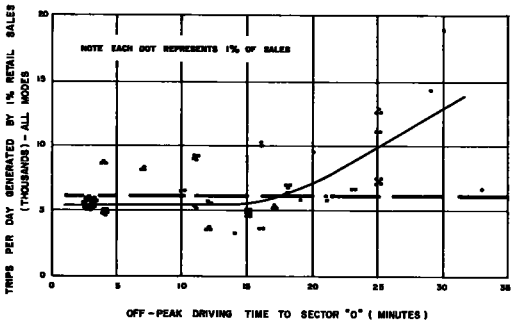

Figure 34. Commercial trips generated by retail centers; trips per 1 percent metropolitan area retail sales in districts which generate 1 percent or more of total metropolitan area sales.

sales. Family shopping in drive-in suburban centers may have been responsible for this. Sector Zero trip patterns were heavily influenced by a large number of "business" trips which added to the rate of trip generation per dollar of retail sales.

The generation of social trips was studied and the conclusion reached that most of them were related proportionately to the populations in each district. The total number of social trips can be estimated at the residential end. The same number of non-home social trip ends may then be assumed for each district, reduced by whatever number can be attributed to specific non-residential recreational trip generators. Thus the National Zoological Gardens, large parks and recreation areas, and commercial centers attract some of the social travel. Estimates of this travel would be based on evaluation of the origin-destination data.

The volume of miscellaneous trips generated throughout the Metropolitan Area was related to the persons who live in each district, as described earlier. Those trips were found to bear consistent relationships to the combined work and commercial generators in each district. Approximately half were made to and from place of employment. The other half were generated by commercial use in the districts in proportion to the percentage of the Region's trade which was transacted in each.

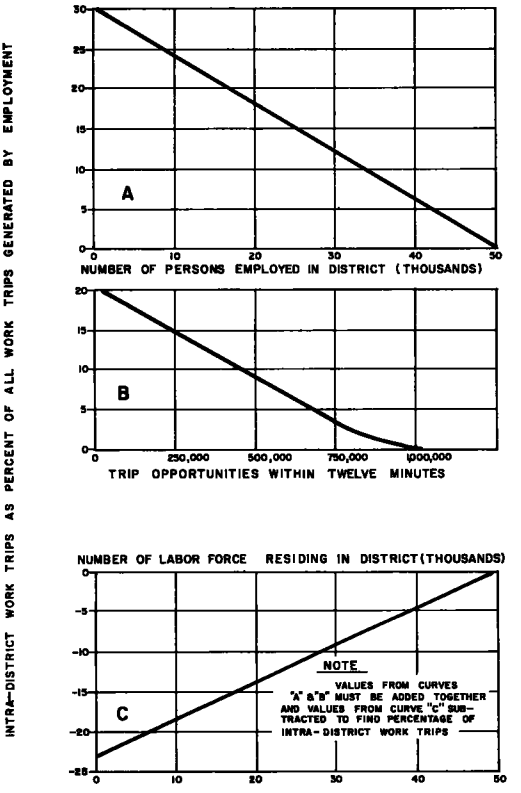

Figure 35. Intra-district work trips, all modes.

Mode of Travel. The relative use of automobile and transit by purpose of trip has been developed in the analysis of trips generated by the residents of each district. The total number of transit trips can thus be established and the home ends identified. An equal number of non-home trip-ends must be accounted for.

No correlations were developed to explain the relative use of transit and automobiles for trips generated by work or commercial terminals. In general, the highest proportions of trips by transit were made to and from Sector Zero, the rate decreasing with decentralization. In a projection of trips to future years it would probably be desirable to assume the same ratio of transit travel to auto travel as found in 1955 data.

Auto occupancies at non-home terminals, like average trip rates, tend to average out because the trips are generated from every social stratum in the community. This "leveling" is not complete, of course, because nearby areas generate travel at higher rates than remote areas. Auto occupancies would be biased somewhat towards the occupancy rates of residential trips generated in the immediate area.

Auto occupancy of commercial trips is shown in Figure 32. Auto trips generated in the downtown retail districts were found to have an average car occupancy of more than 2.0 persons per day. Auto trips generated by commercial terminals within about 12 min of Sector Zero (most districts within the 10-mile square) had an average occupancy of about 1.55 persons per car. Outside this range, the average occupancy was less than 1.5. Commercial trips were relatively short and reflected local economy to a considerable extent. Economic levels within the District of Columbia were lower, on the average, than in Maryland and Virginia, which induced higher car occupancies. Another factor may have been the difficulty of parking in older areas or, conversely,

the ease of parking in drive-in shopping centers in new suburbs.

Work trips are of longer average length than commercial trips and there is no consistent pattern in auto occupancies at employment centers throughout the metropolitan area except in Sector Zero and the Pentagon (District 71). Car occupancy in these areas was higher than average for two reasons. Both Sector Zero and the Pentagon were concentrated centers of employment which helped to make group riding convenient. In Sector Zero there was a parking space deficiency which did not exist in most other areas, and this, too, encouraged group riding. Also, in some instances, federal employees were required to double-up in order to acquire parking permits.

In Sector Zero, average work trip occupancy was found to be about 1.68 persons per car. Throughout the rest of the metropolitan area average work trip occupancy was about 1.27 persons per car, including drivers.

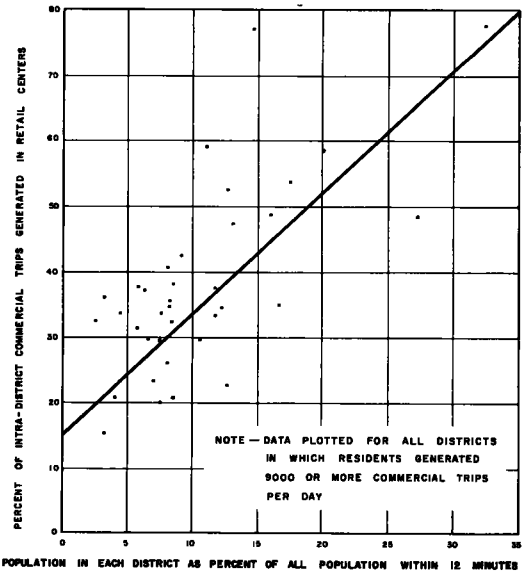

Figure 36. Intra-district commercial trips to and from retail centers, all modes.

Social trips did not develop a consistent occupancy pattern, except that average occupancy was much higher than for other purposes. Sector Zero trips averaged 3.6 persons per car. Throughout the remainder of the study area, over-all occupancy was 3.2 persons per car. Miscellaneous trips averaged about 1.25 persons per car.

Trip Distribution Between Districts

The foregoing examination of the home-interview surveys has shown that the number of trips that urban residents make in cars and public transit correlates quite well with their economic condition, auto ownership, and the relative density of land occupancy (decentralization and isolation). The studies produce a static measure of a dynamic quantity, however. In order to make use of the information on trip generation, it is necessary to discover the rules which govern the distribution of trips between districts.

The home-interview origin-destination surveys have been developed during the past 15 yr as a source of reliable urban traffic information. During that time many U. S. cities have been surveyed, and several methods of trip analysis have been developed for use in forecasting travel patterns based on travel statistics from the origin-destination surveys. Most of these are analogy methods which employ growth factors to increase or decrease the estimate of trips produced in each subdivision of the study area. The growth factors are applied uniformly to all trips emanating from each area. An averaging process (successive approximations) is usually employed to reconcile the differences in traffic estimated to move between pairs of areas to which different growth factors have been applied. There are certain qualities inherent to analogy techniques which limit their usefulness:

1. Large growth factors applied to areas of small trip generation create difficulties because the original trip reports may contain no record of travel for many possible movements. Either an artificial value must be created or these blanks must remain in the projected data. The same is true of over-reported movements which will be more greatly exaggerated by application of growth factors.
2. The relative standards of traffic operation which existed at the time the origin-destination study was made are projected into the future without change. This may con-

stitute a serious deficiency because the construction of a new express highway or the avoidance of a natural barrier by means of a new bridge or tunnel can produce radical changes in the time required to travel between different parts of an urban area.

3. Growth factors work best when applied to a system of zones or tracts identical with those upon which the origin-destination survey was based. The introduction of boundary changes or extension of the area of coverage may vastly complicate the method.

More recently, methods have been developed in an attempt to overcome these problems. By relating the generation of trips to the population which produces them, a formula can be devised with which to synthesize the trips that will be made in each part of a city and the patterns of their distribution.

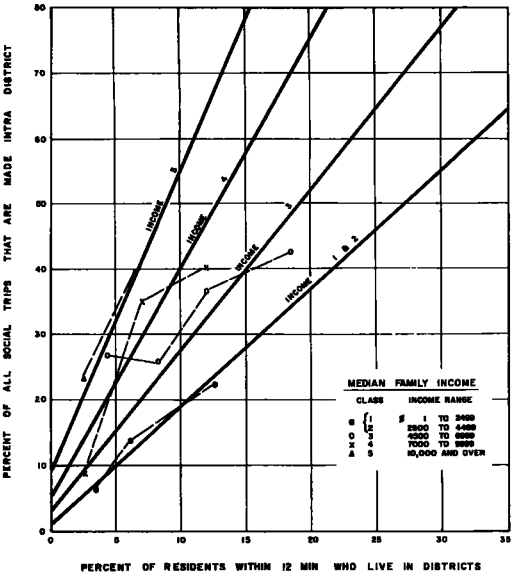

Figure 37. Intra-district social trips: district of social terminus, all modes of travel.

Methods derived for the synthetic distribution of trips between the subdivisions of a study area are sometimes called "gravity" formulae because of superficial similarity to the law of gravitational attraction, which states that the attraction of one physical body (mass) to another is directly proportional to the size of the bodies and inversely proportional to the distance between them ($\frac{m^1 \times m^2}{D^2}$). In the studies reported here the number of trips between pairs of districts was found to relate directly to the populations which produced trips and inversely to the distance (driving time) between districts, but other variables were also found to affect trip rates such as mode of travel and purpose of trip. Travel between districts relates to interaction among a variety of factors and the statements which have been derived to describe these relationships may be called "interactance formulae."

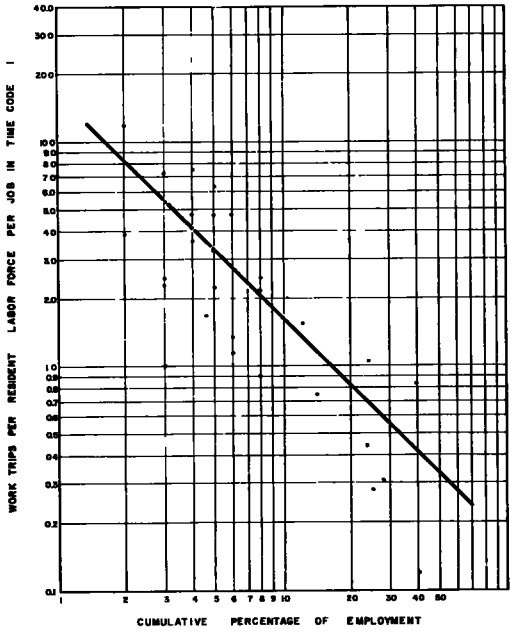

Figure 38. Auto driver and passenger work to and from home, time code 1.

The interactance formulae can be represented graphically in the form of decay curves which predict diminishing rates of travel between areas as trip length (travel time) increases. Two independent estimates of travel are developed for movements between each pair of districts in the study area. These are then averaged by the technique of successive approximations used in the analogy methods described earlier.

The principal advantage of this synthetic technique is its ability to minimize sampling errors and statistical variations. The origin-destination surveys reported no travel at all between many pairs of districts in the study area. Actually, trips

were probably made between many pairs, but the persons interviewed in the studies were only a sample of the metropolitan population and they did not perform all of the movements. The interactance formulae will predict small numbers of trips, and will tend to reduce over-reported travel to more realistic levels.

The reduction of statistical variations is especially important in districts which are expected to experience large growth. Reasonable volumes of travel will be projected between districts for which no trips were reported by small populations in the area when the origin-destinations survey was made.

The interactance formulae may be applied with equal reliability to the system of zones and districts upon which the origin-destination survey was based, or to any other definition of areas. Survey boundaries may also be extended or contracted, provided population statistics are prepared to represent the new definitions of the study area.

The formulae for synthesizing inter-district travel patterns are especially sensitive to time-distance relationships. The effects of highway and transit improvements in

TABLE 13

INTRA-DISTRICT TRIPS BY MODE—1948 AND 1955

Mode of Travel	1948 All Trips	1948 Intra	1948 % Intra	1955 All Trips	1955 Intra	1955 % Intra
Auto drivers	636,150	119,065	18.7	1,222,703	286,998	23.5
Auto passengers	363,360	62,563	17.3	653,376	149,484	22.9
Transit	677,964	57,227	8.5	642,999	70,499	11.0
All trips	1,677,474	238,855	14.3	2,519,078	506,981	20.1

Note: Data compiled from detail tabulations of trips by mode. Totals shown do not necessarily conform to other published summaries.

changing and re-aligning present patterns of travel can thus be predicted. Care must be taken to develop inter-district travel times which are realistic and consistent with the operational characteristics of transport facilities.

The analyses made to develop the synthetic trip formulae are described below.

Intra-District Trips. The survey districts in the study area were quite large. Even within Sector Zero some districts contained more than a square mile of area, and the smallest was at least half that size. Outside Sector Zero, districts graduated upwards in size as intensity of land use decreased. Most districts within the 10-mile square were one to two miles in average diameter. Between the external cordon and the 10-mile square many districts were 5 to 8 square miles in extent, with some even larger.

Most of the trips made by city residents were short. Highest rates of travel were reported for trips about 2 miles in length. Longer trips accounted for decreasing proportions of all travel as trip length increased.

Because most trips were short, many of them began and ended within the same district. This was especially marked in large districts and in districts which contained many trip attractions. Intra-district travel accounted for 14.3 percent of all trips reported in the 1948 home-interview survey, and 20.1 percent of all trips reported in the 1955 study (Table 13).

The smallest proportions of intra-district trips were reported by transit riders (8.5 percent in 1948, 11.0 percent in 1955). Transit users were generally in the low income population and the immediate out-of-pocket cost was very likely a consideration in reducing the volume of short rides. On the other hand, autos were used extensively for short trips. In 1948, 18.7 percent of auto driver trips were made intra-district and in 1955 nearly a quarter of the reported auto travel (23.5 percent) was in this class.

Intra-district trips have a somewhat negative significance in the analysis of transit and highway needs. They represent local travel which cannot be expected to make use of high speed highways or rapid transit installations, except as intra-district move-

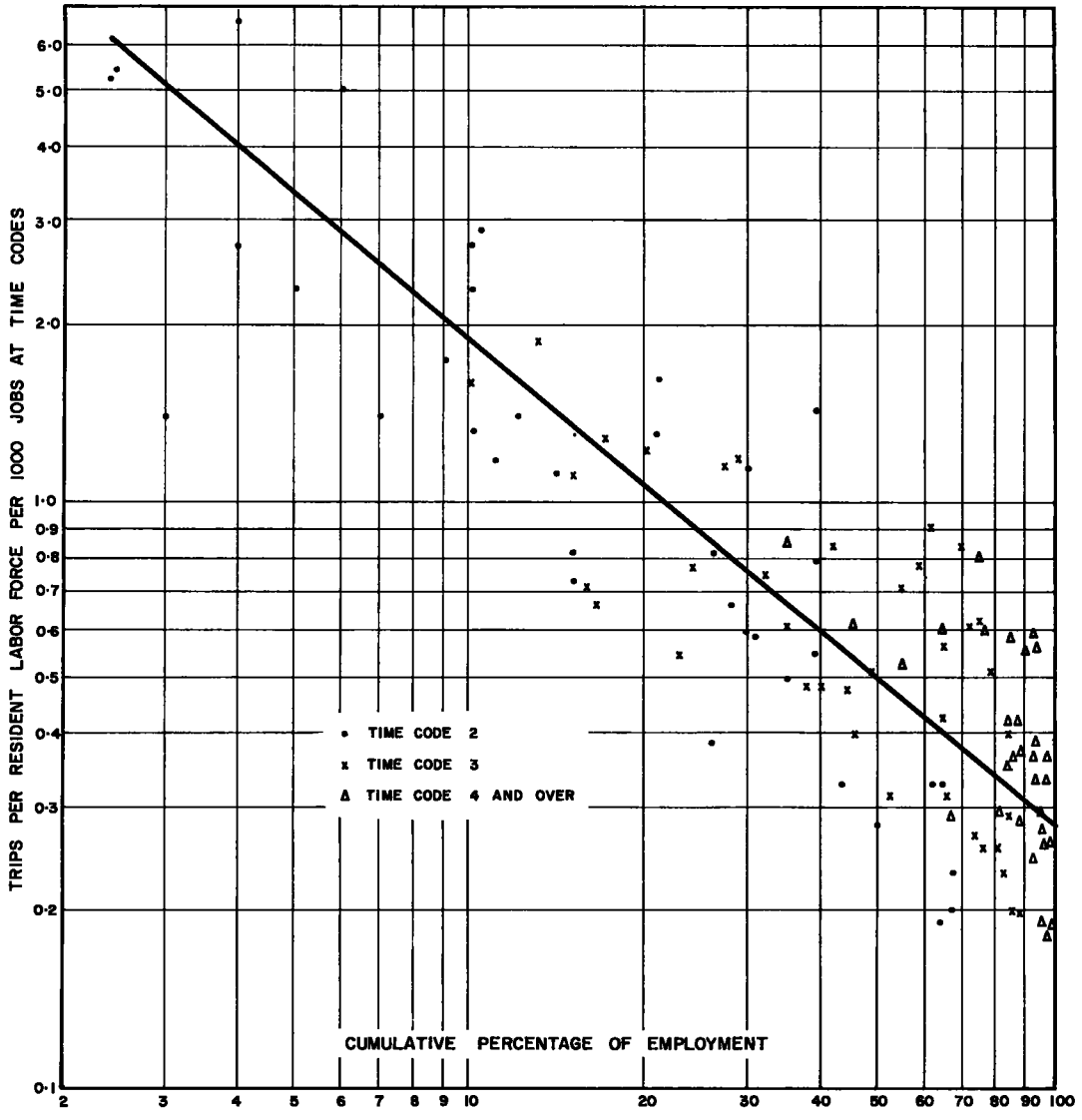

Figure 39. Auto driver and passenger work trips to and from home, time codes 2 and over.

ments might be re-oriented to longer inter-district travel and thereby be diverted to new facilities.

The proportion of intra-district trips was related to district size so that they could be predicted. In order to do this, the size of districts had to be expressed in terms that were consistent with the purposes for which trips were made. Most trips were home-based with either origin or destination at home. Most intra-district trips were home-based, then, and the measure of district size, by purpose, depended on the number of non-home trip generators within the district. Clearly, if there were neither employment nor commercial generators in a residential district, there was no home-based intra-district travel for those purposes.

Figures 35, 36, and 37 show how intra-district trips for work, commercial and social purposes related to the concentration of trip attractions within each district as percentages of all attractions within a reasonably short distance (12 min driving time).

Intra-district work trips were related to the amount of employment and labor force in the district itself and to trip opportunities within a 12-min range.

The correlation of commercial trips with population was much simpler. The curve in Figure 36 represents analysis of trips generated by commercial centers. The number of trips which remained intra-district was directly related to the percent of all populations within 12 min who resided in the district. The effective trading radius of most retail centers in the Washington area was found to be less than 12 min.

Social trips (Fig. 37) were found to relate to income level as well as population concentration. Some of the relationships shown may be accidental—low income areas were usually densely settled and much of the intra-district movement may have been made on foot.

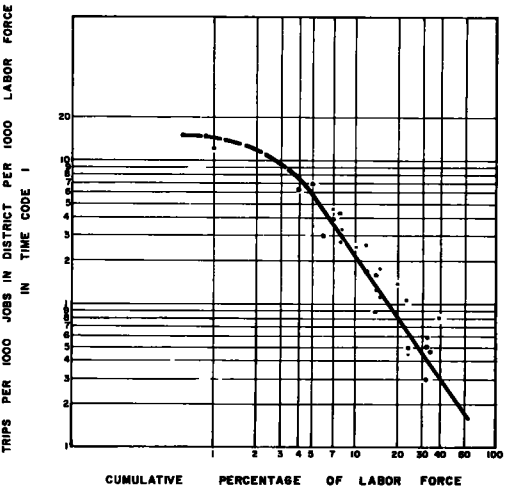

Figure 40. Auto drivers and passengers to and from work, time code 1.

The Interactance Formulae. Trips which terminated outside the districts of origin accounted for 80 percent of all travel in the National Capital Region in 1955. This was travel that used arterial streets and public transit and which would realize substantial time savings and other economic benefits if improved transportation facilities were made available. The distribution patterns of this travel were very significant. The shortest movements were the heaviest. Most trips in the city were no longer than they had to be to accomplish the purpose for which they were made. Work trips generated by residents of a district were of short average length if there were many work opportunities within short range. Trips averaged much longer in suburban communities which were some distance removed from principal sources of work. The same was true of trips in each of the other purpose categories.

A few years ago it was found that the volume of travel between cities and towns was roughly proportional to the size of each community and inversely related to the distance between communities. These relationships were consistent and predictable (6, 7, 8).

Trips made between parts of an urban area have also been found to interact in a similar way to distance and trip attraction. The best correlations can be obtained if trips are segregated by purpose and an interactance formula derived from the specific populations (labor force and employment, for instance) which account for the generation of each kind of trip.

Travel Time. Trip length is a critical measure in studies of the interactance effect. Within urban areas, trip length may be expressed in miles (either airline distance or by way of streets) or in terms of travel time. Mileage measurements are easily made by scaling from maps, but travel time provides a better expression of relative distance between areas because speed of travel varies a great deal on different kinds of roads and in different parts of a city.

Travel times by car and by transit were compiled for peak-hour and off-peak conditions throughout the National Capital Region and studies were made to find which of these measures was best suited for trip analysis. Correlations obtained using off-peak driving time were found to be better than those derived from the other measures. Even work trips, which are predominantly peak-hour movements, were described better by off-peak time measurements.

The Decay Curve. Trips between pairs of districts were expressed as "trip rates" to relate them to trip length. Units of population, labor force, or employment were divided into volumes of inter-district trips to develop average rates (trips per person, trips per labor force, trips per job). In the case of commercial trips, trip rate was stated in terms of trips per dollar of retail sales, or trips per 1 percent of metropolitan area sales.

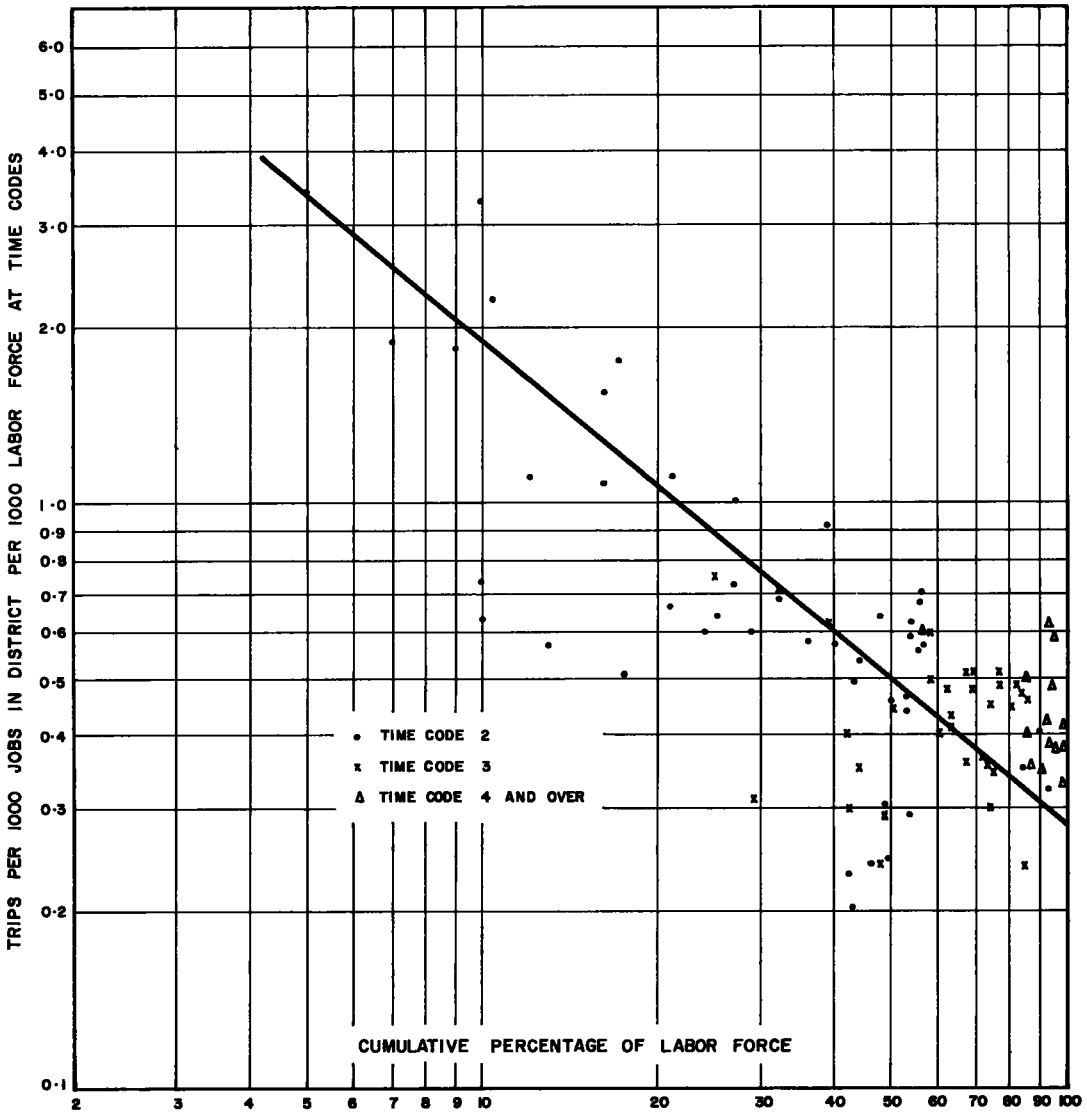

Figure 41. Auto drivers and passengers to and from work; time codes 2 and over.

In these analyses, correlations were developed graphically. In most cases free-hand curves were fitted to plotted data to express the correlations found. For instance, the rate of travel between districts at various distances (time codes) apart would be computed and the results plotted on graph paper. A cluster of points would be averaged and linked to other average values to indicate an average trend for the effect of distance. A straight line or smoothed curve would then be fitted to the trend line by eye.

When trip rates were plotted against distance, the interactance effect developed in the form of a decay curve. The shortest trips did not necessarily produce the highest value on the curve, however, because the origin-destination data did not represent all of the travel between districts. Many very short trips were made on foot and were not recorded in the study. The high point on the curve occurred where walking trips were no longer important (5 or 6 min driving time).

The distribution of trips generated in each district produced a decay curve unique

to that district when the values of all points were averaged. When plotted on log-log or semi-log paper a straight line could then be fitted to the plot of points, although considerable variation about such a line is to be expected because of unequal "competition" between district pairs. It is significant, though, that the curves for most districts, for particular classes of trips, exhibited almost the same average slope. The relative effects of distance were thus shown to be about the same.

The element of competition mentioned above imposes a special problem. Residents located close to their destinations produce a lower rate of travel to nearby areas than persons who are relatively isolated. For example, a thousand workers living within five minutes driving time of 100,000 jobs would nearly all find employment within five minutes distance. Yet if all were employed there, the rate of travel to sources of work within five minutes from the district would be one worker per 100 jobs. On the other hand, 1,000 workers living in the suburbs are relatively isolated. There may only be 10,000 jobs within five minutes driving time. If all 1,000 of these workers found employment at five minutes distance, the rate of travel would be one worker per 10 jobs—ten times the rate for the larger pool of employment.

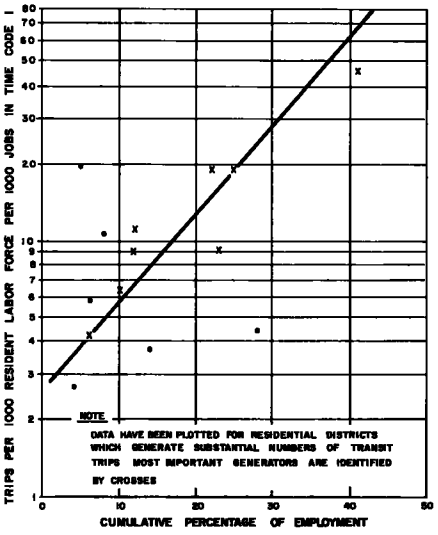

Figure 42. Transit rider work trips to and from home; time code 1.

Curves were developed to describe the distribution of trips generated at home for work and commercial trips. Similar curves were prepared to show distribution of work and commercial trips to home. Although both curves for work (or commercial) trips dealt with the same trips, the curve for trip ends at home was somewhat different from the curve describing the distribution of trips from places of work because the residential land uses were dispersed much differently than industrial and commercial uses. Places of employment tended to be centrally oriented within the metropolitan area, while residential districts were decentralized. Commercial locations were centralized to a lesser degree than employment.

Social trips did not require such detailed treatment. Residential populations generated both ends of the trips, and the competition between districts was more nearly equal than for work and commercial travel.

Miscellaneous trips exhibited much the same characteristics as trips in taxis, few of which were home-based. Treatment similar to that applied to social trips provided good correlation.

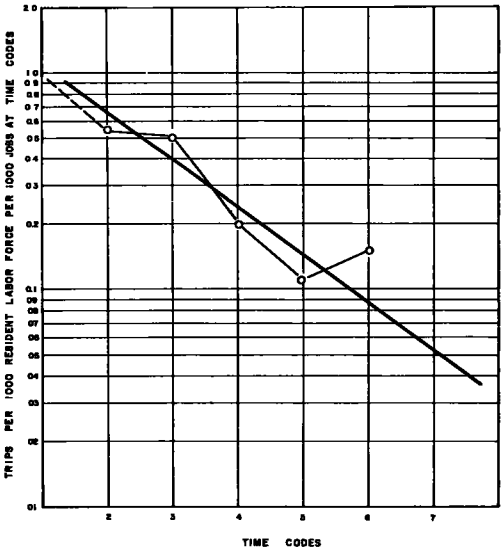

Figure 43. Transit rider work trips to and from home; time codes 2 and over.

Work Trips to and from Home. Work trips were first separated by mode of travel. Auto passenger trips were combined with drivers, since distribution patterns are virtually identical. Trips between district pairs were then classified by length and trip rates were computed for all travel generated between districts of residence and employment at successive distance intervals. Distance intervals

were labed by the time code number used to identify them during machine processing. Time code 1 represented travel between the centroid of a district of residence and the centroids of all other districts within 6 min off-peak driving time. Time code 2 represented trips 6 to 12 min in length to or from the centroids of districts in the next distance interval.

Figure 38 for auto travel within time code 1 shows how the rate of travel per unit of employment decreased as the amount of employment within 6 min of the residences increased. Only the more important trip generators were plotted on the drawing since samples of data from smaller districts were not stable when broken down into small volumes. Note that several districts were within 6 min driving time of one-fourth or more of all employment in the study area. These were heavily populated districts near the center of the city.

Figure 39 illustrates the distribution of trips to employment in all time codes except the first one. A straight line has been fitted to the average rates of travel in successive 6-min intervals of distance (time code).

Figures 42 and 43 illustrate the patterns of transit work trip distributions. Data for districts of heaviest trip generation are shown on both drawings. Figure 42 shows the use of transit for work travel within time code 1. For districts to be within a short distance of many jobs, they had to be located near the center of the city where transit service was best. These districts generated the highest rates of work travel via transit. Figure 43 shows the typical decay curve—declining rates of trip generation through successive time codes. Only the median values have been plotted on the drawing.

Work Trips to and from Employment. Auto travel to and from jobs is illustrated in Figures 40 and 41. Variations from the average did not range as widely on these drawings as in studies of trip distribution from home, possibly because employment was more concentrated and was centrally located, assuring less variability in trip rates from one district to the next.

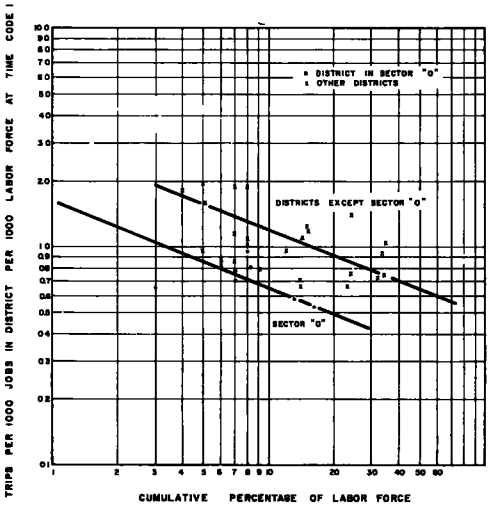

Figure 44. Transit riders to and from work; time code 1.

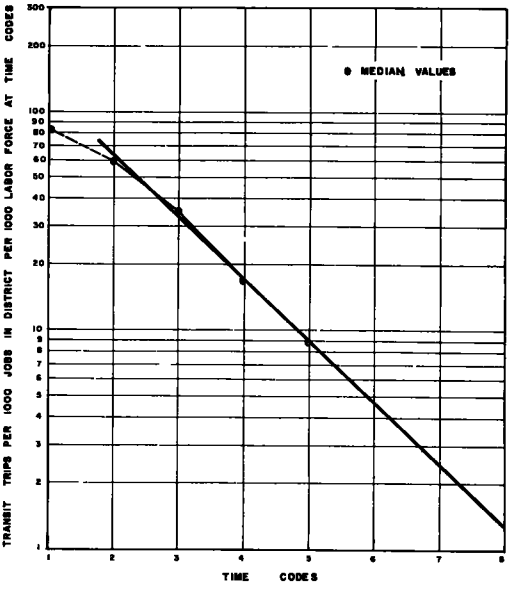

Figure 45. Transit riders to and from work; time codes 2 and over.

Transit trips to and from employment are described in Figures 44 and 45. Trips generated by employment in Sector Zero distributed to labor force at distinctly lower rates than did trips out of other districts. Travel to time code 1 from other districts was nearly twice the rate. This was probably related to the high proportion of white-collar employment in Sector Zero and to the preponderance of lower income families in adjacent residential districts.

Figure 45 illustrates the rate of transit trips generated between places of employ-

ment and the labor force in time codes 2 and larger. Only the median values have been shown on the drawing. The most effective use of transit was generally confined to districts inside the 10-mile square. A large proportion of the labor force residing in this area was within 12 to 15 min driving time of most large employment centers.

Commercial Trips to and from Home. Figures 46, 47, and 50 illustrate the relationships which were found for the distribution of commercial trips generated at place of residence. For auto travel, time code 1 required special treatment because these nearby commercial establishments had a most profound effect on the over-all pattern of trip distributions. Beyond time code 1, trip distributions followed a typical decay pattern.

Commercial Trips to and from Commercial Generators. Figures 48 and 51 show the decay curves which reflect the distribution of commercial trips from retail centers back to places of residence. Trip data plotted more closely to the curve than those for trips from home, because the significant commercial centers for which trips were plotted were compact and quite large, assuring stability in the trip data from which the curves were derived.

In Figure 51 the rates of transit travel from commercial trip generators in specific districts have been plotted for successive time intervals and the points connected. Travel from all districts is shown to decay at about the same rate.

Social Trips Between Districts. Figures 52 and 53 reflect the inter-district patterns of social trips. The social trip data were quite consistent from district to district, each showing a very rapid decline in rate of travel as trip lengths increased.

Miscellaneous Trips Between Districts. Miscellaneous trips were made mostly by car and only one curve was developed to show their inter-district relationships. Figure 49 related miscellaneous trips to the concentrations of employment and commercial activity. Miscellaneous trips decayed very rapidly, as shown by the median values through which the decay curve was drawn.

Correlation Studies—Auto Drivers at External Cordon

The 1948 and 1955 cordon lines were located so that they would include all of the urbanized portions of the National Capital Region, related primarily to Washington, D. C. This placed the cordon line at rural locations on most highways. Traffic across the cordon was going to or from the city, rather than traveling within it.

The 1955 cordon bounded an area slightly larger than that studied in 1948, but many interview stations were located at almost identical sites in both years. In the discussion below, the 1948 and 1955 cordon lines are considered to be the same.

Traffic Increases at Cordon. Traffic at the cordon doubled in the 7-yr period between origin-destination surveys. The number of cars owned by residents of the study area also doubled, due to population growth and increased rates of car ownership. The number of cars owned in the area was an approximate measure of the amount of auto travel the community generated, and this was reflected in the increased travel across the cordon from 1948 to 1955.

Through trips were about the same proportion of vehicles in traffic in 1955 as in 1948. Through trips tended to emerge from the city at points opposite their places of entrance. Highest ratios of through trips to local trips occurred

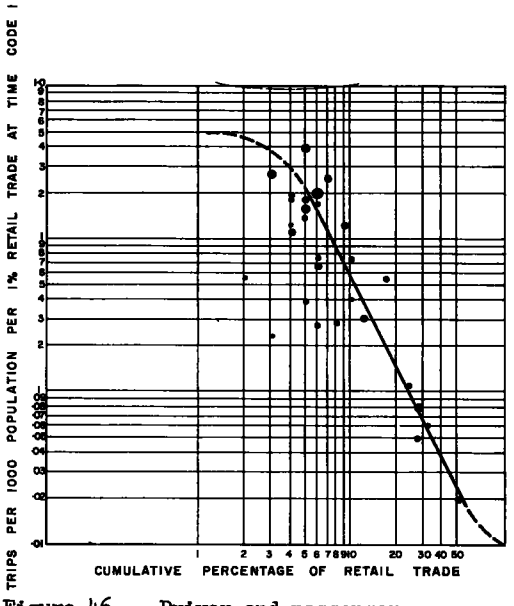

Figure 46. Driver and passenger commercial trips to and from home; time code 1.

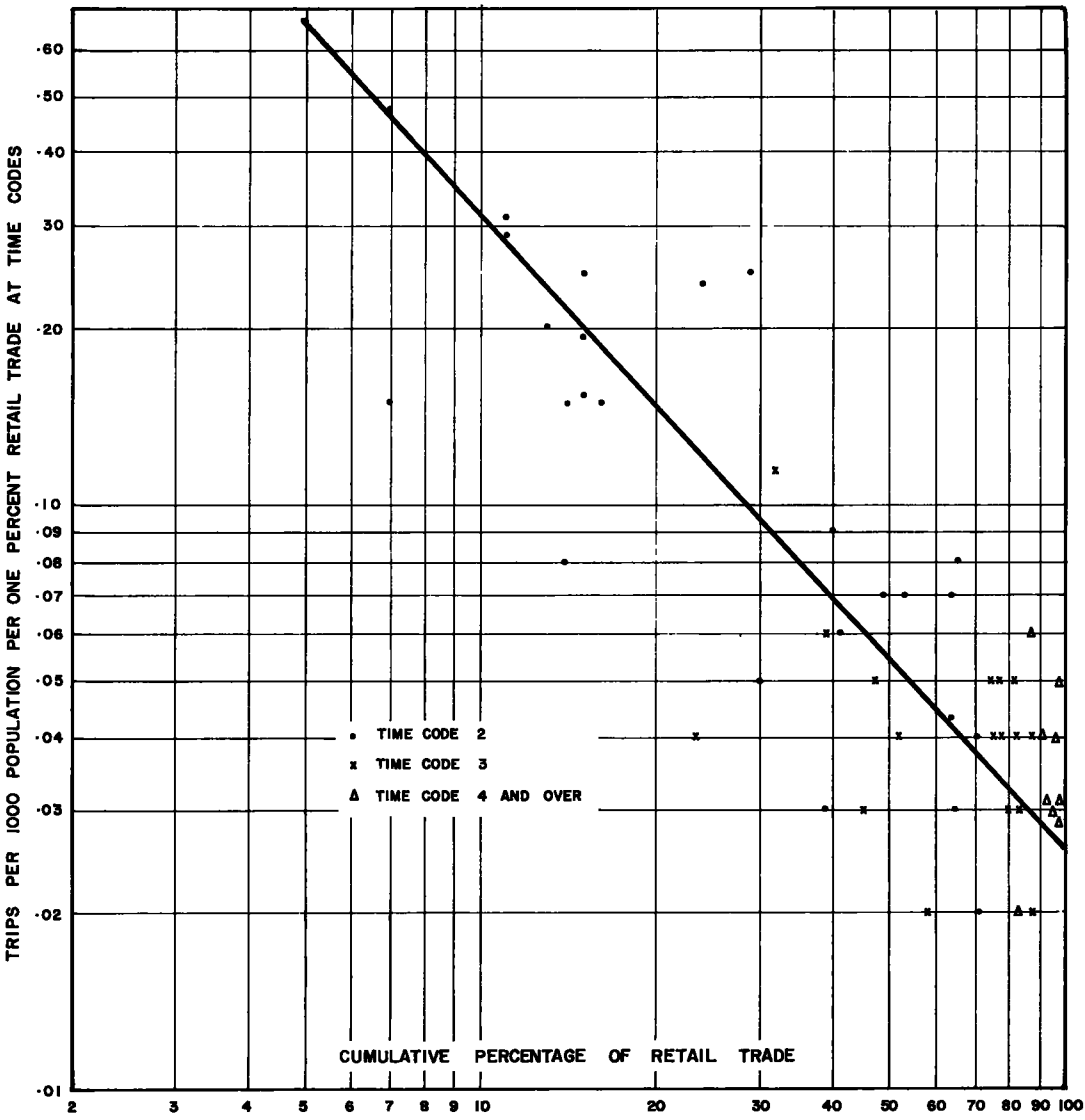

Figure 47. Driver and passenger commercial trips to and from home; time codes 2 and over.

on the major highways which give access to other large cities.

Station Groups. Highways which crossed the cordon varied considerably in relative importance. The principal highways approaching the metropolitan area accommodated both local and inter-state travel. These were the important U. S. numbered highways (US 1, US 29, and US 240) and major state highways, radiating from the District of Columbia like the spokes of a wheel. Each served an important "traffic corridor" and was supplemented by other highways which varied widely in importance and amount of use.

A cross-section of highway travel was contained in the combined travel on all radial streets and highways in each corridor. To consolidate existing traffic data for this analysis, trip interviews from the 1948 and 1955 roadside stations were merged into 10 groups, each centered on a principal radial route (Table 14). The grouped trip data represented a balanced cross-section of travel to and from Washington in each corridor.

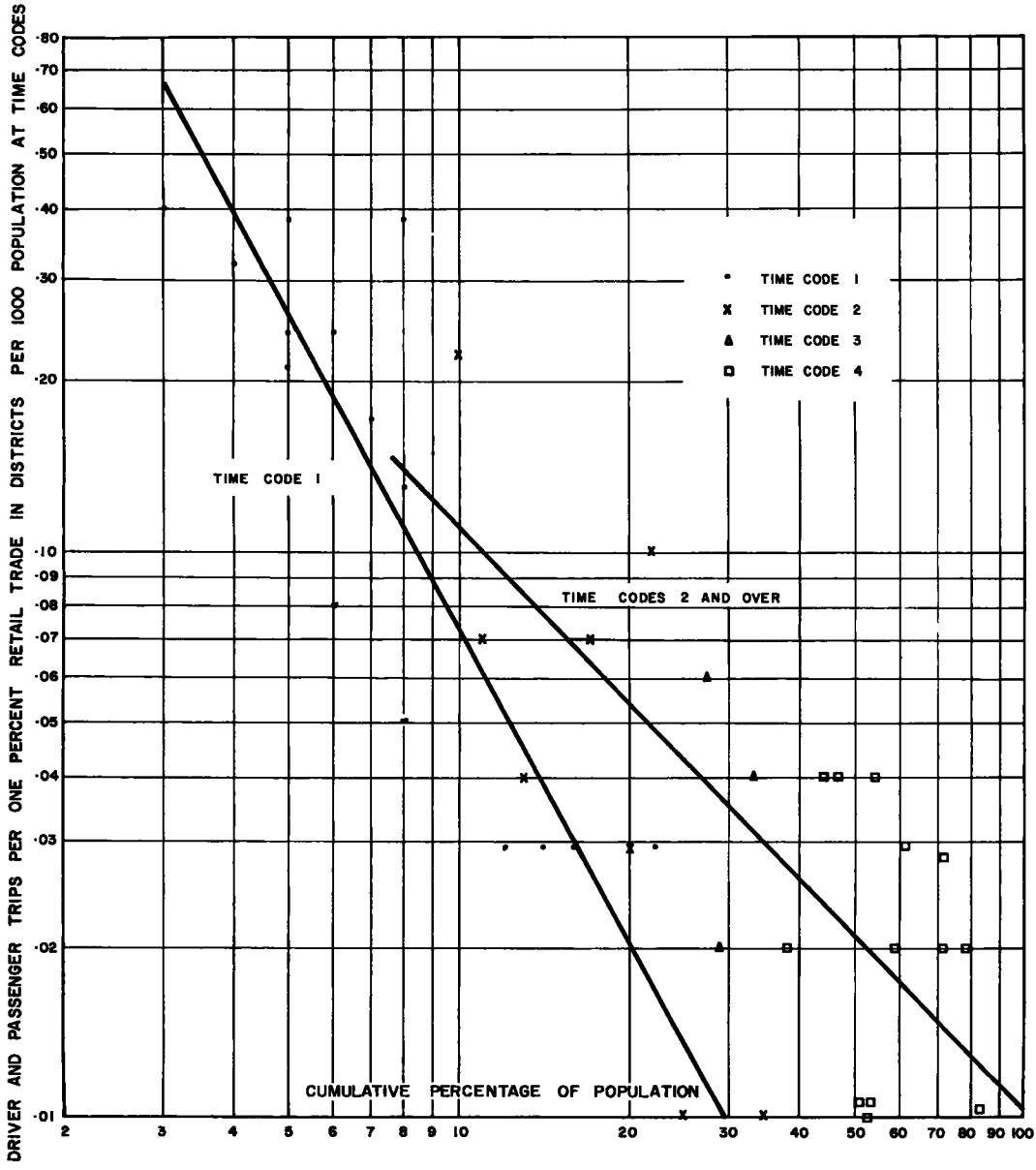

Figure 48. Drivers and passengers to and from commercial purposes; all time codes.

Internal Distribution of External Auto Trips. The 1958 roadside interviews were made for only one direction of travel and did not contain information on purpose of trip. Although this information was available in 1948 data, the considerable change in trip purposes in internal travel discouraged efforts to infer purposes in 1953 data. Instead, relationships were sought which would describe the traffic movements between stations and districts without regard to purpose. Analysis of trip distribution was tested against a number of variables. Each test incorporated travel time between stations and districts as a measure of trip length and assumed that the station itself was one terminus of the trips which passed through it. Trips were found to relate well to attraction units in each district. As noted earlier, about half of the trips made

TABLE 14

TRAFFIC AT EXTERNAL CORDON, 1948 AND 1955

Roadside Stations			Passenger Cars		Trucks	
1948	1955	Location	1948	1955	1948	1955
Sta.	Group 1	Virginia, US 1 Jefferson Davis Hwy.				
1	71	Mt. Vernon Blvd.	6,211	5,756	163	123
	72	Va. 629 Fort Hunt Rd.	-	3,516	-	644
2	73	US 1, Jefferson Davis Hwy.	14,351	17,038	4,079	2,234
-	74	Va. 633 Old Kings Hwy.	-	2,275	-	459
3	75	Va. 611 Telegraph Road	4,969	6,235	1,346	1,523
-	76	Va. 350 Shirley Hwy.	-	18,683	-	6,704
4	81	Va. 236 Duke St.	4,229	10,329	944	2,524
Total Station Group 1			29,760	63,832	6,532	14,211
Sta.	Group 2	Virginia, US 50 Arlington Blvd.				
5	82	Va. 244 Columia Pike	3,989	7,296	978	1,852
6	83	Va. 649 Annandale Rd.	1,479	3,639	384	934
7	84	US 50 Arlington Blvd.	6,516	14,441	647	1,543
8	85	US 29, 211 Lee Hwy.	5,517	7,865	1,349	1,762
Total Station Group 2			17,501	33,241	3,358	6,091
Sta.	Group 3	Virginia 7 Leesburg Turnpike				
9	91	Va. 7, Leesburg Turnpike	4,361	7,306	814	1,449
10	92	Va. 309, Old Dominion Dr.	1,260	4,092	188	649
11	93	Va. 123 Chain Bridge Rd	3,301	7,511	368	827
Total Station Group 3			8,922	18,909	1,370	2,925
Sta.	Group 4	Maryland, US 240 Rockville Pike				
12	12	MacArthur Blvd.	1,490	2,052	110	159
13	13	Md. 190 River Rd	1,605	3,069	209	530
14	14	Md. 191 Bradley Blvd	1,708	1,936	306	478
15	21	Md. 187 Old Georgetown Rd	1,629	3,196	270	620
16	22	US 240 Rockville Pike	7,548	15,340	1,266	2,224
17	-	Md. 547 Garrett Park Rd.	849	-	215	-
18	23	Md. 586 Viers Mill Road	3,340	9,629	844	2,265
19	31	Md. 97 Brookville Rd.	4,768	5,641	1,060	778
Total Station Group 4			22,937	40,863	4,280	7,054
Sta.	Group 5	Maryland, US 29 Colesville Rd				

Roadside Stations 1948	1955	Location	Passenger Cars 1948	1955	Trucks 1948	1955
20	32	US 29 Colesville Rd	4,620	9,545	1,037	2,108
21	33	Md. 320 New Hampshire Ave.	4,025	9,938	758	1,492
22	34	Md. 212 Riggs Rd	1,109	2,715	264	715
Total Station Group 5			9,754	22,198	2,059	4,315
Sta.	Group 6	Maryland, US 1 Baltimore Blvd.				
23	41	US 1 Baltimore Blvd	23,375	10,674	5,566	8,054
24	42	Md. 205 Edmonston Rd.	2,447	3,659	625	464
-	43	Md. 430 Glendale Rd	-	5,944	-	725
-	44	Baltimore-Wash. Pkwy	-	17,640	-	-
Total Station Group 6			25,822	37,917	6,191	9,243
Sta.	Group 7	Maryland, US 50 Defense Hwy.				
25	-	Md. 412 Riverdale Rd	1,073	-	232	-
26	51	US 50 Defense Hwy	4,875	7,881	1,007	608
27	52	Md. 202 Landover Rd	2,735	6,237	334	571
28	53	Md. 704 G. N. Palmer Hwy	938	3,530	309	974
29	54	Md. 214 Central Ave.	3,141	6,905	406	701
Total Station Group 7			12,762	24,553	2,288	2,854
Sta.	Group 8	Maryland, Md. 4 Marlboro Pike				
30	61	Md. 4 Marlboro Pike	4,178	9,703	1,023	1,796
31	62	Md. 218 Suitland Rd	858	3,488	141	424
32	63	Suitland Pkwy.	4,005	11,887	391	1,106
Total Station Group 8			9,041	25,078	1,555	3,326
Sta.	Group 9	Maryland, Md. 5 Branch Ave.				
33	64	Md. 5 Branch Ave	7,076	12,675	1,820	3,220
-	65	Md. 414 St. Barnabus Rd	-	6,260	-	1,852
Total Station Group 9			7,076	18,935	1,820	5,072
Sta.	Group 10	Maryland, Md. 210 Indian Head Rd				
34	67	Md. 210 Indian Hd.	6,378	14,469	918	2,060
Total Volume at Stations			149,953	299,995	30,371	57,151
Less ½ of Through Trips			6,341	10,833	2,888	5,661
Different Vehicles			143,612	289,157	27,483	51,661

Note: Data in this Appendix from 1948, Vol. III, Washington Metropolitan Area Transportation Study; 1955 - UNIVAC tabulation, 1957.

in the study area were motivated by work purposes; about one-fourth were generated for business and shopping; the remainder were oriented towards residential areas (social, recreational, schools, etc.). Employment, retail trade, and population in each district were evaluated according to the following formula:

1. Each one percent of employment within the study area equal to 50 attraction units;
2. Each one percent of retail trade in the area equal to 25 attraction units;
3. Each one percent of population in the area equal to 25 attraction units.

All attraction units in each district were combined to produce a weighted estimate of trip attractions. Trips generated at station groups developed the relationships shown in Figure 58. A parabola has been fitted to the average points for 6-min time intervals.

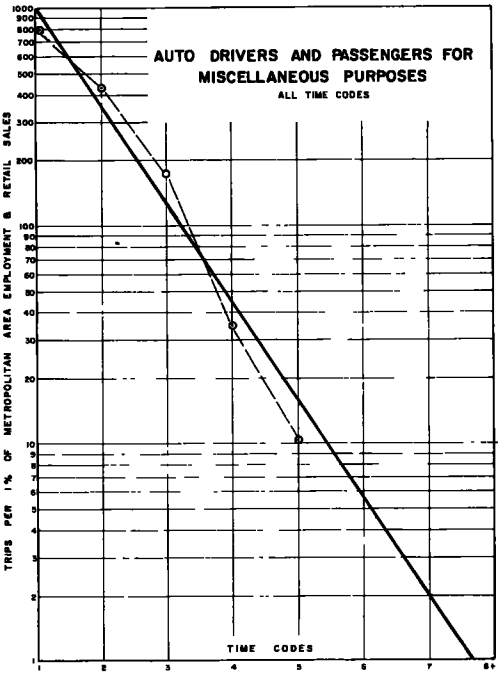

Figure 49. Auto drivers and passengers for miscellaneous purposes; all time codes.

Correlation Studies—Taxi Drivers

More than a quarter of a million taxi driver trips were made each day in the 1955 study area. A slightly smaller number was made in 1948, as shown in Table 8. As noted earlier, taxis accommodated about a third of all trips made in public transportation in 1955.

Trip Generation. Most taxi trips were made by non-residents, or were made between non-residential terminals. Only a small proportion began or ended at the passenger's residence, except transients to hotels. A large proportion of all taxi travel was associated with Sector Zero and the business and industrial areas nearby.

The number of taxi driver trips generated in the District of Columbia was found to relate well to the amount of employment and retail trade, expressed as attraction units; residential populations were not included in these taxi attractions. The generation of trips per attraction unit was highest in Sector Zero and decreased rapidly with distance from the sector.

Taxi travel in Sector Zero was generated at a rate of about 1,000 taxi trips per 2,500 attraction units. Outside Sector Zero the rate of trip generation decreased almost uniformly to the District of Columbia boundaries. Most of the taxicabs operated in the area were registered in the District where fares are charged by zones rather than by meters.

In Virginia and Maryland, outside the District Lines, taxi trips were generated at much lower rates, proportional to the trip attractions within each district. Decentralization did not seem to be especially significant.

Figures 54 and 55 illustrate these relationships. The curves in Figure 54 relate trip generation to employment and trade in the districts. Figure 55 shows the modifying influence of decentralization on trips generated within the District of Columbia. These curves do not apply to Sector Zero.

Intra-District Trips. Some taxi driver trips began and ended within the same district. The amount of such travel could be predicted as a percentage of all taxi trips generated in a district as shown in Figure 56. Most taxi trips were generated by work or retail trade. If the amount of work and trade in a district was expressed as a proportion of all work and trade within a short driving distance (in this case, 12 min from center of district), the proportion of intra-district trips could be predicted with good reliability.

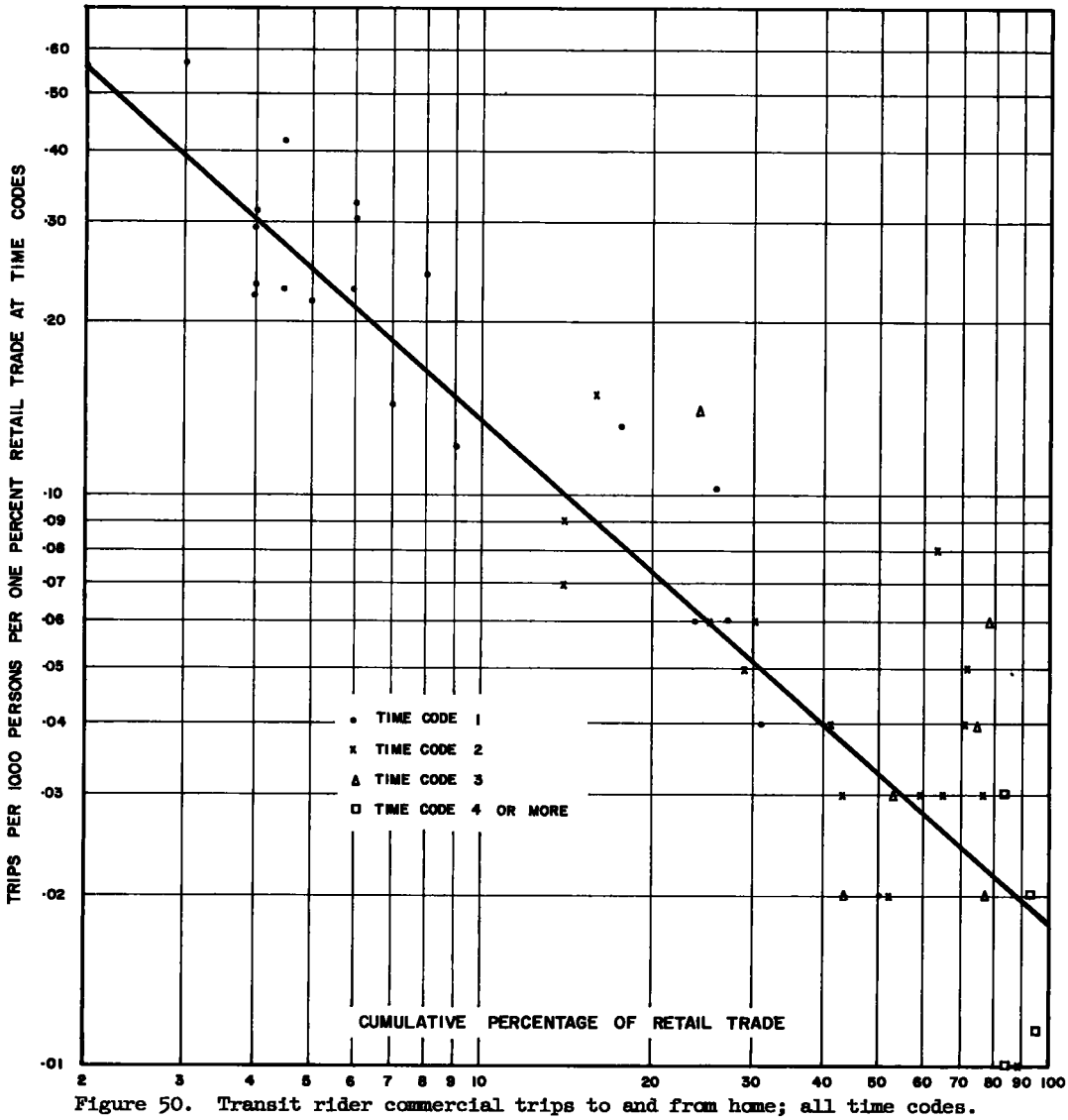

Figure 50. Transit rider commercial trips to and from home; all time codes.

Inter-District Trip Distribution. Inter-District taxi driver trips tended to be very short. The studies found a regular pattern of trip decay with distance when trips were related to employment in each successive time code. Figure 57 illustrates the general pattern of trip distribution from nine districts which generated a substantial number of taxi driver trips. These data, plotted on semi-log paper, showed very similar negative slopes. An average line fitted to median values represents the relative distribution of trips from all districts.

Taxi Passenger Trips. Taxi passengers averaged 1.08 per driver trip. Purpose of travel was known only for about 20 percent of the trips, those made by the Region's residents, but this information was not found to be essential to the analysis since travel patterns by drivers were the same as those by passengers.

Correlation Studies—Truck Drivers

As pointed out earlier, trucks accounted for about one-eighth of all vehicle trips

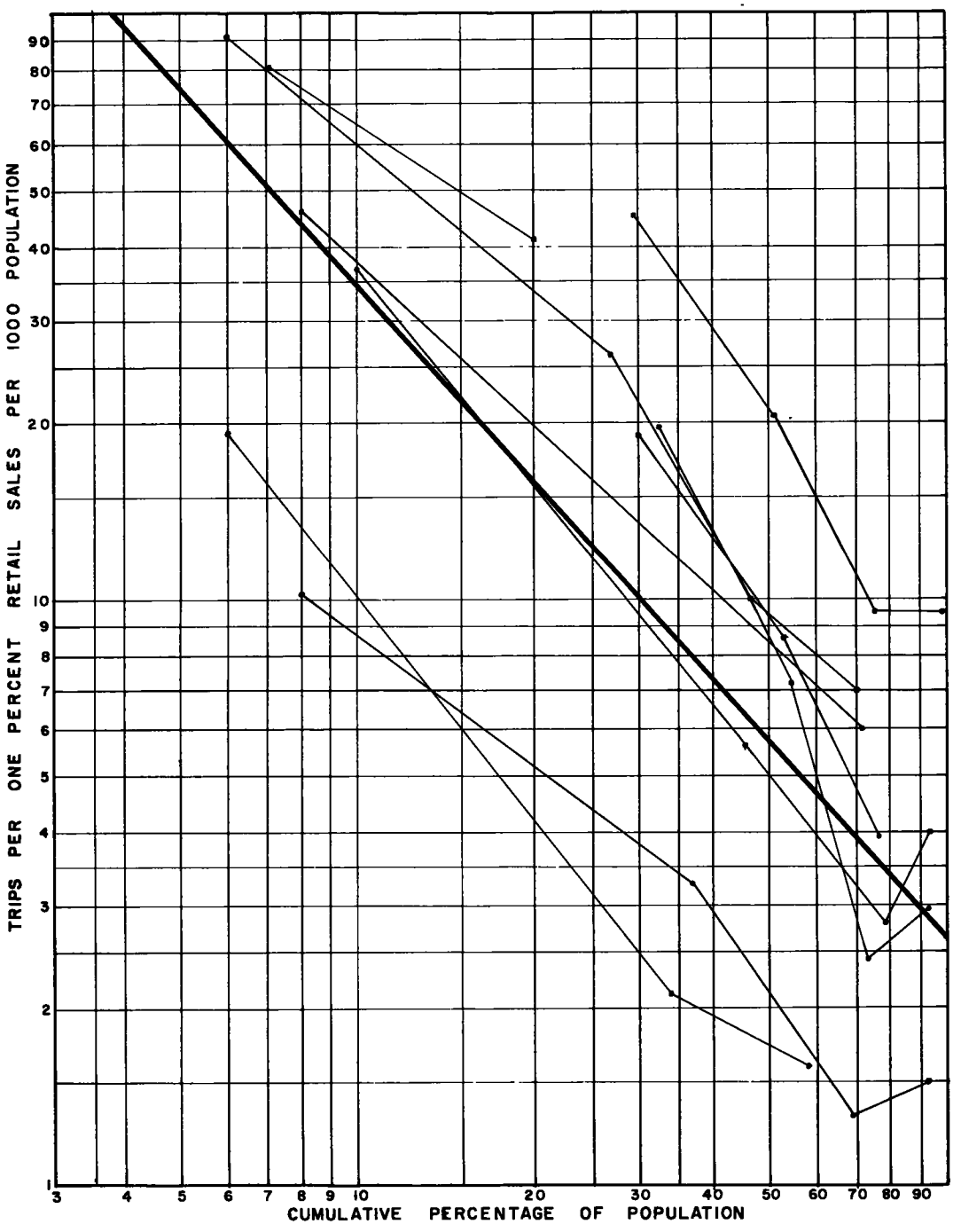

Figure 51. Transit rider trips to and from commercial purposes; all time codes.

in the 1948 and 1955 surveys. Large trucks have a profound effect on street capacity and quality of traffic flow and reduce the number of passenger cars and taxis which could otherwise use existing and proposed streets and freeways.

Truck travel in Washington was attracted to all parts of the city and served a wide variety of uses. Residential areas required trucks for delivery of goods and services,

construction of buildings and streets, and general maintenance. Commercial and industrial areas required trucks for the transport of goods.

Truck trips recorded in the internal survey were not reported as completely as trips by car and taxi. Delivery trucks made many short trips, often several in one block. To avoid reporting a multitude of very short trips which make no significant contribution to the vehicle miles of travel performed on city streets, many of these trips were grouped together. Minimum distance between reported origin and destination was generally kept to 4 or 5 blocks by coding the beginning of one trip and the destination of another trip omitting intermediate stops.

Because of the way trips were combined in the origin-destination reports, correlations which relate the number of truck trips to the number of people and jobs in the city were difficult to derive.

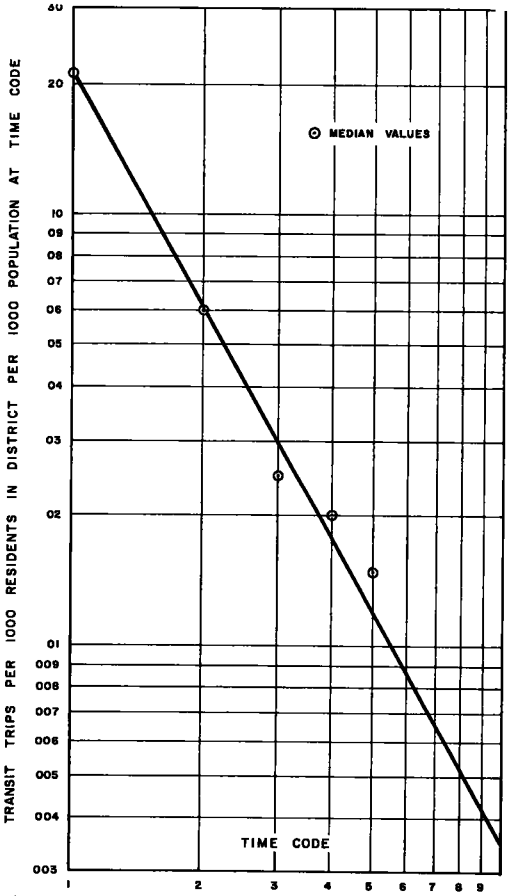

Figure 53. Transit trips for social purpose; all time codes.

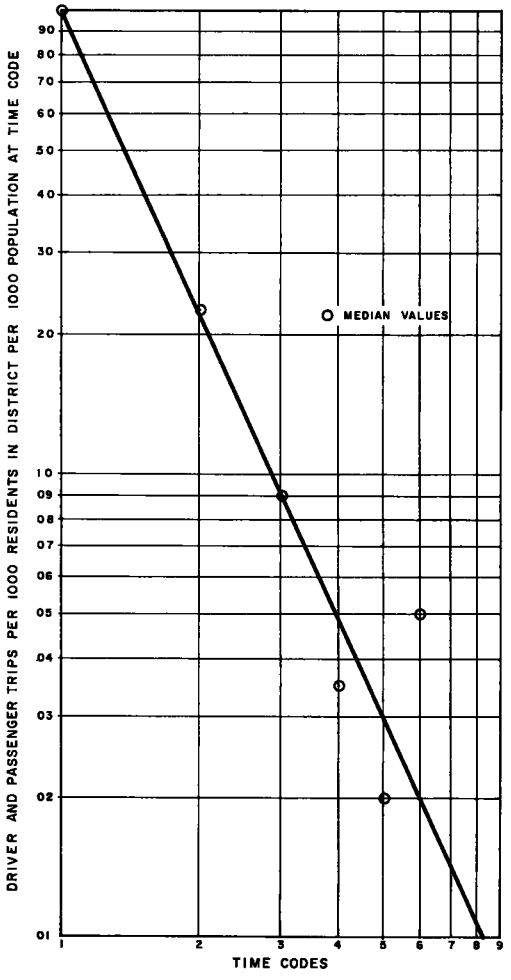

Figure 52. Driver and passenger social trips between districts; all time codes.

Intra-district trips were seriously underreported in the truck survey and no satisfactory correlation with total trips could be developed. Instead, an analogy method has been devised to evaluate such travel in the 1948 and 1955 districts. Analogy methods have also been used to describe the over-all truck trip attractions to Sector Zero and to modify estimates of travel in specific commercial and industrial districts.

Truck Trip Generation. A series of multiple correlation formulae were developed to describe the average generation of truck trips in districts in Washington, based on 1955 data. Employment, retail trade, and population were elements of the formulae. The equations have the following form:

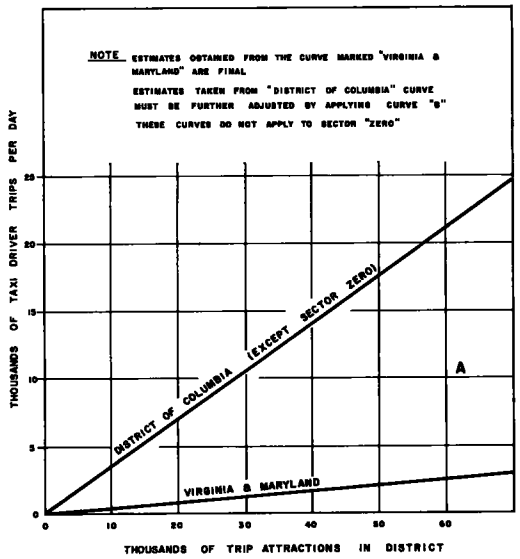

Figure 54. Taxi driver trips generated in districts.

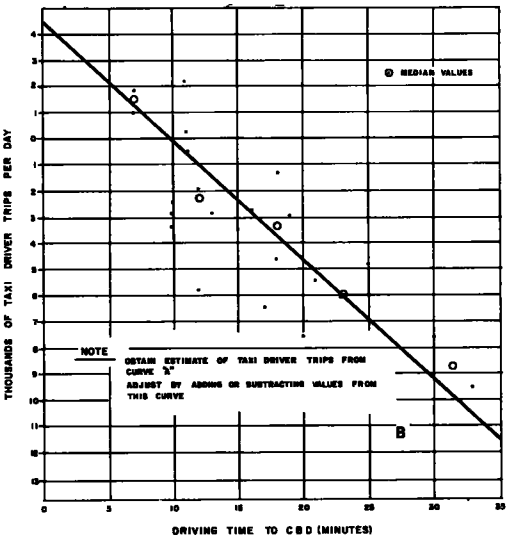

Figure 55. Taxi driver trips generated in District of Columbia.

(1) Income 5: Truck Trips = 0.36 G + 0.672 E + 0.489 R + 0.136 P
(2) Income 4: Truck Trips = 0.36 G + 0.672 E + 0.489 R + 0.077 P
(3) Income 1, 2, 3
Truck Trips = 0.36 G + 0.672 E + 0.489 R + 0.038 P

When
G = government employment in the district;
E = non-government employment in the district;
R = percent of National Capital Region's retail sales in district; and
P = number of persons who live in district. The value of P varies with median income level.

Arbitrary adjustments were applied to certain business and industrial districts to improve quality of estimate derived from the formulae. These were developed by relating non-government employment (E) to the residuals in each district after the above formulae had been used to synthesize an estimate of truck trips. The use of trucks was found to be less than the estimate in districts where many office workers are employed (retail centers and the National Airport). Truck use was higher than estimated in the few industrial districts, due to goods handling out of proportion to the number of workers in those areas. Truck trip generation was modified in selected districts by the following adjustments:

Retail centers and airport - districts 36, 49, 36 and 72:
subtract -0.25 (non-government employment)
Industrial districts 42, 43, 45, 51, 52, and 57

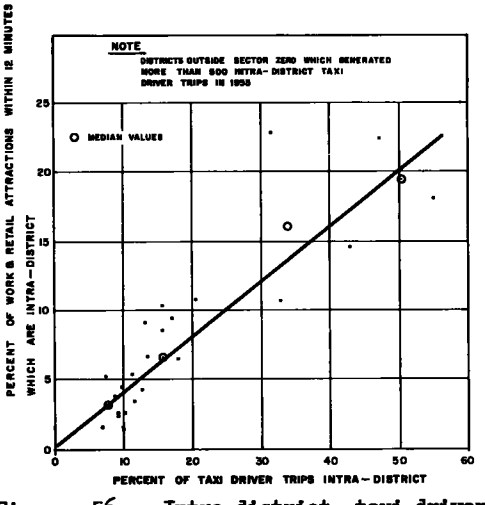

Figure 56. Intra-district taxi driver trips.

add +0.30 (non-government employment)
Industrial districts 62, 63, 35, 37
add +0.35 (non-government employment)
Industrial district 11
add +0.25 (non-government employment)

When the formula was applied to 1955 data, with the suggested adjustments for business and industrial districts, the estimates produced were close to the number of trips reported in the 1955 survey.

Note that government and non-government employment were evaluated separately. Most government work did not involve tranportation of goods. Much non-governmental work, except in Sector Zero, was closely related to goods handling and industrial production which created a high demand for trucks. The demand for trucks was also high in retail centers.

Higher income populations seemed to require more truck service than low income areas. However, this may simply reflect the method of trip reporting. Lower income areas were more densely occupied, as a rule, than higher income areas. The method of reporting truck travel, by combining several very short trips would develop a smaller number of destinations in the high-density areas than was actually the case.

To the extent that arbitrary adjustments are suggested, the formula utilizes an analogy technique. This may be acceptable in districts that are unlikely to grow or to appreciably change in character. Most of those listed are in this group.

In Sector Zero the high densities of land use resulted in the loss of many truck trips from the reported data because of the combination of short trips. No consistent relationships were developed.

Intra-District Trips. Intra-district truck travel is especially sensitive to the methods used to reduce the number of short delivery trips. The means suggested

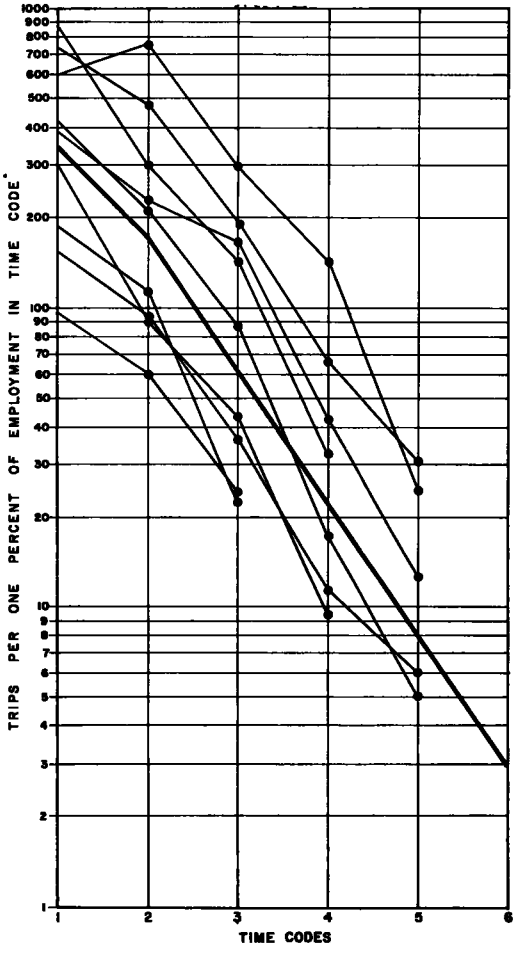

Figure 57. Taxi driver trips; all time codes.

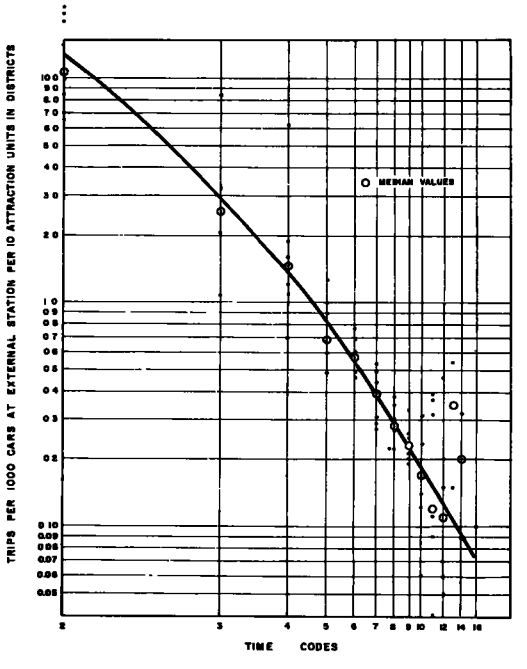

Figure 58. Auto driver trips between stations and districts; all time codes.

to estimate future truck attractions in Sector Zero can also be used to predict the number of intra-district trips generated in districts within the 1955 cordon.

Correlation analysis was used to develop an equation for estimating intra-district trips in areas for which survey data were not available, as follows:

(4) Intra-district truck trips = 0.125 D + 0.040 E + 133.4 R - 261

When D = number of dwelling units in district;
E = number of non-government employmees in district; and
R = percent of the Region's retail sales in district.

A variation of the formula was developed for district which did not contain many residents. If the number of dwelling units is less than 3,000 the formula is as follows:

(5) Intra-district truck trips = 0.050 D + 0.040 E + 133.4 R - 36

Truck Trip Distribution. The distribution of inter-district trips was investigated in detail. Inter-district travel was affected but slightly by the combination of short trips so that good correlations were easily developed. The best ones

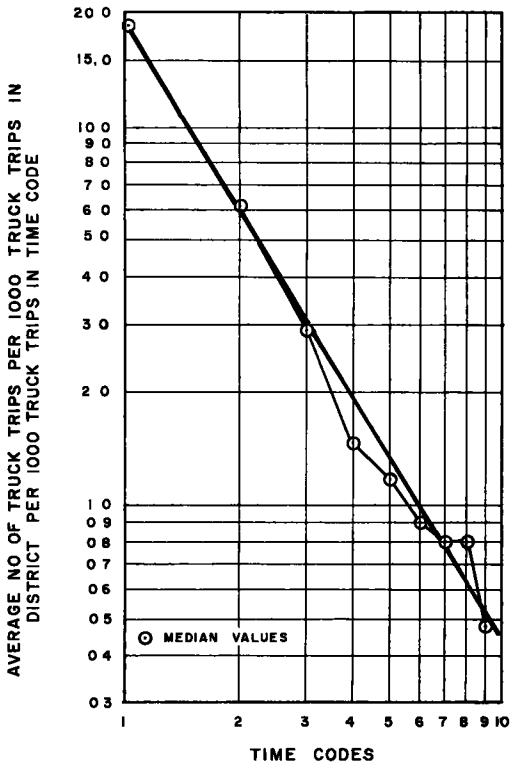

Figure 59. Truck trips between districts.

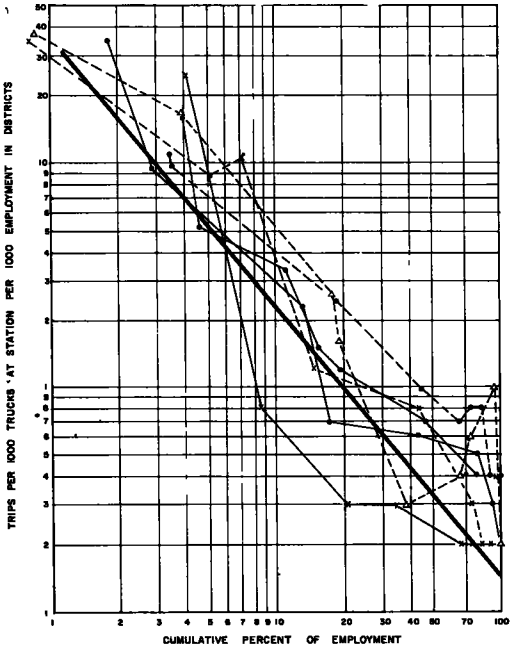

Figure 60. Truck trips between stations and districts.

were found by relating trip attraction between districts to the number of truck trips generated in each district. This was a direct application of the interactance effect (Fig. 59). The plotted points represented the mean rate of travel between district centroids and all districts within the 6-min range of each time code. Rate of travel between districts was shown as the average number of trips out of each 1,000 trips at the district centroid which would be generated in districts within the time code, based on the number (1,000's) of truck trip ends in the time code.

External Trips. The estimates of total trucks derived from formula 1 include trips generated at the external cordon. In the years between surveys, truck travel at the cordon did not increase as much as auto travel. Because trucks are engaged competitively to fulfill demands for service and transport, truck use was probably much nearer saturation in 1948 than was car ownership. Related to population in the study area, external truck trips per

person increased about 21 percent while auto trips increased 30 percent. Through trips increased somewhat more, but the volume of through trips was very small—less than 6,000 trips in 1948; a little over 11,000 trips in 1955—and the difference in growth rates may not be significant.

External trips were related to stations and districts according to the curve shown in Figure 60. The relative rate of attraction between stations and districts was computed according to the number of jobs (employment) in each successive time interval. The percentage of metropolitan area employment in each time code was established and accumulated by distance so that the pattern of trips distributed from different stations could be compared.

Summary

Two post-war origin-destination surveys for 1948 and 1955 provide an unusually good source of information on travel in the National Capital Region. Both surveys, made under the direct supervision of the Bureau of Public Roads, were conducted along very similar lines and the field data are, in most respects, directly comparable. The perspective which may be gained from a comparative analysis of the two studies is enhanced by the numerous changes which took place in the years between studies. Urban population increased about 41 percent; car ownership doubled, the average income level of residents increased substantially. Travel increased more rapidly than population in the years between surveys, from an average of 1.55 trips per person per day in 1948 to 1.62 trips per person per day in 1955 (data adjusted by deleting "interrupted" trip-ends.)

While population within the study area increased 41 percent in the seven years, 1948 to 1955, personal travel by residents increased 53 percent, from 1,723,870 trips in 1948 to 2,626,532 trips in 1955. Significant changes also occurred in modes of travel. The number of private cars owned by residents more than doubled; use of public transit declined about 5.5 percent, from 677,860 reported trips per day in 1948 to 639,413 trips per day in 1955.

Profound changes were also found in the proportions of travel for commercial (business and shopping) and social purposes. Trips in the commercial category almost doubled, with most made by car. A distinct change in shopping hours was noted, with a new emphasis on evening shopping. Home television and evening shopping in 1955 apparently cut into the time previously allotted to social travel. Social trips and school travel increased by only 25 percent. Excluding school travel, social-recreational trips actually declined from over 365,000 in 1948 to about 331,000 in 1955, despite the 41 percent population increase.

The hourly distribution of trips throughout the day changed very little between 1948 and 1955. Street use is heaviest during the hours 7:00 to 9:00 a. m. and 4:00 to 6:00 p. m. During these 4 hr about 40 percent of the average week day travel (24 hr) in automobiles takes place. Nearly half of the daily transit use and about one-fourth of the truck and taxi travel is accounted for in the 4-hr period.

Trip data from the origin-destination surveys have been related to population, land uses, and trip lengths to derive trip-estimating procedures. The number of trip-ends generated in a district may be developed in two parts—the home-based ends and the purpose ends. About 90 percent of the trips made by area residents for work, commercial, or social purposes were found to begin or end at place of residence and were classified as home-based. The remainder (miscellaneous trips) neither began nor ended at home.

The distribution of trips between pairs of districts (inter-district) or entirely within a district (intra-district) was found to relate directly to the number of trip opportunities of each specific type within the study area and, in the case of inter-district travel, was related inversely to the distance or travel time between districts. Logarithmic interactance curves were prepared to show these relationships, by mode of travel, for trips in each principal purpose category.

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