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Trip Generation and Urban Freeway Planning

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

F. HOUSTON WYNN, Wilbur Smith and Associates

●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 subzone level.

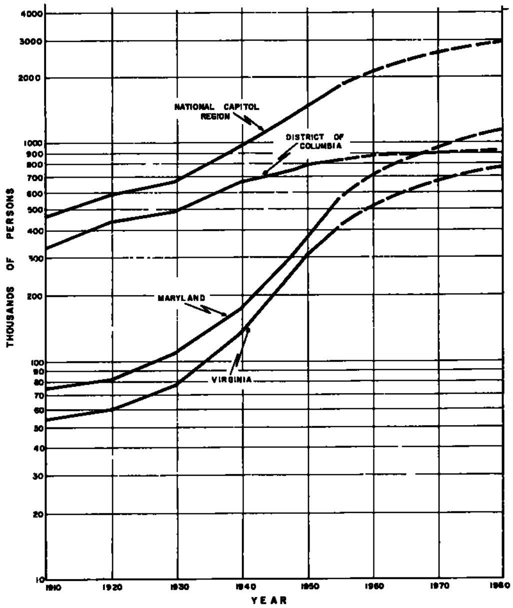

Figure 1. Population trends—National Capital Region, 1910-1980.

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.

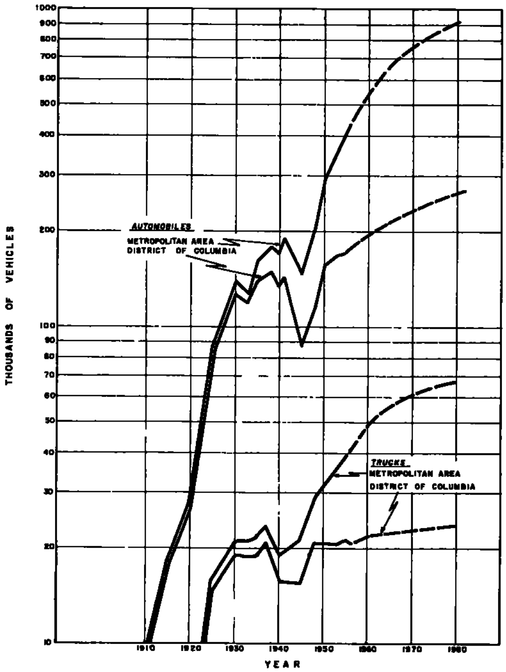

Figure 2. Estimated automobile ownership and truck registration, 1910-1980.

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-

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[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 nonpedestrian 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	1948 Com'l	1948 Social	1948 Misc.	1948 Total	1955 Work	1955 Com'l	1955 Social	1955 Misc.	1955 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.

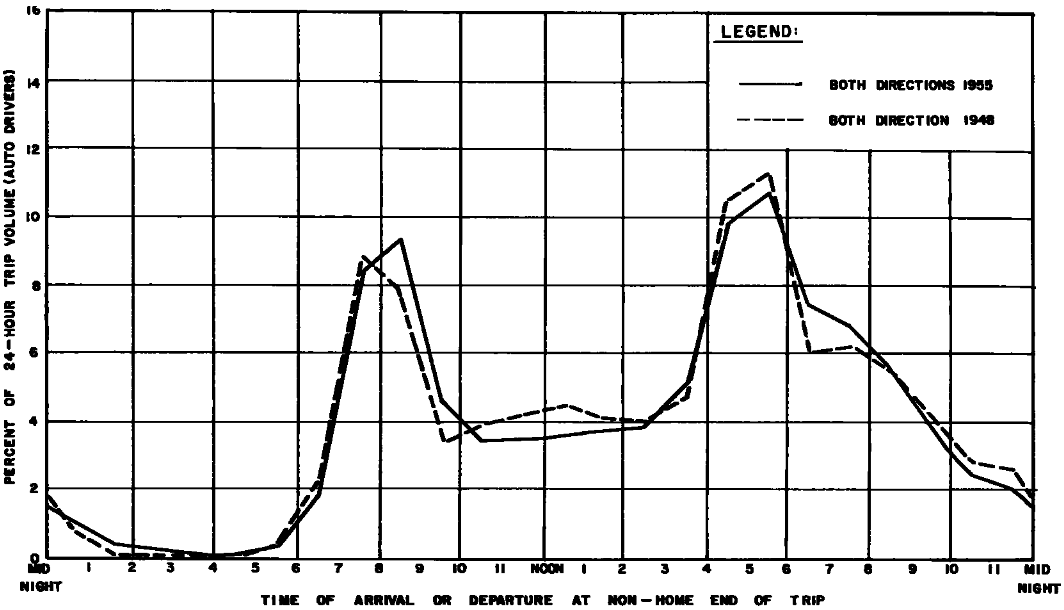

Figure 3. Hourly distribution of trips made by residents of area, 1948 & 1955; auto drivers (all purposes).

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

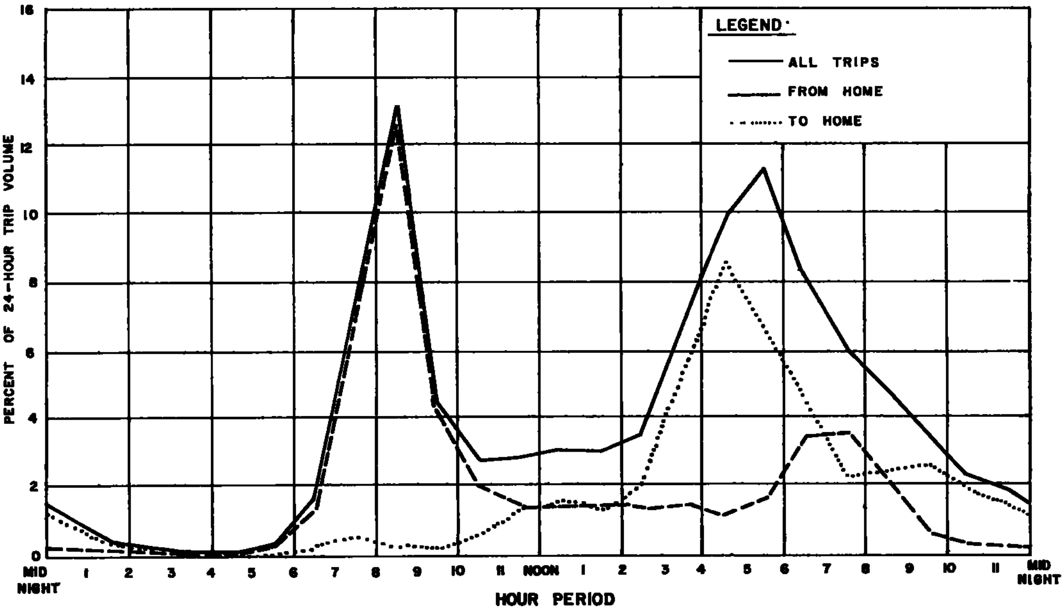

Figure 4. Hourly distribution of trips made by residents of area, 1955; all modes and purposes.

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.

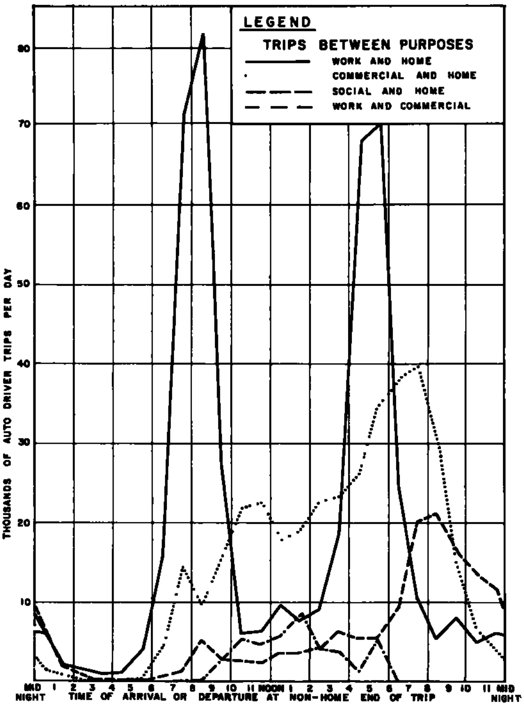

Figure 5. Hourly distribution of trips made by residents in 1955; auto drivers by purpose of trip.

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.

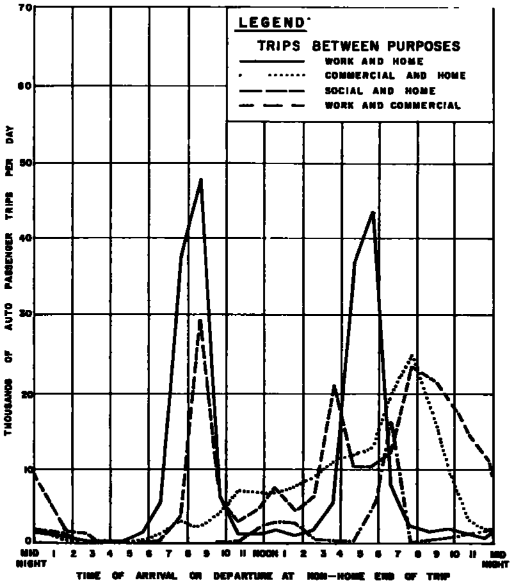

Figure 6. Hourly distribution of trips made by residents in 1955; auto passengers by purpose of trip.

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 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

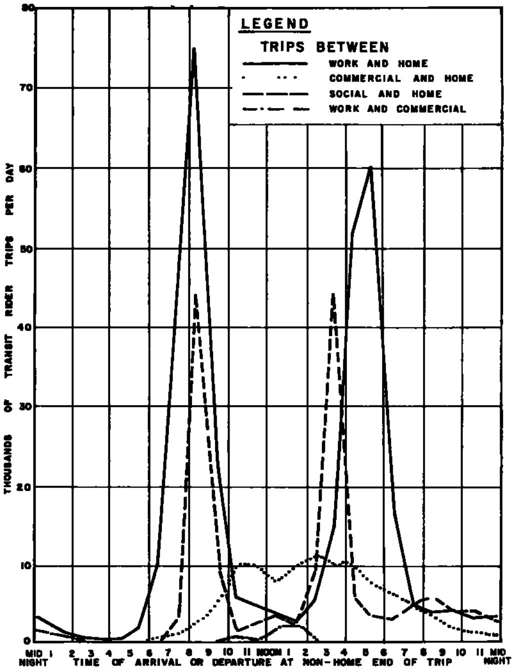

Figure 7. Hourly distribution of trips made by residents in 1955; transit riders by purpose of trip.

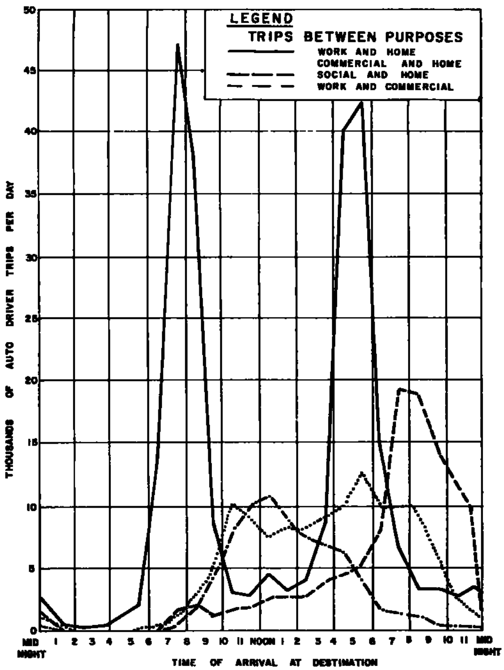

Figure 8. Hourly distribution of trips made by residents in 1948; auto drivers by purpose of trip.

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.

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.

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.

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

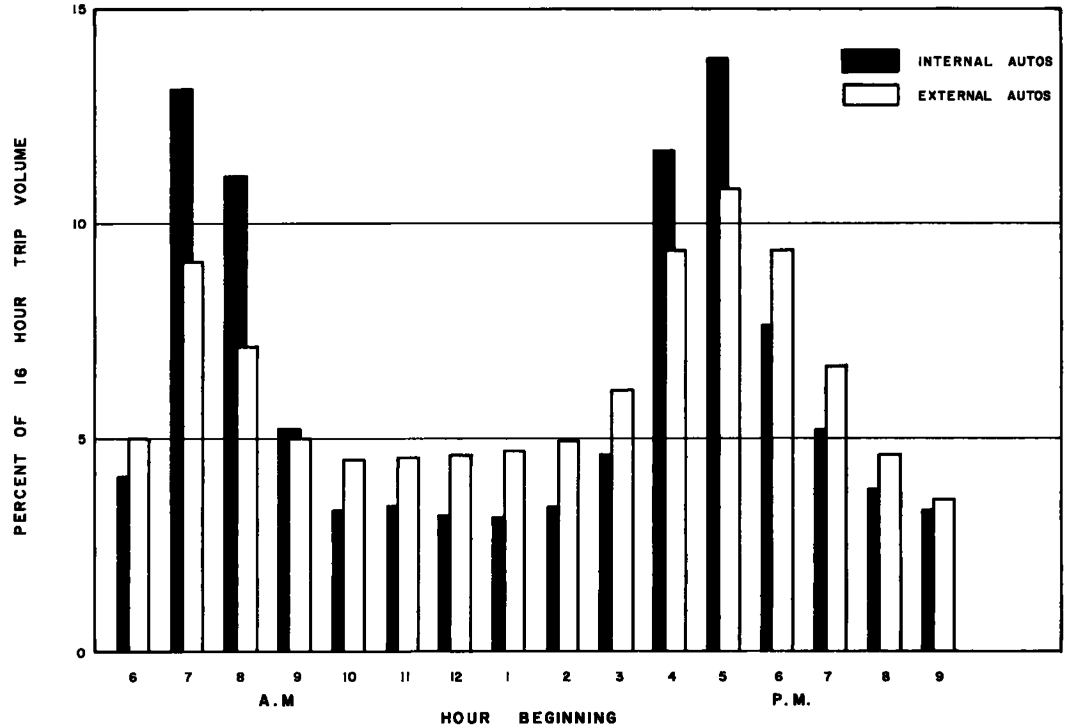

Figure 9. Comparison of internal and external auto driver trips, 1955; hourly distribution at Potomac River screenline.

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.	Outbound Trips %	Inbound Trips No.	Inbound Trips %	Both Directions No.	Both Directions %	% 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

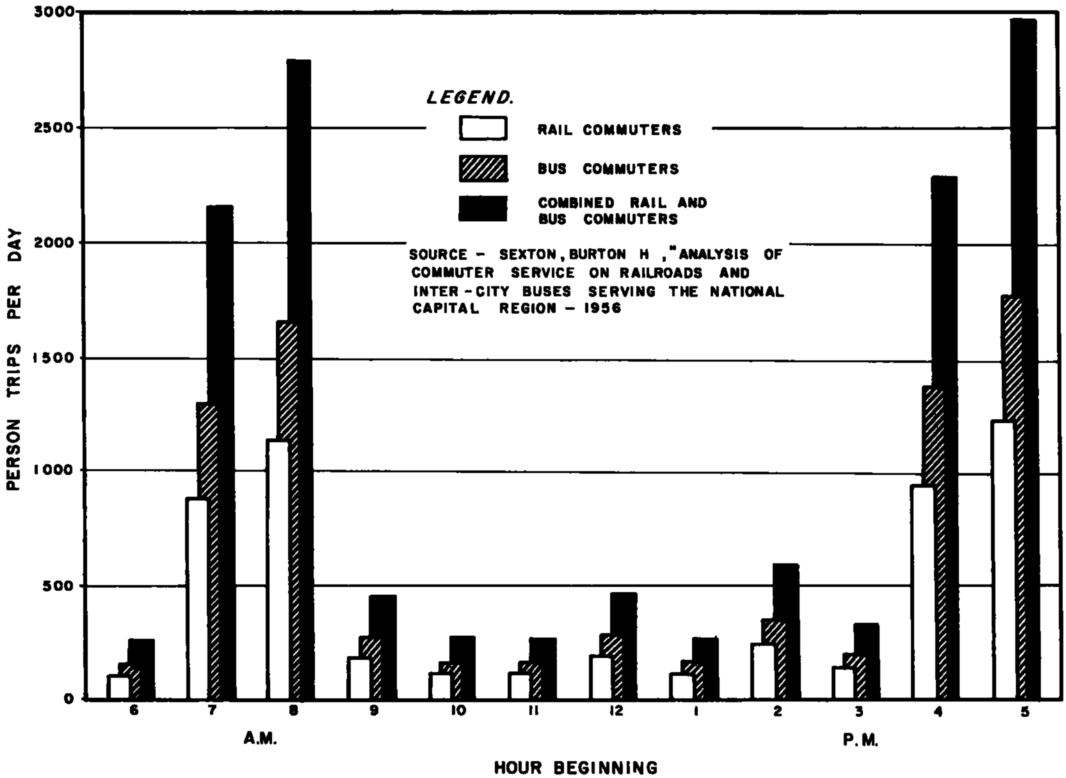

Figure 10. Hourly distribution of bus and rail commuters to and from the National Capital Region, 1956.

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.

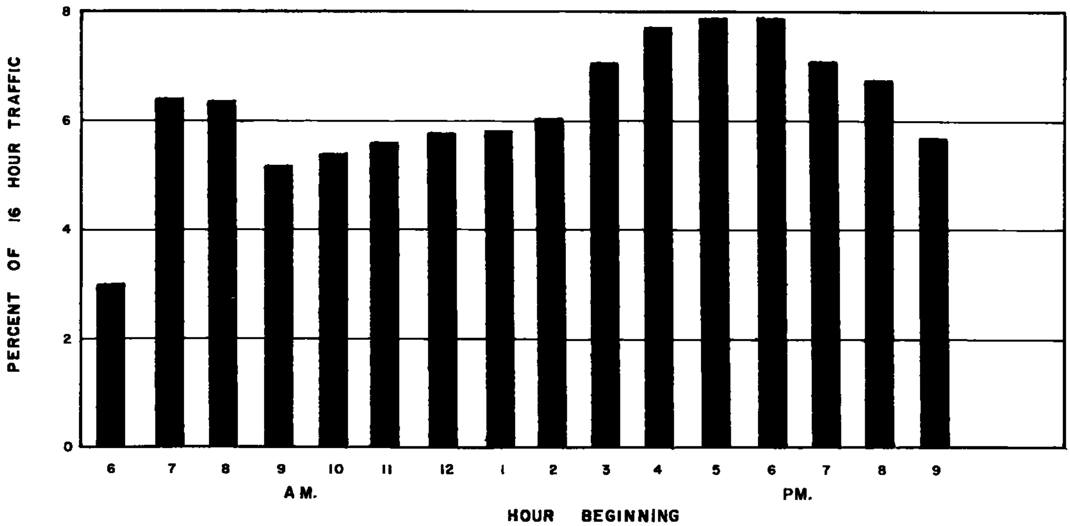

Figure 11. Hourly distribution of taxi trips—groundcounts at screenlines, 1948.

[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 nonresidents.

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-

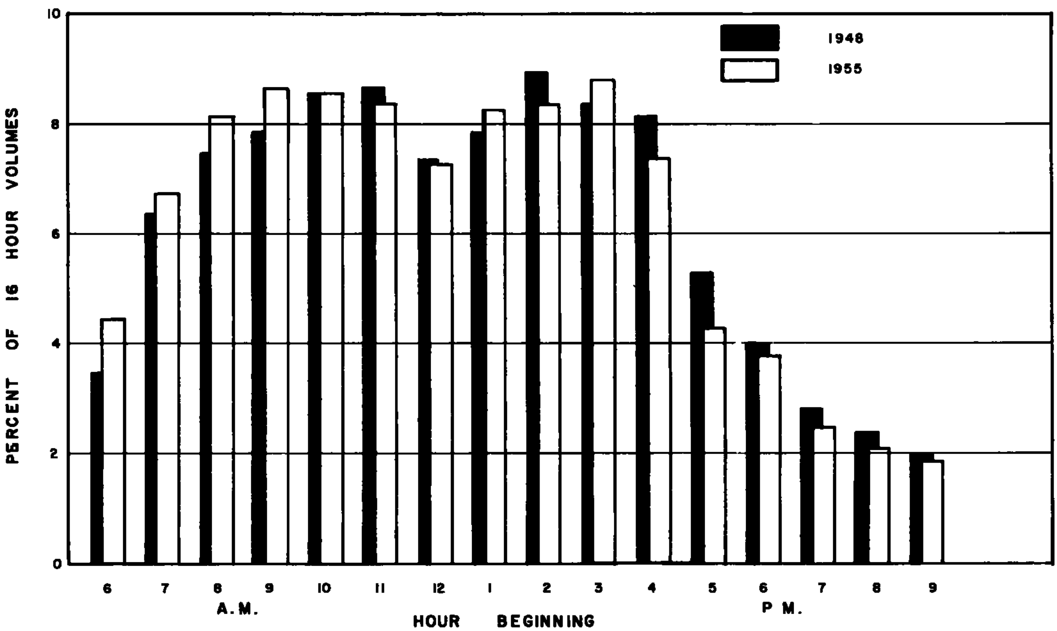

Figure 12. Hourly distribution of truck trips at combined Potomac and Anacostia River screenlines, 1948-1955.

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.

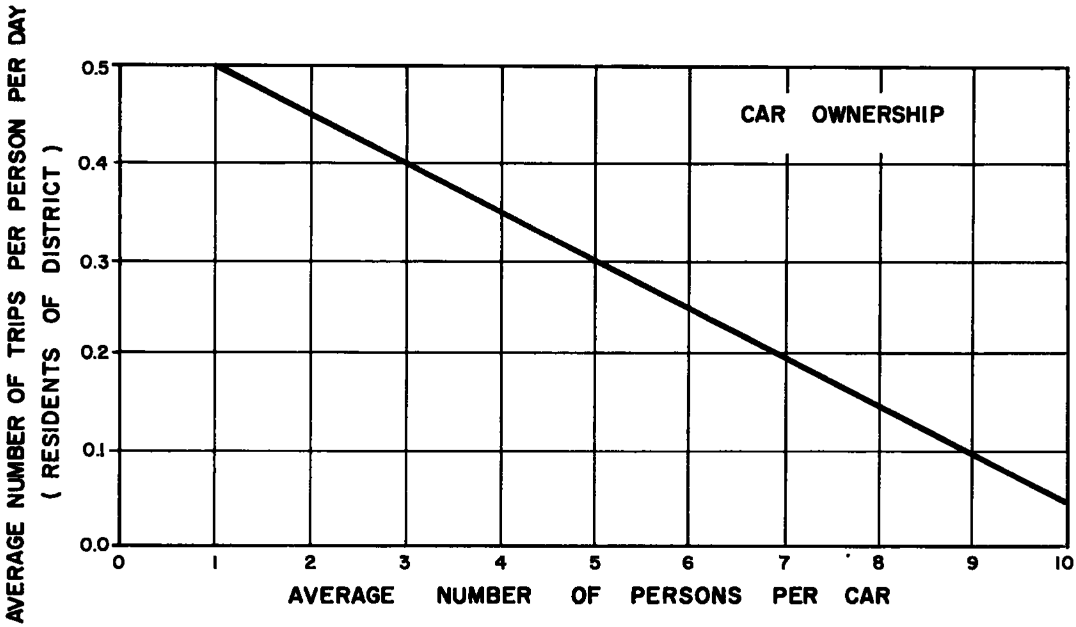

Figure 13. Trips made by residents of metropolitan area.

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.

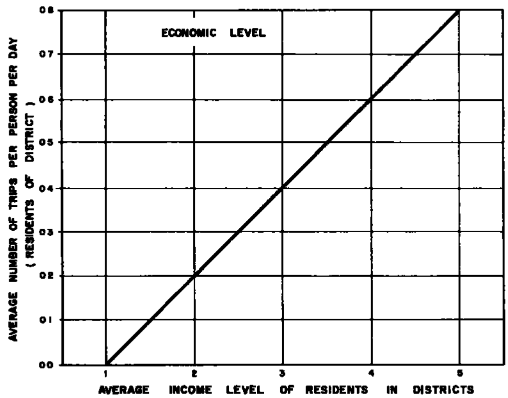

Figure 14. Trips made by residents of metropolitan area.

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.

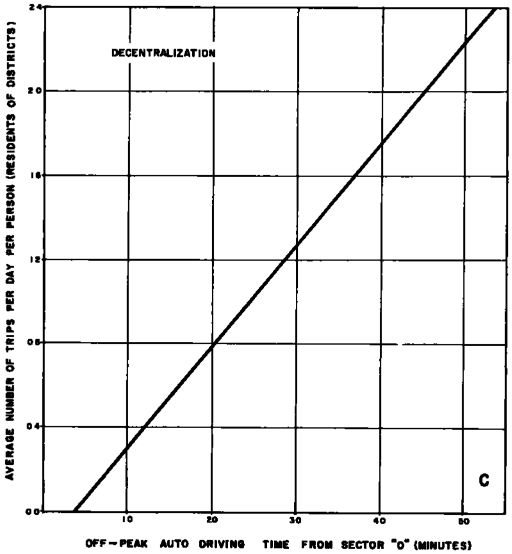

Figure 15. Trips by residents of metropolitan area.

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.

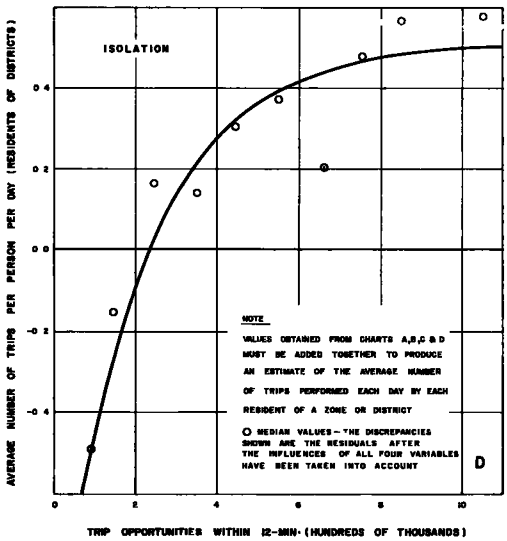

Figure 16. Trips by residents of metropolitan area.

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.

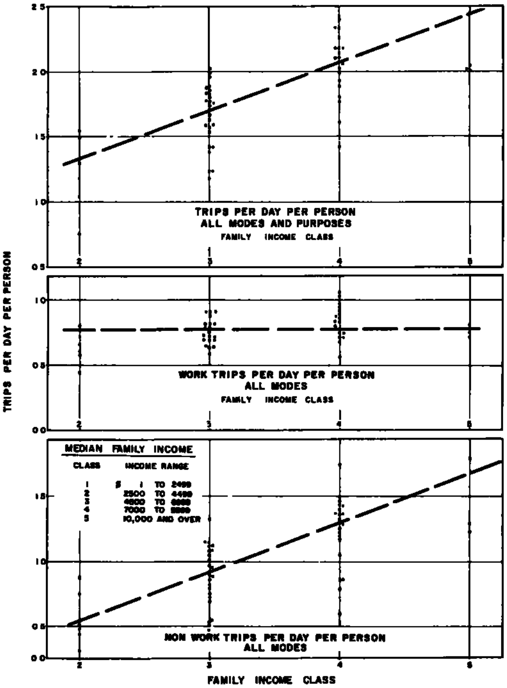

Figure 17. Trips by residents, 1955.

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

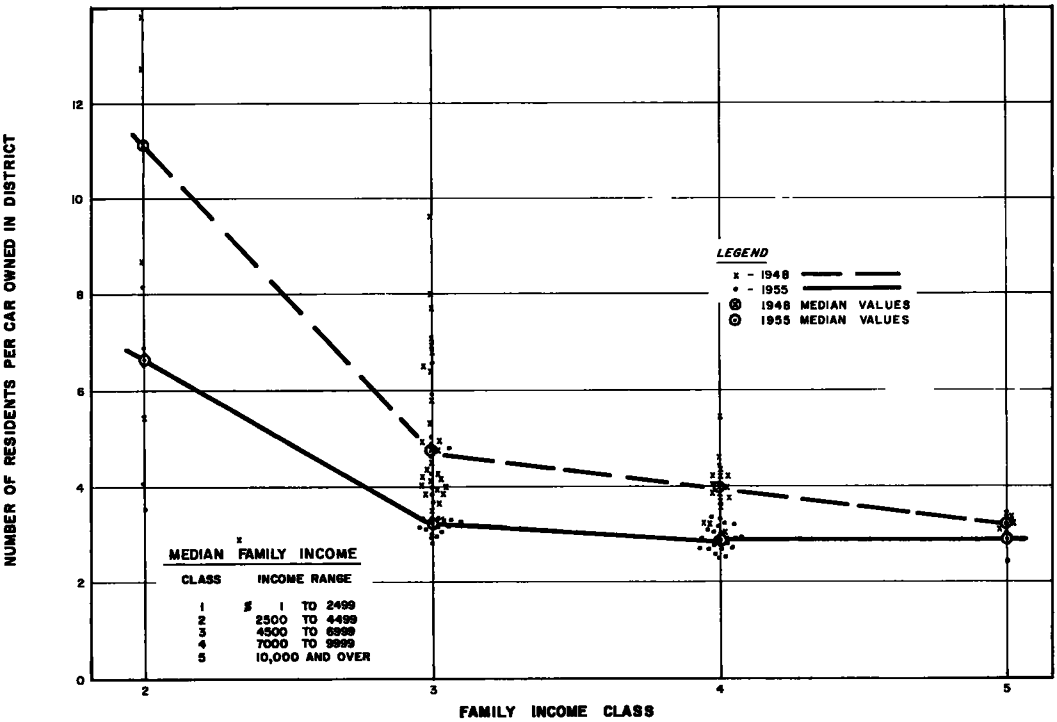

Figure 18. Car ownership related to family income, 1948 & 1955.

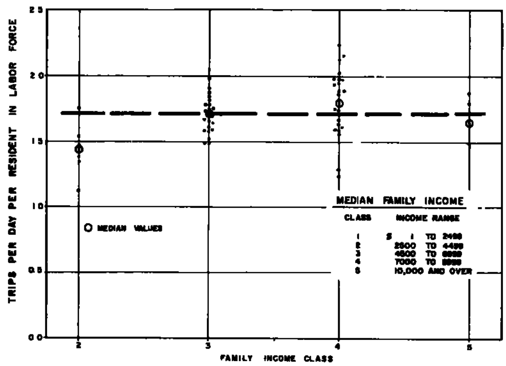

Figure 19. Work trips by labor force vs family income, 1955.

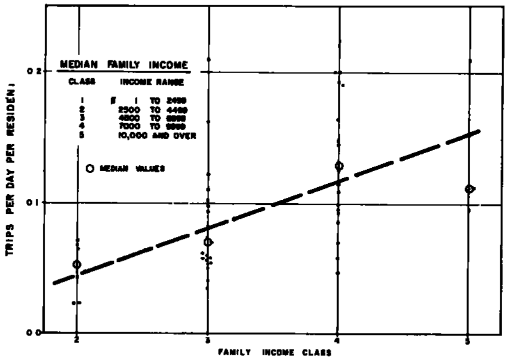

Figure 20. Miscellaneous trips (work-commercial) by residents, 1955.

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.

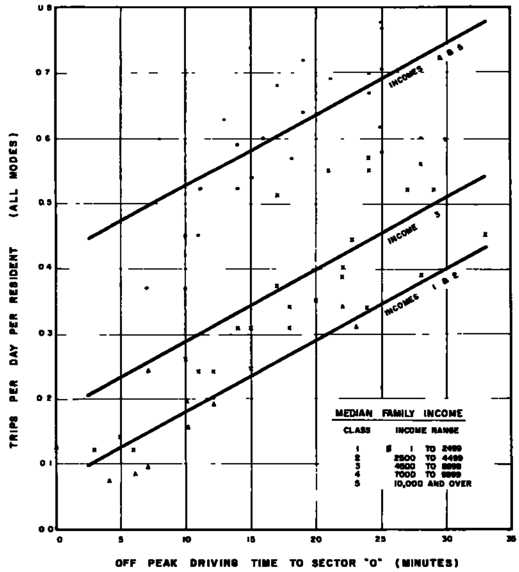

Figure 21. Work trips by labor force vs. family income, 1955.

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:

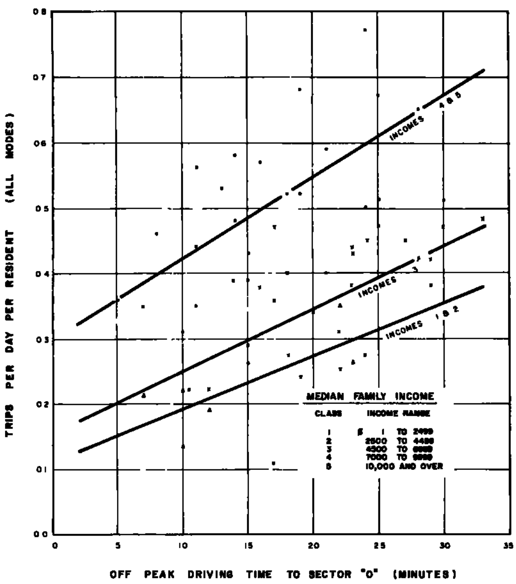

Figure 22. Social trips by residents, 1955.

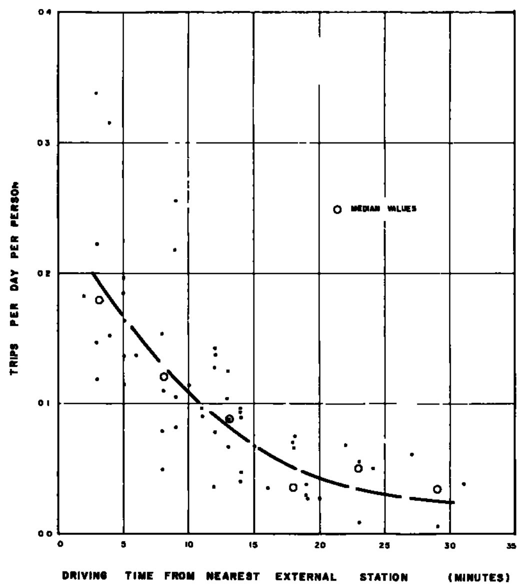

Figure 23. External trips by residents, 1955.

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.

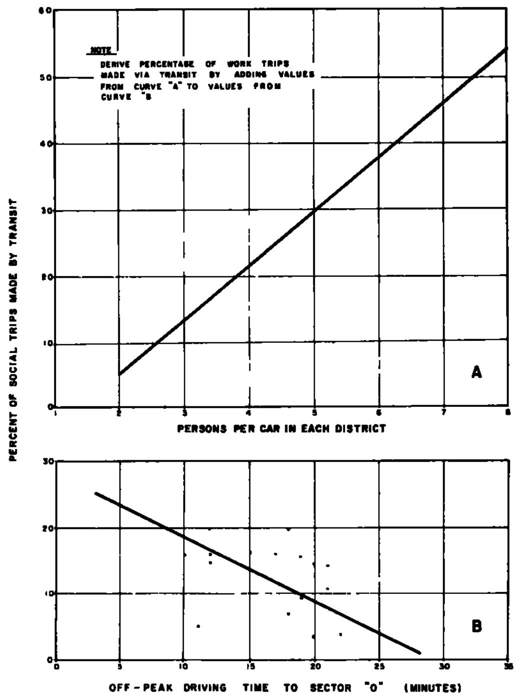

Figure 24. Internal social transit trips as percent of all social trips by District of Columbia residents, 1955.

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.

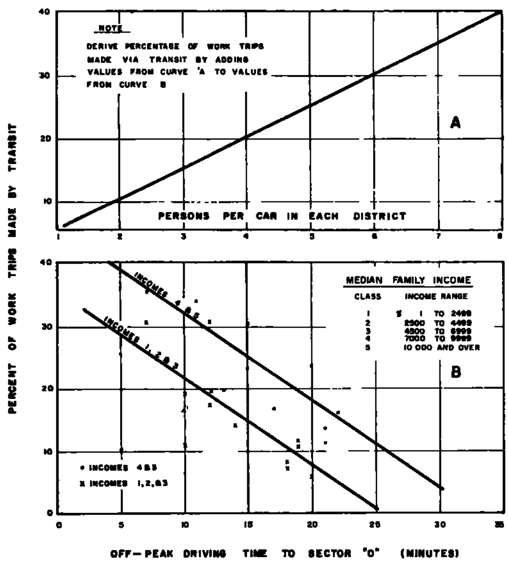

Figure 25. Internal transit trips for work as percent of all work trips by District of Columbia residents, 1955.

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.

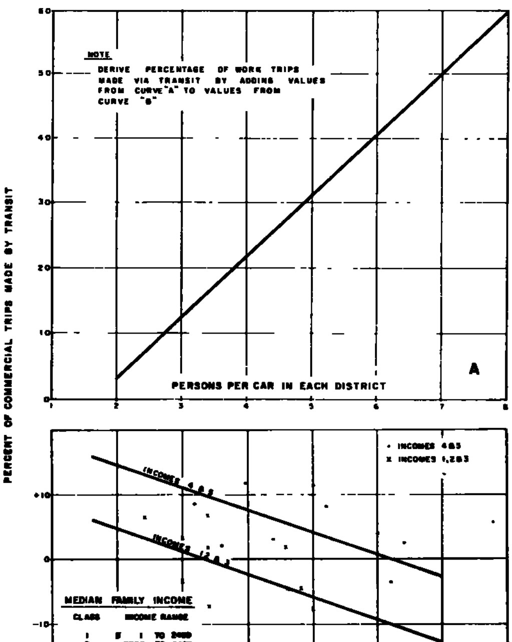

Figure 26. Internal commercial transit trips as percent of all commercial trips by District of Columbia residents, 1955.

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[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."

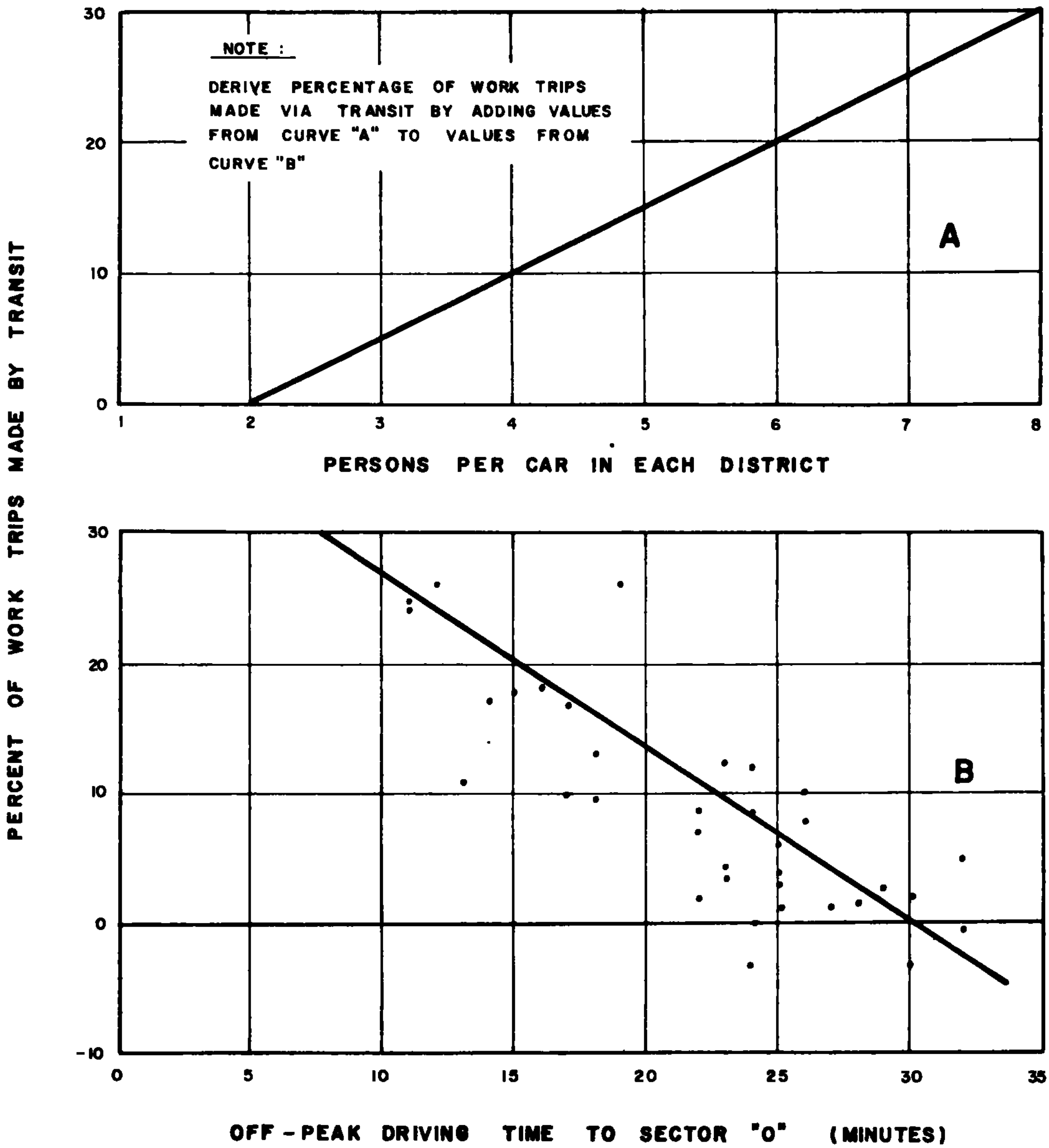

Figure 27. Internal transit trips for work as percent of all work trips by Maryland and Virginia residents, 1955.

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

		Work Trips			Commercial Trips			Social Trips		
		All	Transit Trips		All	Transit Trips		All	Transit Trips	
Area		Modes	No.	%	Modes	No.	%	Modes	No.	%
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.

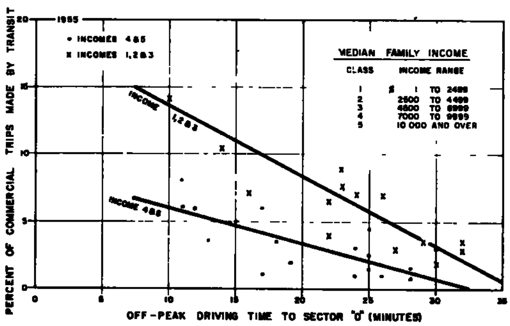

Figure 28. Internal commercial transit trips as percent of all commercial trips by Maryland and Virginia residents.

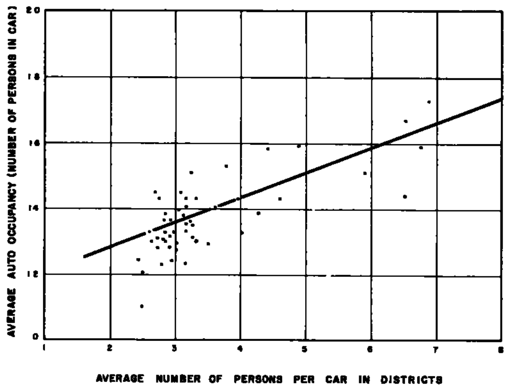

Figure 29. Average occupancy of automobile trips for work, 1955.

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

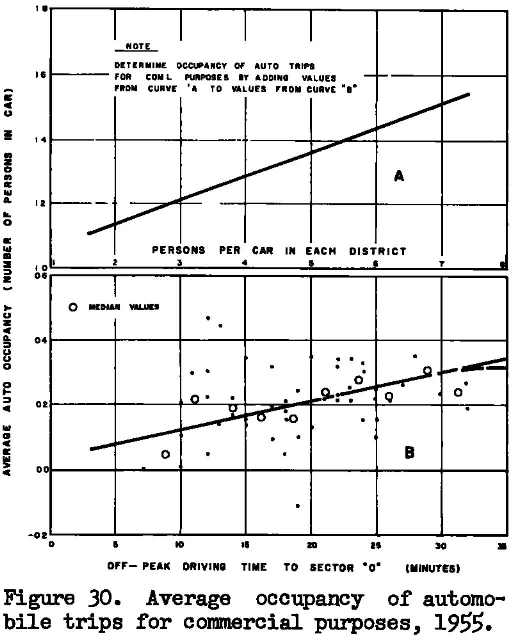

Figure 30. Average occupancy of automobile trips for commercial purposes, 1955.

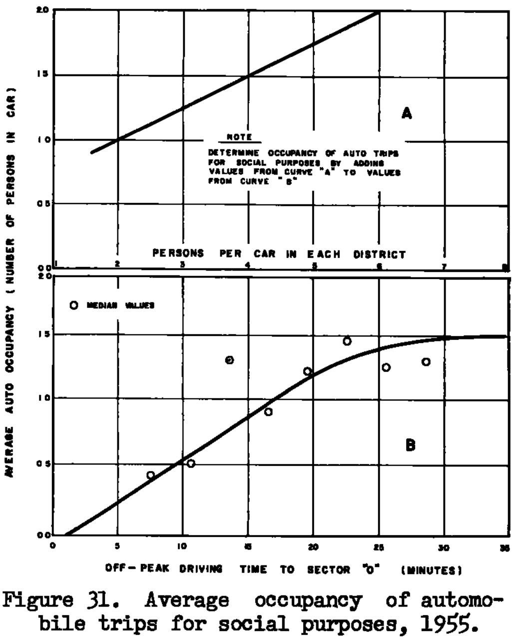

Figure 31. Average occupancy of automobile trips for social purposes, 1955.

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.

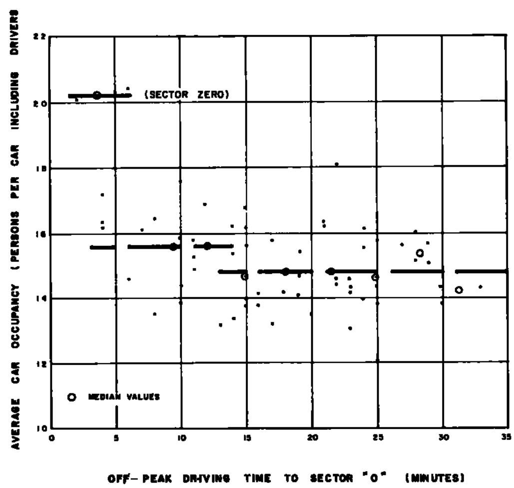

Figure 32. Average car occupancy—commercial trips to and from retail centers.

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.

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.

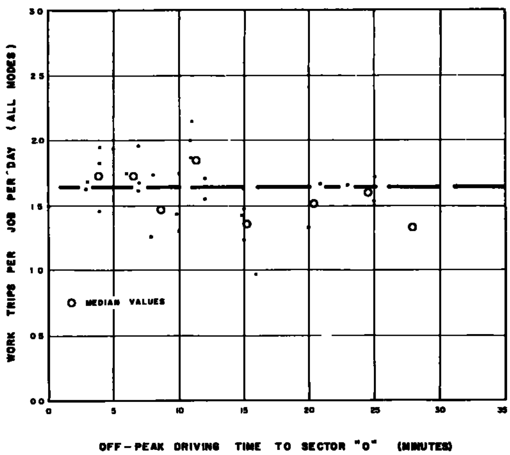

Figure 33. Work trips generated by employment.

[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	8-9	p.m. 4-5	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

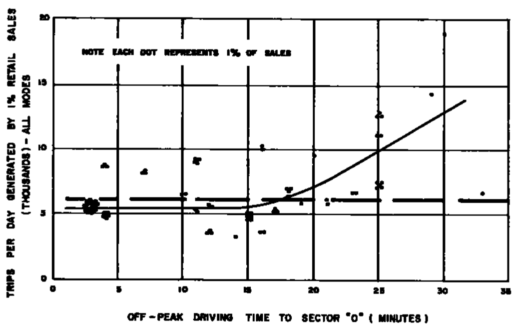

Figure 34. Commercial trips generated by retail centers; trips per 1 percent metropolitan area retail sales in districts which generate 1 percent or more of total metropolitan area sales.

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.

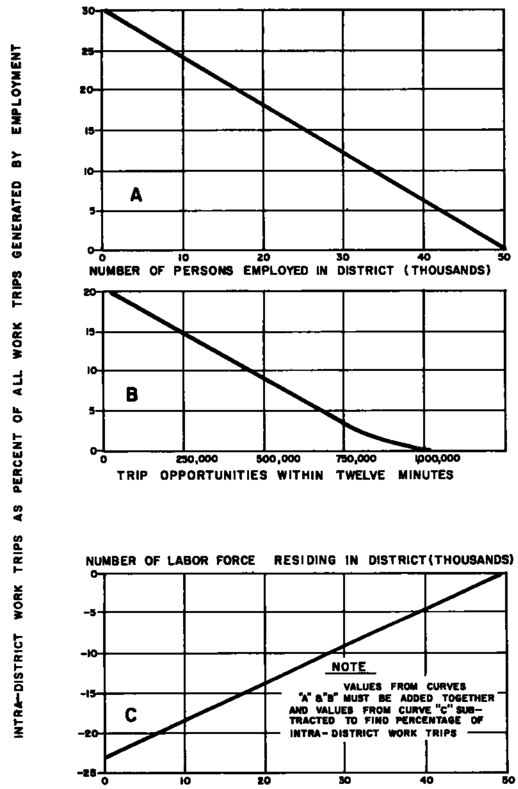

Figure 35. Intra-district work trips, all modes.

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.

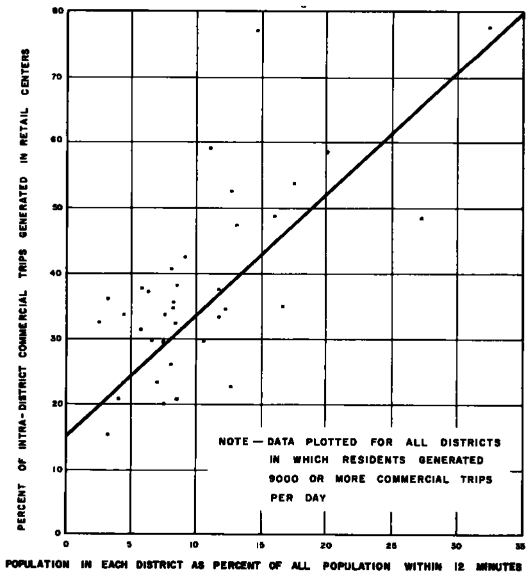

Figure 36. Intra-district commercial trips to and from retail centers, all modes.

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.

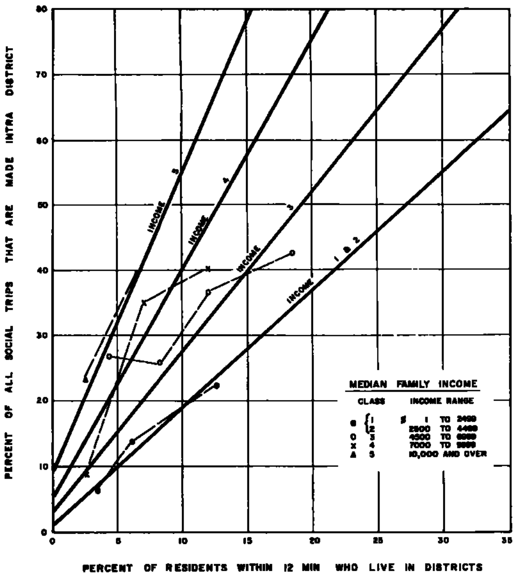

Figure 37. Intra-district social trips: district of social terminus, all modes of travel.

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."

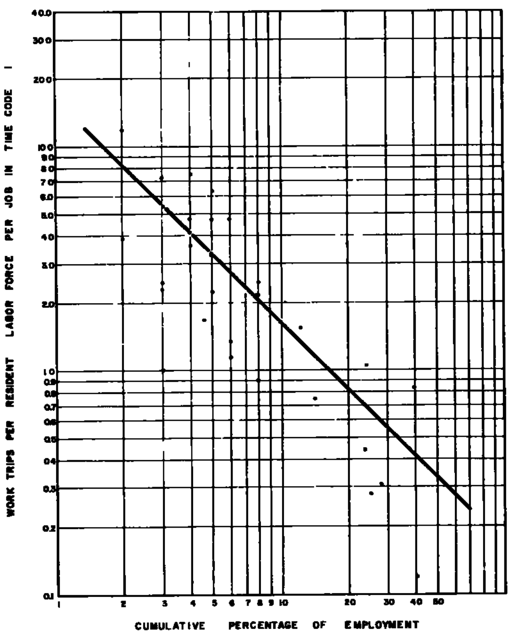

Figure 38. Auto driver and passenger work to and from home, time code 1.

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	All Trips	1948 Intra	% Intra	All Trips	1955 Intra	% 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-

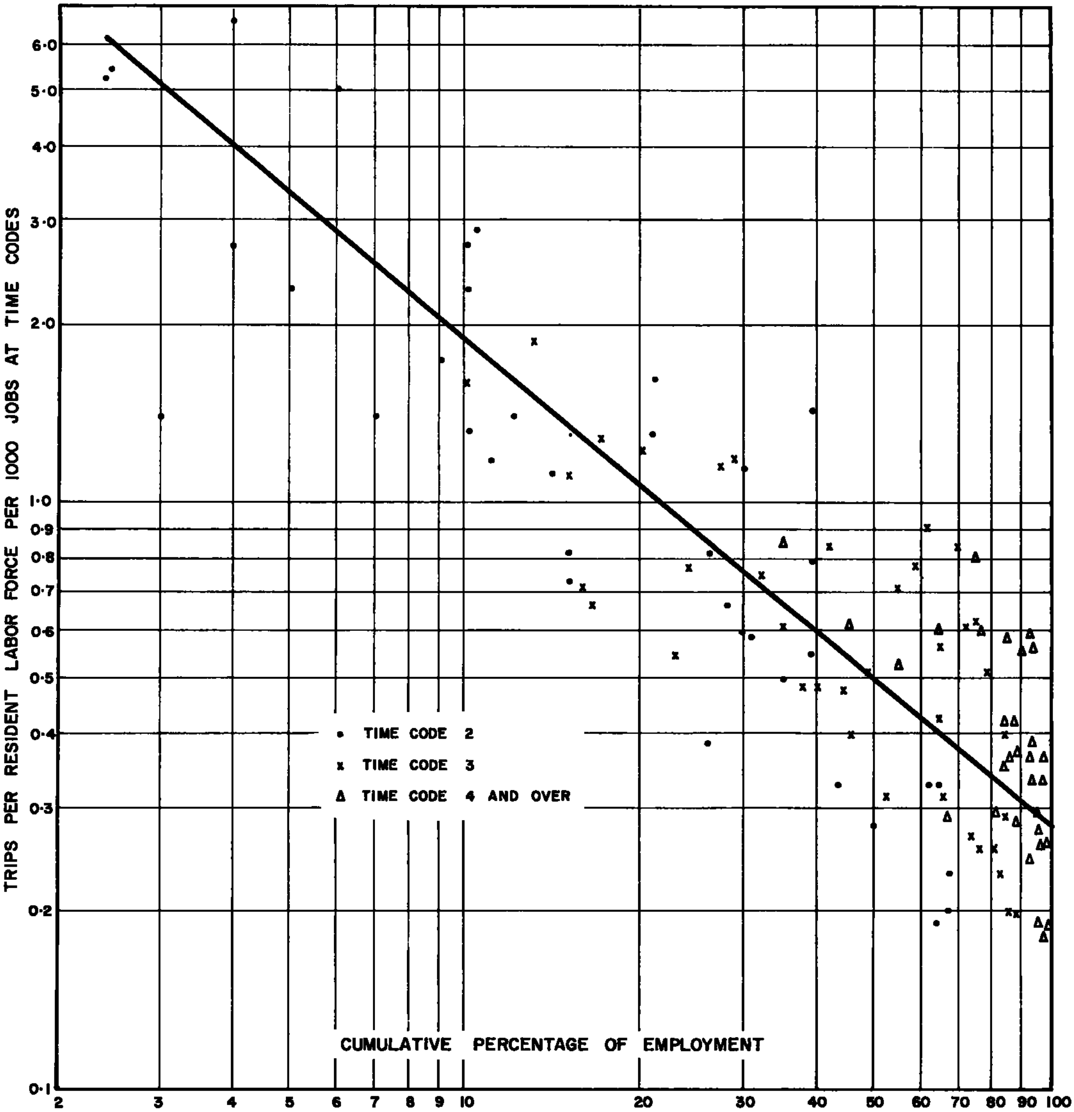

Figure 39. Auto driver and passenger work trips to and from home, time codes 2 and over.

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.

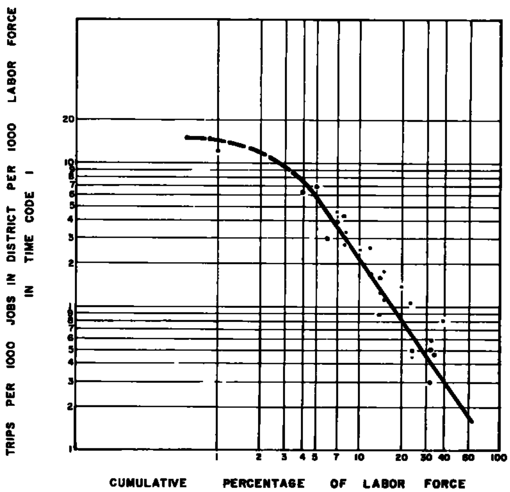

Figure 40. Auto drivers and passengers to and from work, time code 1.

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.

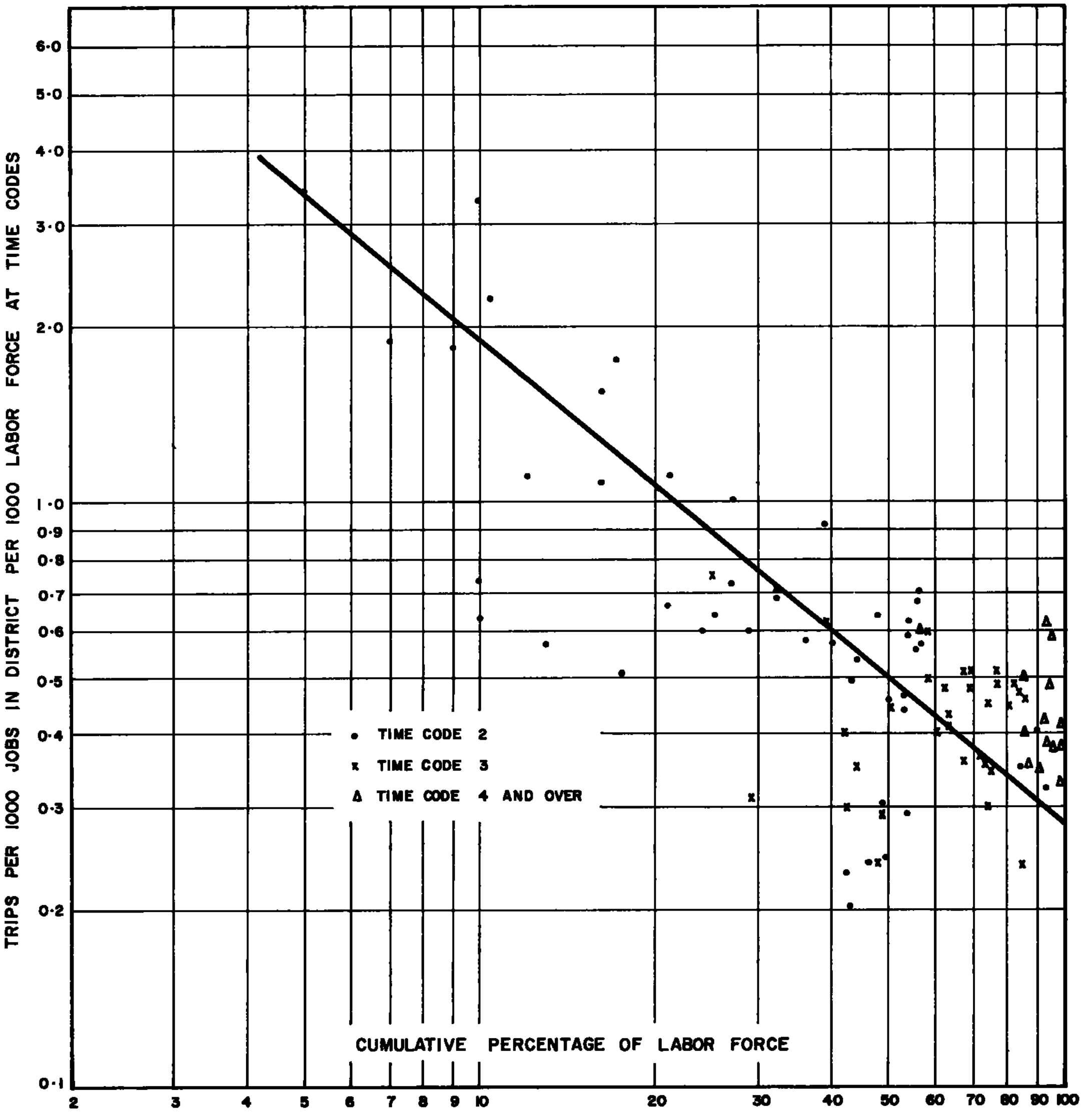

Figure 41. Auto drivers and passengers to and from work; time codes 2 and over.

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

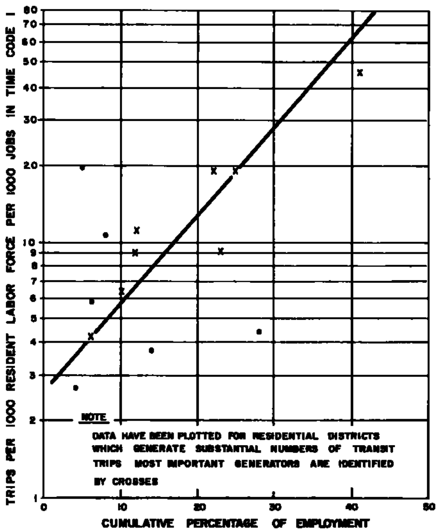

Figure 42. Transit rider work trips to and from home; time code 1.

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.

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 emplovment tended to be centrally oriented within the metropolitan area, while residential districts were decentralized. Commercial locations were centralized to a lesser degree than employment.

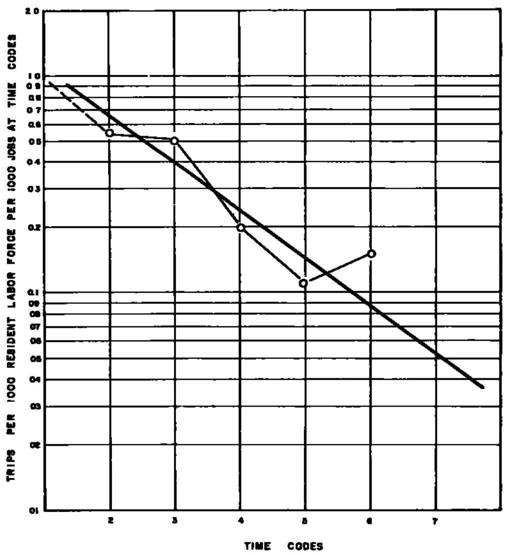

Figure 43. Transit rider work trips to and from home; time codes 2 and over.

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.

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.

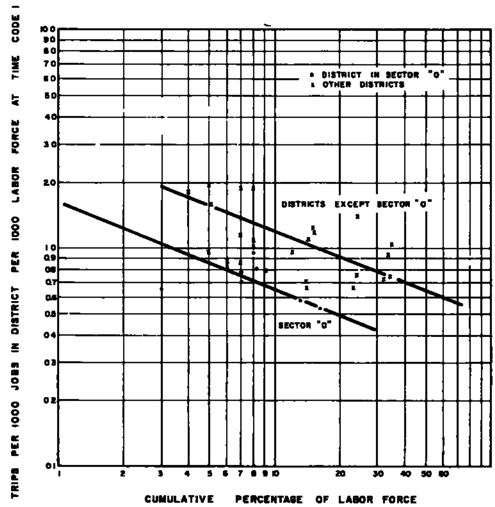

Figure 44. Transit riders to and from work; time code 1.

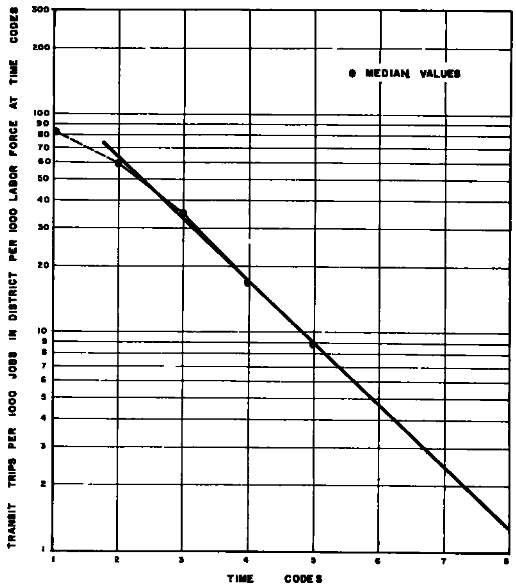

Figure 45. Transit riders to and from work; time codes 2 and over.

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.

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 employment 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

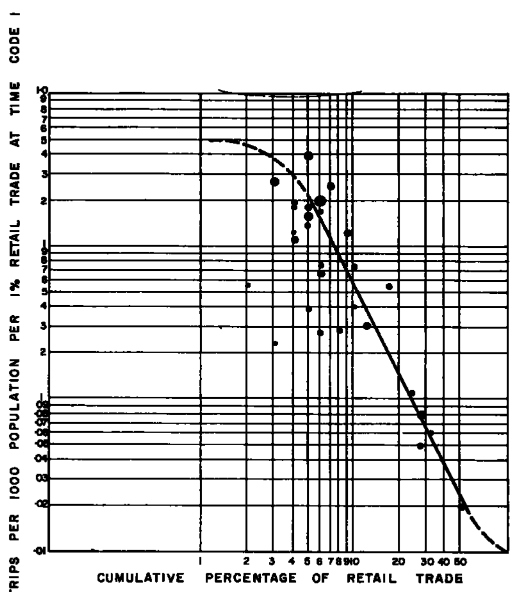

Figure 46. Driver and passenger commercial trips to and from home; time code 1.

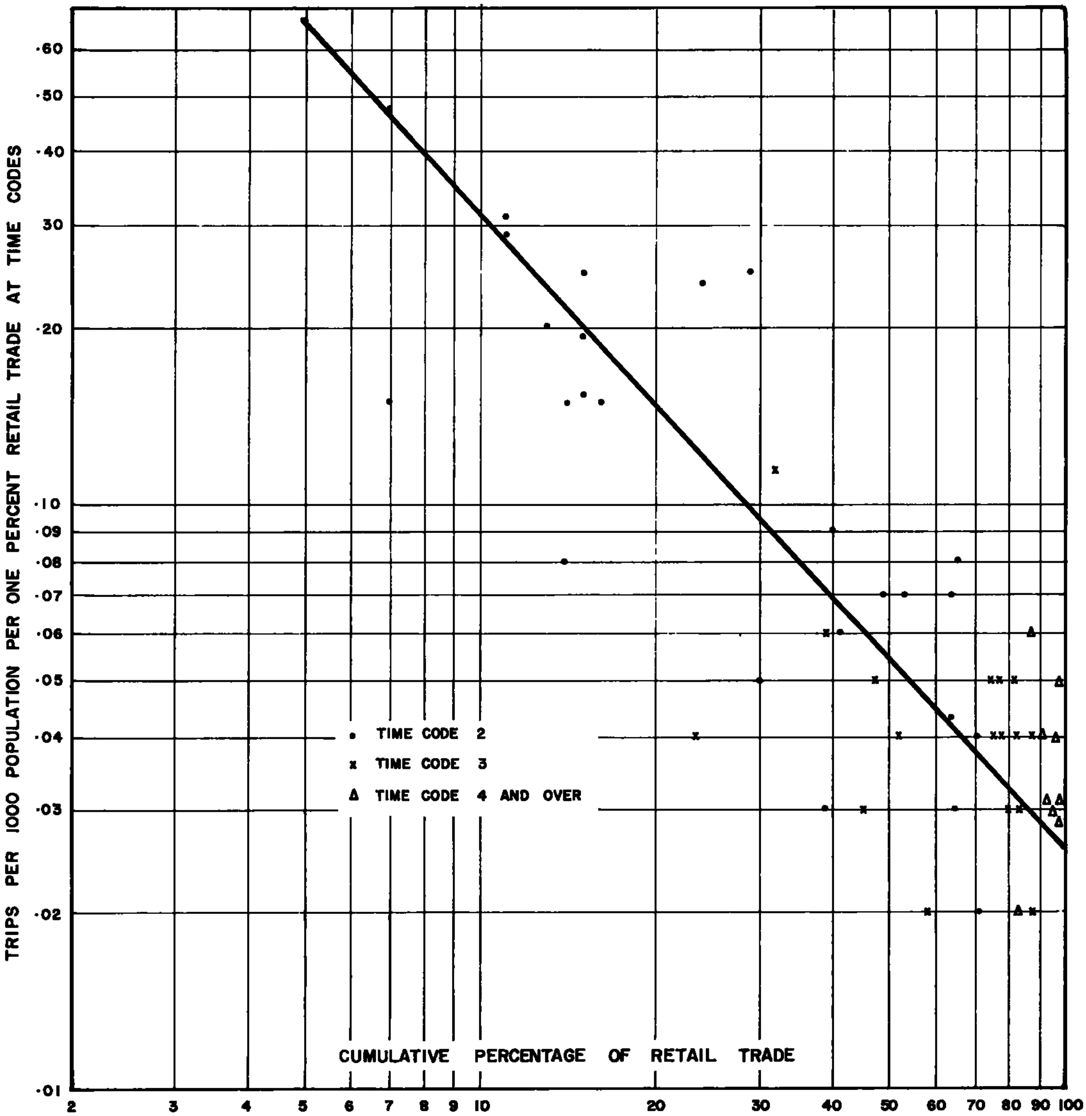

Figure 47. Driver and passenger commercial trips to and from home; time codes 2 and over.

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.

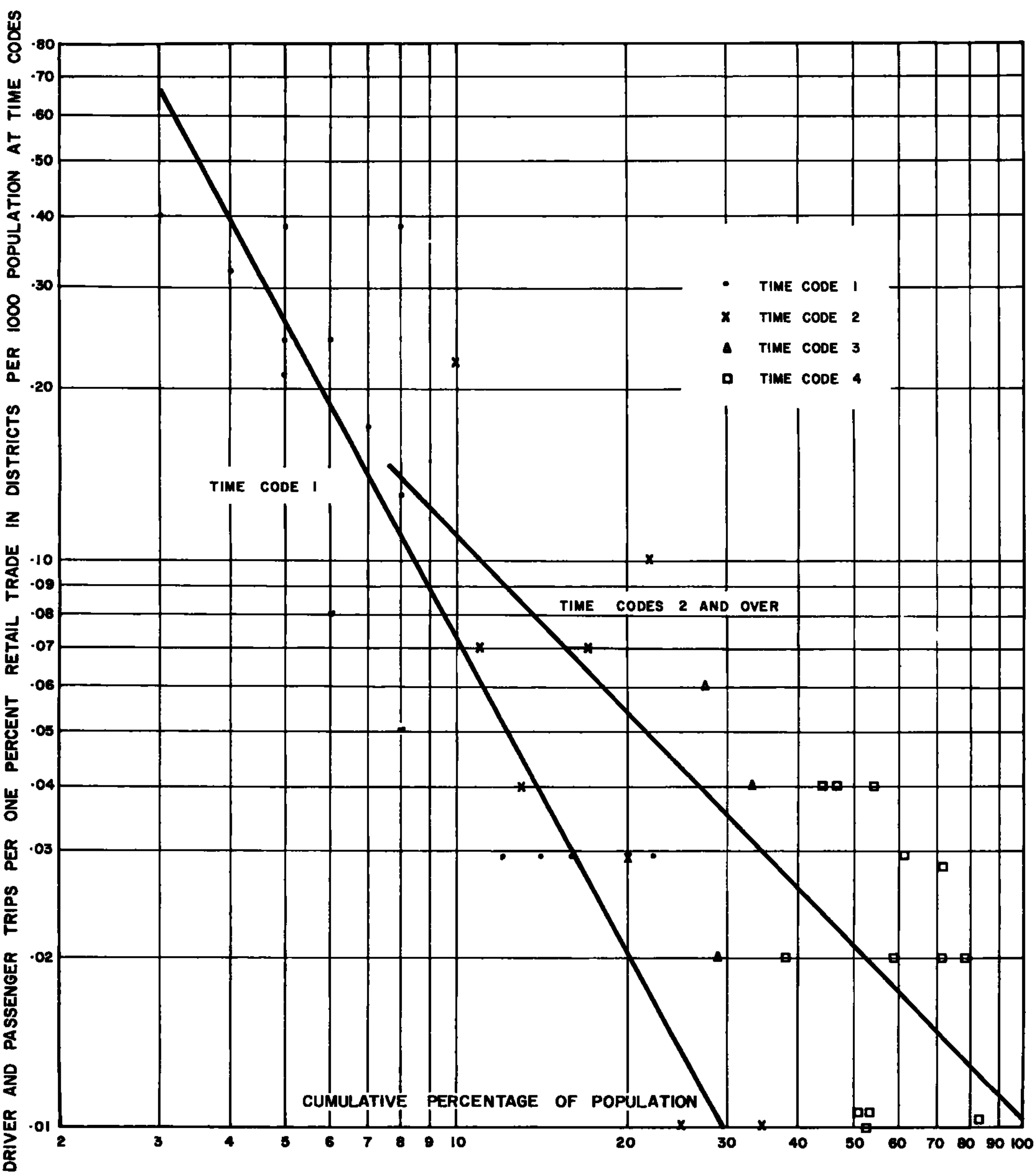

Figure 48. Drivers and passengers to and from commercial purposes; all time codes.

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.

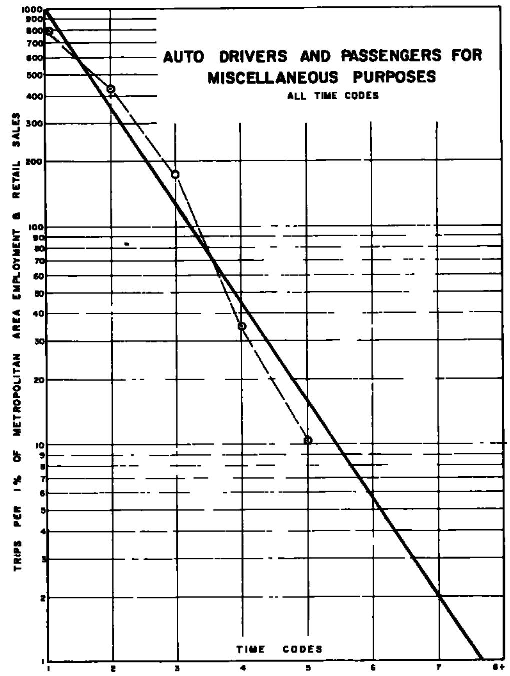

Figure 49. Auto drivers and passengers for miscellaneous purposes; all time codes.

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.

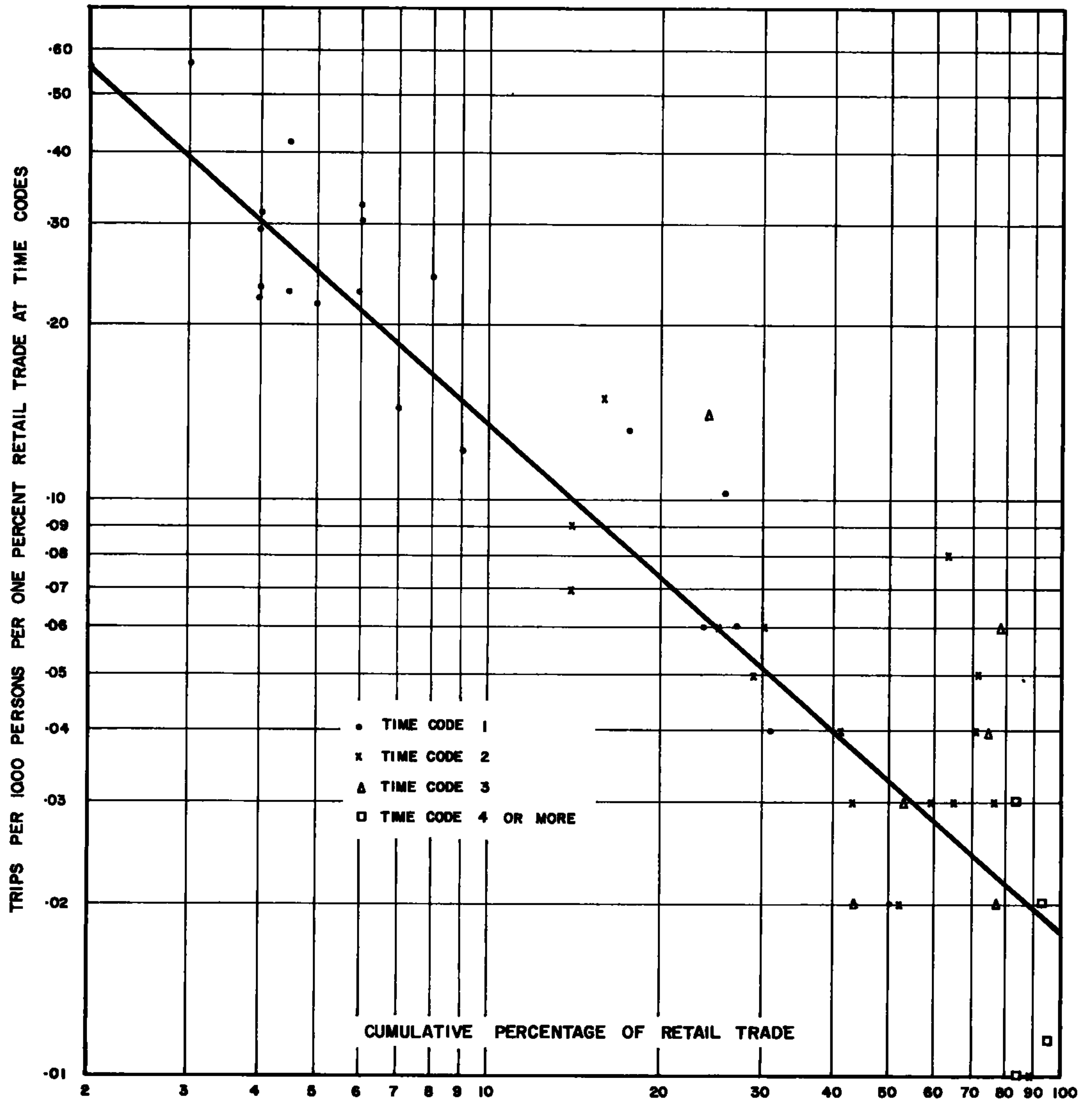

Figure 50. Transit rider commercial trips to and from home; all time codes.

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

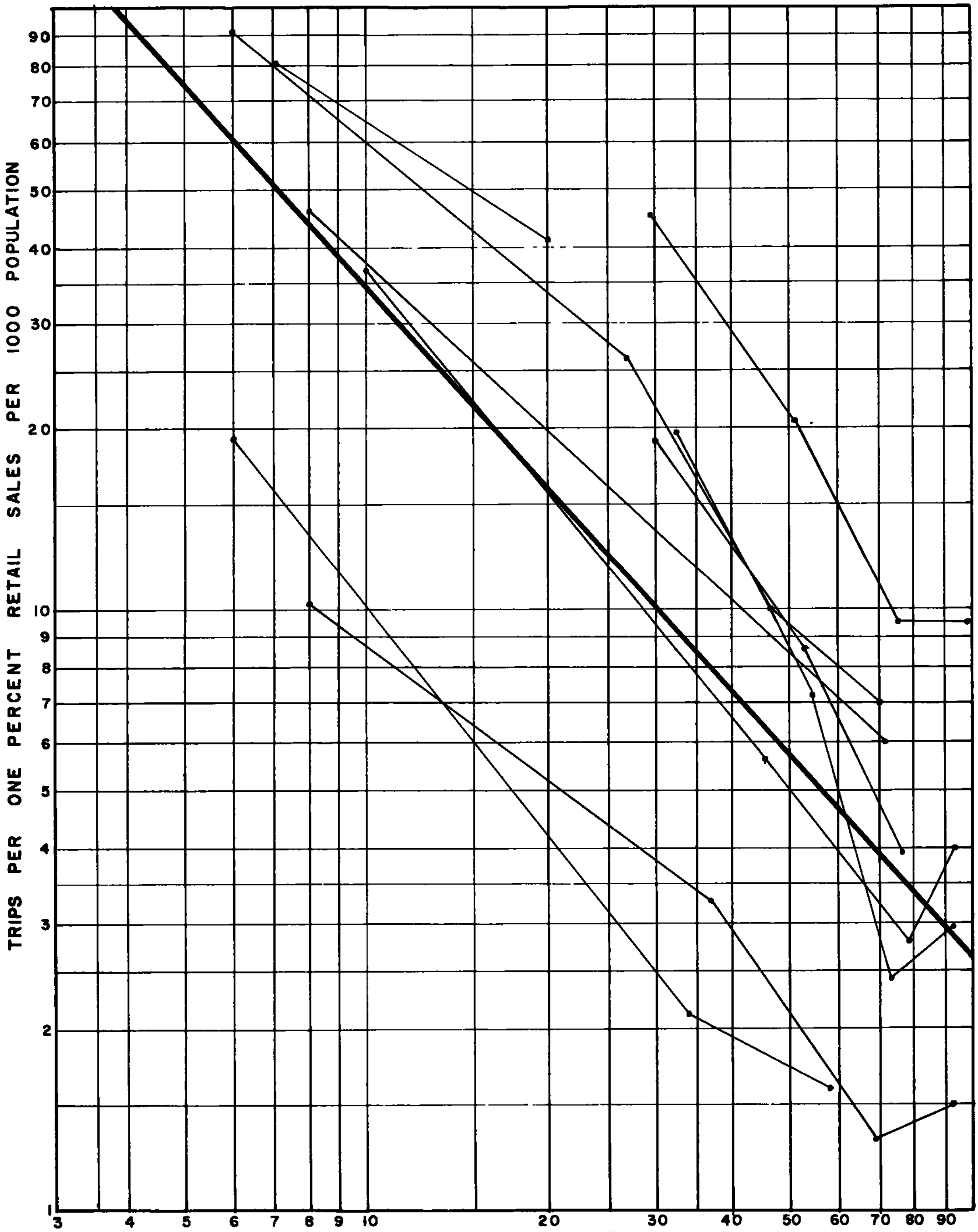

Figure 51. Transit rider trips to and from commercial purposes; all time codes.

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.

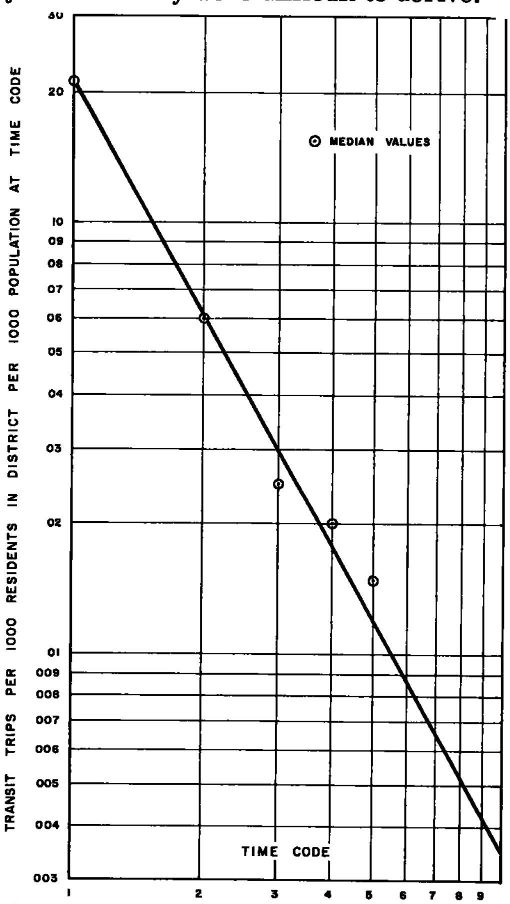

Figure 53. Transit trips for social purpose; all time codes.

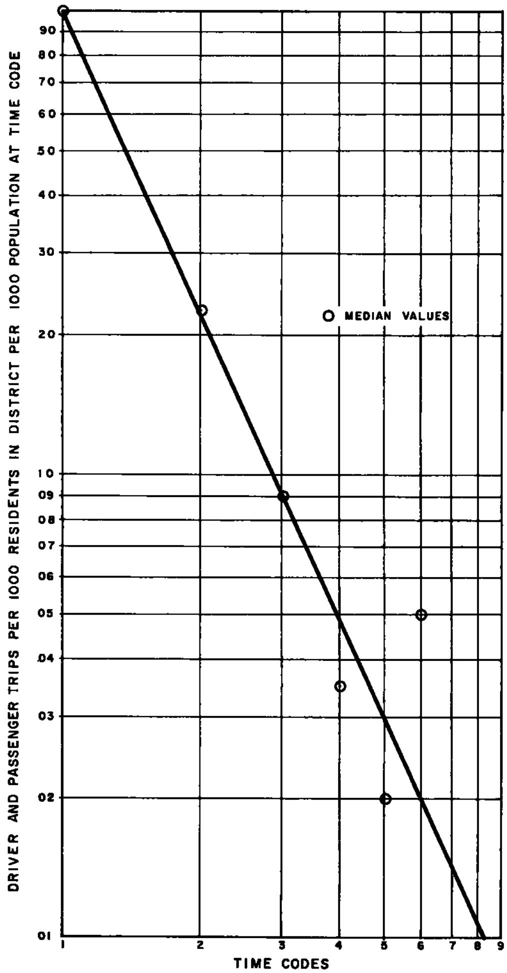

Figure 52. Driver and passenger social trips between districts; all time codes.

Intra-district trips were seriously under-reported 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:

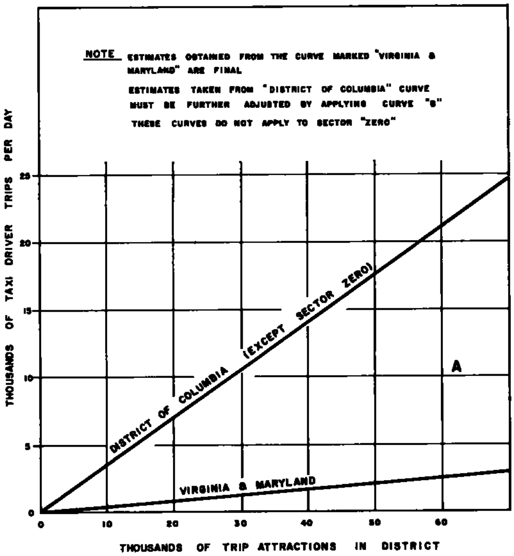

Figure 54. Taxi driver trips generated in districts.

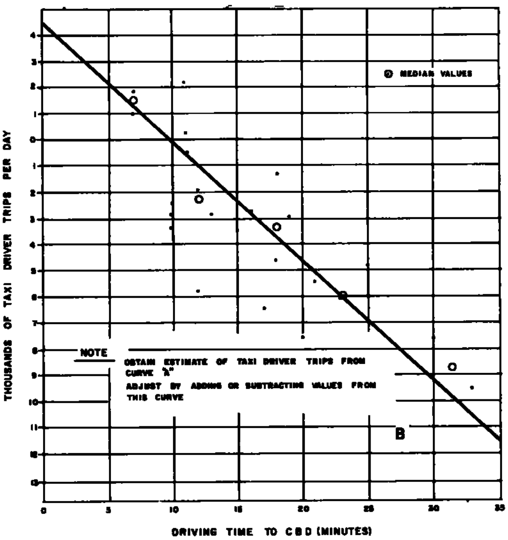

Figure 55. Taxi driver trips generated in District of Columbia.

(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:

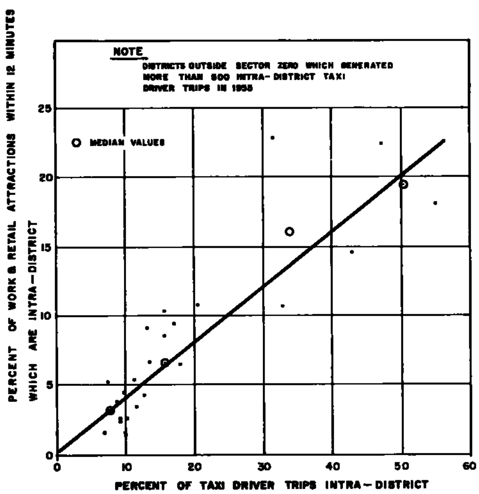

Figure 56. Intra-district taxi driver trips.

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

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

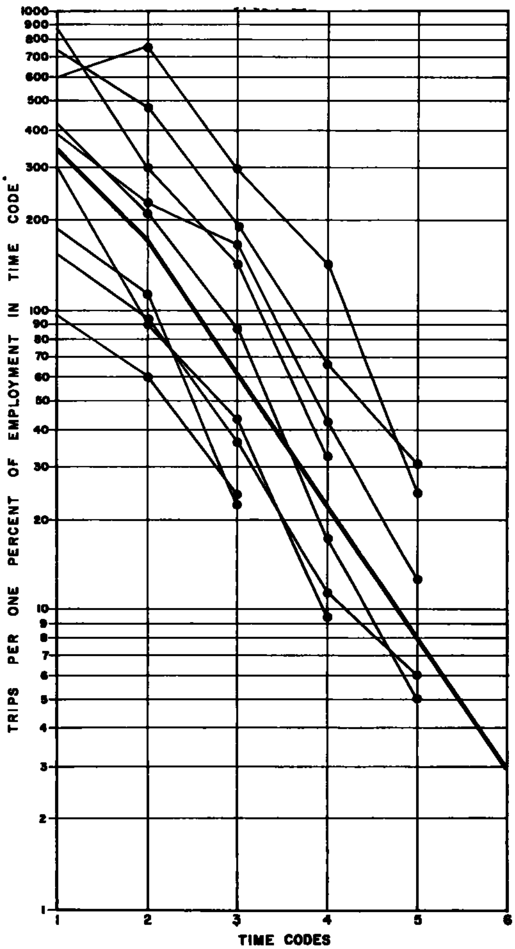

Figure 57. Taxi driver trips; all time codes.

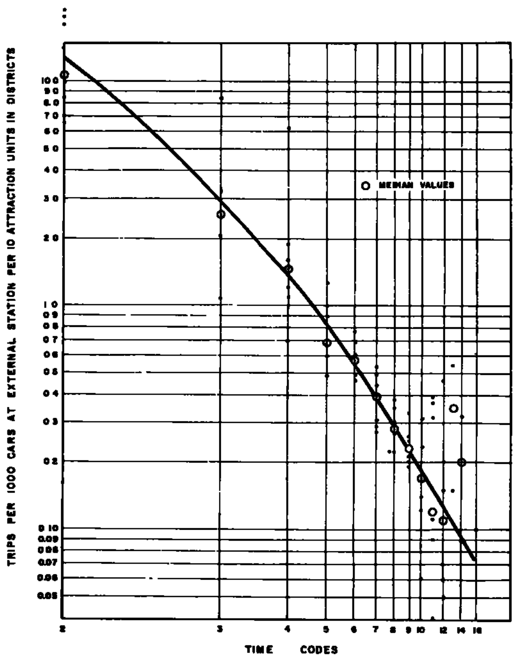

Figure 58. Auto driver trips between stations and districts; all time codes.

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 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

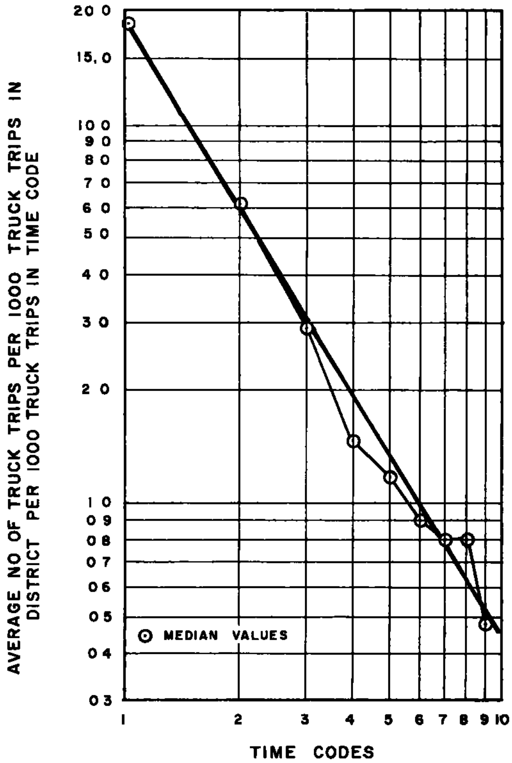

Figure 59. Truck trips between districts.

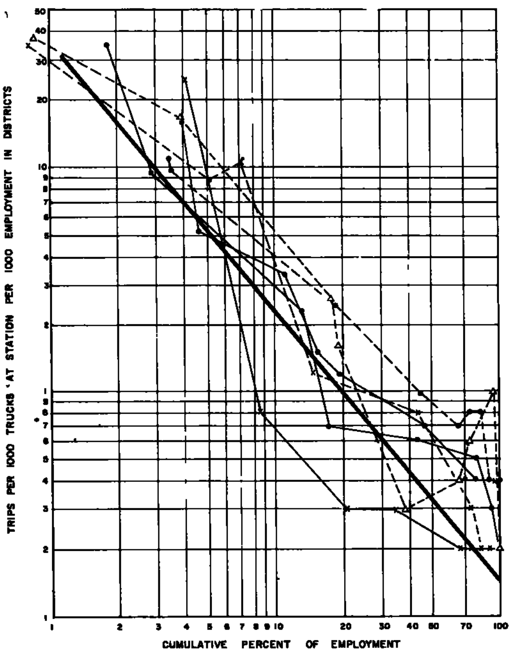

Figure 60. Truck trips between stations and districts.

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 6:00p. 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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Traffic Characteristics of Massachusetts Route 128

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This paper presents an analysis of the travel patterns of employees of new industrial development adjacent to Massachusetts Route 128, a limited-access circumferential highway located about 10 mi from the central business district of Boston. These travel patterns are compared with those of in-town industrial employees, and the impact of the "generated " traffic is evaluated.

Most of the data presented are separated according to two major classifications: (a) Route 128 user, and non-user; and (b) present employees who worked for a company before it moved to Route 128, and those who joined a company after it moved. Additional separations are made for each of four types of industry and for each of seven industrial locations along the highway. Also, average times, distances, and speeds to work are presented for the employees who live in outlying, intermediate, and in-town residential areas.

Also included is other information concerning the parking facilities of the new industries along the highway, as well as data on employment-vehicle ratios for various types of industry and ranges of employment.

Finally, an evaluation is made of the study and its methodology, together with comments regarding future areas of research.

●THE INFORMATION in this paper is based on an employee travel pattern survey conducted as part of the survey of new industrial development along Route 128, and has been integrated with an origin-and-destination (O-D) survey of the entire route made by the Traffic Division of the Massachusetts Department of Public Works. The purpose of these surveys was to determine the amount and character of traffic generated by industrial development and the impact of this traffic on Route 128 and on the metropolitan area as a whole.

More specifically, answers were sought for such questions as: are employees moving closer to their place of work; are distances to work becoming longer or shorter; are travel times longer or shorter; are modes of travel changing; to what extent are car pools being used; does the availability of Route 128 permit longer distances to work in less time; what parking capacities are needed; and what are the effects of industrial traffic on the operation of Route 128?

The answers to many of these questions will be influenced by the fact that Boston is on the sea coast, and that Route 128, therefore, is only a semi-circumferential highway. The traffic patterns developed in this section will reflect these characteristics.

Description of Route

Route 128 is a circumferential highway describing an arc of 8- to 10-mile radius around metropolitan Boston (Fig. 1). The northeast section continues as a radial route to Gloucester. The present route replaces an earlier route composed of local roads connecting and passing through the business centers of most of the cities and towns surrounding Boston. Most of the route followed heavily traveled 2-lane roads of obsolete design. Although it appeared upon road maps as a bypass of Boston, it actually had little to offer in time savings or congestion relief.

Though portions of Route 128 were built during the 1930's, the section of highway from Wakefield (west of Route 1) to Route 9 in Wellesley which was completed in August 1951 provided for the first time an effective, high-speed circumferential highway around the most congested districts of the metropolitan Boston area. This 23-mile link was a 4-lane, fully controlled-access highway bypassing the congested business districts of Wakefield, Stoneham, Woburn, Lexington, Waltham, and Newton.

Subsequently, the highway was extended south of Route 9 as a 6-lane limited-access divided highway, mostly on new location, and was opened as far as Route 138 in December 1956. Construction is continuing to a junction with Route 3 in Braintree. This will substantially complete the new Route 128 around Boston. The length of the route from Gloucester to Braintree is about 70 miles, though this study is principally concerned with the portion from Route 1A to Route 138, a distance of about 55 miles.

The Master Highway Plan for the Boston Metropolitan Area issued in 1948, included Route 128, but no traffic assignment was made to it and no priority established for its construction. The following comment was made: "Most of the route is in suburban areas beyond the limits of congested developments. The new location is such that right-of-way takings will be held to a minimum and the highway can be developed prior to further expansion of population outward from the Metropolitan Area. This highway should serve a useful purpose in connecting the various radial expressways and other important arterial highways, as well as a bypass and outer distribution route."

When the middle section from Route 1 (north) to Route 9 opened in 1951, daily traffic volumes of 12,000 to 15,000 were predicted with possibly 20,000 on Sunday. During 1957 daily volumes exceed 30,000 with over 50,000 common on summer Sundays (Fig. 2). At the time the highway was opened little thought was given to the development of commercial or industrial uses along the roadsides. It was generally believed that the limited-access feature would discourage such development. However, much development has occurred, and the traffic characteristics of the route have been greatly influenced by this development.

Methods and Procedures

During the survey of industrial development along Route 128 (1, 2), interviews were held with management officials at each plant. At the conclusion of each management interview, the company was requested to distribute to each of their employees a questionnaire which was designed to yield travel pattern information with the fewest number of questions, the least effort on the part of the employee and the least possibility of ambiguity. Excellent cooperation was obtained. Most industries preferred to circulate the employee questionnaire in their own way and at their own convenience. Some prepared their own directives urging their employees to cooperate, and distributed them with pay checks; others merely placed them in a convenient place, such as near the lunch room door, and left it to the initiative of the employee to fill them out. Some decentralized the responsibility for distribution by routing the forms to department heads and sub-department heads. The latter method proved most effective.

To verify the reliability of the data obtained from the questionnaire regarding vehicles and people at each plant and their use of Route 128, "gate" counts were made at several individual industries and at the New England Industrial Center.

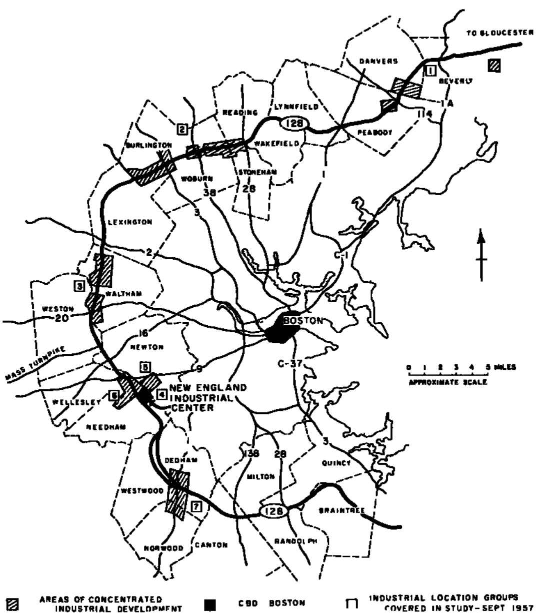


Figure 1. Layout of Route 128 showing areas of industrial development.

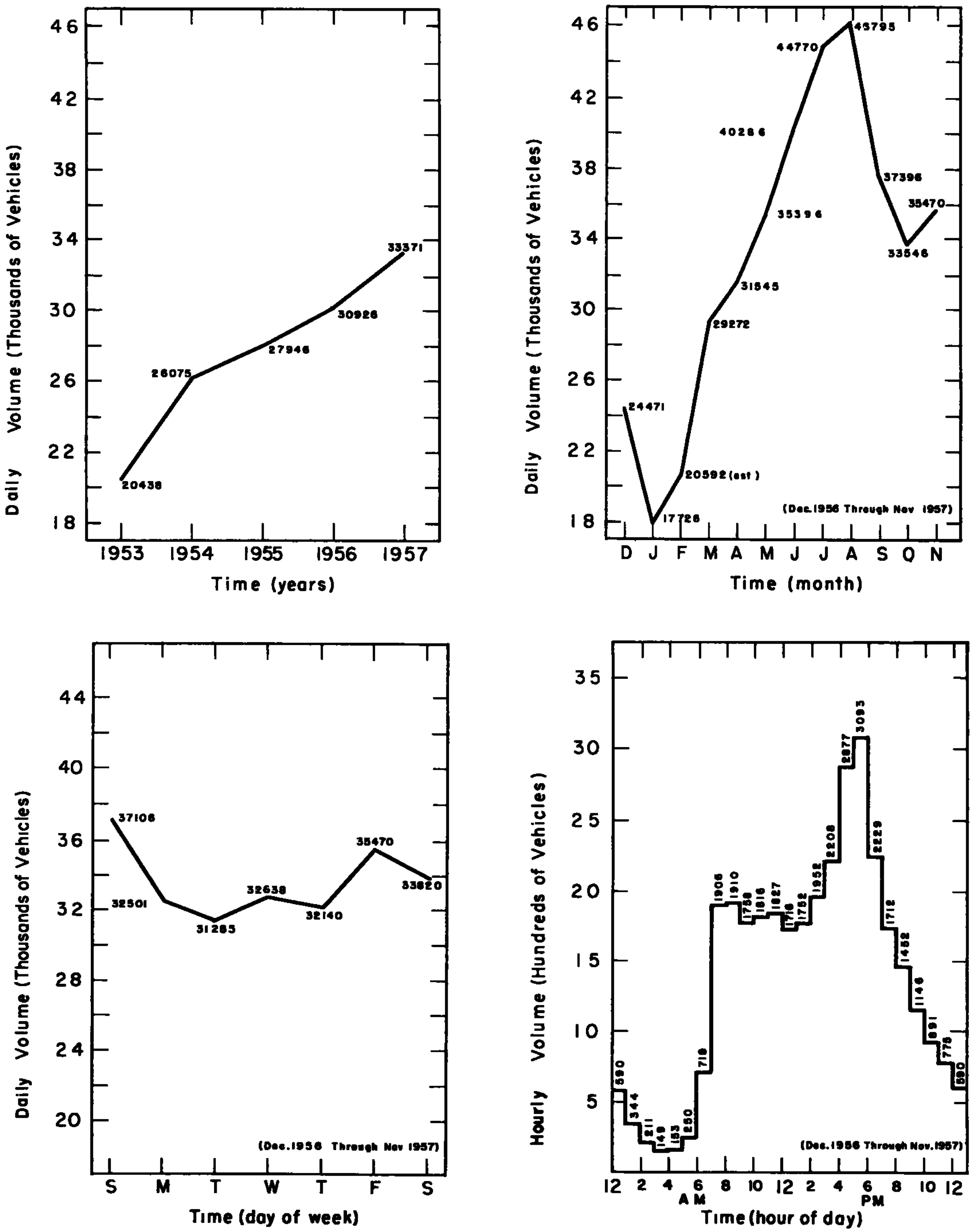


Figure 2. Traffic characteristics on 4-lane divided section of Route 128 at automatic counting station in Burlington, Massachusetts.

The counts were made at the end (or beginning) of the day shift.

The traffic information obtained from the employee questionnaires was supplemented by an O-D survey of all the traffic using Route 128. This was necessary in order to obtain information which would permit an evaluation of the effect of the traffic generated by the industrial development along the highway on over-all highway usage. The O-D survey was conducted by the Traffic and Planning Division of the Massachusetts Department of Public Works during the fall of 1957.

TABLE 1

CHARACTERISTICS OF ROUTE 128 EMPLOYMENT

Type of Industry	Total Employees (%)	Old and New Employees (%) New	Old	Sample Obtained (%)
Distribution	12	46	54	37
Production	72	47	53	45
R and D	13	57	43	43
Service	3	32	68	42
All types	100	48	52	44
Locational Area				
1 North of US 1	14	82	18	45
2 Burlington	18	48	52	57
3. Waltham	26	40	60	55
4. NEIC	13	36	64	31
5. Newton	10	54	46	15
6. Needham	2	45	55	33
7. Dedham	17	36	64	42
All areas	100	48	52	44

Results and Analysis

Description of the Major Separations of Data. The results have been presented in various ways in order to reveal the differences in travel patterns or any correlations which might be useful in future traffic prediction and assignment studies. Data for employees are usually separated into one of the following groups:

1. According to the industrial locational area where the workers are employed;
2. According to the type of industry; and
3. According to the regional zones where employees live.

For most of these three groupings the data are presented separately for:

1. Old Employees—those employed by the company before it moved to Route 128, and
2. New Employees—those who joined a company after it moved to Route 128.

The information is also given separately for Route 128 users who use Route 128 on their trip to work, and non-Route 128 users, who do not use Route 128 in the journey to work.

Characteristics of Route 128 Employment. The distribution of employment along Route 128 has considerable influence on the resulting travel patterns and traffic char-

TABLE 2

DISTRIBUTION OF EMPLOYMENT AND EMPLOYEE QUESTIONNAIRE RETURNS BY YEAR PLANTS STARTED OPERATION ON ROUTE 128

Year Plants Started Operating on Rte. 128	Sept. 1957 Employment (%) At Plants Starting in Each Year	Cumulative	Employee Questionnaires Obtained (%) At Plants Starting in Each Year	Cumulative	Sample Obtained from Plants Starting in Each Year (%)
Before 1951	2	2	2	2	58
During 1951	5	7	7	9	77
During 1952	24	30	19	28	37
During 1953	0[1]	31	1	29	46
During 1954	11	42	10	39	44
During 1955	23	65	18	57	50
During 1956	20	85	27	84	65
To Sept. 1957	15	100	16	100	66
All years	100		100		52

[1]Less than 0.5 percent.

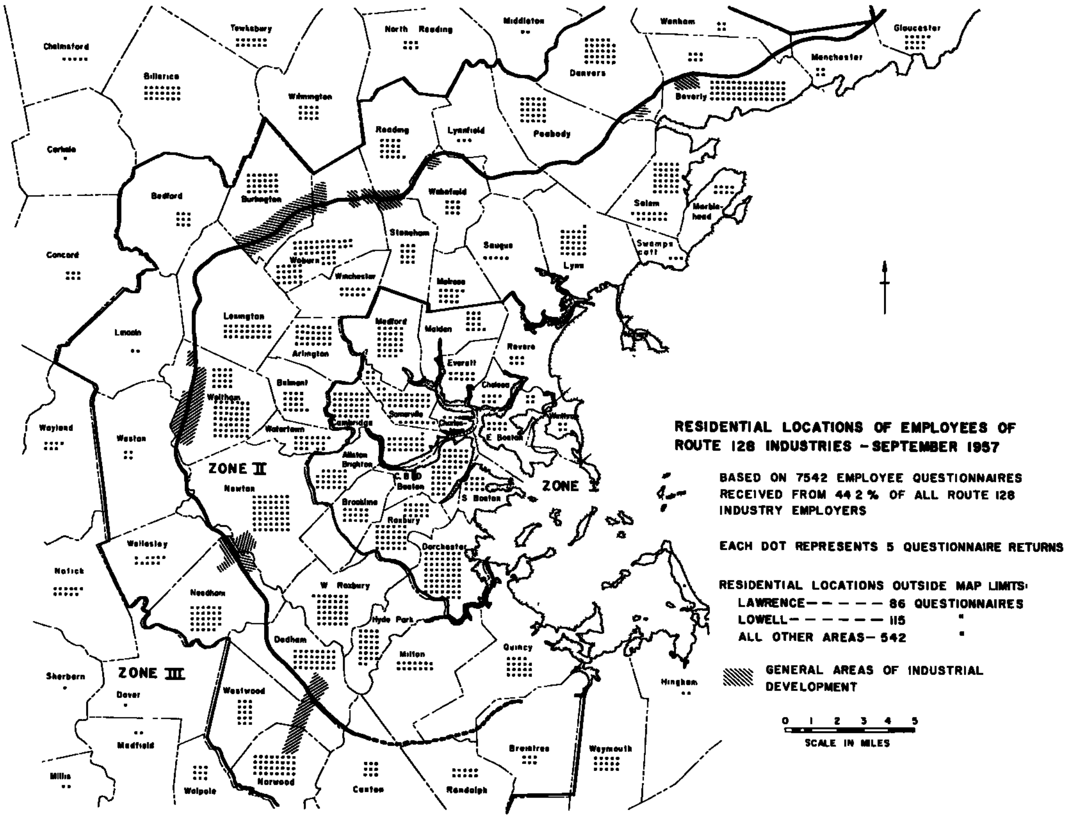


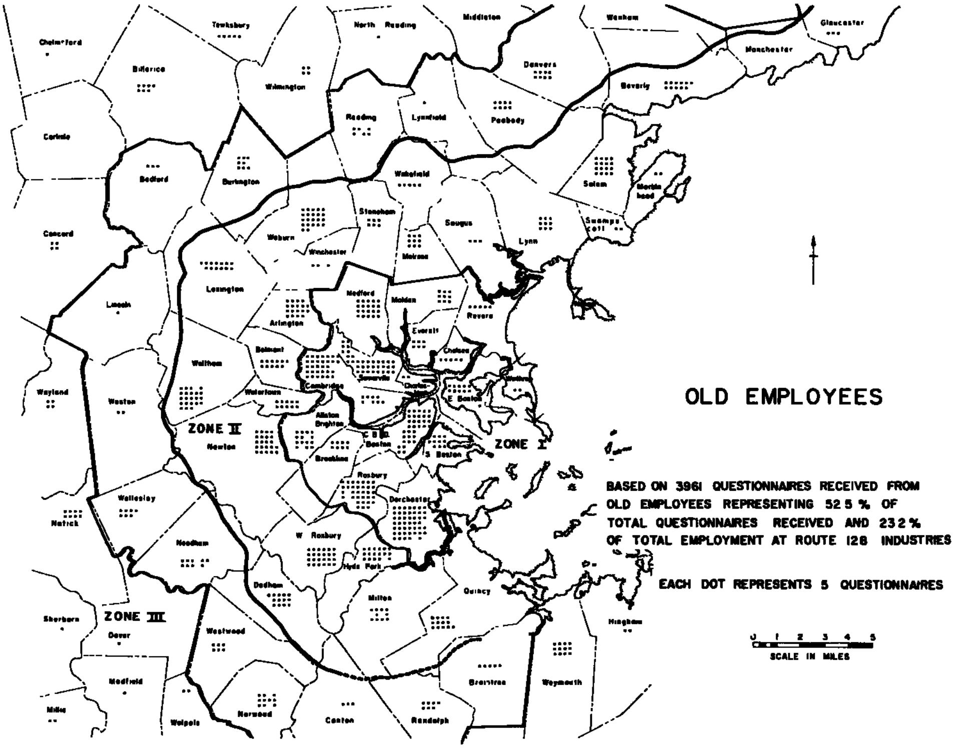
Figure 3.

acteristics. The employment opportunities are distributed among the seven locational areas and the four types of industry as shown in Table 1; this table also includes new and old employee percentages and the size of the questionnaire sample.

The percentages of new and old employees in each locational area or type of industry are influenced by the changes in employment that have occurred after a company moved to Route 128 and by the proportion of "new" and "relocated" plants in each group. New plants represent the start or founding of new enterprises or outlets, while relocated plants indicate those firms which moved to Route 128 from other locations. In the locational area north of Route 1, the relocated industries showed a large increase in employment with 82 percent new employees. Similarly, the research and development companies expanded their staffs more than other types of industry resulting in 57 percent of new employees. On the other hand, the relocated service companies curtailed their employment somewhat on moving to Route 128 and only 32 percent new employees are noted. At the same time, R and D firms had the highest percentage of new companies and service the lowest, further accounting for the high and low percentages of new employees of these two types of industry.

Fifty-two percent of the total employment along the route was concentrated in 4 of the 7 areas, Waltham through Needham; this concentration of employment was spread out over an 11-mile stretch in the central portion of Route 128, or over only 20 percent of the total linear distance between the end locational areas. The high employment density in the central region may be expected to increase even more since a large number of plants have been completed or are under construction particularly in the Waltham area.

A distribution of the percentages of employees working at plants which have started operations on Route 128 since 1951 is shown in Table 2, together with questionnaire


OLD EMPLOYEES
BASED ON 3961 QUESTIONNAIRES RECEIVED FROM
OLD EMPLOYEES REPRESENTING 52.5 % OF
TOTAL QUESTIONNAIRES RECEIVED AND 23.2 %
OF TOTAL EMPLOYMENT AT ROUTE 128 INDUSTRIES
EACH DOT REPRESENTS 5 QUESTIONNAIRES
ZONE I
ZONE II
ZONE III
SCALE IN MILES

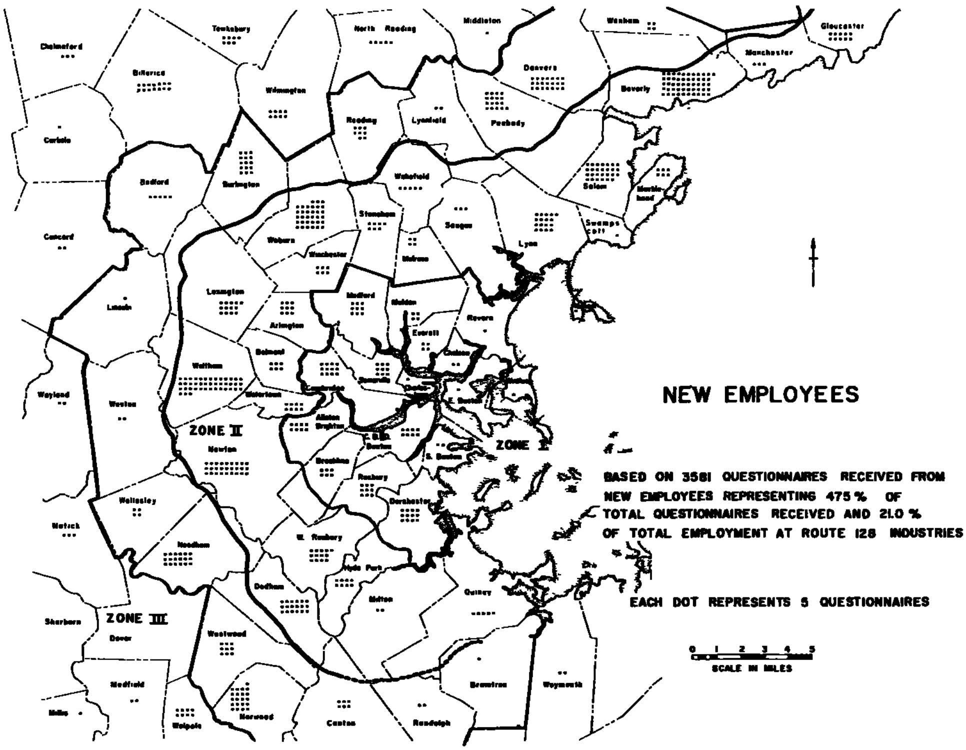

NEW EMPLOYEES
BASED ON 3581 QUESTIONNAIRES RECEIVED FROM
NEW EMPLOYEES REPRESENTING 47.5 % OF
TOTAL QUESTIONNAIRES RECEIVED AND 21.0 %
OF TOTAL EMPLOYMENT AT ROUTE 128 INDUSTRIES
EACH DOT REPRESENTS 5 QUESTIONNAIRES
ZONE I
ZONE II
ZONE III
SCALE IN MILES

Figure 4.

sample size expressed in percent of total employment in each case. The growth of employment on Route 128 is obviously closely related to the amount of traffic generated.

The percentage of employees who returned questionnaire forms in the areas (Table 1) should be quite sufficient to yield reliable results. In order to determine if these returned forms represented a reasonable cross-section of the employment, percentages of the employee questionnaires obtained were summarized by years in Table 2. The cumulative percentages of questionnaire returns and employment are comparable for each year. Therefore, it is concluded that travel pattern trends developed from the employee questionnaire sample can be considered representative.

Living Areas of Route 128 Industrial Employees. The locations of the homes of Route 128 industrial employees is shown in Figure 3. The dot representation allows a visual picture of the relative distribution of homes among the in-town, intermediate, and outlying zones. The zone breakdown is employed to clarify reading of the plot and to allow comparisons between travel pattern data for employees living in the suburbs and those living in-town. Additional plots have been made for new and old employees (Fig. 4). Table 3 supplements the plots and gives a summary of the percentages of employees of each type of industry that live in each of the three zones.

TABLE 3

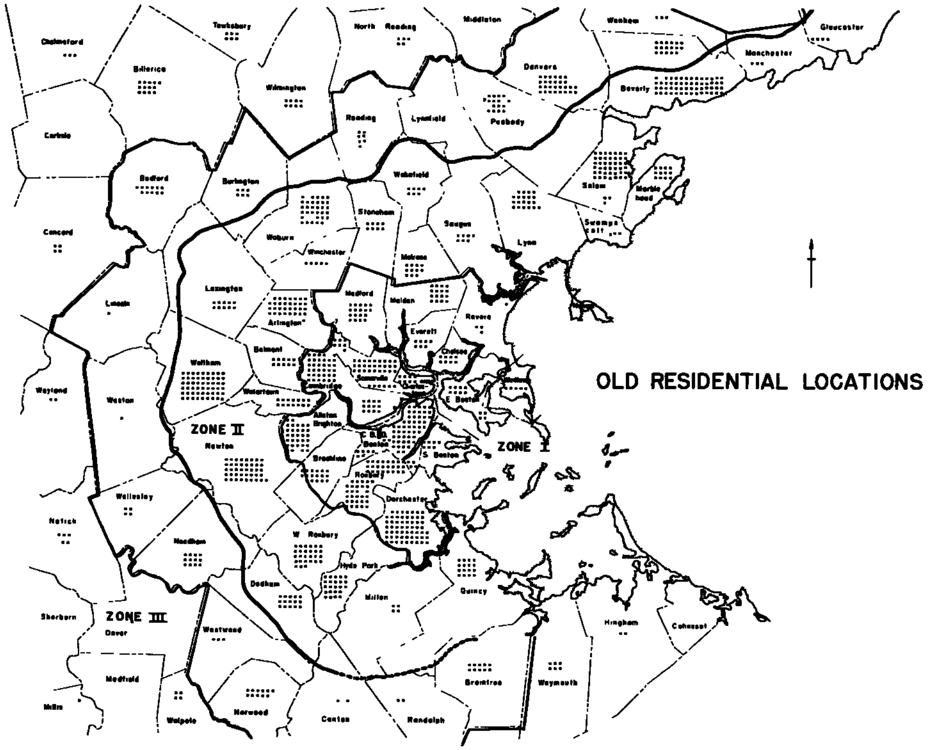
PERCENT OF EMPLOYEES OF EACH TYPE OF INDUSTRY THAT LIVE IN THE IN-TOWN, INTERMEDIATE, OR OUTLYING ZONES

Zone	Type of Industry: Distribution	Production	R and D	Service	All Industries
(I) In-Town	31	25	22	17	25
(II) Intermediate	53	56	51	65	55
(III) Outlying	16	19	27	18	20
All areas	100	100	100	100	100

Since the communities in the in-town zone are grouped together, the plot gives the impression that most of the employees live in this zone. Actually, more than half (55 percent) of the employees live in the intermediate zone, one-fifth in the outlying zone and only one-quarter in-town. In contrast, of the total metropolitan population living in both zones I and II, 46.5 percent live in the in-town zone (zone I) whereas only 31 percent of the Route 128 employee residences in these two zones are in zone I. A majority of the employees of each type of industry lives in the intermediate zone. More employees of distribution type industries live in the in-town zone than employees of other types of industry. A reason for this might be that these employees are on a lower wage scale than the employees of the other types of industry, and for that reason they cannot afford to live in many of the more desirable and expensive residential areas in zones II and III.

The home locations of new and old employees (Fig. 4) are revealing with respect to changes in labor market of companies after moving to Route 128. Although more than half of either old or new employees live in outer zones II and III, a decidedly lower percentage of new employees lives in the in-town zone. For example, referring to Table 4, only 12 percent of all new employees live in-town as compared to 37 percent of all old employees. A more important difference is found in the intermediate zone where only 46 percent of all old employees live, but 65 percent of new employees. These relationships are significant when assigning traffic to a particular area or route on the basis of land use.

Change in Residence by Route 128 Industry Employees after Starting to Work. The survey sample of old and new home locations of those Route 128 industry employees who moved after starting to work at a Route 128 plant is shown in Figure 5. These employees are definitely shifting their homes to the suburban areas. Table 5 supple-


OLD RESIDENTIAL LOCATIONS
ZONE I
ZONE II
ZONE III

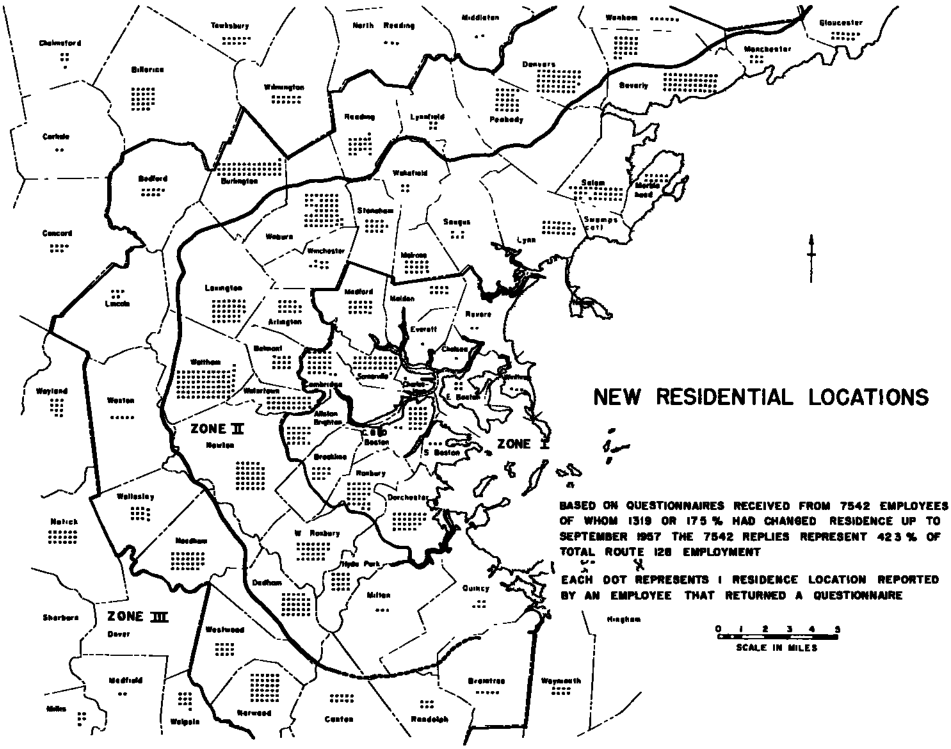

NEW RESIDENTIAL LOCATIONS
ZONE I
ZONE II
ZONE III
BASED ON QUESTIONNAIRES RECEIVED FROM 7542 EMPLOYEES OF WHOM 1319 OR 17.5 % HAD CHANGED RESIDENCE UP TO SEPTEMBER 1957 THE 7542 REPLIES REPRESENT 42.3 % OF TOTAL ROUTE 128 EMPLOYMENT
EACH DOT REPRESENTS 1 RESIDENCE LOCATION REPORTED BY AN EMPLOYEE THAT RETURNED A QUESTIONNAIRE
0 1 2 3 4 5
SCALE IN MILES

Figure 5.

TABLE 4

PERCENT OF NEW AND OLD EMPLOYEES OF EACH TYPE OF INDUSTRY THAT LIVE IN THE IN-TOWN, INTERMEDIATE AND OUTLYING ZONES

	Type of Industry and Class of Employee									
	Distribution		Production		R and D		Service		All	
Zone	Old	New	Old	New	Old	New	Old	New	Old	New
I In-Town	44	16	39	10	31	21	24	3	37	12
II Intermediate	42	67	46	67	40	54	57	80	46	65
III Outlying	14	17	15	23	29	25	19	17	17	23
Total	100	100	100	100	100	100	100	100	100	100
All zones	54	46	53	47	43	57	68	32	53	47

ments this figure by indicating the percentage of these employees living in the in-town, intermediate, and outlying zones (zones I, II and III, respectively) both before and after changing their home location, and by comparing these data with data on home locations of Route 128 employees who have not moved.

Of the employees who have moved since starting to work at industries on Route 128 over four times as many now live in the intermediate zone as in the in-town zone. Also, considerably more of those who have moved live in suburban areas than those who have not moved.

The distributions of the new employees among zones (Table 4) and of those who have moved (Table 5) are almost identical, even though most of those moving are old employees. This points to the possibility that those employees who are moving are adopting the same living patterns as new employees. As the data in later sections will show, the travel patterns of the new employees and those workers changing residence are almost identical.

Trip-to-Work Travel Times, Distances, and Speeds of Route 128 Industrial Employees. This information has been presented in several ways in order to determine differences in travel patterns between new and old employees, and between Route 128 users and non-users. In addition, the data on Route 128 users were further divided according to the percentage of the trip-to-work distance traveled on Route 128. A general summary of the travel pattern data is given in Table 6.

The Route 128 employment is almost evenly split between new and old employees, and about half of each group uses Route 128 in making its journey to work. There are considerable differences, though, between the travel patterns of the old and new employees, and between those of the Route 128 users and non-users. For example, both the average time and distance to work for old employees are over 30 percent higher than those for new employees, but the average speed is the same for both groups. On the other hand, the distance to work for the Route 128 users is about 75 percent greater than that for non-users, but the time for the trip is only 33 percent greater; consequently,

TABLE 5

PERCENT DISTRIBUTION OF RESIDENCES OF ALL ROUTE 128 EMPLOYEES BEFORE AND AFTER MOVING

	Employees Who Have Moved			Employees Who	All
Zone	Before	After	% Change	Have Not Moved	Employees
I In-Town	31	14	-54	27	25
II Intermediate	49	60	23	54	55
III Outlying	20	26	26	19	20
All zones	100	100		100	100

TABLE 6

SUMMARY OF ROUTE 128 EMPLOYEE TRAVEL PATTERN DATA

Trip-to-Work Characteristics	Old Employees	New Employees	All Employees
Class of employee (%):			
Old employees			52
New employees			48
All employees			100
Route 128 Usage (%):			
Route 128 users	49	49	49
Non-users	51	51	51
Average time-to-work (min):			
Route 128 users	31	25	28
Non-users	25	17	21
All employees	28	21	24
Average distance-to-work (miles):			
Route 128 users	16.6	13.4	15.0
Non-users	9.9	6.9	8.5
All employees	13.2	10.1	11.7
Average speed-to-work (mph):			
Route 128 users	32	33	32
Non-users	24	24	24
All employees	28	29	29

the average speed for the users is 33 percent higher than that for non-users.

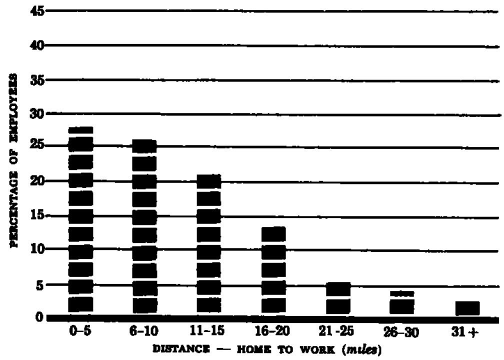
In general, for all four types of industry the time, distance, and speed patterns of old employees are quite similar. These patterns of new employees are nearly the same except for the research and development employees who travel a longer distance to work but still maintain higher trip speeds. In attaining this higher speed, 65 percent of the R and D employees use Route 128 as compared to an average 49 percent usage by employees of all industries along Route 128.

The travel pattern data of the old employees in each of the locational areas, except for area 1 (North of US 1 - N), show almost the same distance to work, although some variance occurs in Route 128 usage and average speeds. Home locations of employees in locational area 1 are closely distributed about that area, resulting in shorter distances to work and shorter distances on Route 128; the homes of employees in other areas are more widely spread out, resulting in longer distances to work.

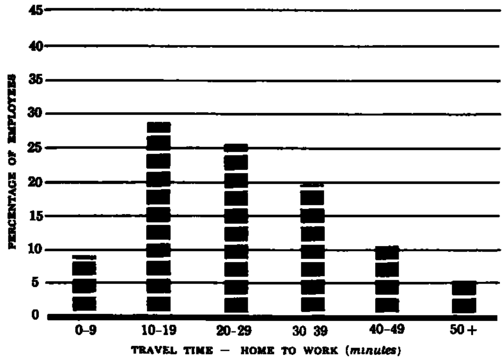
Table 7 gives more detailed information relating percent of home-to-work distance traveled on Route 128, distance-to-work, and average speed of trip. These data indicate that as a greater percent of the trip is made on Route 128, the distance-to-work increases, but the average speed increases at an even greater rate, resulting in nearly the same time to work for all percents of use.

There is little variation in the average speeds and distances of employees in the various locational areas within each percentage range of Route 128 usage. For example, for employees using Route 128 for 1 to 20 percent of their trip, the average distances to work in the central areas, which include over 50 percent of the total Route 128 employment, vary less than 14 percent from the over-all average distance (excluding the end areas) and the speeds for these vary less than 12 percent.

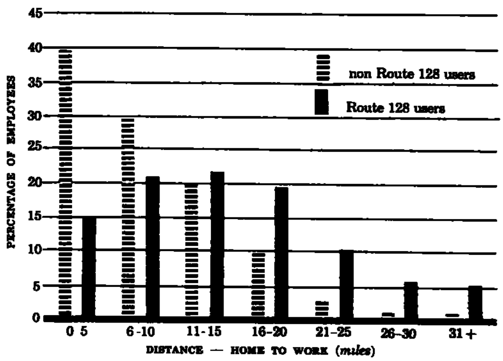
Actually, because of the semi-circular shape of the highway, the travel patterns of the end areas should not be expected to be the same as those in the central portions. For this reason, the planning of a highway such as Route 128 must certainly take into account these differences. It seems reasonable that a full circumferential highway would experience travel patterns more of the nature of those found in the central portions of Route 128 than those at the ends, or than the over-all data given here.



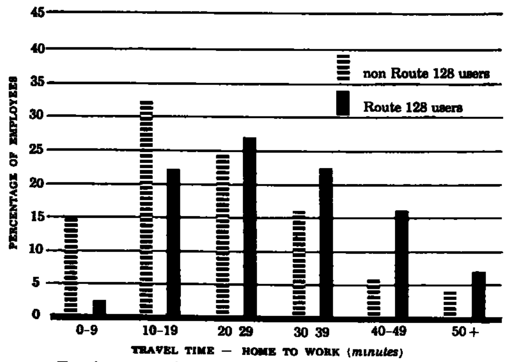
Distance home to work for employees of industries located on ROUTE 128
September 1957



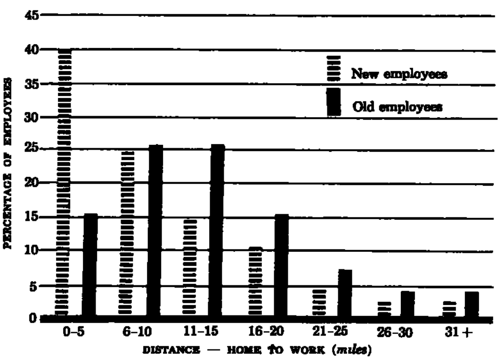
Travel time to work for employees of industries located on Route 128
September 1957



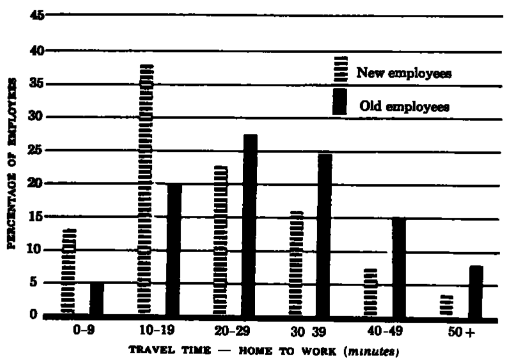
Distance home to work for employees of industries located on Route 128
Route 128 users vs non Route 128 users *September 1957*



Travel time to work for employees of industries located on Route 128
Route 128 users vs non Route 128 users *September 1957*



Distance home to work for employees of industries located on Route 128
Old employees vs New employees *September 1957*



Travel time to work for employees of industries located on ROUTE 128
Old employees vs New employees *September 1957*

Figure 6.

The distribution of the average distances and times-to-work of all Route 128 employees is shown in Figure 6. The differences between the Route 128 users and non-users and between the new and old employees are readily apparent. The range of distances for most of the non-users and new employees is much more limited than that for users and old employees. For example, 90 percent of the non-users travel 15

TABLE 7

PERCENTAGE USE OF ROUTE 128 RELATED TO EMPLOYEE TIME-TO-WORK TRIP, DISTANCE AND AVERAGE SPEED

No.	Locational Area	Percent of Area Employment Using Route 128 in Their Trip-to-Work for the Following Percent of the Trip Distance: None	1-20	21-40	41-60	61-80	81-100	% Total Employment in Area
1	North of US 1 (N)	46.3	9.5	14.4	13 1	9.4	7.3	14.3
2	Burlington	45.1	14.2	10.3	9.6	14.9	5.9	17.5
3	Waltham	44.3	6.8	12.8	15.6	14.2	6.3	26.2
4	NEIC	56.7	5.6	7.8	17.5	8.5	3.8	12.8
5	Newton	69.0	10.0	3.8	6.5	6.5	4.2	10.4
6	Needham	55.9	0.4	11.8	13.4	2.4	7.1	2.2
7	South of Needham	76.3	3.6	14.7	2.2	2.4	0.8	16.6
	All Areas	52.1	8.4	12.0	11.5	10.8	5.2	100.0

Average Distances and Speeds-to-Work of the Employees in Each Area Using Route 128 in Their Trip-to-Work for the Following Percent of the Trip Distance:

No.	Locational Area	None a	None b	1-20 a	1-20 b	21-40 a	21-40 b	41-60 a	41-60 b	61-80 a	61-80 b	81-100 a	81-100 b	All Users a	All Users b
1	North of US 1 (N)	6.7	26	9.4	28	7.3	27	6.3	25	9.8	31	11.4	36	8.4	29
2	Burlington	8.0	25	15.4	32	12.3	32	15.3	33	17.8	35	15.9	37	15.6	34
3	Waltham	9.7	24	13.7	28	15.7	31	17.0	33	18.0	34	19.0	38	16.8	33
4	NEIC	8.5	23	14.2	30	14.3	29	17.0	33	13.2	32	17.4	33	15.4	32
5	Newton	7.3	22	12.5	26	19.0	39	18.4	33	16.6	30	19.0	32	16.3	31
6	Needham	7.4	23	13.0	31	16.2	32	22.6	39	13.7	33	16.9	47	17.4	36
7	South of Needham	8.8	23	17.1	30	14.7	28	17.2	34	19.3	35	28.1	39	16.2	30
	All Areas	8.5	24	14.1	30	13.4	30	15.0	33	16.6	34	16.7	37	15.0	32

miles or less to work, while 90 percent of the users travel 20 miles or less to work but 90 percent of the old employees travel 30 miles or less. Thus the radius of the old employee labor market can be extended significantly by re-locating an established company on a highway of this nature. On the other hand, those companies who employ new personnel upon opening a plant will find them drawn from a smaller radius. In locational area 1, however, there is little difference in the distance to work distribution for different groups of employees, mainly because most of the employees live in that immediate area.

In the time and distance-to-work distributions for all employees (Fig. 6) there is a strong similarity between the patterns of Route 128 users and old employees, and between those of non-users and new employees. Since only half of both new and old employees use Route 128, it is obvious that the Route 128 users and old employees are not the same people; the same is true for the non-users and new employees. This seemingly strong correlation was analyzed to determine whether or not any significant relationship really exists. Table 8, which gives trip-to-work data for the employees according to the zone of their residence, may help to clarify this point (Fig. 3 gives boundaries of Zones I, II, and III, that is, in-town, intermediate, and outlying).

Most of the workers in Zone I (in-town) are old employees, and most of these workers do not use Route 128 in their trip to work. In Zone III (outlying), the reverse is true; most of the workers

TABLE 8

SUMMARY OF AVERAGE DISTANCE, TIME AND SPEED-TO-WORK OF ROUTE 128 EMPLOYEES BY REGIONAL ZONES IN WHICH THEY LIVE

Regional Zones Where Employees Live	Zone I In-Town	Zone II Intermediate	Zone III Outlying
Percent of employees living in each zone			
1. Using Route 128	31	52	61
Non-users	69	48	39
2. New employees	23	56	55
Old employees	77	44	45
Distance-to-work (miles)			
Route 128 users	16 4	12.4	20.6
Non-users	12 4	4.6	13.2
All	13.6	8 7	17.7
Time-to-work (min)			
Route 128 users	34.5	22 9	35.0
Non-users	31.5	13.3	25.5
All	32.5	18.3	31.3
Speed-to-work (mph)			
Route 128 users	28.5	32.5	35.3
Non-users	23.6	20.8	31.1
All	25.1	28.5	33.9

are new and use Route 128. Therefore, it would seem that the similarities in distributions that occur in the time and distance-to-work graphs between old employees and users and between new employees and non-users are merely a result of the fact that their trip distances are almost the same rather than any correlation between the groups.

Most of the employees living in-town do not use Route 128, while half of those in the intermediate zone use the Route, and most of those in the outlying zone use Route 128 in their trip-to-work. In some respects this is the expected pattern, since the in-town people are near the center of radial highways and therefore have a number of resonably direct routes to get to work. On the other hand, the people living in the outlying zones have less choice of radial routes leading into Route 128 industrial areas and fewer connecting roads between the widely separated radial routes. Consequently, people in the outlying zone generally must use Route 128 if their work center is not located directly on the nearest radial.

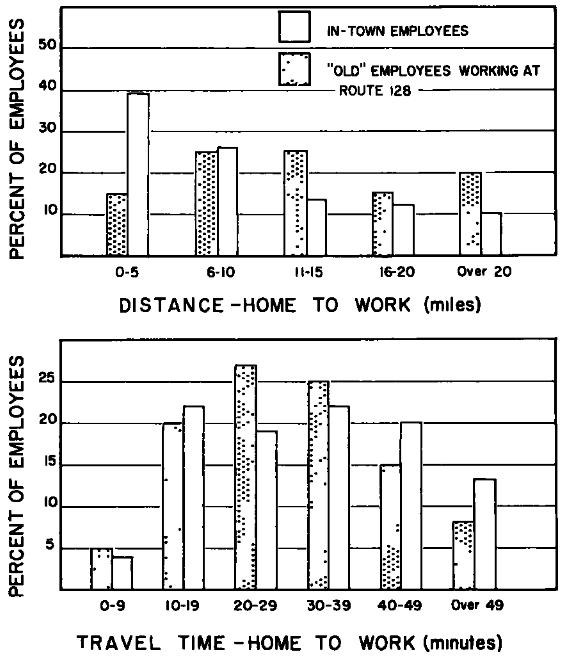


Figure 7. Home to work travel time and distance of old Route 128 and in-town employees.

The effect of Route 128 usage by workers is again apparent when the times, distances, and speeds for the users and non-users are compared for each of the 3 zones. In all 3 zones the Route 128 users travel longer distances and take greater times, but at the same time, are able to maintain greater speeds. It is particularly interesting that the Zone I (in-town) workers who use Route 128 have 30 percent longer trips than non-users but their travel time is little higher than the non-users. One might suspect that this would tend to cause a higher percent of Route 128 usage by these in-town

TABLE 9

SUMMARY OF TRAVEL PATTERN CHARACTERISTICS FOR EMPLOYEES WORKING AT AN IN-TOWN PRODUCTION PLANT AND FOR OLD ROUTE 128 EMPLOYEES AFTER STARTING TO WORK AT A ROUTE 128 PLANT

Employee Group and Mode	Employees in Mode (%)	Average Travel Time Home-to-Work (min)	Average Distance Home-to-Work (miles)	Average Speed of Trip (mph)
In-town workers				
Car	73.9	30	10.5	21
Public transit	16.8	36	5.5	9
Walk	4.1	14	0.9	4
Combinations	5.2	40	7.5	11
All Modes	100.0	30	10.5	21
Old Route 128 workers				
All Modes	100.0	28	13.2	28

TABLE 10

TRAVEL PATTERNS OF EMPLOYEES WHO HAVE MOVED SINCE STARTING TO WORK ON ROUTE 128[1]

No.	Locational Area	Rte. 128 Users (%)	Rte 128 Non-Users (%)	Avg. Dist. to Work (miles)	Avg. Dist. to Work of Rte. 128 Users (miles)	Avg. Travel Time to Work of Rte. 128 Users (min)	Avg. Speed of Rte. 128 Users (mph)	Avg. Dist. to Work of Non-Rte. 128 Users (miles)	Avg. Travel Time to Work of Non-Rte. 128 Users (min)	Avg. Speed of Non-Rte. 128 Users (mph)
1	North of US 1 (N)	55	45	7.5	7.7	17	28	7.1	16	26
2	Burlington	58	42	11.3	14.5	26	33	6.8	17	24
3	Waltham	55	45	12.2	14.9	27	33	8.9	22	25
4	NEIC	59	41	11 7	14.3	26	33	7.9	19	24
5	Newton	48	52	11.6	15.6	29	32	7.9	20	23
6	Needham	50	50	12.9	14.8	28	32	11.1	22	30
7	South of Needham	20	80	10.1	16.0	30	32	8.7	21	25
	All Areas	51	49	10.7	13.4	25	32	8.0	20	25
Type of Industry										
Distribution		58	42	11.9	14.7	27	33	8.1	20	24
Production		48	52	10.1	12.6	24	32	7.8	19	25
R and D		57	43	12.8	16.0	27	35	8.8	20	26
Service		69	31	13.1	13.9	25	33	11.6	29	24
All Types		51	49	10.7	13.4	25	32	8.0	20	25

[1]Based on questionnaires of employees of those who have moved: 1,319 out of 7,542 questionnaires.

people. Also, as the homes become farther removed from the congested center of the metropolitan area, the workers are able to maintain increasingly higher speeds in their journey to work. The only exception to this is for the non-users in Zone II; the reason for this probably lies in the fact that this group of workers has such a small trip-to-work (4.6 miles) that their average trip-to-work speed is considerably reduced by delays at the trip ends.

Comparison of the Travel Patterns of Employees Working at Industries along Route 128 with the Travel Patterns of Employees at an In-Town Location. In September 1958 a special questionnaire was distributed to 580 employees of one production industry located in Cambridge, Massachusetts, and almost 400 forms were returned. The purpose of this separate study was to obtain travel pattern data of employees working at an in-town location for comparison with that of old Route 128 employees, and, therefore, to determine the differences that have taken place since changing from an in-town to suburban place of work.

A comparison between in-town workers and old Route 128 employees to determine travel pattern trends seems reasonable since almost all of the old suburban workers formerly worked at an in-town location.

A summary of travel pattern characteristics of these two groups of workers is shown in Table 9, and distributions of home-to-work travel times and distances are shown in Figure 7. It is apparent that the old Route 128 workers who formerly worked in-town are traveling longer distances from home-to-work than the present in-town workers but are making the trip in slightly less time. Consequently, the old Route 128 employees are making their home-to-work trip at a 30 percent greater speed.

Another trend worth noting is that the distributions of travel times of old Route 128 employees and of in-town employees follow regular patterns even though the distance distributions are quite different and even though one group is working in-town and the other group at Route 128. For example, 26 percent of the in-town employees and 25 percent of the old employees at Route 128 travel to work in less than 20 minutes; similarly, 45 percent and 52 percent travel to work in less than 30 minutes.

On the other hand, 65 percent of the in-town workers but only 40 percent of the old employees at Route 128 travel less than 11 miles from home-to-work. In other words, the differences in each range are much more pronounced with regard to the distance-to-work than with travel time to work.

Travel Patterns of Employees Who Have Moved since Starting to Work on Route 128. Information on employees who have moved since starting to work at a Route 128 plant was presented previously (Table 5, Fig. 5). It was found that these employees are moving outward from the in-town areas, and tend to be distributed among the three regional zones in the same pattern as new employees. Detailed travel characteristics of these workers who moved are shown in Tables 10 and 11. (In analyzing these tables it will be helpful to make comparisons with data in Tables 1, 6, and 7.)

A slightly higher percentage of the employees who have moved are using Route 128 than all workers. Since the percentage of all employees using Route 128 includes the employees who have moved (about 20 percent of the total), it is evident that employees make more use of Route 128 after moving. In each locational area except south of Needham, about half of those employees moving use Route 128 in their trip-to-work, and most of the travel patterns of the central area employees vary little from the averages. The small usage of Route 128 by employees working in the area south of Needham is caused by the fact that most of these employees live in the southwest quadrant of metropolitan Boston and

TABLE 11

COMPARISON OF TRAVEL PATTERNS OF EMPLOYEES WHO HAVE MOVED WITH THOSE WHO HAVE NOT MOVED SINCE STARTING WORK ON ROUTE 128

Employee Group	Avg. Dist. to Work (miles)	Avg Time to Work (min)	Avg. Speed to Work (mph)
All Route 128 employees	11 7	24	29
1 New employees	10 1	21	28
Old employees	13 2	28	28
2 Those who have not moved	11.9	25	28
Those who have moved	10 7	22	29
Difference	1 2	3	1
Route 128 users[1]	15.0	28	32
Those who have moved	13 4	25	32
Difference	1 6	3	0
Non-Route 128 users[1]	8.5	21	24
Those who have moved	8 0	20	25
Difference	0 5	1	1

[1]Includes the 18 percent of employees who have moved.

TABLE 12

COMPARISON OF BEFORE AND AFTER HOME-TO-WORK DISTANCES OF THOSE EMPLOYEES WHO MOVED AFTER STARTING TO WORK AT A ROUTE 128 PLANT[1]

Employees	Percent of Each Group Who Moved	Average Distance to Work (miles) Before Moving	After Moving
New employees who moved:			
Closer to place of work	37	18.1	8.5
Farther from place of work	44	8.1	16.8
No change in distance to work	19	9.2	9.2
All in group	100	12.1	11.9
Old employees who moved:			
Closer to place of work	39	15.0	7.1
Farther from place of work	43	10.2	17.5
No change in distance to work	18	13.7	13.7
All in group	100	12.7	12.7
All employees who moved:			
Closer to place of work	39	16.3	7.7
Farther from place of work	44	9.3	16.8
No change in distance to work	17	11.8	11.8
All in group	100	12.4	12.4

[1]Based on 2,134 questionnaire returns from 47 industries; one-half these returns were from new employees. Seventeen percent of all the forms indicated a change of residence after starting to work at a Route 128 plant. Of those moving, 42 percent were new employees.

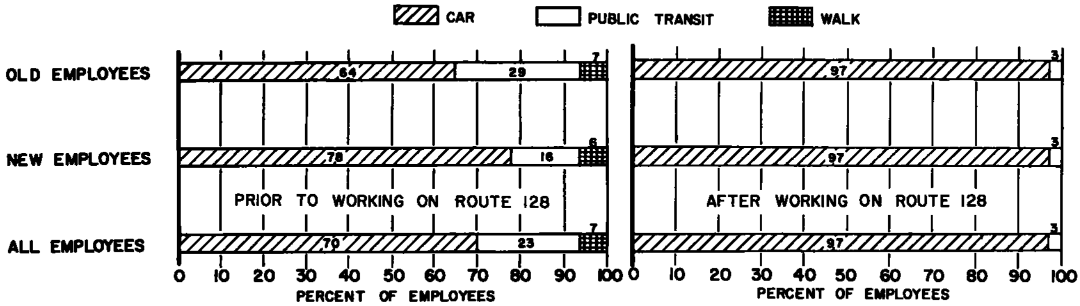


Figure 8. Mode of transportation used by employees of industries located on Route 128, September, 1957.

are limited in their choice of route to work and access to Route 128. Consequently, only those workers living east of the Route 1 and 128 interchange where this locational area industry is concentrated (Fig. 1) would gain access to Route 128 at Route 138 and find any advantage in using the circumferential highway. Otherwise, workers would find Route 1 most convenient for the trip to work. As industrial expansion takes place in areas at other Route 128 interchanges in this general region, more use of that route may be expected.

A comparison of travel patterns of employees who have moved with those who have not moved is given in Table 11. These data indicate that the average distance to work for those employees who have moved was about 1.2 miles less than the average distance to work for those employees who have not moved. The corresponding difference in time was about 3 min. and in speed about 1 mph. The average distance to work for those employees who have moved and use Route 128 was about 1.6 miles less than the average for all Route 128 users. These data give a general indication that there is a slight shortening of the distance to work when employees move. However, this is not true. A comparison of the distance to work before and after moving is shown in Table 12. The data in Table 12 are based on employee questionnaires from 47 industries. The difference in the average distance to work before and after moving for all or either new or old employees is negligible. Thirty-nine percent of the employees moved closer to work, 43 percent moved farther away from work, and there was no change in the distance to work of 18 percent of the employees. The employees who moved closer to their place of work shortened their work trip by an average of 53 percent, while those employees who moved farther from their place of work increased their work trip by an average of 80 percent. Perhaps a more significant comparison could be made on the basis of travel times; however, these data were not available.

<u>Modes of Travel Used by Route 128 Employees Before and After Working at a Route 128 Plant.</u> Modes of travel utilized by new and old employees before and after starting to work at a Route 128 plant are summarized in Figure 8. Nearly all Route 128 employees now travel to work by motor vehicle whereas 30 percent formerly used public transportation or walked. Before working at a Route 128 plant, 64

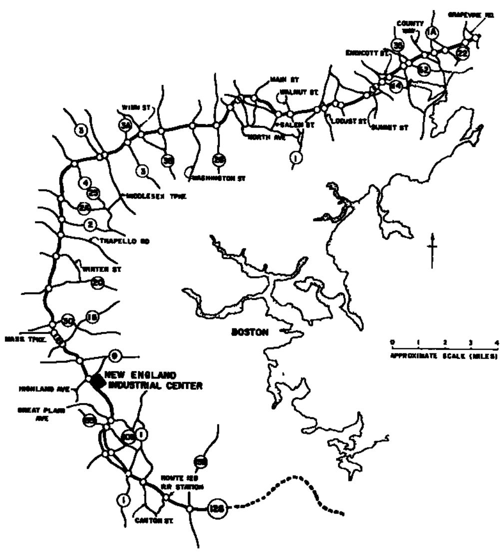
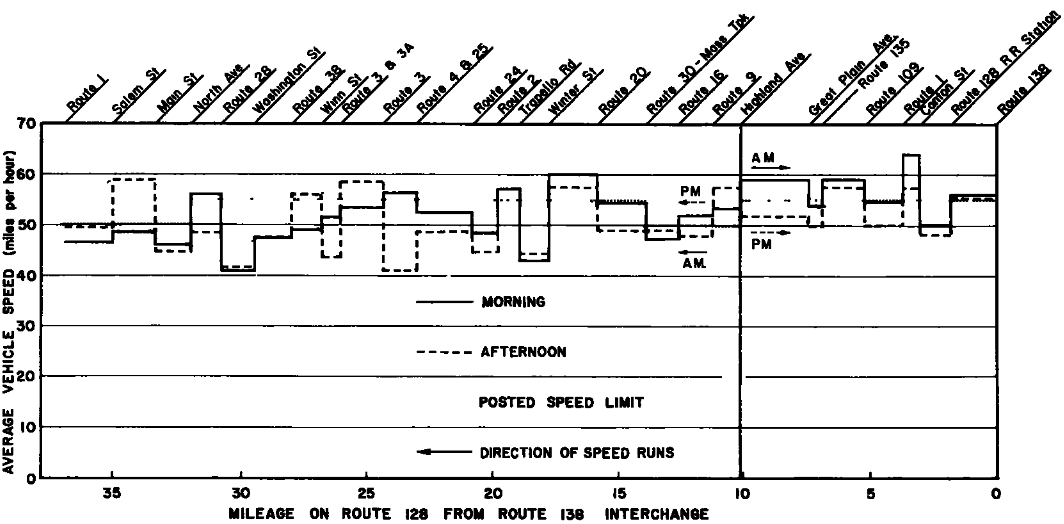
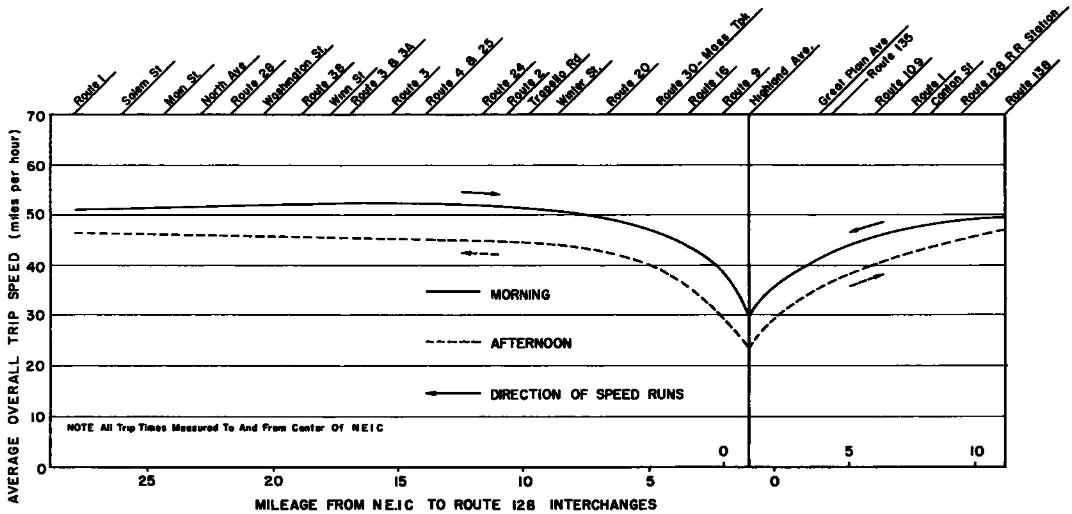


Figure 9. Layout of Route 128 showing interchange locations.



AVERAGE SPEEDS BETWEEN ROUTE 128 INTERCHANGES DURING A.M. & PM WEEKDAY PEAK HOURS FOR TRIPS TO AND FROM NEW ENGLAND INDUSTRIAL CENTER



AVERAGE OVERALL TRIP SPEED BETWEEN THE NEW ENGLAND INDUSTRIAL CENTER AND ROUTE 128 INTERCHANGES DURING A.M. & PM. WEEKDAY PEAK HOURS

Figure 10.

percent of the old employees used cars in the trip-to-work in contrast to 78 percent of the new employees; after starting to work on Route 128, the use of cars by both groups was about the same. Consequently, there has been a 51 percent increase in automobile usage by old employees and a 27 percent increase by new employees.

Often statements are made that Route 128 employees are forced to use automobiles in their trip-to-work and this is the cause of the high percent using cars. This is not entirely true, however. Many companies have set up bus systems at their own expense to provide their employees with means of connecting with public transit; also, the Middlesex and Boston Street Railway provides a scheduled public transit service to the NEIC. Experience has shown, however, that within 6 months of starting operation on Route 128 nearly every company has abandoned special transportation service because the employees did not use it. Public transportation is not available to most of the locational areas, although it seems obvious that public or private transportation agencies would provide the service if they thought it would pay for itself. The great majority of Route 128 employees evidently do not want to use public transit; they prefer to use their cars or join car pools.

TABLE 13

AVERAGE TRAVEL TIMES AND SPEEDS OF EMPLOYEES AT NEW ENGLAND INDUSTRIAL CENTER

Type of Trip	Distance (miles)	Time (minutes)	Average Speed (mph)
Trip-to-work, a. m.:			
From north			
On streets	6.6	18 5	22
On Route 128	7.7	8.3	56
Into NEIC	1.1	2 2	29
Total trip	15.4	29.0	32
From south			
On streets	6.8	18.8	22
On Route 128	7.7	8 3	56
Into NEIC	0.9	1 9	28
Total trip	15.4	29.0	32
Trip home, p m.:			
To north			
NEIC to Route 128	0.9	2.4	16
On Route 128	7.7	9.2	50
To south			
NEIC to Route 128	1.1	2.8	22
On Route 128	7.7	8.7	53

Average Speeds on Route 128 and From the Highway into an Industrial Center. A series of speed runs were made along Route 128 and from the Highland Avenue interchange (Fig. 9) to a point near the center of the New England Industrial Center (NEIC). In the a. m. peak hours one set of runs started at Route 1 on the northern end of Route 128 and proceeded south to the NEIC, and another set was started at Route 138 in Canton and proceeded north to the center. These trips were made along Route 128 and into the NEIC in the morning to simulate the employee travel conditions in the trip from home-to-work. In the p. m. peak hours, the runs were reversed, simulating the trip from work-to-home. Two types of speed information were obtained: (1) the average running speed en route between interchanges; and (2) the average over-all speed from the middle of the NEIC to the first contact with a through lane of Route 128 at each interchange (or in the reverse direction). The "floating car" method was used, maintaining as closely as possible the average speeds of other drivers. The average speeds were based on ten runs over each of the four courses.

The results of this investigation are plotted in Figure 10. The top graph shows the average speeds being maintained on various sections of Route 128 and the bottom graph shows the average over-all speed of trips from the NEIC to various points along Route 128. The average speeds on Route 128 during the p. m. peak hours were lower than those during the morning. There are two reasons for this. First, the hourly volume and density are considerably higher in the afternoon peak than in the morning, causing a drop in speed as the road approaches capacity use. Second, in the morning the workers' times of arrival at the NEIC are spread over a longer period than in the afternoon when many of the employees leave work at the same time causing traffic congestion and delay at the plant parking lots and between them and the nearest entrance to Route 128. The results of these factors are apparent in Table 13 which shows average speeds on streets, on Route 128, and into the NEIC from Route 128. In compiling this table the speeds on Route 128 and into the NEIC were obtained from the speed runs, while those on streets were derived from the speed and distance of the average home-to-work trip reported on NEIC employee questionnaire forms. Since the total trip data were obtained by asking the employees the time and distance of their trip from home-to-work, the on streets

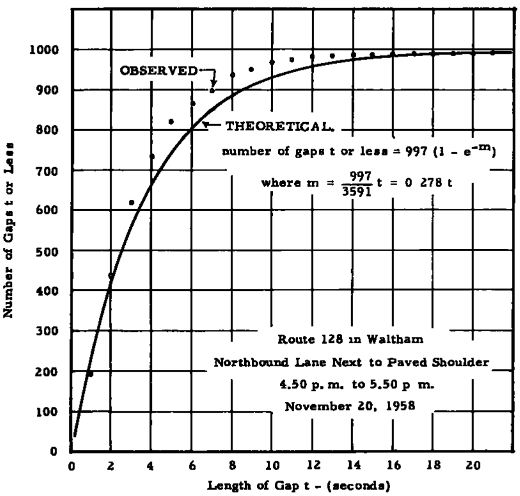


Figure 11. Distribution of gaps on Route 128.

TABLE 14

MODES OF TRANSPORTATION AND CAR-POOLING BY ROUTE 128 EMPLOYEES

Locational Area	Average Number of: Vehicles Per Employee	Employees Per Vehicle	Percent of Rte. 128 Users Who: Drive Alone	Car-Pool	Percent of Non-Users of Rte. 128 Who: Drive Alone	Car-Pool	Walk	Public Transit	Percent of Total Route 128 Employment
North of US 1 (N)	0.431	2.32	22	78	22	74	1	3	14.3
Burlington	0.589	1.70	38	62	39	60	1	[1]	17.5
Waltham	0.578	1.73	33	67	31	65	1	3	26.2
NEIC	0.610	1.64	41	59	35	62	1	2	12.8
Newton	0.654	1.53	45	55	40	50	2	8	10.4
Needham	0.800	1.25	49	51	43	45	6	6	2.2
South of Needham	0.426	2.35	34	66	23	66	4	7	16.6
All areas	0.546	1.83	35	65	32	62	2	4	100.0
Types of Industry									
Distribution	0.645	1.55	46	54	40	55	1	4	11.7
Production	0.535	1.86	36	64	32	62	2	4	72.5
R and D	0.555	1.80	32	68	37	62	[1]	[1]	12.8
Service	0.467	2.14	25	75	24	72	0	4	3.0

[1]Less than 0.5 percent.

data in Table 13 were computed only for a.m. trips.

The average speeds maintained along Route 128 during peak commuting periods are relatively high, and in many cases higher than the posted speed limit. The section having the heaviest hourly volume is a 4-lane divided highway with limited access and with daily peak lane volumes of about 1,000 vehicles per hour. If the distribution of headways occurring in this flow is taken into account, it is apparent that the users are traveling at short headways much of the time. An actual observation of the time gaps shows that over 60 percent are less than 3 seconds and 44 percent less than 2 seconds. The actual distribtuion of these gaps closely follows a theoretical curve, where 56 percent would be less than 3 seconds and 43 percent less than 2 seconds. Curves showing actual and theoretical gap spacings are plotted in Figure 11. The median gap spacing of this particular flow is about 2.5 seconds. At an average vehicle speed of 50 mph, this means the average distance between these vehicles would be in the order of 180 ft, with over 40 percent traveling less than 150 ft apart. These distance spacings are dangerously close, and have resulted in multiple rear-end collisions.

The standard geometric design of sections along Route 128 generally follows the period of the construction of the road, with the poorer design occurring in the older sections. The road was constructed for the most part in three stages, with the portion north from Wakefield being built first, that from Wakefield south to Route 9 next (1951), and the portion from Route 9 south following in 1955 and 1956. While the standards have improved considerably since the northern end was built, most of the ramps are of low-speed design and have inadequate speed change (acceleration-deceleration) lanes. Consequently, the driver is forced in most cases to reduce his speed when leaving (or gain his speed when entering) on through-lane portions of the highway, thus causing a reduction in the traffic carrying capacity of the route. Nevertheless, the improvements in the design of the highway over the years are apparent when the average speeds on the three design sections are taken into account. The average speeds on the southern section, that of newest design, are definitely higher than on the other portions; also, on the Route 9-Wakefield section speeds are slightly higher than those to the north, even though the northern section carries the lightest volumes of traffic.

In July 1951, prior to the opening of new construction of Route 128 between Wakefield and Route 9, travel time runs were made over the old Route 128 which ran through the business centers of Newtonville, Waltham, Lexington, Woburn, Stoneham and Wakefield. The average speed of trips over this old Route between Needham and Wakefield was 23 mph or less than half of that on the new Route.

Car Pooling Information Obtained from Employee Questionnaire Forms and Gate

TABLE 15

PARKING SPACE PER EMPLOYEE RATIOS OF THOSE COMPANIES HAVING ADEQUATE PARKING FACILITIES

Employment Range	Number of Plants	Average Number of Employees per Plant	% of Total Rte. 128 Employment in Range	Parking Space per Employee Ratio	Average Number of Vehicles per Employee
0-50 employees	39	24	7.7	1.43	0.870
51-100	13	78	8.4	1.01	0.746
101-150	3	120	3.0	0.85	0.657
151-200	5	163	6.8	1.06	0.606
201-500	9	322	23.9	0.84	0.561
501-1,000	2	788	13.0	0.71	0.520
Over 1,000	3	1,500	37.2	0.54	0.476
All ranges	74	163	100.0	0.79	0.594

Counts. The questionnaire form distributed to the Route 128 employees included a question designed to obtain information on car pooling among these employees. This information was desired to determine the number of vehicles and vehicle trips resulting from the industrial development.

In order to provide a check on the questionnaire form data regarding car pools, vehicle and passenger "gate" counts were made at 9 separate industries and at the NEIC. The gate counts showed approximately the same percent of Route 128 users as were tabulated from questionnaire forms. A serious discrepancy developed, however, between the number of vehicles counted and the number represented by questionnaire form data. Since each questionnaire represents one employee, the number of occupants per vehicle must be accurately known to establish a relation between number of questionnaires and number of vehicles. The question on car pooling was intended to accomplish this, but apparently it did not.

In all areas where gate counts were made, the number of vehicles per employee as computed from gate count data were significantly lower than the number computed from employee questionnaires. Two possible explanations are offered for this discrepancy. A disproportionate number of forms may have been submitted by those who actually drive alone, or those persons riding with or driving with others misunderstood the question regarding "car pool." For example, if an employee drives his own car to work every day and a fellow worker rides with him every day, the driver may not consider the arrangement a car pool. Another possibility is that a car pool may have been interpreted to mean only an arrangement where the owner of the car receives monetary compensation for carrying passengers on a regular basis.

The data from the 10 field counts were compared with that developed from the questionnaire forms of the same 10 industry groups (9 companies and the NEIC). At 8 of the 10 places where a field count was taken, more questionnaires were returned marked "drive alone" than the number of employees actually observed. Thus, it appears that most of the error resulted from car poolers with one rider misunderstanding the question. Further analysis of the data revealed that no correlation exists between the percentage of returns and the error in the number of vehicles reported on questionnaire forms.

The questionnaire data from the companies where gate counts were made were compared with that from all of the companies in the same locational area. A close correlation was apparent which indicated that the results obtained at plants where gate counts were taken were representative of those at all plants in the same locational area, and supported the validity of the application of an "adjustment factor" based on the gate counts. The adjusted data appear in Tables 14 and 15, and Figure 12.

Table 14 not only shows adjusted modes of transportation, but it also reveals some

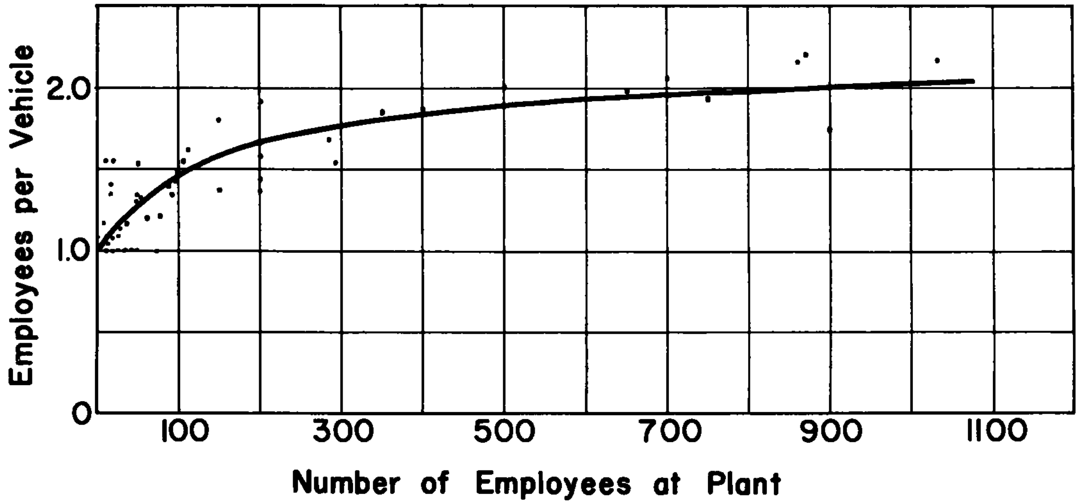


Figure 12. Relationship between employees per vehicle and plant employment.

relations between car pooling and concentrations of employment on Route 128. Table 14 shows that in a general way the larger the percent of employment in a given area the greater is the number of employees per automobile. This trend is also brought out by a plot (Fig. 12) of employees per vehicle against number of employees at each plant on Route 128. Each point represents one company, and the curve is a least squares fit. Although there are exceptions, it is evident that car pooling tends to increase as employment concentration increases.

Parking Lot Characteristics at Route 128 Plants. In the industrial survey, management personnel of the Route 128 plants were asked to give the number of parking places provided for employees and to comment as to whether or not their lot was adequate. Information was also obtained on the number of employees working on each shift and the starting and ending times of these shifts.

Parking space per employee ratios are tabulated in Table 15, grouped by employment ranges, for those companies that considered their parking lots adequate. Of those 86 companies giving information on parking spaces 74 had adequate facilities.

In computing the parking space ratios, the shift times and number of employees on each shift were checked in order to determine the maximum number of workers using the parking lot at one time. This number was then used to compute the ratios. If a company had two shifts which did not overlap, the employment during the largest shift was used in computing the ratio; if they overlapped, the total employment in the two shifts was used.

The lowest ratios of spaces per employee are found in the larger plants, while the ratios in the smallest plants are almost three times greater. This trend is consistent with the finding that car pooling is more prevalent at the larger companies and, therefore, their parking needs are less. It is also consistent with the vehicles per employee data given in Table 15 for each of the employment ranges. The companies with adequate parking facilities are providing an extra 30 percent ($\frac{0.79 - 0.594}{0.594} = 0.30$) of parking space over their needs to account for losses from improper parking, snow accumulation, and variations from average conditions.

Origin-and-Destination Study Conducted on Route 128. An origin-and-destination (O-D) study was conducted on Route 128 to determine the traffic characteristics of all the users of Route 128 and to provide information for determining the impact of the traffic contributed by the Route 128 industrial development. This survey was conducted by the Traffic Division of the Massachusetts Department of Public Works.

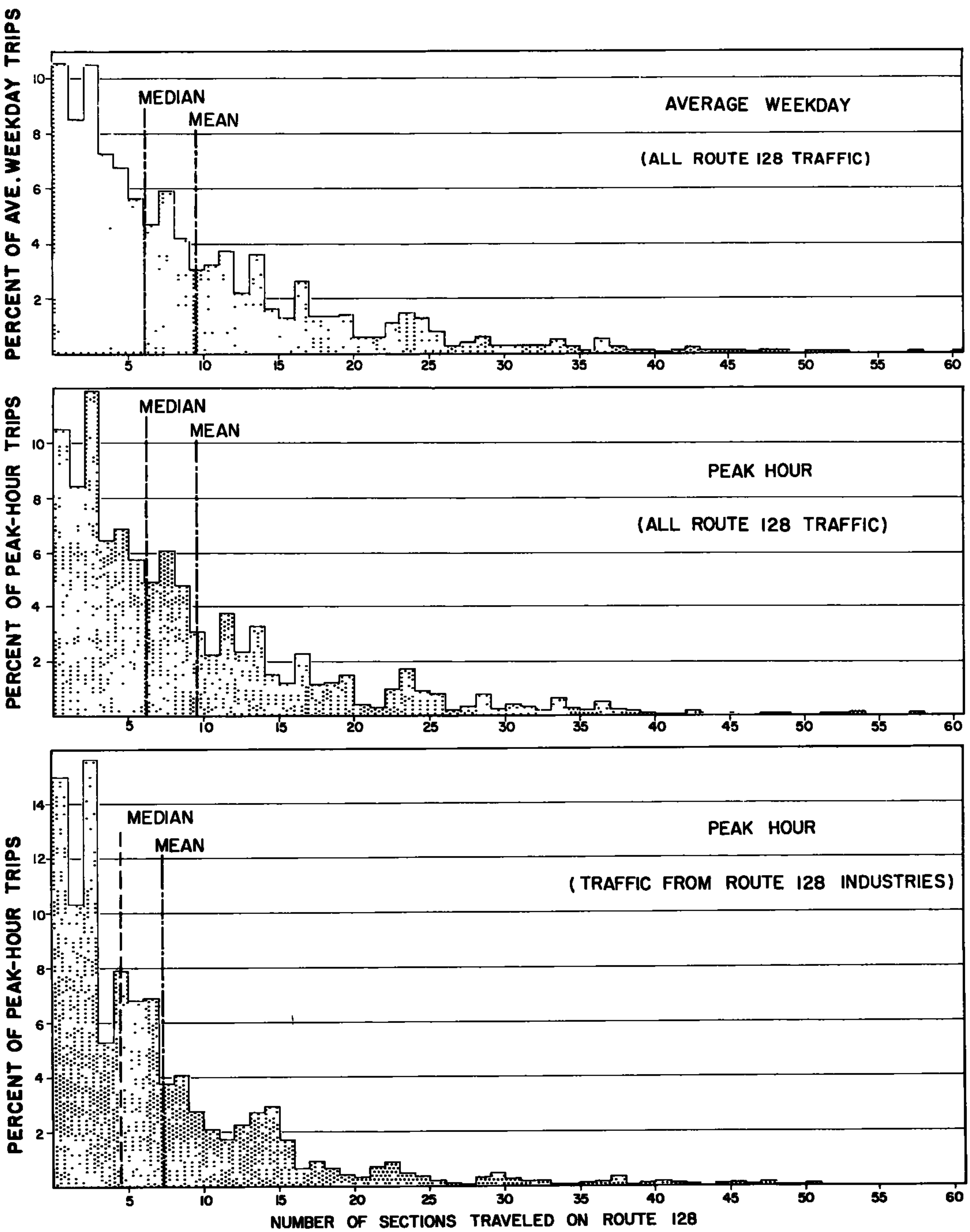


Figure 13. Distribution of traffic according to number of sections traveled on Route 128.

O-D stations were occupied on all southbound exit ramps between Grapevine Road in Wenham and Route 138 in Canton (Fig. 9). The interviews were all conducted on weekdays and for a minimum of 8 hr. The survey was started on October 15, 1957 and continued through January 24, 1958. Over 97 percent of all traffic leaving the ramps was interviewed. Manual volume counts were taken at all stations. The interview and manual count data were adjusted by the Traffic Division of the Massachusetts Department of Public Works, as follows:

"From various manual and recorder counts which were available, a 24-hour count was selected as the average volume for the ramp on the day on which the interview station was operated. All of these counts were then doubled to take care of the assumed matching northbound movement. From analysis it was determined that the counts taken in October were representative of an average annual weekday volume. Counts taken during the following months were adjusted by factoring:

November	1.05
November and December	1.10
December or January	1.15

TABLE 16

SUMMARY OF AVERAGE ANNUAL WEEKDAY TRIPS ON MASSACHUSETTS ROUTE 128

Trip Description	No. of Avg. Weekday Trips	% of Avg. Weekday Trips
Trips within Zone I (in-town)	237	0 1
Trips within Zone II (intermediate)	65,880	38.2
Trips within Zone III (outlying)	6,063	3.5
Trips between Zones I and II	19,868	11.5
Trips between Zones I and III	15,152	8.8
Trips between Zones II and III	46,017	26.7
Trips with origin or destination out-of-state	17,476	10.2
Trips with origin and destination out-of-state	1,807	1.0
All trips	172,500	100.0

Source: 1957 O-D Study, M. D. P. W.

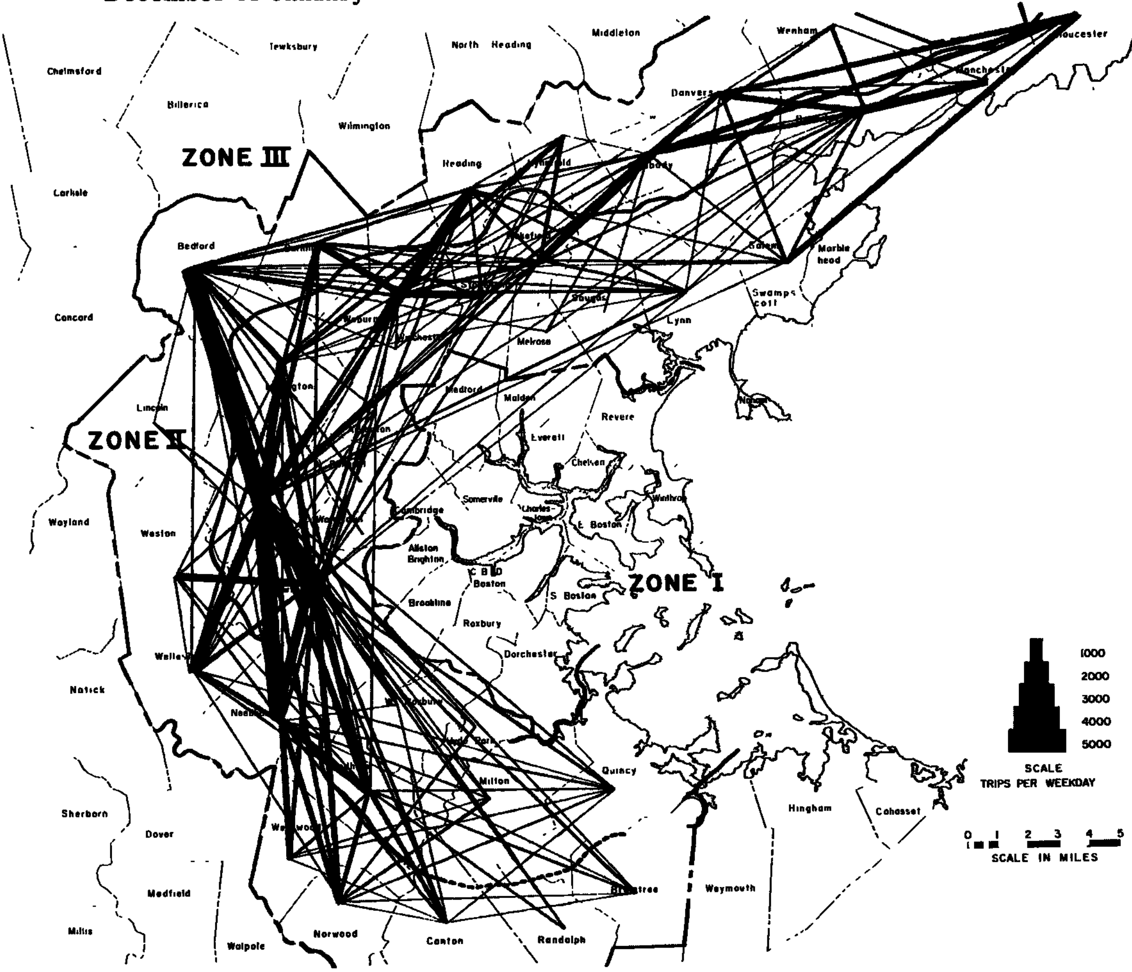


Figure 14. Desire lines for 1957 average weekday traffic on Route 128 with both origin and destination in Zone II.

Interviews were expanded to the volumes resulting from the above procedure."

After adjusting the data obtained from the roadside interviews, the M. D. P. W. prepared tabulations of average annual weekday trips and average weekday peak hour trips according to origin, destination, entrance ramp and exit ramp. Additional tabulations were made for trips between and within three regional zones: in-town, intermediate, and outlying (Fig. 3). The information regarding purpose of trip asked for on the survey form could not be used, however, because of incomplete data obtained in the field survey.

In interpreting the results of the O-D data (desire lines, etc.) it must be kept in mind that they apply to weekday traffic in the months of October through January. Most of this traffic would logically be of an "essential" nature such as trips to work and for business, shopping, etc. During the summer months, considerable recreational use is made of Route 128, particularly on weekends, by motorists driving to north or south shore resorts, and to places in Maine and New Hampshire. The extent of this seasonal variation is shown in Figure 2. This summer traffic tends to increase volumes on the northerly and southerly ends of Route 128, producing a somewhat different desire-line pattern than is presented in this report.

Error Introduced by Interviewing Only Southbound Exit Ramps. Since only the traffic on one side of the road was interviewed, it had to be assumed that the traffic mov-

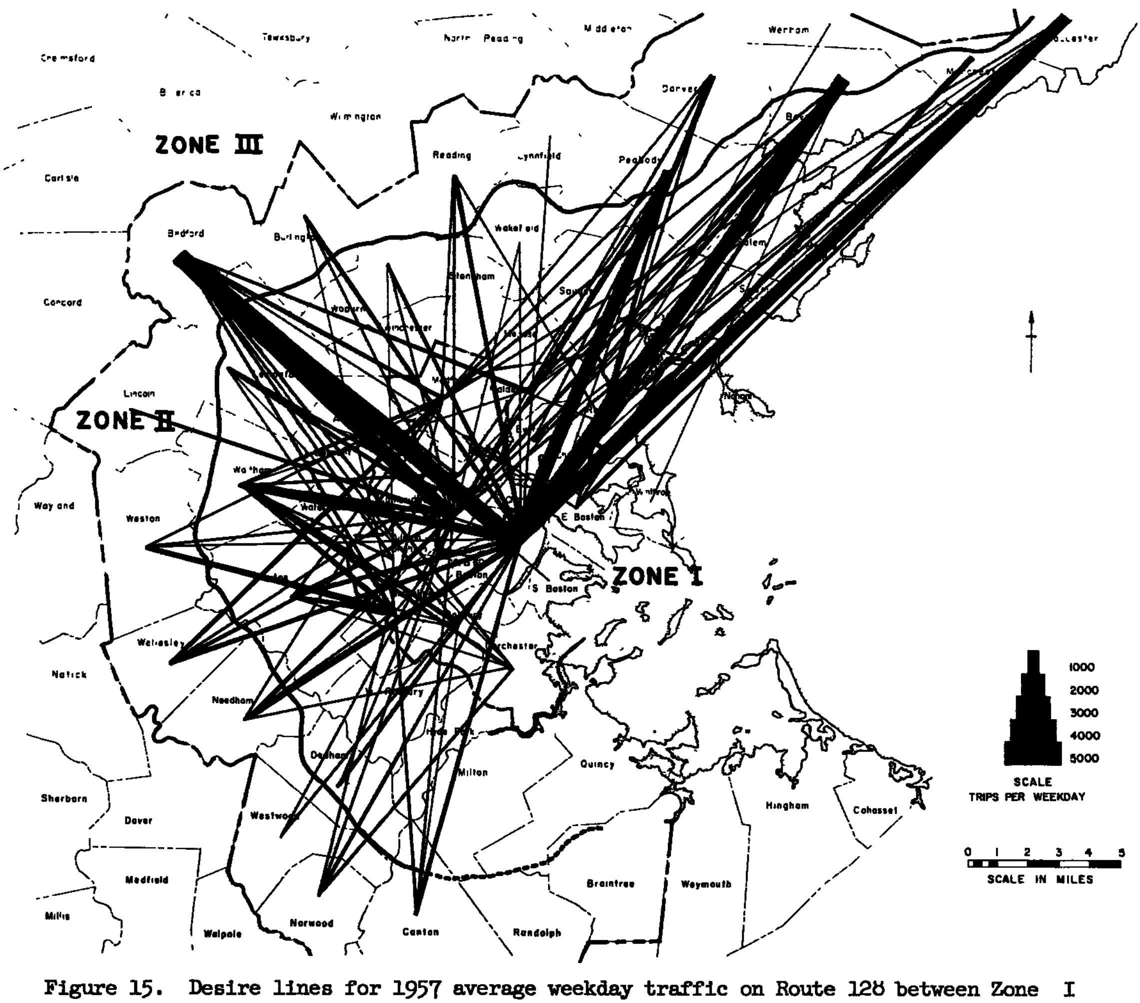


Figure 15. Desire lines for 1957 average weekday traffic on Route 128 between Zone I and Zone II.

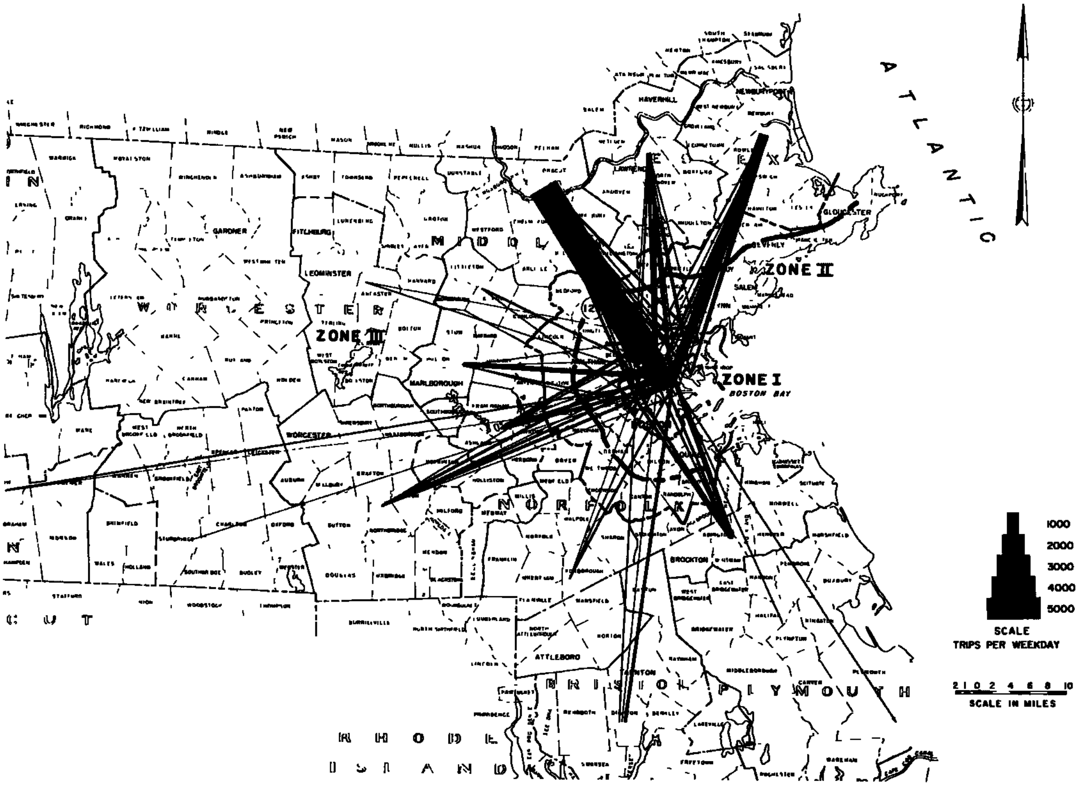


Figure 16. Desire lines for 1957 average weekday traffic on Route 128 between Zone I and Zone II.

ing in the opposite direction on the other side of the road followed a similar though reverse pattern. Traffic counts were made on all ramps of thirteen interchanges along Route 128 to determine whether or not this "reflection" principle was valid. The counts showed a 2.0 percent over-all difference between southbound and northbound ramp traffic, and a 0.9 percent difference between southbound exit and northbound entrance traffic. However, larger variations occurred at the individual interchanges. The differences were computed for the individual interchanges and weighted according to interchange ramp volume giving a weighted difference of 11 percent between southbound exit and northbound entrance traffic. The error thus introduced was not considered great enough to justify the extra expense that would have been necessary to interview both sides of the road.

Trip Characteristics of All Traffic Using Route 128. The average weekday trips were grouped into trips occurring between and within the in-town, intermediate, and outlying zones (Zones I, II, and III, respectively). The trips with an origin and/or destination out-of-state were tabulated separately. These results were summarized in Table 16. Part of this information is presented in desire-line form in Figures 14 through 17.

At least 76 percent of all the average weekday trips have either origin and/or destination in Zone II, the intermediate zone. Also, 65 percent of all trips were between Zones II and III, or within Zone II. Consequently, it is evident that the primary use of the Route 128 is being made by persons living, working, or shopping in towns close to it.

Only 20 percent of Route 128 trips start or end in Zone I which contains the central business district. The traffic generated in this internal area is mostly radial and appears to make little use of Route 128.

There is little evidence that Route 128 is being used much as a complete bypass for

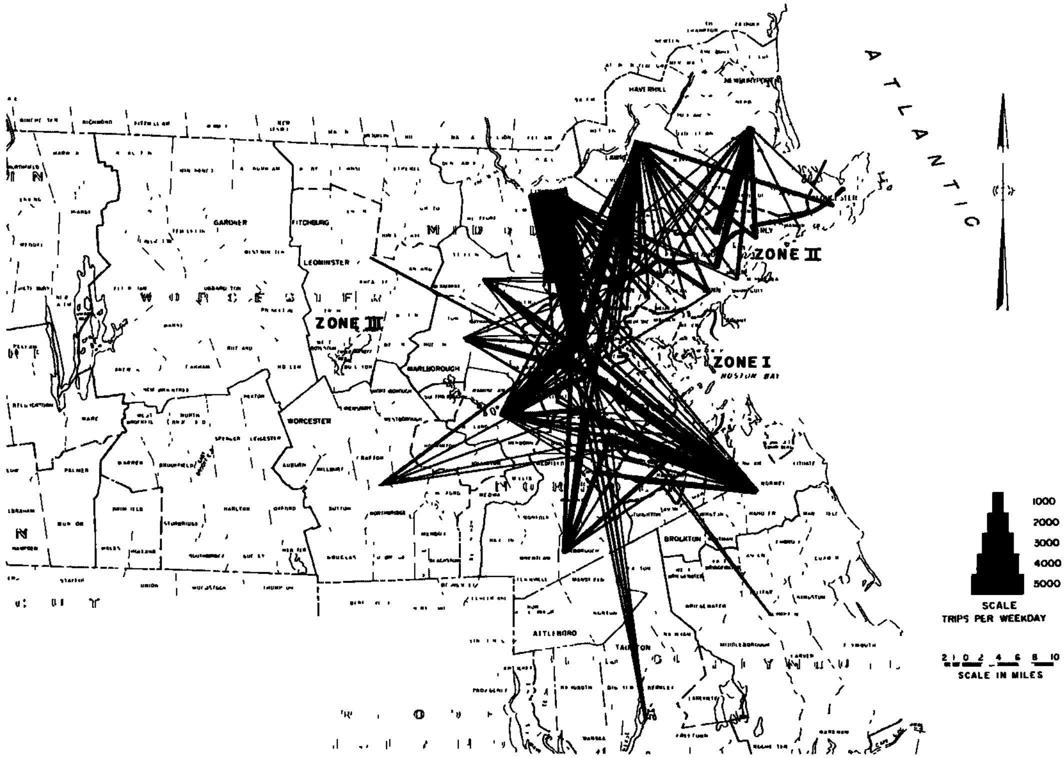


Figure 17. Desire lines for 1957 average weekday traffic on Route 128 between Zone I and Zone II.

the in-town area. For example, only 6 percent of average weekday trips on Route 128 have origins or destinations both out-of-state or both in Zone III or start or end in Zone III from out-of-state. Also, only 11 percent of all weekday Route 128 trips are from or to out-of-state points, and 91 percent of these trips have destinations or origins in Zones I, II, or III; 66 percent have origins in Zone I or II.

The trip data were tabulated according to Massachusetts towns, or, if outside Massachusetts, by state or origin and destination. The town data were further grouped according to regional zones (that is, in-town, intermediate, or outlying) or out-of-state. A summary is given in Table 17. All trips between these towns comprise about 80 percent of the total number of weekday trips. These data again emphasize the importance of the towns along the route as generators of traffic on the route and also emphasize the small contribution made by out-of-state and in-town traffic. The passenger vehicle and truck trips follow relatively similar patterns, though more trucks than passenger cars have in-town origins and out-of-state destinations.

The average weekday and peak hour trips on Route 128 were separated according to the number of sections of Route 128 used in each individual trip. A section is the length of road between two successive interchanges on Route 128. The average length of a section on Route 128 is about 1.2 miles. Figure 13 shows the percentages of the weekday and peak-hour trips using the route for different numbers of sections. The same information is also included for peak-hour traffic from Route 128 industrial developments.

The peak-hour and weekday trip length distributions for all Route 128 traffic are almost identical.[1] Nearly one-half of the weekday and peak-hour trips cover 6 sections or less, and about 30 percent of trips are 3 sections or less. Less than 20 percent of

[1]This "trip length" refers only to the portion of the trip made on Route 128.

the trips extend over 15 sections. Trucks follow patterns similar to those of passenger vehicles, except that trucks use the route for one section trips more than do passenger cars. The median trip length for both trucks and passenger cars, however, is the same. Again it is evident that the principal use of the route is for short distances rather than for long, bypass-type trips.

The average trip length of all route users is 9.5 sections, and the median trip length only 6.1 sections. On the other hand, the average trip length of the Route 128 industrial employees was only 7.2 sections, and the median length was

TABLE 17

PERCENT OF AVERAGE WEEKDAY TRIPS HAVING ORIGIN OR DESTINATION IN ZONE I, II, III, OR OUT-OF-STATE

Zone	Origin	Destination
Zone I (in-town)	10.6	12 4
Zone II (intermediate)	61.9	58.1
Zone III (outlying)	21.0	18 3
Out-of-state	6 5	11.2

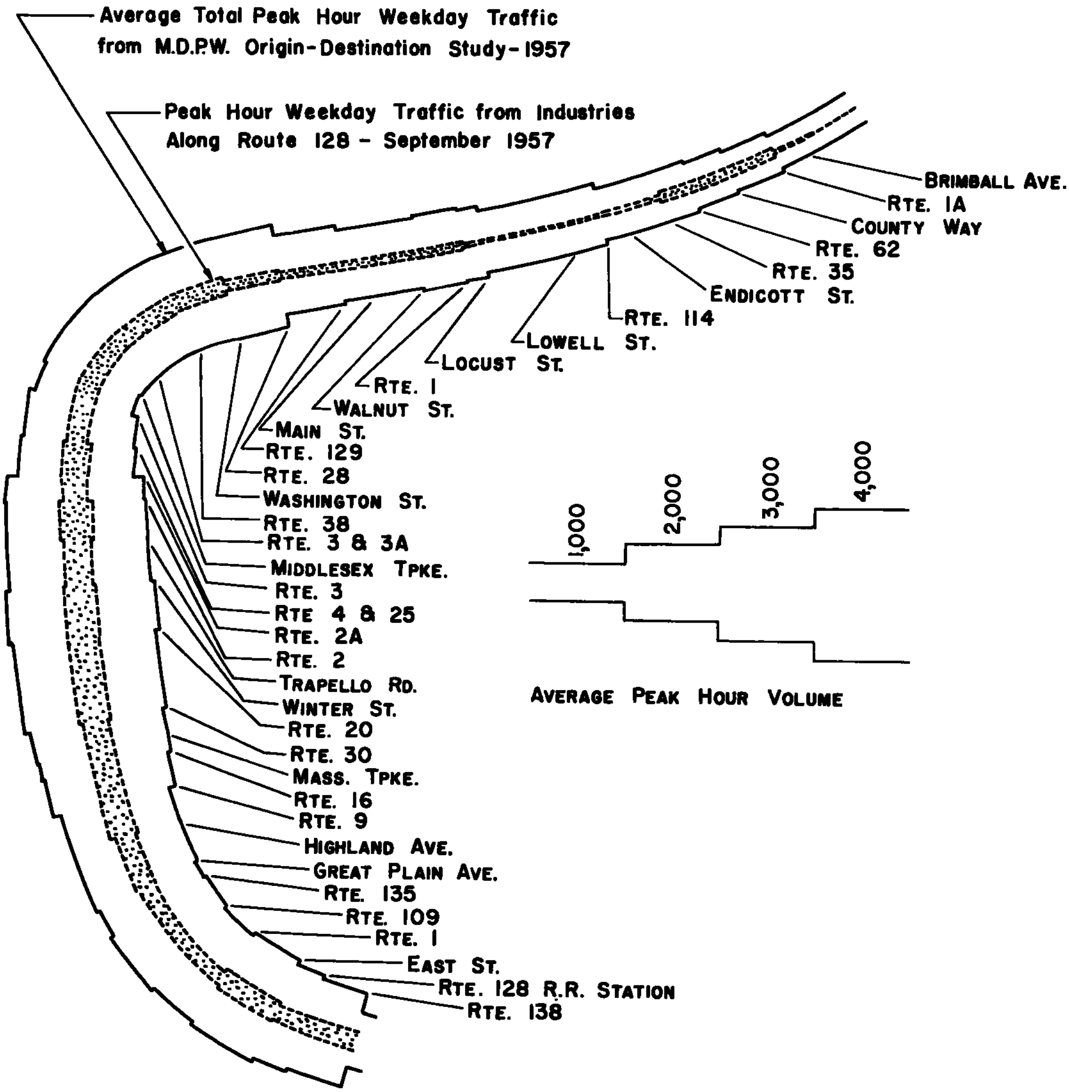


Figure 18. Average weekday peak hour traffic volumes on Route 128 in 1957.

4.5 sections. Thus, the median trip of the Route 128 employees is over 25 percent shorter than that for all Route 128 users.

From general observation it is known that much of the long-distance traffic approaching or leaving the metropolitan area uses Route 9 and the Massachusetts Turnpike on the west, and Routes 28 or 1 to the north. This traffic travels between these radial highways, using Route 128 for a range of 23 to 29 sections. An inspection of Figure 13 shows a jump in daily trips between this range, adding to about 6 percent of all daily trips or about 10,000 vehicle trips.

Figures 14 through 17 show desire-line charts of intrazonal weekday trips for the intermediate zone and interzonal trips for the in-town, intermediate, and outlying areas. Intrazonal trips for the in-town and outlying areas are not shown, as they represented only 0.1 and 3.5 percent of the weekday trips, respectively.

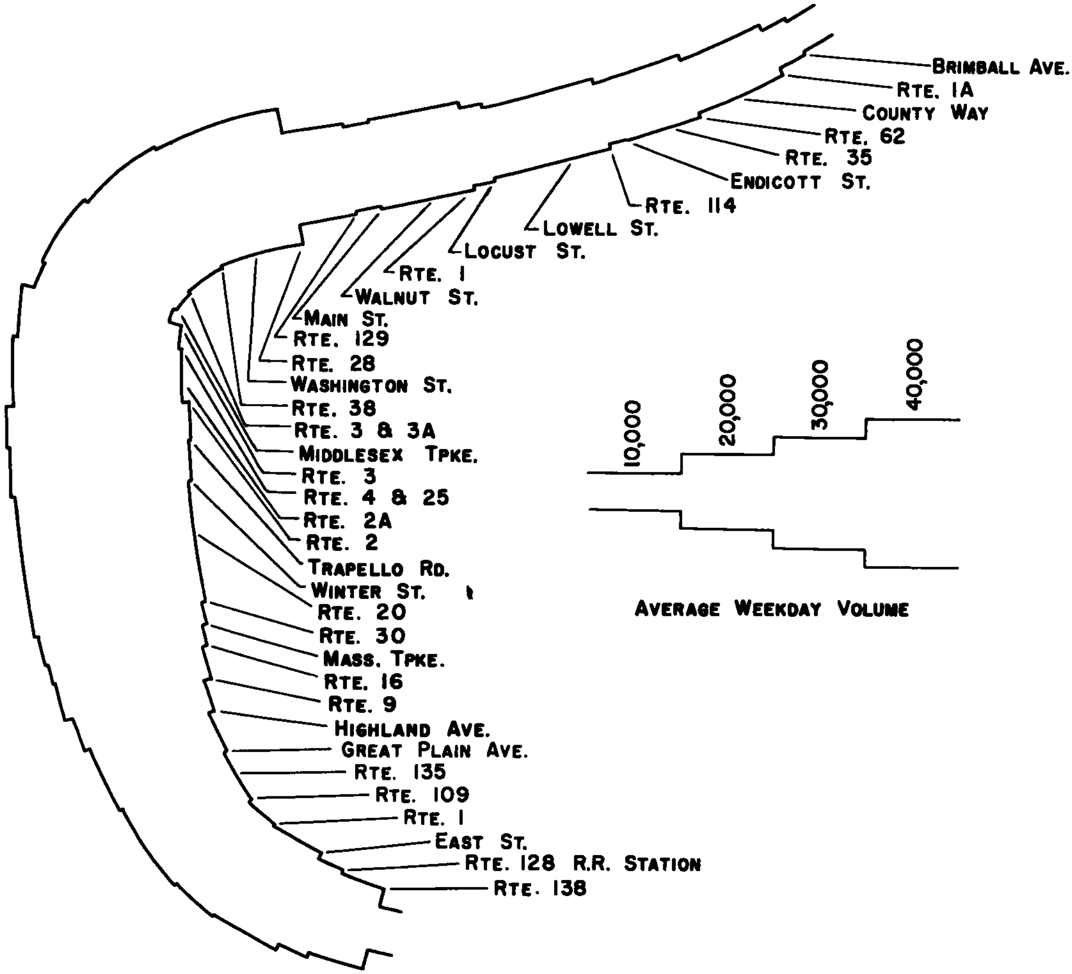
The average weekday trips which have both origins and destinations in Zone II are plotted as desire-lines in Figure 14; these Zone II internal trips represent 38 percent of the total weekday trips on Route 128. For clarity, only 35 percent of them are shown on the chart.

The advantages of using Route 128 for people making trips within Zone II are apparent. Inspection of Figure 14 shows that these internal trips follow the general location of the route; consequently, little transverse or radial movement is necessary in order to reach the route. Most of these trips appear to be relatively short; that is, in range of 7 to 8 miles. It seems reasonable to speculated that many of these trips would have been impossible without the circumferential highway, as most of them are made between or across radial highways where no adequate street connections formerly existed. This traffic might well be considered "generated traffic."

Part of the internal trips in Zone II are a result of Route 128 industrial employment. But it is not known how many other trips are also using the route for work purposes, and how many for shopping, etc. Of the Route 128 industrial employees (a total of 17,000), about 9,300 were living in Zone II as of September, 1957; the average number of vehicles per employee for these workers was 0.546, indicating 5,100 vehicles used by employees living in Zone II. Since each vehicle makes two trips per day to a Route 128 plant, and since 52 percent of these vehicles use Route 128, these industrial development workers contribute over 5,300 Route 128 trips a day, or about 8 percent of the internal Zone II weekday trips on Route 128. Considering that an estimated additional 11,000 employees are expected to be working at Route 128 plants completed or under construction since September 1957, the traffic contributed by suburban industry will become an increasingly important component of Route 128 traffic.

The desire-lines of the interzonal transfers between Zones I and II are plotted in Figure 15. These trips account for 11.5 percent of the average weekday trips. The great majority of the Zone I (in-town) trip ends are found in CBD Boston, though a sizeable number are found in Cambridge. The Zone II trip ends are spread along the towns adjacent to Route 128. Bedford serves as the largest source of trips, followed by Beverly, Gloucester, and Peabody. The fact that the desire-lines between Zone I and Bedford, Beverly, Gloucester, and Peabody are so large is not due to the fact that these towns are so highly populated or have many places of employment (relative to the other suburban towns), but rather it is due to the character of the radial access to these towns. Because of congestion on local radials, people living in Peabody, Gloucester, and Beverly use Route 128 in order to get on Route 1 or Route 28, which are the nearest radial highways leading into Zone I which offer reasonably good travel for the motorist. Similarly, the people living or working in Bedford find it highly advantageous to use Route 128 in shifting to the better radial routes; this is particularly true since Route 4-25 east of Route 128 goes through the congested center of Lexington and is therefore unattractive to motorists. Since Route 3 (north of Route 128) ends at the circumferential highway, the users of Route 3 must use Route 128 in order to continue their trip. Again the Route 128 industrial development contributes to this Zone I to II traffic. Over 4,000 of the Route 128 employees live in Zone I, and use Route 128 for 31 percent of their work trips and make approximately 1,450 trips per weekday on Route 128. This represents over 7 percent of the Zone I to II traffic.

In 1958 a very large shopping center was opened in Peabody, which eventually will



Source: Origin-Destination Study, Massachusetts Department of Public Works

Figure 19. Average weekday traffic volumes on Route 128 in 1957.

change the patterns in the northeastern section of the road considerably. However, at the time of the survey, only a small portion of the shopping center was in operation, and therefore it probably had little effect on the desire-lines.

The Zone I to Zone III trip desire-lines are shown in Figure 16. These trips represent only 8.8 percent of the average weekday trips on Route 128, and generally have the same characteristics as those from Zone I to II, in that they follow a radial pattern. The Lowell area serves as the largest generator of this traffic and is followed by the Newburyport and Ipswich areas. Most of this traffic has its other trip end in the CBD.

The extremely heavy desire-line from the Lowell area results from a temporary situation where a new relocation of Route 3 from Lowell dead-ends at Route 128 and Route 3 traffic is routed northerly for about 2 miles over Route 128 to make a connection with old Route 3 going in-town. Consequently, users of Route 3 from the Lowell region must use Route 128 for a portion of their journey.

The Zone II and III interzonal desire-lines in Figure 17 account for 26.7 percent of the Route 128 traffic. It is evident that these trips are of a different character than those internal trips in Zone II and those between Zone I and II or III. Whereas the others followed the axis of the road or were essentially radial, these trips are a combination; that is, they are partly radial and parly longitudinal. Motorists travel onto Route 128 by the nearest radial and then follow it until they find the radial which will take them closest to their destination. These trips making a portion of their trip along radials and part between or across radial highways where no adequate street connections existed prior to Route 128 were probably "generated" by the construction of the circumferential highway.

Approximately 3,400 Route 128 industry employees live in Zone III, and account for about 2,250 weekday trips on Route 128 (61 percent of the workers in this zone use Route 128). These industrial employee trips thus represent about 5 percent of the total Zone II to III trips.

The desire-lines for trips within Zone III are not included as they only represented 3.5 percent of the total weekday trips on Route 128. Most of these trips are in the range of 25 to 30 miles and tend to be of a bypass nature. It is quite evident that most of the trips would be much more difficult to make in the absence of Route 128.

The total trip distances of all Route 128 users have not as yet been analyzed to determine what percent of the trip is being made on Route 128. However, an inspection of the desire-line charts seems to indicate that this will vary according to nature of the zonal movement. The trips which are essentially radial in character, or the trips between Zone I and II or III, are apparently on Route 128 for only a few sections representing a small percent of the total trip. On the other hand, it would seem that the internal Zone II movement would use the Route for the majority of the trip distance.

Proportion of Industrial Employee Trips on Route 128 During Average Weekday and Peak Hour. Of the 172,420 average weekday trips only 5.4 percent or 9,224 were made by Route 128 industrial plant employees. However, this industrial traffic is concentrated in the afternoon peak hour when 3,147 of a total of 14,225 trips, or 22 percent, are contributed by Route 128 employees. These employee trips (3,147) represent 68 percent of all work-to-home trips of Route 128 industry employees.

During much of the year the percentage of employee traffic will be higher than the average, since total traffic reaches a peak in the summer months while employee traffic remains nearly constant all during the year.

Of the total average weekday trips, passenger cars comprise 147,458 trips, or 86 percent, and trucks 24,962, or 14 percent. During weekday peak hours the percentages are 88 and 12. During the peak hours Route 128 employee trips amount to 25 percent of the total 12,448 passenger car trips.

Figure 18 shows the manner in which the peak hour traffic is distributed along Route 128 and, by the inside band, the traffic which industry adjacent to Route 128 contributed to these peak volumes. The largest percentages of employee traffic are to be found in Needham, Waltham, and Newton areas, where most of the industrial development is located and where total Route 128 volumes are the largest. The importance of considering adjacent industrial development in traffic prediction is evident. New plants and business establishments under construction and planned for the future will further swell the volume of employee traffic, especially in the central portions. For example, 11,000 additional employees are predicted for plants completed or under construction since September 1957. If they produce the same proportion of Route 128 trips as did 1957 industry, 5,200 additional peak-hour employee trips may be expected. If all trips follow the trend indicated in Figure 2, the total peak hour trips will increase to 15,500. On the basis of these estimates, the employee traffic in 1959 would be 33 percent of all peak-hour traffic on Route 128.

Figure 19 shows average weekday flow along the highway. A maximum of nearly 50,000 per day is reached in the Waltham area. This is about 30 percent higher than at Route 38 in Burlington where the automatic counter is located, and from which data in Figure 2 were compiled.

During 1958 plans were under way for widening the central portion of Route 128 from 4 to 6 lanes with provision for possible 8 lanes. The traffic contributed by industry along Route 128 has been an important factor in requiring this widening only 8 yr after the highway was opened to traffic in 1951.

SUMMARY

Information on employee travel patterns was obtained from 7,500 employee questionnaires, from 10 gate counts at selected plants and from an origin-and-destination survey of the traffic using Route 128.

In September 1957, the employment at 96 companies located along Route 128 was approximately 17,000. About 52 percent of this employment was concentrated at plants located in a 6-mile section of the central portion of the route. Twenty-five percent of the employees lived in-town, 55 percent in the intermediate zone (towns adjacent to Route 128) and 20 percent in the outlying zone (towns beyond Route 128).

The average work trip for all employees was 11.7 miles which took 24 min for an average speed of 29 mph. Forty-nine percent of the employees used Route 128 during some portion of their trip to work. These employees had an average work trip of 15.0 miles which took 28 min for an average speed of 32 mph. Employees who did not use Route 128 in their trip to work had an average trip of 8.5 miles which took 21 min for an average speed of 21 mph.

Old employees (employees who are working for a company both before and after its move to a Route 128 site) comprised 52 percent of the total employment at Route 128 plants. Thirty-seven percent of these employees lived in-town, 46 percent in the intermediate zone, and 17 percent in the outlying zone.

New employees (employees who joined a company after it moved to a Route 128 site) comprised 48 percent of the employment at Route 128 industries. Twelve percent of these employees lived in-town, 65 percent in the intermediate zone, and 23 percent in the outlying zone.

The travel patterns of the new and old employees were quite different. Both the average time and average distance of the work trip of old employees were over 30 percent higher than those of new employees; however, the average trip speeds for both were practically the same.

Approximately 18 percent of the employees had moved since starting to work for a Route 128 company. The change in the average distance to work before and after moving for all, new or old employees was negligible. Of the employees who changed residence 43 percent moved farther from their place of work, while 39 percent moved closer to it.

Although the distance to work for Route 128 users was over 75 percent greater than that for non-users, the time required to make the trip was only 33 percent greater. Route 128 users had consistently longer distances, longer travel times and higher speed than non-users. As the percentage use of Route 128 increased, the distance to work increased, but the average speed increased at an even greater rate so that the time to work was nearly the same for all percentage uses. The higher speeds on Route 128 apparently compensated for the longer distances. Speed runs on Route 128 indicated a range of 45 to 55 mph during the peak hours.

The automobile was used almost exclusively in the trip to work by employees at Route 128 plants. Thirty-six percent of the old employees had used public transit or walked to work prior to working at Route 128 plants. After starting to work at Route 128 plants, only 3 percent of the old employees used these modes of travel. Special arrangements for public transportation have been tried at some Route 128 plants but have been abandoned because of lack of patronage.

The average number of employees per vehicle was 1.8; however, the greater the employment of a company the higher the number of employees per vehicle. This ratio was also higher for service industries and lower for distribution industries.

An origin-and-destination survey of all traffic on Route 128 revealed that the greatest use of the route was made by people starting or ending their trip in towns close to the route (the intermediate zone). Seventy-six percent of all weekday trips had origin and/or destination in the intermediate zone.

The average use of Route 128 by all trips was 9.5 sections or about 11 miles. Route 128 industrial employees used the route for an average of 7.2 sections or about 9 miles. In addition, 30 percent of all trips were for 3 sections (about 4 miles) or less, and 80 percent of all trips were for 15 sections (about 17 miles) or less.

On an average weekday (1957) about 5 percent of the total Route 128 traffic volumes were due to employee traffic from Route 128 plants. During peak hours this employee traffic amounted to 22 percent of all trips on the route.

The desire-line patterns illustrated vividly the lateral type of movement made possible by Route 128. Prior to the construction of the route no road system existed that could accommodate these desires.

ACKNOWLEDGMENTS

The authors wish to express their sincere appreciation to the numerous organizations who contributed to this study and especially to the sponsors, the Massachusetts Department of Public Works and the U.S. Bureau of Public Roads.

Particular thanks is extended to John R. Casey, Assistant Traffic Engineer, and John T. McHugh, Head Clerk, of the Traffic Division of the Massachusetts Department of Public Works for their assistance in assembling and developing the data.

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Also appreciated was the help given by Lawrence V. Hammel, Egons Tons, and A. Scheffer Lang of the Civil and Sanitary Engineering Department of the Massachusetts Institute of Technology.

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The Nature of Urban Freeway Systems

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● THE OBJECTIVE here is to present information concerning emerging freeway systems in urban areas. At the outset it must be realized that it is hazardous to present data on such a rapidly changing subject. Plans are always subject to alteration, and changes will invariably occur between the times of gathering and the time of presentation of the data. Futhermore, few comprehensive urban freeway networks have been conceived. There is a great variation in the degree of progress in urban highway planning and development from one city to another. Also, no specifics have been established as to the total transportation plant necessary to best serve a city, including freeways, expressways, arterial streets, and transit facilities, and it is unlikely that they will be developed soon.

In order to determine the spatial characteristics and development progress of freeway systems, all of the highway agencies in states with standard metropolitan areas (U.S. Census Definition) were contacted by mail. Information regarding both present and planned freeways was requested. From the returns of this inquiry specific information and special reports were gathered.[1] In addition, 12 cities in various stages of freeway planning were visited. Finally, the highway and urban planning literature was examined for additional information on the conceptual framework underlying urban highway networks.

The terminology of this analysis follows the definitions officially adopted by the American Association of State Highway Officials.[2] Briefly, an expressway is "a divided arterial highway for through traffic with full or partial control of access and generally with grade separations at intersections." A freeway is "an expressway with full control of access." A radial highway (or radial) is "an arterial highway leading to or from an urban center" (the CBD), and a circumferential (or belt highway) is an "arterial highway for carrying traffic partially or entirely around an urban area or portion thereof." The circumferential, which generally surrounds the CBD core is termed the "inner-distributor loop."

PATTERNS OF URBAN HIGHWAY SYSTEMS

General Pattern of the Interstate System

The general purpose of the National System of Interstate Highways (the "Interstate System") is to connect the major metropolitan areas of the United States by a system of freeways (Fig. 1). These freewyas are essentially oriented to intercity highway movement (29), but there can be little doubt that the backbone of most intracity urban highway networks will be the urban segments of the 41,000-mile Interstate System. These urban segments of the Interstate System include at least 1, and as many as 5 or 6, radial freeways to the CBD of most standard metropolitan areas. Interior cities like Indianapolis, Nashville, and Dallas are at the focus of 6 radial segments, whereas cities on the perimeter of the system such as Miami, Charleston, and Duluth have usually only 1 Interstate radial route. These radial freeways are merely replacing older radial arterial routes which have become obsolete because of their lack of access control and outmoded design standards.

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[1]Returns were received from the following states: Alabama, Arizona, Arkansas, Colorado, Delaware, Florida, Georgia, Indiana, Iowa, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, and Utah.

[2]Letter from B.M. French, Regional Engineer, U.S. Bureau of Public Roads, Portland, Oregon, November 18, 1958.

Figure 1. National System of Interstate Highways, 1957.

In addition to the radial freeways, the Interstate System will provide many of the medium-to-large cities with outer bypass circumferential routes. These routes, connecting radials at their outer extremities, provide for the increasing traffic demand between outlying portions of the metropolitan areas occasioned by decentralization, and also allow bypass of the city center.

The Interstate System will also provide an inner-distributor loop, or some portion thereof, in about 20 cities. This loop is one of the major improvements in the central distribution of traffic. Obviously, freeways carrying several thousand automobiles an hour cannot intersect at a point. In the pre-industrial city planned radial routes came together at a plaza, in an open central square, or at a monumental circle. This philosophy of route conjunction characterized the planning of the main roads of the Nation's Capital, Detroit, Madison, and part of Central Philadelphia, to mention only a few cities.

Urban freeway systems, as defined by Interstate routes, are shown graphically, and to the same scale, for 16 cities in Figures 2 and 3. These cities were chosen because the system of radials, circumferentials, and inner-distributor loops will be especially well developed by Interstate routes in these urban areas. With the exception of Cleveland and small sectors of Houston and Dallas, all cities shown have complete outer circumferential routes. Those in Detroit and Chicago can only be semi-circumferential, of course, because of natural barriers. Wherever the circumferential routes deviate significantly from the general circular pattern it is usually because of land acquisition problems caused by rectilinear land platting, as in Detroit, or serious topographical difficulties, as in Cleveland. Columbus, Boston, Detroit, Cleveland, and Los Angeles will have complete inner-distributor loops as parts of the Interstate System. Kansas City, Houston, and Washington, D. C., will have partial loops, while most of the other cities will have only intersecting radial routes near the central business district.

The Interstate System configuration in most urban areas will determine the general structure of the urban freeway network, but the degree to which these systems will accomodate intracity highway traffic needs is a matter of conjecture. As part of the In-

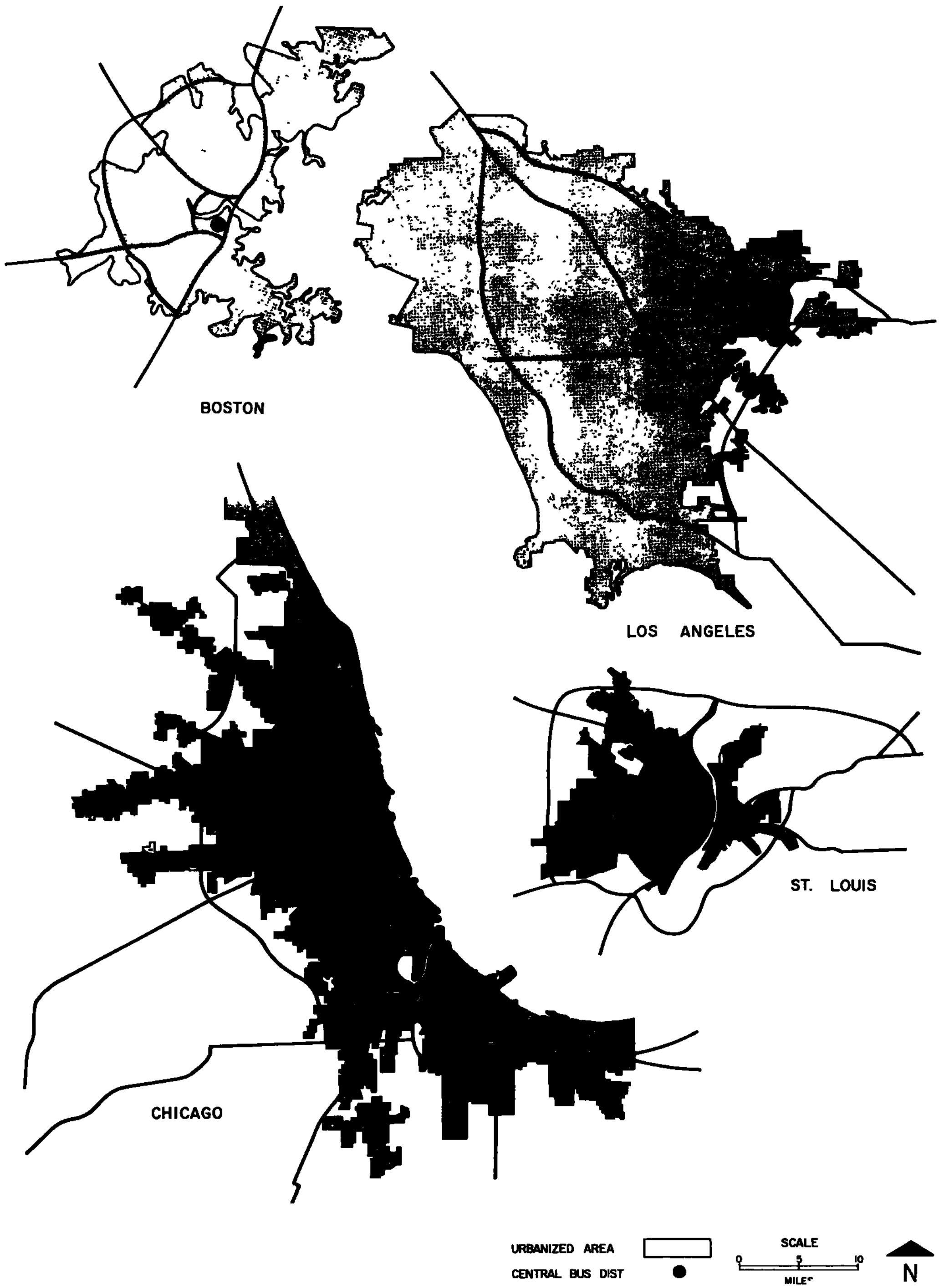


Figure 2. Urban freeway systems as defined by interstate routes (1).

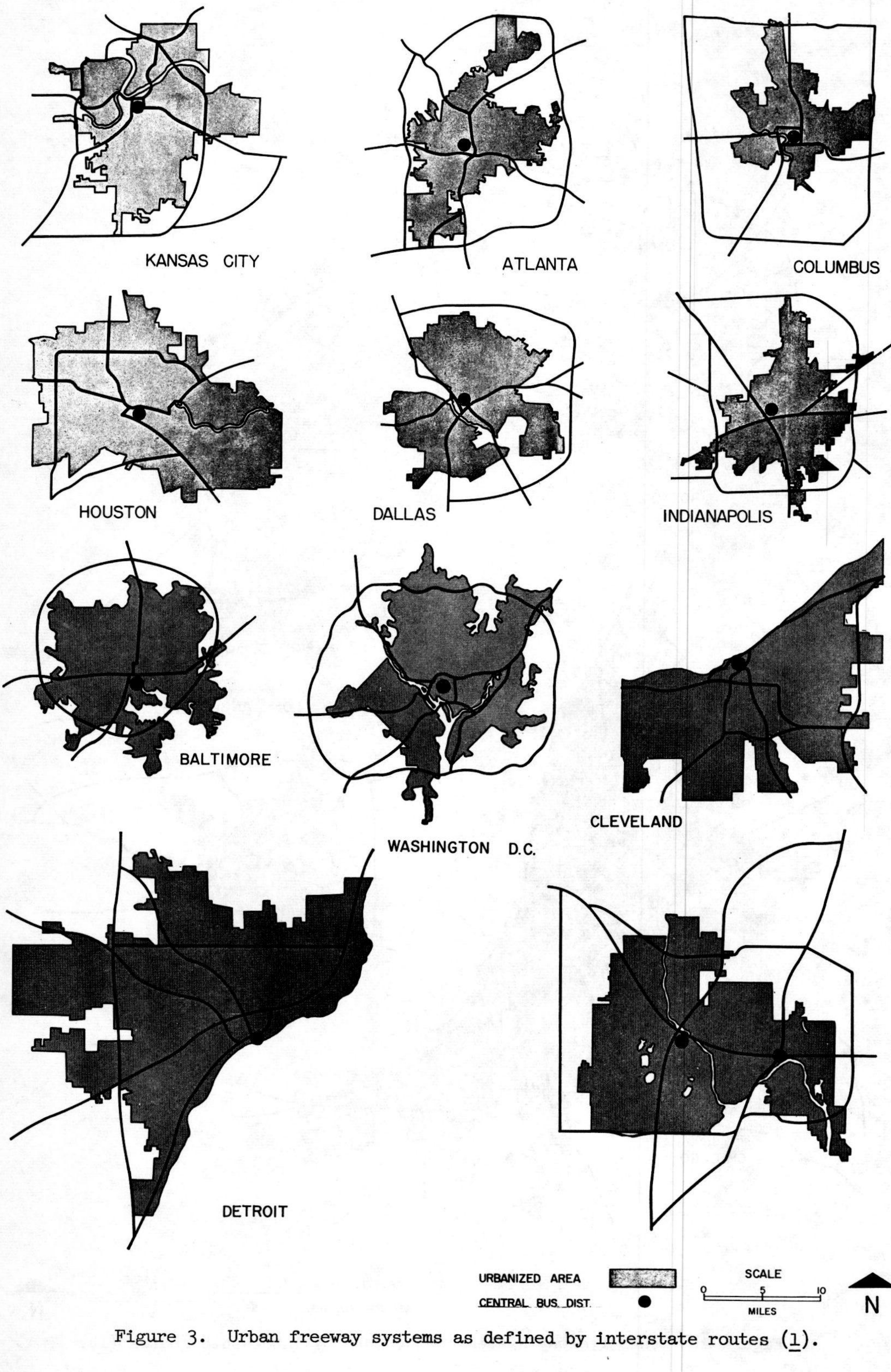


Figure 3. Urban freeway systems as defined by interstate routes (1).

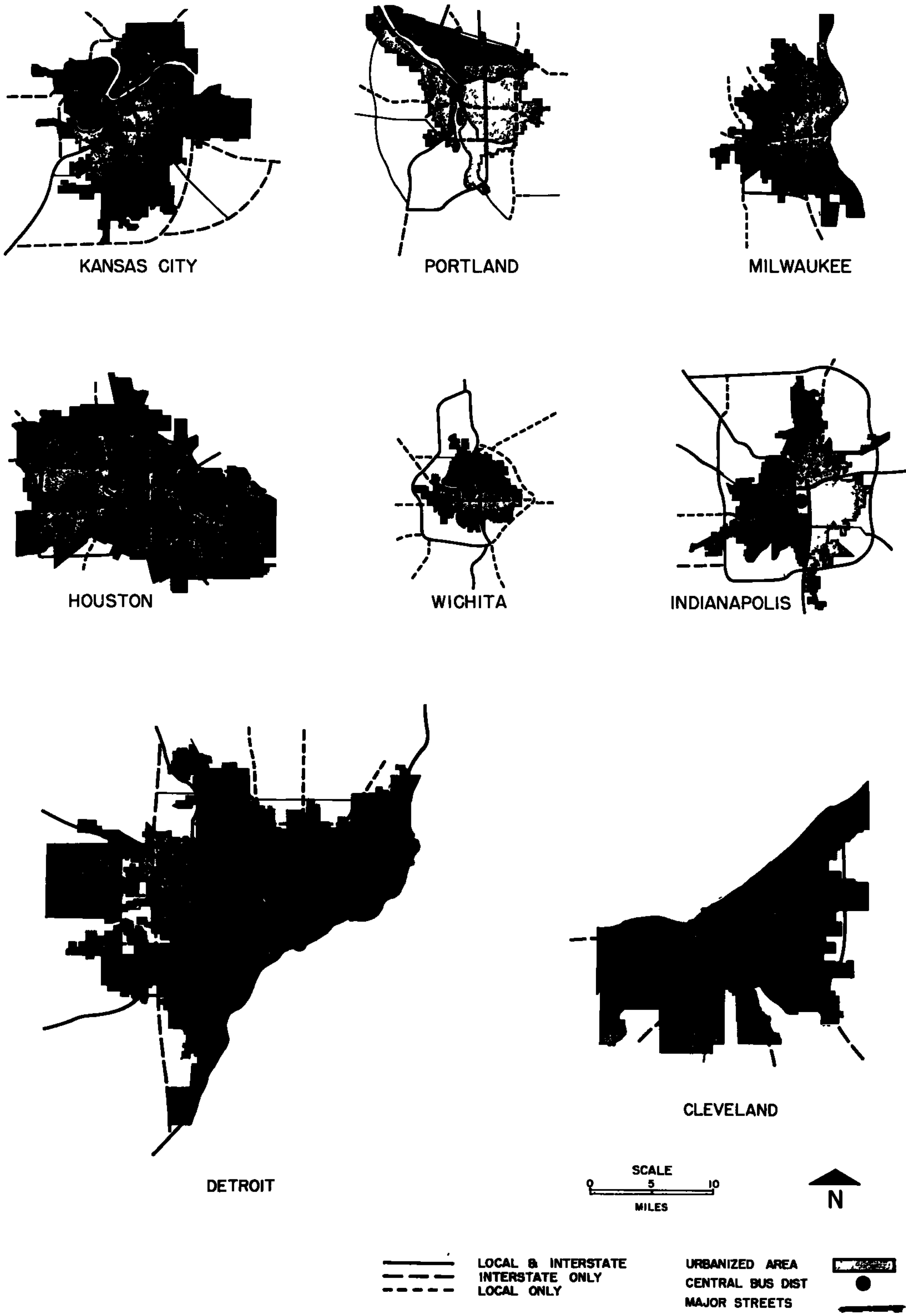


Figure 4. Urban freeway systems as defined by composite plans (1).

TABLE 1

COMPARISON OF TOTAL PERIMETER OF 8 FREEWAY SYSTEMS

City	Urbanized Area Pop. 1950[1]	Miles of Freeway Within Uniform Distance Bands of CBD (Cumulative) (36)				Freeway Miles per 100,000 Population (urbanized area)
		5 mi	10 mi	15 mi	20 mi	
Detroit	2,774,563	65.4	154	211	259	9.34
Cleveland	1,406,813	40.0	119.2			8.5
Milwaukee	826,936	25.5	38.5			4.7
Houston	726,214	40.2	94.2			13.0
Kansas City	720,892	33.6	43.8			6.1
Portland	529,902	53.4	90.6	96.2		18.2
Indianapolis	502,375	26.4	92.4			18.4
Wichita	194,047	55.4	86.8			44.7

[1]Calculated from Figure 4.

terstate System the radial routes owe their locations primarily to intercity linkages, not local traffic demands. The questions naturally arise as to what degree these radials will serve local needs, and specifically, how many more radials, as well as circumferentials, will be needed to supplement the Interstate System in any given urban area?

State and Local Supplementation of the Interstate System

Another indication of the possible size and shape of the entire urban freeway system in the future may be found by the examination of composite highway plans in various cities. Figure 4 shows some of these systems drawn to a common scale. In addition to freeways, these configurations show locally planned routes of an arterial or expressway nature when needed to complete a composite network. The cities were selected on the basis of the existence and availability of studies dealing with their comprehensive freeway needs. It is cautioned that only the generalized route locations are shown, and some licence has been taken to combine Interstate routes and locally designated ones where it is obvious that only one can fulfill the generalized route location. Insofar as the Interstate locations are extremely generalized, preference has been given to the locally designated routes when only one was selected.

The locally planned freeways for the cities shown in Figure 4 represent varied degrees of planning, engineering, and cooperative effort between jurisdictions. This planning involved the following methods: (1) outside consulting service (Indianapolis); (2) state highway planning and engineering, exclusively (Portland and Houston); (3) city effort exclusively (Wichita); (4) combinations of inter-governmental units (Kansas City and Detroit); and (5) a special purpose governmental district (Milwaukee).

The combination of both Interstate and local routes gives a better indication than the Interstate System of the total freeway resource deemed necessary by freeway planners in the urban areas shown. In some instances routes of a lower type than freeways are noted. These are arterials, expressways, or state highways with some degree of access control. They represent either a compromise design, or show that in some cities full freeway control is deemed unnecessary for all parts of the urban highway system.

The non-Interstate routes in the urban areas shown either add radials to the system, provide radially oriented spurs where the Interstate routes deviate from a radial pattern, or complete the circumferential system. For example, Portland's and Detroit's supplementary plans propose 5 additional radials and Houston's 3. In Kansas City and Milwaukee, short radially oriented spurs are added to the Interstate System. Houston's plan completes the circumferential route with a state highway in the southeast sector of the city, and the Kansas City plan completes the inner-distributor loop on the south side of the CBD. Milwaukee's composite freeway plan is exceptional in this group in that it lacks an outer circumferential.

In addition to the visual comparison in Figure 4, an effort has been made to compare the total miles of freeways in these cities in tabular form (Table 1). Some caution should be exercised in interpreting such a comparison, however, because the total highway network of any particular city includes not only freeways, but expressways, arterials, and sometimes city streets. The proportions of urban highways in these various categories may justifiably vary between different urban areas. It may be noted that the outer circumferentials are located about 10 miles from the CBD. There is no apparent relationship between total miles of freeway and urbanized area population. The degree of planning consistency is seen by comparing the miles of freeway per 100, 000 people in the various urban areas shown. This per capita distance ranges from 4.7 miles per 100,000 people in Milwaukee to an improbable 44.7 miles in Wichita. In terms of the group, Wichita's plan appears much too optimistic, whereas Milwaukee's may be inadequate. It should be observed here that the Wichita study is entirely a product of the city planning agency and has no engineering basis or cost analysis.

THE INNER-DISTRIBUTOR LOOP

Physical Characteristics

As has been indicated, the inner-distributor loop is an important innovation in highway development. Insofar as it is also the most expensive element of the urban freeway network, detailed research has been undertaken to show its specific dimensions and its relationships to land use.

Although there are no specific design standards governing the size of an inner-distributor loop, there are certain physical limits based on the conceptual scheme of this type of facility (30). Under optimum conditions the loop would avoid highly valued land and yet be located close enough to the core to provide easy access to parking areas adjacent to the core. Access to and from the loop would be made from the ramp closest to the parking facility, thus keeping through traffic out of the core, thereby minimizing trip conflicts. In other words, a further distance might be traveled on the loop in order to avoid the congestion of city streets.

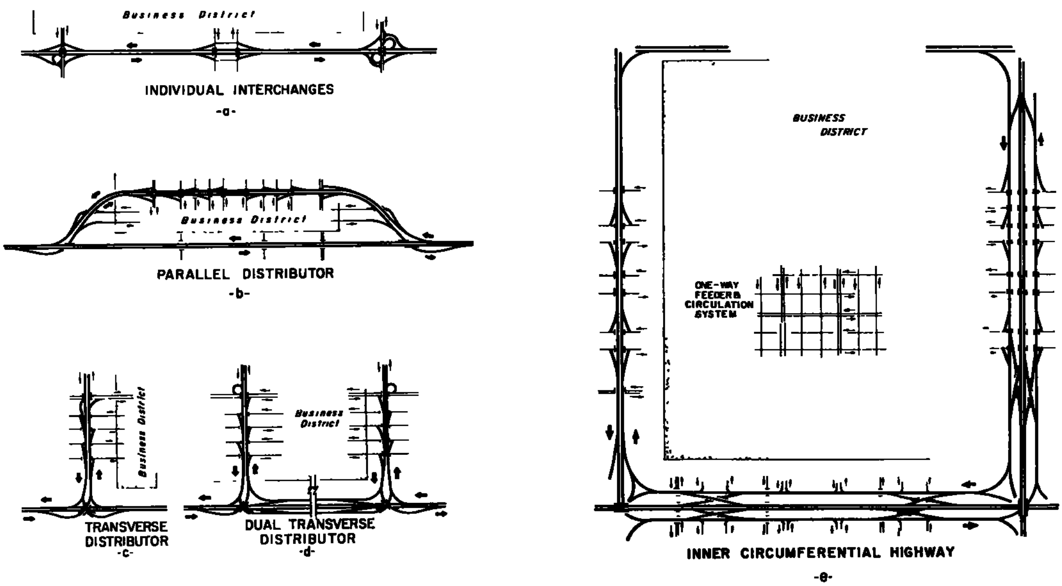


Figure 5. Diagrammatic inner highway distribution systems (1, 2, 3, 4, 5, 6, 7).

The inner loop is designed to supply access to the core throughout its perimeter. The need for complete circulation around the CBD core is partially imposed by the probability that some ramps will be unusable at various times because of accidents or congestion beyond the ramp. Also there are probabilities that some traffic will be unable to weave into the desired lane for off-ramp approach. Under any of these conditions traffic must continue until exit can be made. Therefore, the freeway route should not deviate from a generally circular pattern. Another requirement necessitating the completion of the inner-distributor loop is that inbound traffic will not necessarily enter it at ramps closest to the point of destination, while the reverse of this condition is true for outbound traffic. A complete loop will generally be necessary for the continuous flow of traffic, although some cities have only partial freeway loops planned.[3]

The primary problem with too large a loop is that either long access ramps to the core are required to reach destination points and parking lots, or freeway traffic must disperse on congested city streets for some distance before reaching these locations. Too small a loop cuts down the possible number of access ramps because of the spacing requirements for ramps and thereby limits the amount of traffic which can be deposited in the central area. These individual ramp distributors are major factors in determining the size and shape of the inner-distributor loop. They require from 3 to 8 acres of land each and cannot be closer than about 2,000 ft because of traffic weaving design standards (31). In addition, too small a loop also limits the amount of available parking within it, or cuts into overly expensive land by circumscribing the core too closely.

Additional characteristics of central traffic distribution systems are shown in Figure 5. A quick survey of the systems illustrated immediately points out the significance of a completed inner-distributor loop. Figure 5a shows a single freeway skirting the core on one side. This system is inadequate for all but the smallest cities.

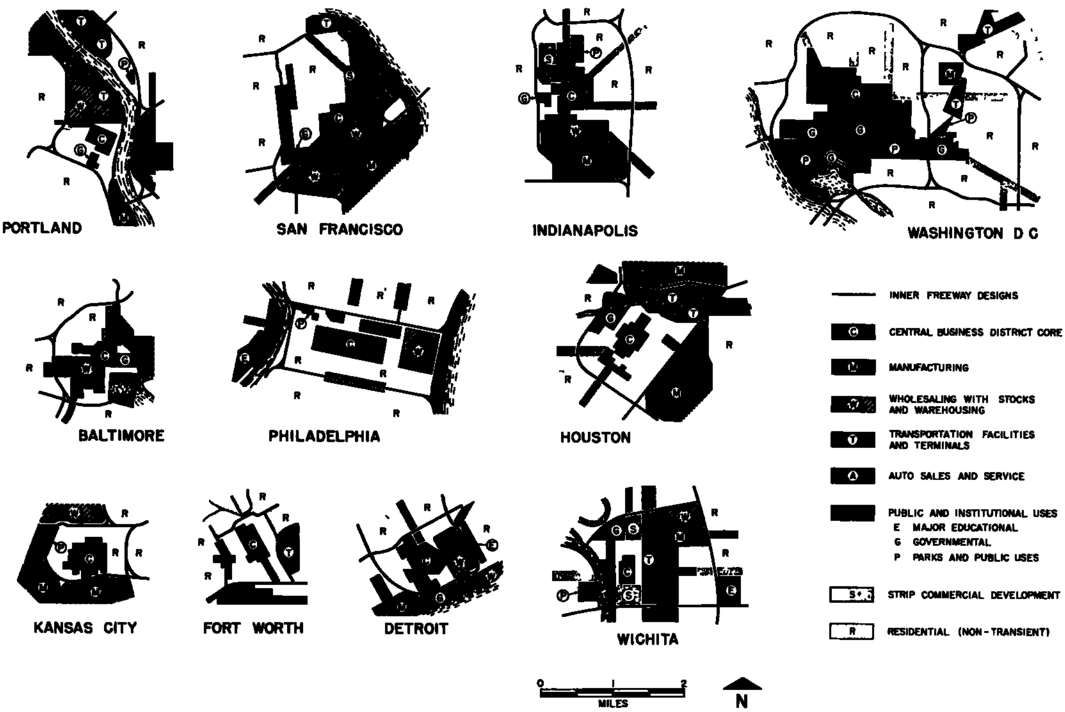


Figure 6. Inner freeway designs and central land use (1, 8, 9).

[3]The north segment of the Planned Cincinnati CBD loop uses city streets. See Cincinnati City Planning Commission, "The Proposed Central Business District Circulation System," pp. 108-119, (1957). Also, the south segment of the Detroit CBD loop is less than full freeway standard (26). The southwest leg of the proposed Houston CBD loop is at present composed of 4 one-way city streets, with a sinchronized plan (4).

Figure 5b shows a parallel distribution system. This system is characteristic of small city highway bypasses. The transverse and dual transverse distributor systems shown in Figures 5c and 5d provide a reasonable perimeter for access to the core but lack the circulatory feature. The complete inner-distributor loop as partially shown in Figure 5e provides the greatest perimeter for access ramps. With 4 sides of 2-way traffic it permits any area inside it to be reached with minimum effort, and allows a bypass of the core from any direction.

Little can be said concerning the adequacy of any inner-distributor loop to serve highway traffic requirements in any particular city unless related to specific data. It is generally realized, however, that no inner loop system yet devised is capable of distributing even the present number of people working in most central business districts if they were to travel by automobile alone. The reason for this is the overlapping of travel on the inner-distributor loop. CBD-bound traffic from origins in opposite segments of the city will jointly occupy the inner loop for a portion of the trip. In view of the relatively limited capacity of all types of inner-distributor systems, continued use of city streets and mass transit for approach to the CBD appears to be absolutely necessary.

The precise size, shape, and location of any specific inner-distributor loop would vary from city to city. Nevertheless, there is considerable similarity in the physical attributes of these loops as demonstrated by Figure 6, which shows planned designs of inner-distributor loops in 11 cities drawn to the same scale. (Note specific legend in Table 2.) These inner loops represent various stages of planning and engineering analysis, and may be substantially changed before being constructed. They reflect also the planning efforts of different agencies in the structure of government, and even a private group, as in the case of Fort Worth.[4]

As to measurable physical characteristics, the inner-distributor loops vary from 8 miles in circumference in Washington, D. C. to slightly over 3 miles in Kansas City and Fort Worth. They are between 1 and 2 miles in diameter. The area encompassed by them varies from 0.7 sq miles in Fort Worth to 4.3 sq miles in Washington, D. C. Most of the loops contain from 4 to 6 major interchanges with radial freeways (Table 3).

TABLE 2

DETAILED LAND USE LEGEND FOR FIGURE 6

Symbol	Classification	General Use Characteristics
C	Central business district hard core	As delineated by tall buildings, high pedestrian volumes and high land values Here the majority of space use is devoted to offices, retail trade in department stores and specialty shops, hotels, theaters, and some medical and dental services. It excludes uses below except in small amounts
W	Wholesaling with stocks and warehousing	Includes usually commission food dealers, supply houses and warehouses for retail goods.
A	Auto sales and services	New and used car sales. Auto specialty repairs, used car sales lots.
T	Transportation facilities and terminals	Rail yards and stations, truck terminals, and waterfront activities.
M	Manufacturing	The manufacturing of hard products.
R	Residential	Housing except for transient accommodations
G	Governmental uses	Distinct centers of governmental activity, including city hall, and state and federal office buildings.
H	Hospital and medical	Distinct centers of health services
E	Major educational institutions	Universities, colleges and large high schools
P	Parks and public institutional uses	Relatively large aggregations of space for meeting places, assembly halls, and museums.
S	Strip commercial development	Stores and outlets outside the CBD core catering mainly to retail trade and customer services, such as line the old public transit arterials. These commercial strips usually merge into the core of the CBD.

Relation to Land Use

Figure 6 also shows the location of the inner-distributor loops in relation to functional areas of land use. It should be cautioned that the functional areas are not directly comparable, or the data completely reliable. Information regarding the functional areas was requested of planning agencies in the particular cities. Each agency was asked to outline areas of similar land use in their CBD according to the classification table furnished (Table 2). Nevertheless, there was still considerable latitude in the interpretations made by the agencies supplying informa-

[4]Based on information from the Fort Worth Planning Agency. The Fort Worth loop does not appear to be developing as originally planned.

tion. For example, the reported core areas of Washington, D. C., and San Francisco are very large when compared with the other cities. This may be because of different interpretations of the core classification, or because of differences in the degree of exactness in mapping it by the various respondents. In other cities vital functions, such as wholesaling, appear to have been unintentionally omitted by reporting agencies. Most of these discrepancies could not be remedied without visiting the cities in question. Nevertheless, there is still a high degree of similarity of functional and spatial structure in the 11 cities, as shown in the following:

1. The CBD core is generally located in a central position within the inner-distributor loop.
2. The core tends to be the smallest major area of functional land use in the CBD.
3. The larger areas of functional land use in the CBD are manufacturing and wholesaling.
4. Railroad and water transportation terminals are always closely tied to wholesaling and manufacturing.
5. Automobile sales and service areas tend to be elongated and arterial oriented, contacting the core at one point.
6. Manufacturing is always located farther from the core than wholesaling.
7. Government buildings are found outside the core, but inside the inner-distributor loop. They are often close to parks.

Once the loop has been constructed, land use on either side may assume different characteristics. Where single functions are split by a loop, as in the case of wholesaling in Detroit, the characteristics of the once single-functional area may become different on either side of the freeway. Another effect of the inner-distributor loop may be to intensify and restrict certain business groupings. Whether uses for permanent residency can long survive within an inner-distributor, except by means of urban renewal or strong public policy support, is questionable. In any event, the chances are great that permanent dwelling units will be relegated to "highrise" structures because of the limited supply of land within the inner-distributor loop.

LAND SERVICE AREAS OF FREEWAY NETWORKS

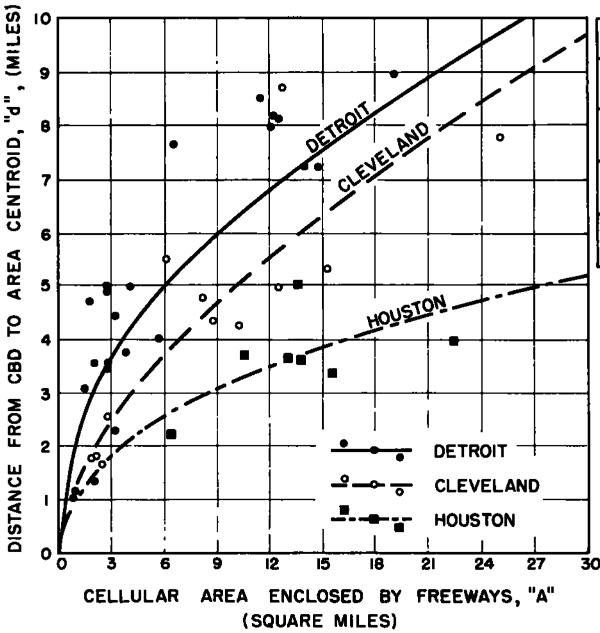
One of the most noticeable features of the urban freeways shown in the foregoing is the relatively similar cellular structure of land units encompassed by them. The ra-

TABLE 3

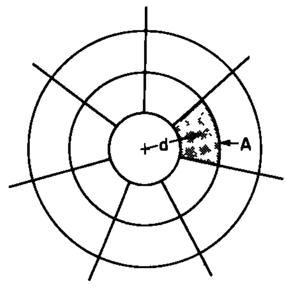
PHYSICAL CHARACTERISTICS OF 11 INNER LOOP DESIGNS

City	Perimeter (mi)	Length (mi)	Width (mi)	Area Enclosed (sq mi)	Major Interchanges (No.)
Detroit	3.9	1.3	0.9	1.03	2
Philadelphia	5.9	2.1	0.9	1.86	5
Baltimore	4.3	1.4	1.2	1.24	5
San Francisco	6.7	2.1	1.8	2.82	5
Indianapolis	6.5	2.2	1.4	2.45	4
Portland	6.0	2.5	1.0	2.13	6
Kansas City	3.3	1.3	0.8	0.75	6
Wash., D. C. No. 1[1]	8.3	2.5	2.2	4.34	6
No. 2	6.1	1.8	1.3	2.29	4
Houston	5.7	2.0	1.2	1.91	3
Fort Worth	3.8	1.1	0.8	0.67	6
Wichita	5.7	1.8	1.4	2.06	4

[1]Washington, D. C. has two connecting central distribution loops. The loop containing the core is the No. 1.
Source: Figure 6.



	DETROIT	CLEVELAND	HOUSTON
MILES OF FREEWAY	259	99 6	94
RADIALS	10	6	7
CIRCUMFER-ENTIALS	2 INTERMED & OUTER	INTERMED & OUTER	OUTER ONLY
CELLULAR AREAS	27	12	8



THEORETICAL DIAGRAM

Figure 7. The cellular structure of urban freeway systems (2, 3, 4, 6, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23).

dial and circumferential elements enclose portions of the urban area within cells with roughly similar shape, but with increasing size outward from the city center.

Insofar as population density decreases with distance from the center of the city, the increasing area of the cellular units with distance outward provides somewhat of a constant population per unit cell. In Detroit, for example, the cells located about 5 miles from the city center have an area of approximately 3 sq miles, a population density of 16,000 to 32,000 people per square mile, and include between 48,000 and 96,000 people. The cells located about 8 miles from the city center are about 12 sq miles in area, have a population density of only 4,000 to 8,000 persons per square mile, but also include between 48,000 and 96,000 people (26).

It is interesting to note that the Detroit freeway plan, a particularly extensive one, develops a cellular structure which encloses areas considerably larger in population than the typical neighborhood and community planning units (32). Neighborhood land planning units usually have 5,000 to 10,000 people each, and community units 15,000 to 30,000 people, except in the older cities. These land planning units are considerably smaller in population than the freeway-defined cells discussed above.

Another way of viewing the extent of a freeway network is by measuring distance between the various highway elements. The interior location of the cellular land units are rarely farther than 2 miles from a freeway, and only 1 mile in cells whose centers are within about 5 miles of the CBD. Even in the Los Angeles freeway network, which has more of a grid than a radial configuration, this observation prevails (33). It appears that a maximum distance of 2 miles from the center of a cell to an encompassing freeway is becoming characteristic of freeway system configurations.

Concerning the freeway network, one school of thought contends that as distance from the center of the city increases, city streets become proportionately less congested, thereby reducing the need for freeways. Under this theory the radial freeways would continue to diverge outward from the core, and circumferentials would also have greater spacing with increasing distance from the city center. Nonetheless, outlying residential density may not diminish with distance from the city center in the future. Under typically developing regional urban complexes, intercity ribbons of land are becoming urbanized without any break in the degree of residential density.

This leads to the notion that many urban freeway networks may develop into a grid system to serve the intercity areas.

The cellular structure of land within the urban freeway network in 3 cities is analyzed in Figure 7. These areas were chosen as representative of cities with moderate, intermediate, and extended freeway systems under development. The cell areas were plotted in relation to distance from the core to their centroids, and lines of best fit were applied to show the general relationships (34). It is immediately notable that the cell areas are considerably larger in Houston, at comparable distances from the core, than in Cleveland or Detroit. In Detroit, for example, the cell areas 4 miles from the core are about 4 sq miles, whereas in Houston at approximately the same distance the cell areas are over 15 sq miles. This is probably because of the lack of an intermediate circumferential in Houston. As a matter of fact, the more extensive the freeway network is, the smaller are the cell areas at given distances from the core. Consequently, cell areas appear to vary from city to city. Even at a distance of 2 miles from the core, the general experience of cellular areas ranges from about 4 sq miles in Houston to 1 sq mile in Detroit.

On a theoretical diagram of a freeway network the area of any particular cell "A" would increase with distance from the core at a rate dependent upon both distance and the number of circumferentials (Fig. 7). The curves of Figure 7 prove this to be generally the case in the 3 cities shown. This analysis is not advanced as a theory of freeway development but as an aid to discussion and analysis of both the total freeway resource and its shape. Actually, cities which are restricted by shorelines from growth in certain sectors may need more radials than cities of similar population size which can spread out in all directions. Detroit and Cleveland may owe their relatively similar characteristics on Figure 7 to this factor.

RATIONALE BEHIND URBAN FREEWAY SYSTEM DEVELOPMENT

This research, in addition to examining the physical characteristics of urban freeway systems, has attempted to investigate the thinking underlying the shape and extent of these systems. The network studied are characterized more by their similarities than differences. Questions naturally arise as to the principles which were applied to produce this situation. For example, to what extent has a conceptual framework of circulation and a philosophy of system planning influenced freeway planning? Where have economic discipline and design considerations been credited with producing the given configuration? And how has the adequacy of these planned systems been judged?

To find answers to these questions all available freeway planning studies were examined in detail for discussion on the specific reasoning behind the system planning. The results of this inquiry are briefed in Table 4. Although a liberal editorializing was necessary to present the rationale in its barest essentials, considerable effort was made to repeat the key phrases of the text and avoid changing meaning.

TABLE 4

REASONING UNDERLYING FREEWAY SYSTEM PLANS

City	Rationale
Baltimore (24)	To provide a complete system of efficient radial arterials and "ring" streets
Boston (25)	To provide a program for the relief of traffic congestion in the area by a network of the latest modern design and capacity expressways
Cleveland (9)	To provide a highway plan fully integrated with the land use pattern, with locations selected and to best serve the community within the framework of the principles of good planning, engineering, and economy (The Cleveland freeway plan was also based on studies of the Cleveland Regional Plan Association made in 1944.)
Detroit (26)	To develop a complete network of expressways to meet requirements within the Detroit area by 1980, and provide facilities affording the most convenient route from origin to destination
Indianapolis (6)	To provide radials, circumferentials, and additional routes to serve the existing circulation needs of the community, plus anticipated needs by 1975.
Kansas City (2)	To provide desirable radial and circumferential routes to adequately serve anticipated traffic needs in the Greater Metropolitan Area in 1970, and to provide a freeway loop surrounding the CBD to serve as a distributor and connector for 5 interstate radials and other expressways.
Milwaukee (7)	To provide radials to connect with principal highways entering the County, as well as connections between principal concentrations of populations and industry, and to serve 1980 traffic needs.
Minneapolis (27)	To provide maximum transportation for residents of the Area and a central distributor system based on estimated 1975 traffic volumes.
Omaha (28)	To develop a system of expressways for the Metropolitan Area to serve local and through traffic volumes of 1970.
Portland (3)	To accommodate future and existing traffic desires
Wichita (5)	To alleviate present traffic congestion and meet 1975 traffic forecasts.

This particular phase of the research on urban freeways has been disappointing because of the very broad generalizations given as the underlying reasoning for the particular transportation plan. Although many of the reports pay cognizance to the emerging principles of land use planning, such as the inviolability of the various homogenous units of settlement, they offer very little else which relates to the rationale behind the freeway system itself. Strangely enough, some of the reports which reflect the greatest output of work say least on the reasoning behind either specific route locations or the configuration in general. Statements such as, "To accommodate existing and future traffic desires," or "To alleviate present traffic congestion and meet 1975 traffic forecasts," present very little to go on in the evaluation of their particular freeway network.

In several of the reports the development of a freeway system is emphasized as a planning goal, and specific mention is made of the need for radials, circumferentials, and inner distributors. Recognition of system needs, however, does not necessarily give a clue as to the philosophy of spacing the various elements of the system. For instance, how many elements are considered enough? Any traffic desire pattern may be handled by a variety of systems, involving varying degrees of investment and service.

There is no doubt that the urban highway planning studies under consideration here reflect not only various approaches to the subject but different degrees of analytical depth. However, they are all distinguished by their attention to the planning of entire systems, as distinguished from the multitude of single element freeway or expressway studies. In most of the planning reports cited careful attention has been given to the traffic studies basic to them, and the routes have been determined only after a trial series of traffic assignments to the system has been made involving factors of future traffic projection or prediction and the cost-benefit ratios of different systems. The Detroit study undoubtedly reflects the most extensive analysis yet reported and the Cleveland study is also very thorough.

Many of the similarities in the planned configurations shown may be the result of both economic and design determinants. For one thing, the relative uniformity of financial support for these facilities, on a per capita basis, stems from user taxes, which do not differ greatly in scale from one jurisdiction to another. In addition, the relative similarity of urban land development, based on nationwide patterns of residential amenity, may result in similar traffic generating characteristics of land use from one city to another. Before a clear picture of this subject can be obtained, significantly more research will have to be undertaken in appraising the freeway planning goals in the various urban areas of the country.

SUMMARY AND CONCLUSIONS

The developing freeway systems are composed of 3 distinguishable elements: (1) radials to serve the needs of intercity travel and the centrally oriented intra-urban trip; (2) circumferentials to serve as bypass routes and meet trip desires between outlying centers; and (3) an inner-distributor to collect and distribute traffic to and from radials and to serve as a city center bypass.

The Interstate System will supply varying percentages of total freeway system needs from city to city. In most cases state or local supplementation of the Interstate System will be required to complete the urban freeway network. In at least a dozen major urban areas supplemental freeway routes to the Interstate System have been proposed. These supplemental plans by and large complete the urban freeway network in these cities. The Interstate System provides the framework for the local network. Where comprehensive urban freeway networks have been planned, an average of about 11 miles of freeway per 100,000 urban area population is developing.

The functional efficiency of the entire urban freeway network may depend on the development of a complete inner-distributor loop. Over a dozen cities have them planned or in various stages of development. These loops are relatively similar in their general spatial characteristics, averaging about 5.5 miles in perimeter, 1.9 miles in length, 1.3 miles in width, and enclosing about 1.93 sq miles of area. These loops are generally located within approximately 1,000 ft of the retail and office core of the CBD, and tend to cut into wholesaling, light manufacturing, and old or dilapidated housing. They take up on the average well over 200 acres of central land, which is usually twice as large as the core area referred to above. There are a relatively similar set of functional areas of land use in the vicinity of the inner-distributor loop.

In the freeway systems analyzed, the maximum spacing of routes is such that any point of urban land is rarely farther than two miles from a freeway. Land within 4 or 5 miles of the city center is rarely more than 1 mile from freeway service.

The basic motivation behind freeway conception is providing a transportation facility to serve existing and anticipated traffic demands. No attention is given to the use of freeways as a land use programing tool (35). This no doubt emanates from the fact that the freeway planning agencies have not been given broader urban planning responsibilities, and machinery has not been worked out to effect freeway development and urban planning as one unit.

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Discussion

EDWARD T. TELFORD, Assistant State Highway Engineer, California Department of Public Works, Division of Highways, Los Angeles—As a first step in any discussion of the matters which Horwood, Boyce and Rieg have set forth in their paper, it would appear reasonable to take up the following matters of background concern: (1) objective; (2) relation of the freeway system to the total street and highway system; (3) area occupied; and (4) spacing in a grid system of freeways and its relation to geometric design and traffic capacity.

1. The objective of the freeway program is to develop a freeway system which will be a part of an integrated motor vehicle transportation system, including not only freeways, but major arterials and local or land use roads.

2. There are no destinations on a freeway. The freeway can only serve the motor

vehicle operator effectively if he can proceed between the freeway and the point of the origin or destination of his trip, via adequate conventional street or highway routes properly connected to the freeway system.

3. In a metropolitan area, planning of land use must be on the basis that each acre of land is expected to produce something, whether it be office space, retail business, residence, manufacturing, parking or transportation. The very nature of the forces with lead to the development of a metropolitan area make it necessary to plan for the most effective use of the land. It therefore becomes obvious that only sufficient area to provide for proper balance in total use should be assigned to each of those functions which are a part of metropolitan life, including all types of transportation. If this line of reasoning is accepted, then the area occupied by a freeway becomes an important factor in reaching a conclusion as to the proper spacing of freeways in the total system. As an example the following information is offered:

(a) The Harbor-Santa Monica Interchange will require 87 acres.

(b) The Harbor Freeway between the Santa Monica and San Diego Freeways requires approximately 38.4 acres per mile.

(c) The Harbor-San Diego Freeway Interchange will occupy 86 acres.

4. In the Los Angeles metropolitan area, early studies of the possibility of development of parkway routes led to some radial development, with its origin in the vicinity of Civic Center. With the spread of population over the entire plain of the Los Angeles Basin, the pattern of traffic desire has changed. The resulting pattern is made up of three elements: (a) the northwest-southeast movements roughly parallel to the coastline and connecting with the areas north and south of the metropolitan area; (b) the east-west movement between the coast and the San Bernardino-Riverside area; and (c) superimposed on these, the east-west, north-south grid pattern of traffic movement within the highly developed metropolitan area of the Los Angeles Basin.

In the course of the studies made in 1955-56 the possibility developed that, for much of the area, a grid system of freeways on a spacing of approximately 4 miles would be desirable. There are several factors which lead to this tentative conclusion—among them, the fact that on a well developed street system, a freeway will draw traffic from about 2 miles on either side. Second, it was found that it is desirable to provide for collection and distribution between the freeway and city streets as a separate matter from the interchange between freeways. Considering the desirable geometric features involved in the spacing of ramps entering or departing from the freeway, it appeared that 4-mile spacing of freeway interchanges would offer interesting possibilities. As a matter of interest a study of the freeway traffic which would probably be generated by a 16-mile square area was started and carried to a partial conclusion in 1957-58. This study will be the subject of a paper which may be prepared and offered for consideration at a later date.

The natural development of the freeway study has resulted in a plan for freeways, east-west and north-south, around the central core of the City of Los Angeles at much closer spacing. In fact, the greatest distance from a freeway at any point in the central core is approximately 1 mile. This may be considered by some as an inner-distributor loop, but it is a natural development of the planning of freeway routes to serve the traffic demand in the area.

As to the relationship between the freeway system and the Interstate System, it is probable that the Interstate System will represent somewhere between 25 and 30 percent of the total mileage of freeways in this metropolitan area. While the Interstate System is a vital part of the metropolitan freeway plan, it is not adequate by itself. It appears that the Interstate System has a definite place and may be expected to do certain work in connection with the motor vehicle transportation system, but it would be unwise to attempt to place upon it the burden of serving as a major part of the metropolitan freeway system. It must be remembered that it is an interstate and defense system.

Factors Influencing Transit and Automobile Use in Urban Areas

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● THE OBJECTIVE of this research is to develop a relationship between the use of public and private transportation on the one hand, and the principal factors influencing that use in urban areas on the other, in order to estimate what use will be made of each of these modes under each estimated set of influencing factors. If that can be satisfactorily done, an estimate can be made of the usage and the total construction and operating costs for such usage of any proposed transportation system, including terminal facilities for each mode. From this the next step is to estimate the benefits of each plan and program in relation to cost.

Within the next 20 to 25 years, there undoubtedly will be changes in modes of urban transportation. It is quite doubtful, however, that any drastic changes will take place so rapidly that the basis for planning will be wiped out over night. At least as far as can be foreseen, establishment of this relationship will permit preparation of transportation plans on a more realistic basis.

It is believed that a start, as reported in this preliminary paper, has been made in establishing this needed relationship. This investigation leads to the conclusion that this approach will yield relationships that will predict within a sufficient degree of accuracy for transportation planning the travel mode split for an estimated set of conditions. Future research may produce modifications in some of the factors and the estimating equations for the entire urban area, and especially in the relationships for subareas and for time periods.

Search for Relative Use Formula

In most urban areas since the late 1920's (except for the depression and war years) the automobile has been supplanting transit as the mass carrier of people. The rate of change, however, has not been uniform from city to city and from year to year. In a number of metropolitan areas, principally the larger ones to the east of the Mississippi River, the decline in transit riding apparently is tending to level off. In many cities, however, the trend from transit to automobile has been continuing at either an accelerated or a constant pace.

Transit, highway, planning, and municipal officials have long been seeking a means for determining the change in both relative use and total trips by transit and automobile. Transit and regulatory officials need this information to establish a fare structure and transit-service characteristics. Highway engineers have been faced with the necessity of determining whether the cost of street and parking facilities and of transit facilities on highways will be justified by future use. Planning and municipal agencies are concerned with the interrelated effect of land-use distribution and population on the one hand, and on the other hand the use of transit and automobile as well as the effect on other utilities. Municipal authorities must also weigh the effect on the tax structure of relative travel mode use, especially if transit operations should become the responsibility of an agency of the public. Primarily all of these are concerned with the factors and elements that cause variations in travel mode use and their relationships in the economic and political system.

PROCEDURE

Factors and Elements Studied

In previous attacks on this problem (1, 2, 3), attempts have been made to establish relationships between transit-riding habit and several factors. In most research these factors have been (a) population, (b) automobile registration, (c) transit service, (d) economic welfare, and (e) transportation costs. These studies, however, have not yielded

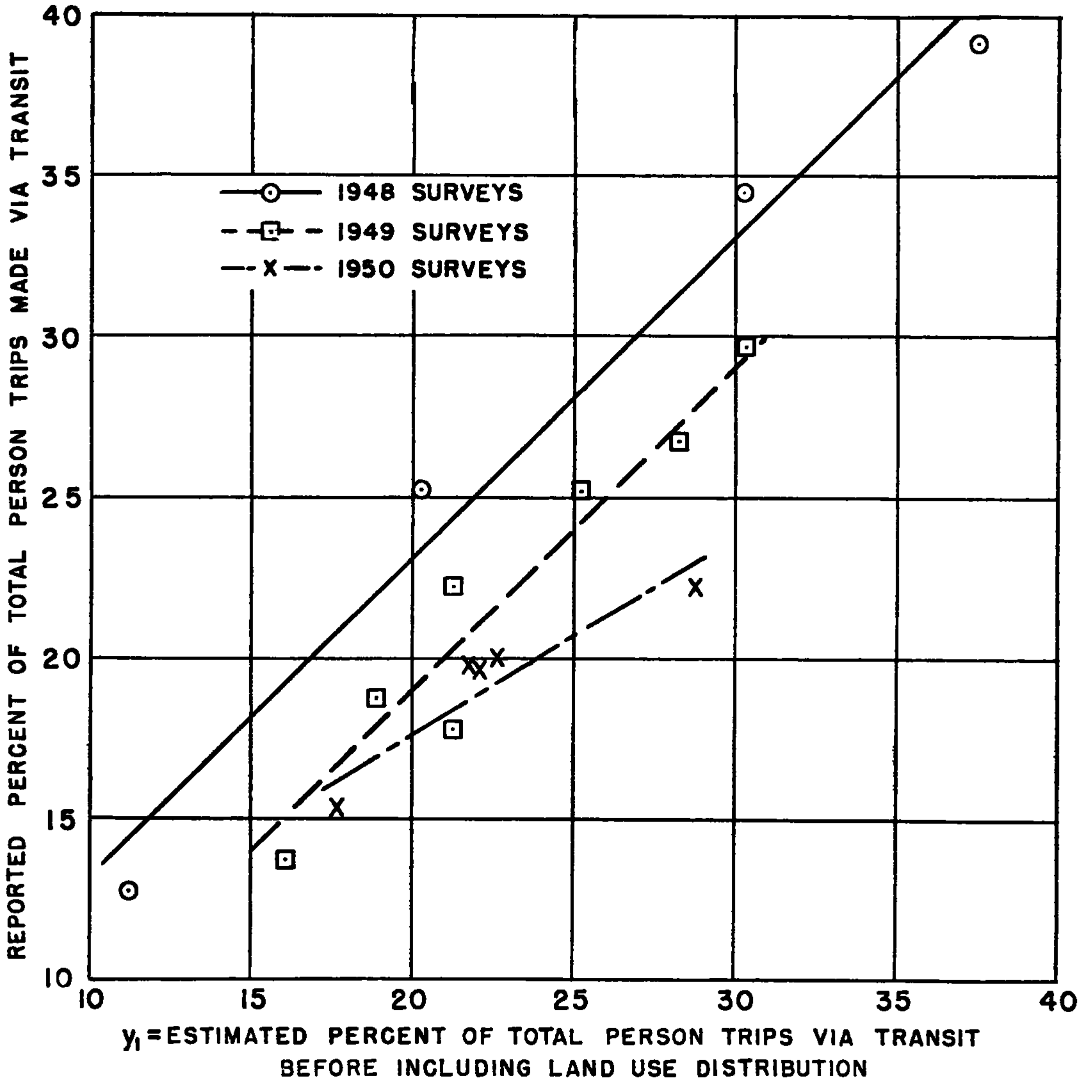

Figure 1. Relationship of reported relative transit use to that derived from estimating equation before including land use distribution factor.

conclusive results. They did not develop relationships that would forecast relative mode use within an acceptable degree of accuracy for the anticipated influencing factors.

In the last few years, more attention has been given to land use as one of the principal factors affecting urban transportation. These studies (4, 5, 6, 7, 8, 9, 10, 11) have indicated that an appreciable degree of correlation exists between travel mode on the one hand and residential, commercial, and industrial land use on the other.

In this project, a land-use distribution factor has been combined with factors relating to population, automobile ownership, employment, dwelling units, transit-service ratio, and urbanized area to attempt to develop a basis for forecasting mode use.

Source of Data

Because of the wealth of information gathered in the home-interview origin-destination surveys, the reports for all cities in which such surveys have been completed since

January 1948 were reviewed. Cities in which surveys were made prior to 1948 were not considered, principally because war-caused distortions still exerted a major influence through 1947 and the quality of many of the early surveys was questionable. Of course, the cities in which there was no transit operation could not be used. Initially, this left 30 cities to be studied. Of these, 8 had surveys in 1948, 7 in 1949, 6 in 1950, and 6 in 1953. There were only 3 in the 2-yr period of 1951-52. The 3 in this last period were at first disregarded because it appeared advisable to test within each year the development of a relationship that might hold from year to year, and for this test 3 cities were insufficient.

Through the cooperation of the American Transit Association, information on transit service at the time of the origin-destination survey was obtained from the transit companies in 22 of the 30 cities. As previous studies had indicated that one of the key factors in any developed relationship might be land-use distribution, land-use information corresponding to the origin-destination survey period was also requested from the planning agencies of each city.

Investigation of Relationships

By means of accepted simple and multiple regression analysis methods, travel mode use was studied in relation to the single and multiple, simple and compound dependent variable factors on which information had been gathered in each origin-destination survey. Among the simple factors examined were those of population, automobile ownership, trips to work, and total survey area. Among the compound factors investigated were population density, automobile ownership per capita, and employment per capita. Also tested was the relationship between travel mode split and combinations, within a minimum-maximum range of more complex, compound factors, such as employment and automobile ownership per capita, in single and multiple linear and curvilinear equations. None of these tests yielded either an acceptable standard error of estimate or a high degree of correlation.

As transit-service information was received, tests were made to determine if there might be any significant relationship between the service data and mode split. As the lone independent variable, transit service did not produce a satisfactory estimating equation. Using a transit-service ratio factor in conjuction with a population factor, a combination automobile and employment factor, and an urbanized land-use factor, semilog multiple variable equations of the form,

$$y_1 = A + b_1 \log P + b_2 \log E + b_3 \log T + b_4 \log M \tag{1}$$

were developed that gave the results shown in Figure 1 for the cities with available data for 1948, 1949, and 1950.

These results indicated that there might be at least one other factor which, if included, would produce the relationship sought regardless of the year. From previous studies, it was believed that this factor might be largely based on land-use distribution, for with each succeeding year since 1948 there has been an increasing decentralization of residential, commercial, and industrial land use with respect to the central business district (CBD). Tests were made of ranges of various ratios and combinations of ratios involving, (a) distribution of land used commercially and industrially within and about the CBD, (b) population distribution with respect to the center of urbanized land area, and (c) population distribtuion with respect to employment location. Although differing in amount of variation explained, nearly all combinations tended to reduce the year-to-year variations. Using the semilog equation,

$$y_1 = A + b_1 \log P + b_2 \log E + b_3 \log T + b_4 \log U + b_5 \log M \tag{2}$$

the land-use distribution factor brought all 16 cities into a straight line relationship, as shown in Figure 2.

Neither the land-use distribution factor nor some of the other factors now being used may prove to be the best ones as additional information is obtained. Variations in these have been investigated. Several satisfactory estimating equations with only minor variations have been developed. All have yielded a standard error of estimate of less than

1.5 percentage points and several of less than 1.0 percentage point of the reported transit use in percent of total person trips for the entire urbanized areas of the 16 cities. Transit usage in these cities ranged from 8 percent to 40 percent of the total person trips, with a mean of approximately 20 percent. Thus a standard error of 1.5 percentage points is equivalent to 7.5 percent of the mean revenue total transit trips per weekday for the 16 cities.

Of the semilog multiple regression equations developed, the following equation has been used in this paper:

$$y_1 = -2.6466 + 3.7084 \log P + 0.3912 \log E + 2.3757 \log T + 0.4918 \log U - 0.9708 \log M \qquad (3)$$

The basic data used in developing Eq. 3 are found in Table 1. In Eq. 3,

y_1 = Percent of total person trips made via transit;
P = Population over 5 years of age in the survey urbanized area, in 10,000;

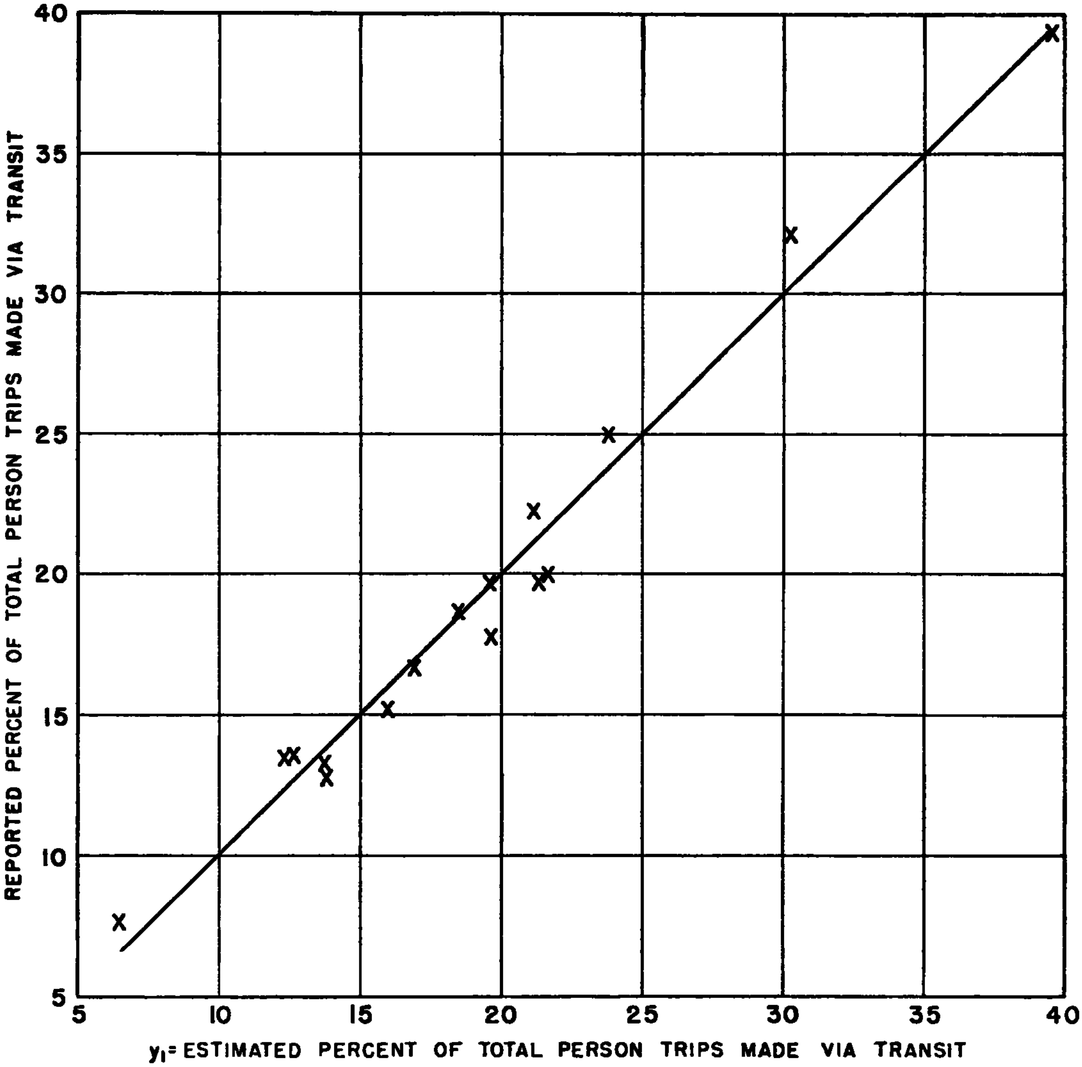

Figure 2. Relationship of reported relative transit use to that derived from estimating equation after including land use distribution factor (studies in 16 cities, 1948-1953).

TABLE 1

BASIC DATA FOR 16 CITIES USED IN DEVELOPING RELATIVE TRANSIT USE EQUATION FOR ENTIRE URBANIZED AREA

O-D Survey Year	City	Population Over 5 Years of Age P (1,000's)	Dwelling Units, H (1,000's)	Employees Going to Work per Average Weekday e (1,000's)	Automobiles Owned a (1,000's)	Equivalent Revenue Veh-Mi per Average Weekday, V (mi)	Urbanized Land Area, M (sq mi)	Land Use Distib. Factor, U	Reported Relative Transit Use, y (%)
1948	Washington, D.C	992 6	336 2	380 8	203.5	155,060	108.80	0.00456	39 3
	Tacoma, Wash.	125 0	48 0	36 1	35 2	11,960	45.80	0.03350	25 2
	Tuscon, Ariz.	113 7	38.7	29 6	32 9	3,610	41.00	0.07398	12.7
	Allentown - Bethlehem, Pa	156.4	48 8	61.6	28 6	12,490	18.95	0 00628	32.1
1949	Albuquerque, N Mex	100 8	34 9	30.4	27.5	4,510	38.93	0.02035	13 6
	Madison, Wis.	94.3	33.4	29.6	25 3	5,780	20 40	0.03034	22 4
	Racine, Wis	69 5	23.3	23.1	18 5	3,210	11.56	0.06204	17.8
	Sharon-Farrell, Pa	44.3	13.7	12 9	9 4	1,530	8.08	0.19520	18 5
1950	Dallas Tex.	471 1	168.1	182 5	153.8	57,900	173 20	0.00253	19 8
	Altoona, Pa.	77 5	24.1	17.1	16.8	3,680	15.82	0.03204	20 0
	Kenosha, Wis	50.2	17.3	21 7	13 4	2,580	8.32	0.19264	19 6
	Rockford, Ill	102.5	36.2	48.7	33.1	6,020	24.54	0 05248	15 1
1953	Houston, Tex.	765.9	272.7	278.8	256 3	48,020	244.50	0.00024	13 6
	Stockton, Calif	124.3	41.6	34 9	70 0	3,000	31.89	0.01109	7.8
	San Diego, Calif	513.0	175 0	152 1	250.5	36,170	152.01	0.00025	13.2
	Detroit, Mich	2,642.2	875.4	971 1	845 8	183,170	548.85	0.00004	16 7

T = Transit-service ratio factor as determined by

$$\frac{V^{1.0}}{P^{1.50} M^{0.25}} \; S_r \frac{F}{D} \qquad (4)$$

in which

V = Equivalent revenue-vehicle-miles operated per weekday during the survey (as explained in subsequent discussion of factors);

M = Urbanized land area, in square miles;

S_r = Ratio of the square root of the average vehicle speed of the different travel modes[1];

F = Terminal or parking facility factor[1]; and

D = Parking demand as related to volume of employment types[1].

E = Economic factor of $(\frac{P}{e})^{3.5} (\frac{h}{e})^{1.5} (\frac{P}{a})^{1.0} (\frac{h}{a})^{1.5}$,

in which, for the urbanized area:

P = Population above 5 years of age, in 10,000;

h = Dwelling units, in 10,000;

e = Employees going to work per average weekday, in 10,000; and

a = Automobiles owned, in 10,000.

U = Land-use distribution factor based on $(r_1)(r_4)(r_5)$, in which

$$r_1 = 1 - \frac{R_p}{R_u}, \text{ in which}$$

R_p = Mean distance (distance from area centroid to CBD center) of population, and

R_u = Mean distance of urbanized area.

$$r_4 = \frac{A_{tc}}{A_{tc} R_{tc}} = \frac{1}{R_{tc}}, \text{ in which}$$

A_{tc} = Area of total commercial and industrial land within the entire urbanized area;

R_{tc} = Mean distance of total commercial and industrial area.

$$r_5 = \frac{A_{1c} R_{1c}}{A_{tc} R_{tc}}, \text{ in which}$$

[1]In the estimating equation used in this paper, these items have not been included due to their apparently small effect on the standard error of estimate and the limited amount of available data. Discussion of these items is included under "Discussion of Factors."

A_{1_c} = Area of commercial and industrial land within a 1-mi radius of the CBD center;

R_{1_c} = Mean distance of commercial and industrial land within a 1-mi radius of the CBD center; and

M = Urbanized land area in square miles.

Testing of Estimating Equation

Since developing this estimating equation, complete information has been obtained from additional cities. In applying this equation, estimated results for all have been within the previously stated standard error of estimate (Fig. 3). Among these recently tested cities, there have been several with surveys between 1955 and 1957.

The sample of cities studied is not a random one. The Geary test for normal distribution, however, indicates that the sample of 16 cities can be considered to have a normal distribution. In population, the survey areas have ranged from 48,000 to 3,000,000. All sections of the United States except the Southeast and New England are represented. Although some information has been received from the Chicago origin-destination survey, it is insufficient to include in the test. Unfortunately, of all the cities in which a survey has been made since 1948, Chicago is the only one having rapid transit.

DISCUSSION OF FACTORS

In this estimating equation, the three compound variables have been developed through testing each (and variations thereof) over a range that would determine the maximum effect of each in correlation with other potential variables. As more information is obtained from the present 22 and additional cities, and as this information is examined through an electronic computer program, it is anticipated that more precise parameters will be established.

Economic Factor, E

Apparently there is a high degree of correlation between relative use of each transportation mode and some economic factor. Many contend that this factor is either income or wealth. But what income or wealth? Is it gross or net? What should be included and what deducted? Moreover, how could accurate measurements of these income or wealth items be made? Correlating travel mode use and related O-D information with sufficiently accurate income and wealth data will be most difficult under present legal restrictions.

There may be other economic items that have a higher degree of correlation with mode use than the ones used in this study. The items investigated in this study seem to be the best available that can be accurately measured with the simple linear correlation coefficient between this and relative mode use varying from 0.40 to 0.60.

The use of both population and dwelling units in relation to automobiles owned and employees going to work per average weekday may be challenged. The correlation obtained by use of these in combination has been greater than when only one has been used. This may be due to compensating errors in the O-D surveys studied, and to the effect of differences in population per dwelling unit.

Transit-Service Ratio Factor, T

There is a significant degree of correlation between the developed transit service item and the dependent transit use variable. The two variables are not, however, perfectly correlated. The simple linear correlation coefficient for this item and relative transit use has ranged from 0.30 to 0.45. The degree of correlation varies not only from city to city, but also within many cities there is likely to be an even greater variation among subdivisions (sectors, districts, etc.) or transportation channels. Furthermore, the effect of each of this factor's components apparently varies among cities and their subdivisions.

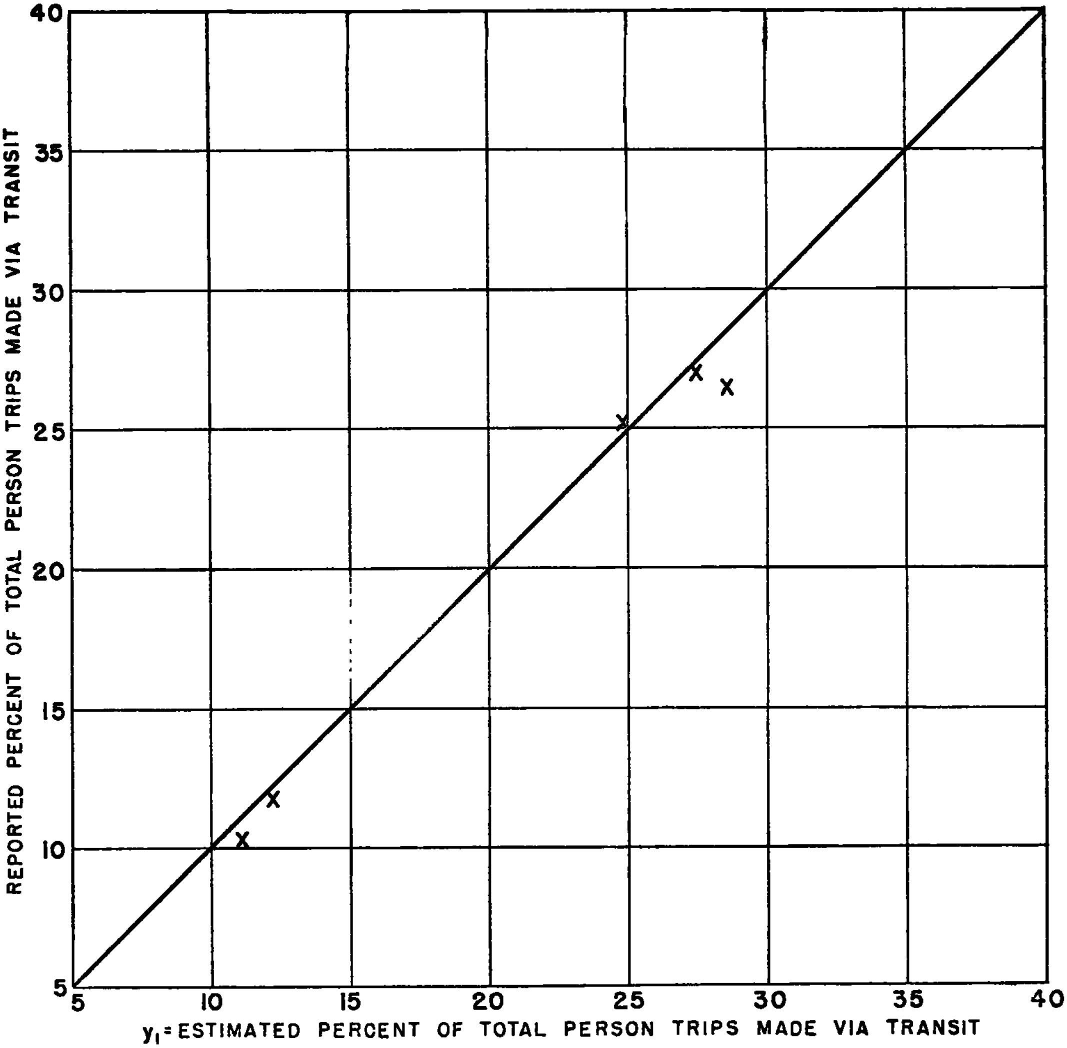

Figure 3. Relationship of reported relative transit use to estimated relative use in cities tested since deriving the equation in Figure 2.

The ratio of the square roots of the speeds of transit and of automobile vehicle travel is one of the components in this factor. There are few who do not consider this ratio as an influencing item. Nevertheless, based on the data available, the standard error is increased by only 0.1 when the speed ratio item is excluded. This would indicate that the variation in this ratio from city to city is not appreciable with respect to the over-all area for each city. Due to the limited amount of data so far available and the apparent relatively small effect on the standard error, this item has not been included in the estimating equation. Using the ratio of the square root of the speed of each mode would, of course, reduce the sensitivity of this item; but the investigation, so far, has borne out that each mode speed should be in proportion to this exponent.

The little work done to date by subdivision of urban areas has pointed to a much greater influence of this speed component for subdivisions and transportation channels. This is due to the greater spread of relative speeds within these subdivisions. It still indicates, however, that the ratio should be based on the square root of the respective speeds.

It is quite possible that additional data may establish that different ratios should be applied to the two principal components of over-all travel time for each mode, namely, vehicle speed and the terminal factor. The effect of these components must be more accurately determined, not only to be able to estimate the use of the two travel modes under specific conditions, but also to develop the required transit, parking, and highway capacity, with attendant capital and operating costs, for the estimated use of each mode.

Equivalent vehicle-revenue-miles operated per weekday are expressed in terms of a 50-seat bus revenue-mile. This includes all vehicle-revenue-miles operated per weekday regardless of the number of passengers carried on each vehicle trip. This item has been derived by applying a carrying capacity factor to the average weekday revenue-vehicle-miles operated during the survey. This factor has been developed through assignment of each vehicle size by time periods in proportion to the ages of the active vehicle groups. Inasmuch as it is impossible to obtain actual average carrying capacity during the survey without a prior uniform arrangement with the transit operators, this derivation gives an arbitrary, but uniform, estimate for all cities that most nearly approaches the actual average.

Land-Use Distribution Factor, U

The land-use distribution factor is a complex one that has been developed from a series of studies with the limitations of available material, time, and computing equipment. Its simple linear correlation coefficient has varied from 0.60 to 0.75. It appears likely that more effecient analysis of present and additional data by means of an electronic computer program will produce either more precise values for those factors now being used or more simple factors that may prove to be more satisfactory. For the entire urban area and for the subdivisions investigated, there appear to be 5 land-use-distribution ratios about the CBD center that should be taken into consideration. These are:

$$r_1 = \frac{1 - R_p}{R_u}$$

$$r_2 = \frac{R_p R_{tc}}{R_u}$$

$$r_3 = \frac{A_{1c}}{A_{tc}}$$

$$r_4 = \frac{A_{tc}}{(A_{tc} R_{tc})} = \frac{1}{R_{tc}}$$

$$r_5 = \frac{(A_{1c} R_{1c})}{(A_{tc} R_{tc})}$$

in which

R_p = Mean distance of center of population from CBD center;

R_u = Mean distance of urbanized area from CBD center;

R_{tc} = Mean distance of commercial and industrial land;

A_{1c} = Area of commercial and industrial land within a 1-mile radius;

A_{tc} = Area of commercial and industrial land within the entire urbanized area; and

R_{1c} = Mean distance of commercial and industrial land within a 1-mile radius.

Mean Distance Derivation. In arriving at the mean distance to the CBD center from the centroid of each of the items used in the land-use ratios, the same procedure has been used for each of these items. Therefore, a detailed description of the derivation of one (commercial and industrial land use) will suffice for all. Each city has been divided into 4 quadrants by rectangular coordinate axes passing through the CBD center. In each quadrant, the area of each industrial and commercial parcel (or each group of adjacent parcels) actually used for one of these purposes at the time of the O-D survey is multiplied by the distance from the CBD center to the centroid of the parcel or group of parcels. These products are then summed for the four quadrants and this summation divided by the summation of the areas of all the industrial and commercial parcels in the urbanized area.

In some instances it has been found more efficient to determine this distance through summing the products obtained by multiplying the areas by their distances to the 2 coordinate axes, and then extracting the square root of the sum of the squares of those 2 product summations.

In the estimating equation in this paper, ratios r_2 and r_3 have not been included in the land-use distribution factor. Studies not concluded indicate that the inclusion of ratios r_2 and r_3 with possible modification of the other ratios would reduce the standard error of estimate.

For the entire urban area, this study has shown that it is not necessary to differentiate between commercial and industrial land. This is apparently due to the balancing effect of the two over a complete urban area. Within highly specialized subdivisions or transportation channels serving predominantly one type of land use, the investigation shows that the two will have to be considered separately. It may even be necessary to subdivide these two classifications into four—industrial, office, shopping durable, and shopping service and convenience. Based on probable accuracy of land-use forecast, the studies make it questionable if a further breakdown can be justified for transportation channel subdivisions (even much less for subdivisions comparable to O-D districts). To justify more classifications of land use would require a much greater specialization of land use in a transportation channel subdivision than has been found or seems probable in the future.

Urbanized Land Area Factor, M

The definition of an urbanized area is of utmost importance in determining the relative use of urban transportation mode. The urbanized area for present studies has been confined to contiguously developed land; future estimates, of course, must be based on anticipated contiguously developed land. Furthermore, to be included such land must have a minimum residential population per area unit—500 per square mile—or a minimum number of total trip ends—2,000 per square mile. Islands of vacant land should be included if the land outside is sufficiently developed to bring the combination of vacant land and adjacent outside developed land up to the minimum. Pockets of vacant land at the boundary not meeting these specifications should be excluded. Even many subdivisions with population or trip ends above the minimum cannot be served by transit without such service costs being partially defrayed by either the subdivision, the entire urban area, or the entire transit system. In border subareas where either the resident population or number of trip ends is less than the minimum, the only mode of urban transportation will be automobile unless transit service is furnished by an intercity carrier, or is almost entirely underwritten on a service charge basis due to relative low transit use. If border land with subminimum population or trip ends is included in an urban area study, the effect of the urbanized area is appreciably changed.

WORK IN PROGRESS

Expansion of Project

Of the factors investigated so far, the three that contribute the most in explaining the variance are those pertaining to: (a) transit-service ratio, (b) land-use distribution, and (c) the economic factor. Some of the factors are still being studied to determine if they should be modified or if they should be replaced by more satisfactory ones. It is possible that the estimating equation may be appreciably changed by these continued studies. However, if the work in the past is a criterion for the future, the estimating equation should not be significantly altered.

In addition to continuing research on the whole metropolitan area, this study is now being expanded in two directions. Generalizing, it can be stated that the developed estimating equation is an expression of the division of trips between transit and automobile in relation to factors pertaining to the home area (employment, automobile ownership, population distribution) and to factors applying to the entire metropolitan area, such as land-use distribution, transit-service ratio, total population, and urbanized land area. Now this equation is being tested to determine if it, or a modification of it, will apply to subdivisions of each metropolitan area. Up to the present, sufficient informaation has been obtained from only three origin-destination survey cities to ivestigate the application within these cities. The results so far indicate that this equation, after modifying the land-use and transit-service ratio factors for the relationship between each home subdivision and the CBD, will probably forecast with acceptable accuracy the split between transit and automobile trips for each subdivision. Two items that apparently have more influence on the mode use within each subdivision than for the whole urban area are (a) the average ratio of over-all trip time by the two transportation modes and (b) the ratio of commercial to industrial land use. Inasmuch as only 20 subdivisions have been investigated, a precise basis for modifying the transit-service ratios and land-use factors has not yet been developed.

The other extension of this project has been to determine the influence of other factors in destination areas on the estimating equation. In this subphase, even less information has been available. A limited amount of information on CBD destination factors has been gathered in several cities, and the relation between these factors and the travel mode split has been tested. Foremost among the items that apparently should be introduced into the equation is a parking facility factor. The equation, modified by this factor, appears to yield a low standard error of estimate in predicting mode split in destination areas. This factor, however, is not confined to total parking supply in each destination area. It also includes accessibility to demand as expressed by a relationship including parking charges and walking and parking time.

Work To Be Done

Much still remains to be done. Only the surface has been scratched in attempting to establish factors and estimating equations pertaining to split by home and destination subdivision. Relationships by subdivision should then be developed for the peak period. Work already is under way on this peak-period relationship for the entire metropolitan area.

From research done so far, it appears that the speed factor varies about as the ratio of the square root of trip speed. Convenience and irritation items, modified somewhat by cost, to the extent that it has been possible to measure them, are apparently as important, if not more so, than absolute vehicle speed. This observation, however, may not hold for freeway and rapid-transit operation. In fact, testing of additional data for vehicle operation on unrestricted rights-of-way may alter the findings in this field. The analysis begun on the Chicago origin-destination survey should yield much information on this phase; however, it is the only origin-destination survey city with both rapid transit and a limited amount of freeway traffic data now available for testing.

Data Needed for Carrying Out Project

To carry out this work, much additional information will be needed. Many cities and transit companies have cooperated. If the needed relationships are to be established, it will be necessary to call on these and other cities for more basic data from time to time. Many of these data should be gathered at the time of the origin-destination survey; in fact, made a part of it. It will take time and money to gather and assemble the information, but it should be to the advantage of both the cities and transit companies to do this.

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A Method for Predicting Speeds Through Signalized Street Sections

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This paper presents the results of research work undertaken by the Chicago Area Transportation Study. It explains the development of a series of curves relating speed to the ratio of volume to capacity for signalized urban arterials.

The close similarity of the actual distribution of traffic to the Poisson distribution is shown for hourly volumes ranging from 300 to 2,100 vehicles. The Poisson distribution was used as a basis for generating vehicle arrival rates per minute for various hypothetical locations. Using these arrival rates in conjunction with known discharge rates, delays and stopped time were calculated and converted to speed for sections of known length. These speeds were plotted according to volume, resulting in a series of speed-volume curves, which were then converted to show the relationship of speed to the ratio of volume to capacity.

The need for and the application of these curves in urban traffic planning is also commented upon.

●THE GOAL of the research reported in this paper was to develop a method of relating travel speed to volume, so that one could be used to predict the other. The principal reason for wanting to establish this relationship was to make the process of traffic assignment more realistic. Current assignment techniques make use of a time or speed estimate based on existing traffic conditions. These values are used as a basis for assigning traffic over a particular route. Often when the assignment is completed the assigned volume bears no relation to the initial assumption of time or speed. In fact, it is often the case that the traffic load assigned to an expressway could not be carried at any speed. This weakness in current assignment methods became more and more apparent as the work to develop an assignment technique progressed. Thus, if a relationship between speed and volume were established, it could be used in the assignment process to obtain more reasonable traffic estimates.

Another useful application of the relationship of speed to volume is in evaluating the efficiency and quality of service provided by a street system. For example, this kind of relationship provides data useful in determining how the entire street network would operate under loaded conditions, that is, after assignment of estimated future traffic volumes. Future bottlenecks could be detected immediately and, in addition, basic data could be provided to measure the quality of service for the entire street system.

Since defining this relationship seemed to provide a powerful planning tool, major emphasis was placed on this work. Several approaches were used to get at the problem. First, a carefully controlled study involving a moving vehicle (1) was used. In this study, route sections were selected and a car made runs each way recording the time between check points and observing the vehicles moving each way. Using the moving vehicle method (2), the volume of traffic in the section was estimated for each run. Unfortunately, this method did not produce the desired results so another approach was tried.

The second approach was based on the idea that speed on urban route sections was controlled largely by the ability to move through signalized intersections. Therefore, if the delay at intersections could be measured, the time to traverse a given route section, and thus the speed, could be determined. A further hypothesis was that if traffic were random on urban route sections, and thus described by a Poisson-type distribution, then the arrivals in any given time interval could be determined for any given hourly rate of flow. If this were true, and the output of the signal were known, then the difference between the input and output could represent delayed vehicles and, therefore, the effect of the signal on delay, and thus speed, could be determined for any hourly rate of flow. By setting up test examples, it would be possible to define an average relationship between speed and volume which could be used for any type of street.

This paper presents the results of the research following the hypothesis just described. The first part shows how the randomness of traffic was tested; the second part describes the estimations of average speed; the third part suggests some applications of this work; and, finally, a brief summary of the paper is given.

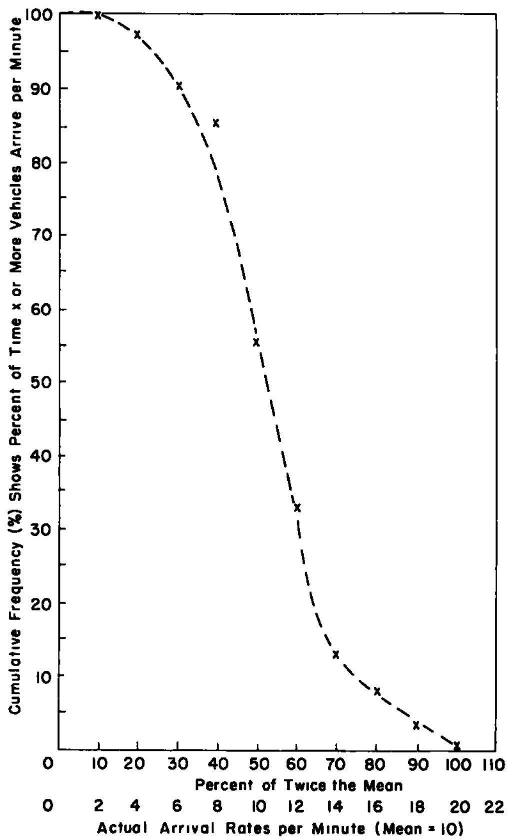

Figure 1. Cumulative distribution for hourly volume with mean arrival of 10 vehicles per minute. Arrivals stated in vehicles per minute and as a percent of twice the mean rate.

RANDOMNESS OF TRAFFIC

Previous Research

The success or failure of this research depended upon whether or not traffic on signalized urban streets was randomly distributed through time. Other researchers have concluded that traffic follows a random distribution on a 2-lane road (3). Greenshields, in a study made in Ohio in 1937 (4), found that "traffic may be considered purely random on a two lane road with volumes not exceeding four hundred vehicles per hour for the two lanes." In this same report a table is presented showing a theoretical distribution of traffic, as determined by Poisson's law, compared with observed vehicle spacings on 2 and 4 lanes (4). The difference between theory and observations is insignificant.

New Research

To determine if traffic is, in fact, random on signalized urban arterials, a series of field observations was made at 75 different locations. These arterials included 2-, 4-, and 6-lane surface streets and 8-lane expressways operating at various volumes and in 2 different cities—Chicago and Detroit.

The field study consisted of recording the traffic passing a point in one direction each minute for 90 min. A mid-block location was selected so there would be no interference from the signal ahead of the observation point. In addition, the width of pavement, the signal timing for signals on either side of the observation point, and the number of travel lanes was recorded.

The data were summarized to show a cumulative frequency of arrival rates per minute. The cumulative frequency shows the percentage of time that x or more vehicles arrive in a minute interval. In this case, the number passing the observation point each minute was termed arrivals (Fig. 1). In Figure 1 the x axis is identified in two ways, that is, by actual number of arrivals per minute, and as a percentage of the mean arrival rate. In the latter scale the mean arrival rate is equated to 50 percent. Thus, 100 percent on the scale equals twice the mean arrival rate. Figure 1 simply demonstrates the relationship of the mean arrival rate value to the scaled percentage values. Stating the arrivals as a percentage of the mean arrival rate gives a common base for plotting any distribution on the same chart regardless of its mean value.

Figure 2 shows a composite of cumulative distributions for mean arrival rate values ranging from 5 to 36 vehicles/min. The curves rotate clockwise around the 50 percent arrival rate as the mean value increases. It may also be noted that in the higher rates (above 17 veh/min) there is no time when more than twice the mean number arrive. For example, at a volume of 1,200 vehicles per hour, or a mean of 20 vehicles per minute, it would be expected that 2 percent of the time more than 36 vehicles a minute would arrive—but never more than 38 vehicles would arrive in any one minute. This is a significant finding in itself.

Figures 7 through 12 show a comparison of observed values to values based on the Poisson distribution for the accumulated percentage of the time that x or more vehicles arrive in any 1-min interval. These figures are plotted for mean arrival rates ranging from 5 to 36 vehicles per minute. The observed values are averages of observations from 3 to 10 locations which have an average mean value as shown on the figure. This average mean value was used as the mean for the Poisson distribution plotted on the same chart.

These figures demonstrate a very similar distribution for observed and Poisson values. For any mean arrival rate, both observed and Poisson distributions have about the same range, and the shape and location of the accumulation curve is very similar.

The field data were summed to show the number of minutes any number (x) of vehicles passed the point in 1 hr. Using the calculated mean value of each observed distribution, a theoretical distribution was calculated showing the number of minutes containing x number of vehicles. The usual chi-square test for goodness of fit was applied and the conclusion was that the observed data behaved in accordance with the Poisson law at the 5 percent significance level.

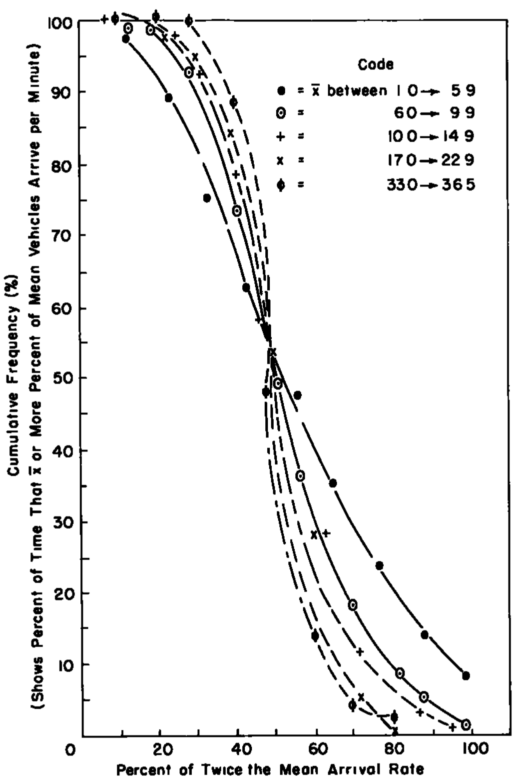

Figure 2. Cumulative distribution for arrival rates varying from 1 to 36.5 per minute.

The randomness of arrivals for 60-sec intervals has been demonstrated. The question naturally might arise as to whether the pattern of arrivals remains Poisson when observed at shorter time intervals. Gerlough (5) showed that the arrival pattern for intervals of 10 sec was nonrandom. However, his observations were that the arrivals in 30-sec groups could be considered random. His conclusions were based on a chi-square test using a 95 percent confidence level.

To test this conclusion, the authors made observations at 10-sec intervals for 2 hr at one location. These 10-sec observations were grouped to represent intervals of 20, 30, 40, and 50 sec. The chi-square test was used to test arrival rates for each of these time groups against the Poisson distribution. The results indicated that arrivals during 10-, 20-, and 30-sec intervals are non-Poisson. However, those at 40- and 50-sec intervals indicated a Poisson pattern.

Tests were also run for 70-, 80-, and 90-sec groupings. These also proved to

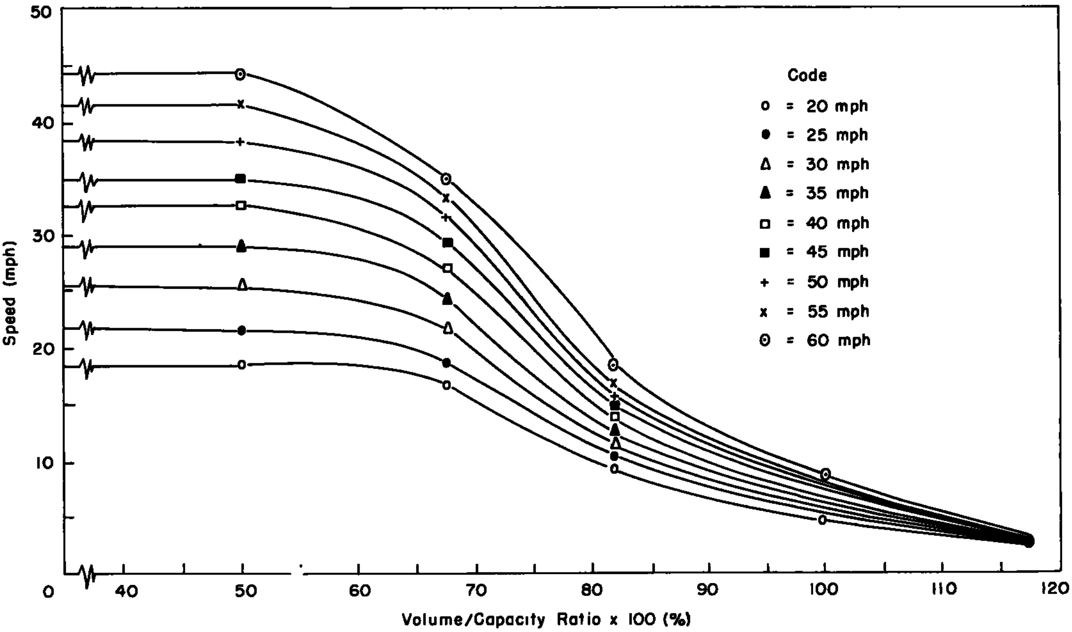

Figure 3. Relationship of speed to volume-capacity ratio for 9 free speeds on a 2-lane section one-half mile long.

be Poisson. Thus, it was concluded that, in general, arrivals within the time span of the usual signal cycle, that is, 40 to 90 sec, are similar to a Poisson distribution.

The results of these field studies and their comparisons to theoretical Poisson distributions have been given as evidence that traffic, even on urban arterials under heavy pressure, can be considered to have random characteristics. The conclusion of the authors is that the distribution of traffic, through time, on urban arterials can be treated as being random and has a pattern similar to the Poisson distribution. Therefore, it became feasible to use the Poisson formula or tables to determine the range and distribution of arrival rates for known hourly traffic volumes.

ESTIMATION OF AVERAGE SPEED

It has been shown that where the hourly one-directional volume on a signalized urban street is known, and hence the mean per-minute volume, the minute-by-minute arrivals can be predicted according to a Poisson table. If the minute-by-minute average maximum departure rate (essentially capacity) is known, or can be approximated, then it is a simple matter to predict the queue length at the signal at any minute during the hour. A table of queue lengths at each minute of the hour can be used to determine the number of partial or complete signal failures that occur.

A method of predicting the average speed of the stream, then, involves adding the accumulative stopped time, due to signal failures, at the signal or within the queue, to the known, or hypothesized accumulative travel time using best attainable legal speed, or so-called free speed, through the section at very low traffic volume. The following paragraphs discuss the estimation of accumulative stopped time, accumulative travel time and, finally, average speed.

Maximum Accumulative Stopped Time

The maximum accumulative stopped time in a particular street section can be assumed to result when, (1) all entering vehicles within each signal cycle arrive at the signal, or at the end of the queue, instantaneously with the start of the red phase; and

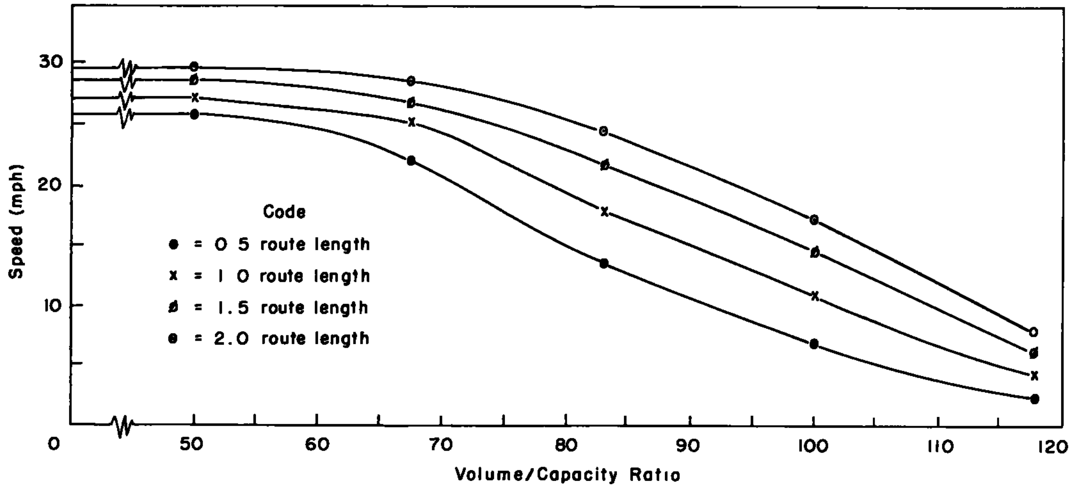

Figure 4. Effect of route length on speed plots for free speed of 30 mph at volume= 600 vph.

(2) the number of vehicles which arrive within the first signal cycle of the observation hour is the largest predictable by the Poisson distribution of the total hourly volume entering the section; the number which arrive within the second signal cycle is the next largest; and so on through the hour. It can be assumed further, for simplicity, that there were no vehicles in the section prior to the first signal cycle.

Within the framework of these assumptions, there may be 3 types of stopped time resulting from the signal itself. Signal failures which, by definition, occur when arriving vehicles fail to discharge during the next following green phase, cause the greatest amount of stopped time ordinarily. Additional stopped time results from: (1) the assumption that all entering vehicles arrive at the beginning, and are stopped for the duration of the red phase; and (2) the fact that all vehicles are stopped for some portion of the discharging green phase. The latter types of stopped time may occur with or without accompanying signal failures. Eq. 1 expresses a method of solving for each type of stopped time separately.

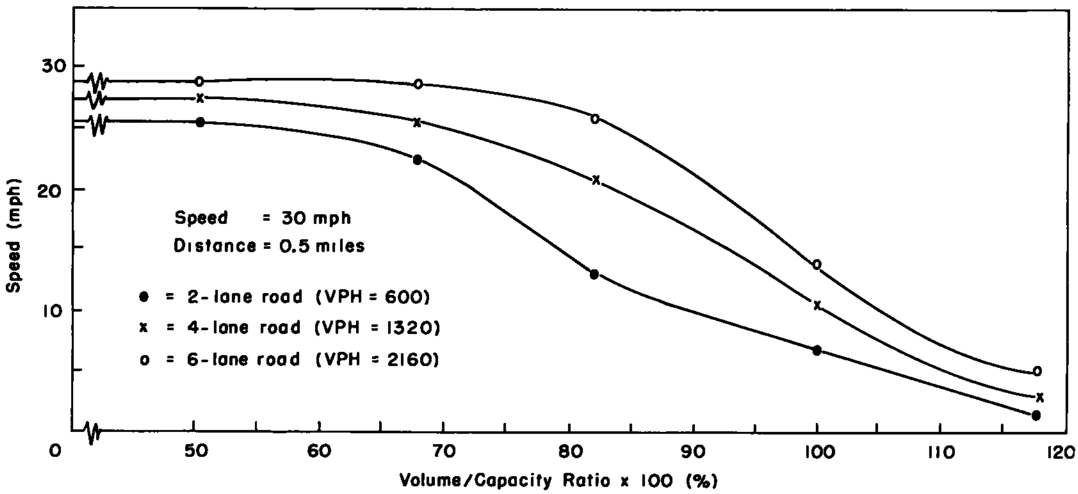

Figure 5. Relationship of speed to volume-capacity ratio for 2-, 4-, and 6-lane facilities.

$$ST_{max} = (C) \sum_{c=1}^{n} (E_c + R_{c-1} - D_c) + (r)(\sum_{c=1}^{n} E_c) + \sum_{n=1}^{c} (\frac{D_c}{Cap})(\frac{g}{2})(D_c) \qquad (1)$$

in which

ST_{max} = maximum accumulative stopped time (hr);
C = total cycle length (hr);
r = total red phase (hr);
g = total green phase (hr);
n = number of cycles in the observation hour;
E_c = number of vehicles entering the test section during cycle c;
R_{c-1} = number of vehicles remaining in the test section from cycle c-1 (the previous cycle);
D_c = number of vehicles discharging from the test section during cycle c; and
Cap = average maximum discharge rate per cycle.

The term $(C) \sum_{c=1}^{n} (E_c + R_{c-1} - D_c)$ accounts for the total stopped time resulting from signal failures. (C) is the total cycle length in hours. $\sum_{c=1}^{n} (E_c + R_{c-1} - D_c)$ is the summation for n cycles of the number of vehicles entering the section each cycle (E_c) plus the number of vehicles remaining from the previous cycle (R_{c-1}) minus the number of vehicles discharging during the cycle (D_c). The entire term might be written simply $(C)(\Sigma SF)$ where (ΣSF) is the total number of complete signal failures in the observation hour.

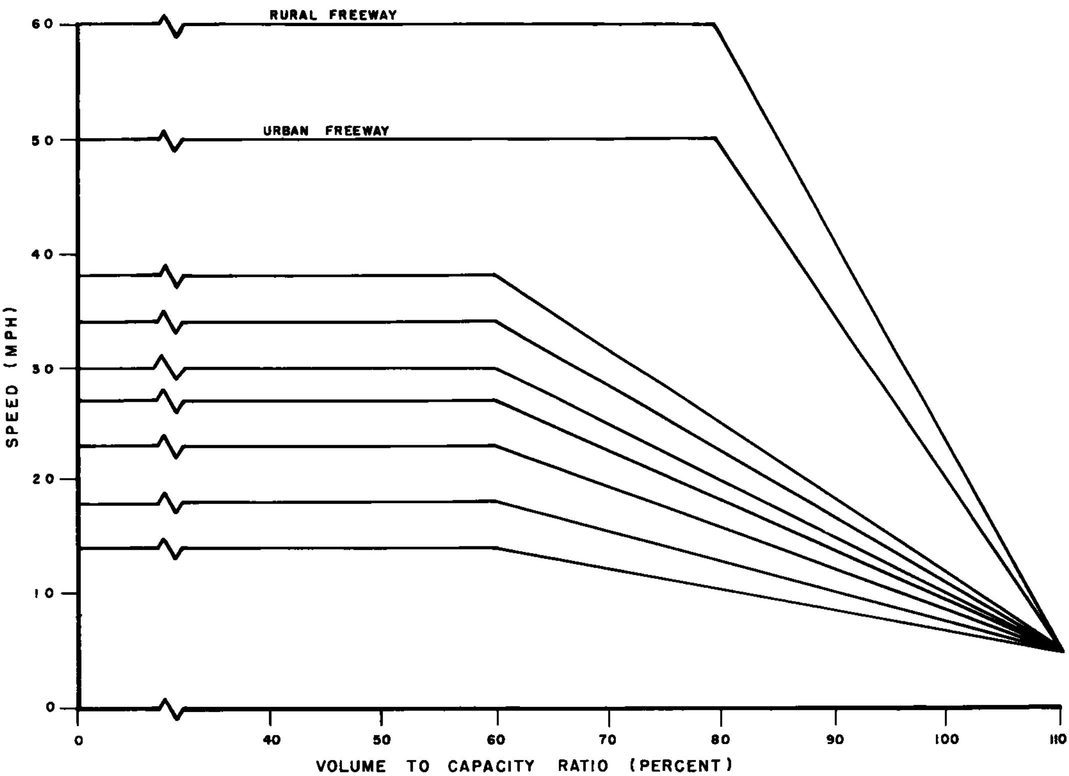

Figure 6. Final speed to volume-capacity ratio curves for free speeds as indicated.

The term $(r)(\sum_{c=1}^{n} E_c)$ accounts for the total stopped time resulting from the assumption that all entering vehicles arrive at the signal, or at the end of the queue, instantaneously with the start of the red phase. (r) is the total red phase in hours. $(\sum_{c=1}^{n} E_c)$ is the total number of vehicles entering the section during the observation hour.

The term $\sum_{c=1}^{n} (\frac{D_c}{Cap})(\frac{g}{2})(D_c)$ accounts for the total stopped time resulting from the fact that all vehicles are stopped for some portion of the discharging green phase. When the number discharging equals the average maximum discharge rate (D_c = Cap), it is assumed that all discharging vehicles depart midway of the green phase, or $(1.00)(\frac{g}{2})(D_c)$. But when the number discharging is less than the average maximum discharge rate ($D_c <$ Cap), it is assumed that all discharging vehicles depart proportionately nearer the start of the green phase, or $(\frac{D_c}{Cap})(\frac{g}{2})(D_c)$.

Table 1 shows an example of the method of calculating these three terms for a hypothetical street section one mile long, where the total cycle length is 60 sec (0.017 hr), the total red phase and the total green phase are each 30 sec (0.0085 hr), the total entering volume is 1,794 vehicles, the total hourly maximum discharge rate is 1,920 vehicles or 32 vehicles per cycle, and the cyclical arrivals are arranged in descending order of their Poisson distribution. The latter arrangement can be demonstrated to produce the greatest number of signal failures for any given entering volume. Some experimentation with Table 1 will show clearly how the various terms are accumulated. It may be noted that repeated signal failures by any particular vehicles are automatically accounted for.

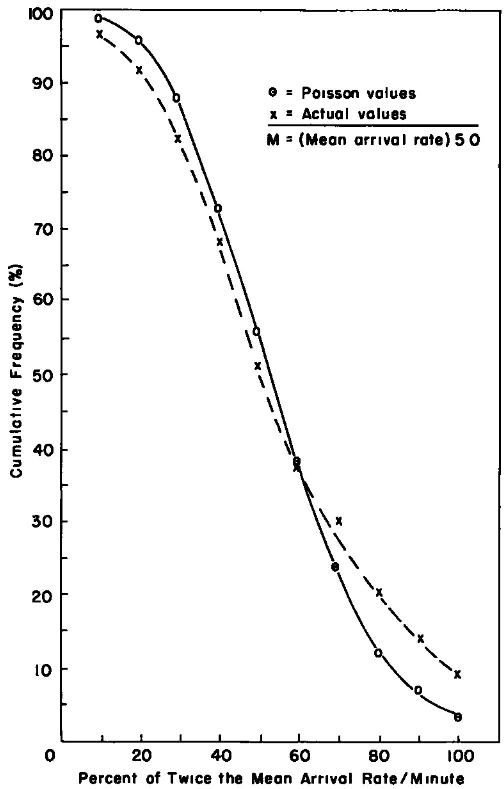

Figure 7. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

Minimum Accumulative Stopped Time

The minimum accumulative stopped time in a particular street section can be assumed to result when, (1) all entering vehicles within each signal cycle arrive at the signal, or at the end of the queue, instantaneously with the start of the green phase, or as the last vehicle in the queue ahead clears, and (2) the number of vehicles which arrive during the first cycle of the observation hour is the largest predictable by the Poisson distribution of the total hourly volume; the number which arrive during the second cycle is the smallest predictable; the number which arrive during the third cycle is the second largest; the number which arrive during the fourth cycle is the second smallest; and so on through the hour. As before, it is assumed that there were no vehicles in the section prior to the first cycle.

Within the framework of these assumptions, there again may be three types of stopped time, although differing slightly from those described previously. Signal failures in this case may be one-half or

TABLE 1

DERIVATION OF ST_{max} FOR A SIGNALIZED STREET SECTION ONE MILE LONG, WITH AN AVERAGE MAXIMUM DISCHARGE RATE OF 32 VEHICLES PER CYCLE, AN ENTERING VOLUME OF 794 VPH, AND A 60-SECOND CYCLE LENGTH WITH 50-50 TIMING

Cycle Number (c)	Arriving Vehicles Each Cycle (E_c)	Discharging Vehicles Each Cycle (Avg. Max. Capacity = 32) (D_c)	Vehicles Stopped for Complete Cycle ($E_c + R_{c-1} - D_c$) (R_c)	Proportion of Discharging Green Phase Stopped $(\frac{D_c}{Cap})$	One-half Green Phase in Hr, Times Proportion Stopped $(\frac{D_c}{Cap})(\frac{g}{2})$	Total Stopped Time During Discharging Green Phase $(\frac{D_c}{Cap})(\frac{g}{2})(D_c)$
1	42	32	10	1.00	0.0042	0.1344
2	41	32	19	1.00	0.0042	0.1344
3	40	32	27	1.00	0.0042	0.1344
4	39	32	34	1.00	0.0042	0.1344
5	38	32	40	1.00	0.0042	0.1344
6	37	32	45	1.00	0.0042	0.1344
7	37	32	50	1.00	0.0042	0 1344
8	36	32	54	1.00	0.0042	0.1344
9	36	32	58	1.00	0.0042	0.1344
10	35	32	61	1.00	0.0042	0.1344
11	35	32	64	1.00	0.0042	0.1344
12	35	32	67	1.00	0.0042	0 1344
13	54	32	69	1.00	0.0042	0.1344
14	34	32	71	1.00	0.0042	0.1344
15	34	32	73	1.00	0.0042	0.1344
16	33	32	74	1.00	0.0042	0.1344
17	33	32	75	1.00	0.0042	0.1344
18	33	32	76	1.00	0.0042	0.1344
19	33	32	77	1.00	0.0042	0.1344
20	32	32	77	1.00	0.0042	0.1344
21	32	32	77	1.00	0.0042	0.1344
22	32	32	77	1.00	0.0042	0.1344
23	32	32	77	1.00	0.0042	0.1344
24	31	32	76	1.00	0.0042	0.1344
25	31	32	75	1.00	0.0042	0.1344
26	31	32	74	1.00	0.0042	0.1344
27	31	32	73	1.00	0.0042	0.1344
28	30	32	71	1.00	0.0042	0.1344
29	30	32	69	1.00	0.0042	0.1344
30	30	32	67	1.00	0.0042	0.1344
31	30	32	65	1.00	0.0042	0.1344
32	29	32	62	1.00	0.0042	0.1344
33	29	32	59	1.00	0.0042	0.1344
34	29	32	56	1.00	0.0042	0.1344
35	29	32	53	1.00	0.0042	0.1344
36	28	32	49	1.00	0.0042	0.1344
37	28	32	45	1.00	0.0042	0.1344
38	28	32	41	1.00	0.0042	0.1344
39	28	32	37	1.00	0.0042	0.1344
40	27	32	32	1.00	0.0042	0.1344
41	27	32	27	1.00	0.0042	0.1344
42	27	32	22	1.00	0.0042	0.1344
43	27	32	17	1.00	0.0042	0.1344
44	26	32	11	1.00	0.0042	0.1344
45	26	32	5	1.00	0.0042	0.1344
46	26	31	0	0.97	0.0041	0.1271
47	26	26	0	0.81	0.0034	0.0884
48	25	25	0	0.78	0.0033	0.0825
49	25	25	0	0.78	0.0033	0.0825
50	25	25	0	0.78	0.0033	0.0825
51	24	24	0	0.75	0.0032	0 0768
52	24	24	0	0.75	0.0032	0.0768
53	24	24	0	0.75	0.0032	0.0768
54	23	23	0	0.72	0.0030	0.0690
55	23	23	0	0.72	0.0030	0.0690
56	22	22	0	0.69	0.0029	0.0638
57	22	22	0	0.69	0.0029	0.0638
58	21	21	0	0.66	0.0028	0.0588
59	20	20	0	0.63	0.0026	0.0520
60	19	19	0	0.59	0.0025	0.0475
Totals	1,794	1,794	2,438			7.1653

$$ST_{max} = (C)(\sum_{c=1}^{n} E_c + R_{c-1} - D_c) + (r)(\sum_{c=1}^{n} E_c) + \sum_{c=1}^{n} (\frac{32}{Cap})(\frac{g}{2})(R_c)$$

$= (0.017)(2{,}438) + (0.0085)(1{,}794) + 7.1653$

$= 41.4460 + 15.2490 + 7.1653$

$= 63.8603$ hr

one and one-half signal failures (two of the three types). By assumption, there is no stopped time because of arrival during the red phase, but there is still stopped time during the discharging green phase. Eq. 2 accounts for each type separately.

$$ST_{min} = (r)\sum_{c=1}^{n}(E_c + R_{c-1} - D_c) + (1.5C)\sum_{c=1}^{n}(E_c + R_{c-1} - 2D_c) + \sum_{c=1}^{n}\left(\frac{R_c}{Cap}\right)\left(\frac{g}{2}\right)(R_c) \qquad (2)$$

Whether or not there is half or one and one-half failures depends upon the relation between $(E_c + R_{c-1} - D_c)$ and D_c. When the former is greater than the latter, the difference is the number of vehicles experiencing one and one-half signal failures. When the former is smaller than the latter, there are only half signal failures. Table 2 illustrates this.

During Cycle 1, 54 vehicles arrive at the start of the green phase and 32 vehicles discharge, leaving 22 vehicles stopped for a complete red phase (or a half signal failure). During Cycle 2, 26 additional vehicles arrive at the start of the green phase of which 10 can discharge after the 22 held over from Cycle 1. The remaining 16 are stopped for a complete red phase (or one-half signal failure). During Cycle 3, another 53 vehicles arrive of which 16 can discharge after the 16 held over from Cycle 2. There are then 37 vehicles remaining. Since only 32 can discharge during Cycle 4, the remaining 5 vehicles must be stopped for a complete red phase, plus a complete green phase, plus another complete red phase—altogether a signal failure and a half. The first two terms of Eq. 2 account for both types of stoppage.

The last term of Eq. 2 is changed slightly from Eq. 1. The basic difference results from the assumption that all vehicles arrive during the green phase. Those that are discharged immediately are assumed to suffer no stoppage. Only those that are held over from a previous cycle are assumed to suffer a stoppage during the discharging green phase. Thus, it is the remaining vehicles (R_c) that must be considered in the last term, rather than the discharging vehicles (D_c) as before.

Table 3 will make this distinction more clear. During Cycle 1, 42 vehicles arrive and 32 discharge without breaking speed. The ten remaining discharge during Cycle 2, but they are stopped during some portion of the green phase. Thus, $(\frac{10}{32})(\frac{g}{2}) = 0.0013$ each, and (0.0013)(10) = 0.0130. This type of stopped time is negligible when calculating ST_{min} but is important when finding ST_{max}.

Why is it necessary to know both the minimum and maximum accumulative

TABLE 2

Cycle	E_c	D_c	R_c	One-Half Signal Failure	One and One-Half Signal Failure
1	54	32	22	22	0
2	26	32	16	16	0
3	53	32	37	32	5
4	27	32	32	32	0

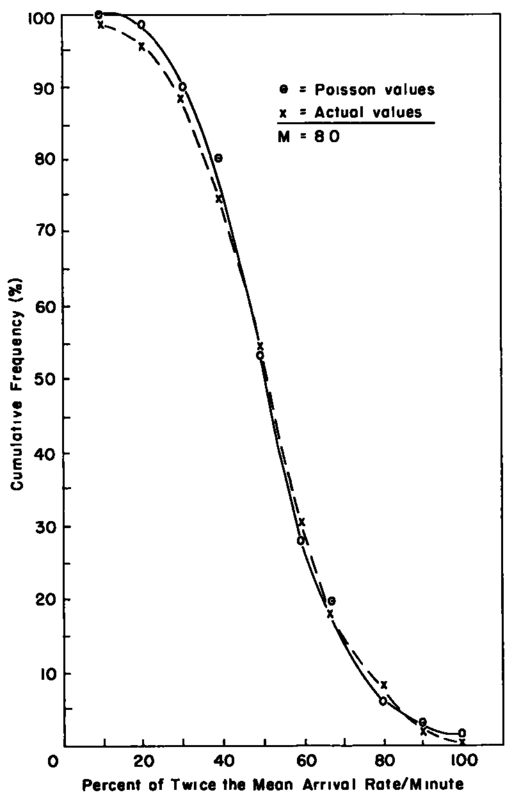

Figure 8. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

TABLE 3

DERIVATION OF ST_{min} FOR A SIGNALIZED STREET SECTION ONE MILE LONG, WITH AN AVERAGE MAXIMUM DISCHARGE RATE OF 32 VEHICLES PER CYCLE, AN ENTERING VOLUME OF 1794 VPH AND A 60-SECOND CYCLE LENGTH WITH 50-50 TIMING

Cycle No. (c)	Arriving Vehicles Each Cycle (E_c)	Discharging Vehicles Each Cycle (Average Max. Capacity = 32 Veh./Cycle) (D_c)	Vehicles Stopped for Half Cycle ($E_c + R_{c-1} - D_c$) (R_c)	Vehicles Stopped for One and A Half Cycle ($E_c + R_{c-1} - 2D_c$)	Proportion of Discharging Green Phase Stopped $(\frac{R_c}{Cap})$	One-Half Green Phase in Hr, Times Proportion Stopped $(\frac{R_c}{Cap})(\frac{g}{2})$	Total Stopped Time during Discharging Green Phase $(\frac{R_c}{Cap})(\frac{g}{2})(R_c)$
1	42	32	10		0 31	0 0013	0 0130
2	19	29					
3	41	32	9		0.28	0 0012	0 0108
4	20	29					
5	40	32	8		0.25	0.0011	0 0088
6	21	29					
7	39	32	7		0.22	0.0009	0.0063
8	22	29					
9	38	32	6		0.19	0 0008	0.0048
10	22	28					
11	37	32	5		0 16	0 0007	0 0035
12	23	28					
13	37	32	5		0 16	0 0007	0 0035
14	23	28					
15	36	32	4		0.13	0.0005	0 0020
16	24	28					
17	36	32	4		0.13	0.0005	0.0020
18	24	28					
19	35	32	3		0.09	0.0004	0.0012
20	24	27					
21	35	32	3		0.09	0.0004	0.0012
22	25	28					
23	35	32	3		0.09	0.0004	0.0012
24	25	28					
25	34	32	2		0.06	0.0003	0 0006
26	25	27					
27	34	32	2		0.06	0 0003	0.0006
28	26	28					
29	34	32	2		0.06	0 0003	0 0006
30	26	28					
31	33	32	1		0.03	0 0001	0.0001
32	26	27					
33	33	32	1		0 03	0.0001	0.0001
34	26	27					
35	33	32	1		0.03	0.0001	0 0001
36	27	28					
37	33	32	1		0.03	0.0001	0.0001
38	27	28					
39	32	32					
40	27	27					
41	32	32					
42	27	27					
43	32	32					
44	28	28					
45	32	32					
46	28	28					
47	31	31					
48	28	28					
49	31	31					
50	28	28					
51	31	31					
52	29	29					
53	31	31					
54	29	29					
55	30	30					
56	29	29					
57	30	30					
58	29	29					
59	30	30					
60	30	30					
Totals	1,794	1,794	77				0.0605

$$ST_{min} = (r)\left(\sum_{c=1}^{n} E_c + R_{c-1} - D_c\right) + (1.5C)\left(\sum_{c=1}^{n} E_c + R_{c-1} - 2D_c\right) + \sum_{c=1}^{n} \left(\frac{R_c}{Cap}\right)\left(\frac{g}{2}\right)(R_c)$$

$= (0.0085)(77) + (0.026)(0) + 0.0605$

$= 0.6545 + 0.0605$

$= 0.7150$ hr

stopped time? Because it still is impossible to predict the arrangement of cyclical arrivals even when the frequency within the hour of various sized arrival increments is known from the Poisson distribution of the total hourly volume. The maximum and minimum accumulative stopped time values are simply the limiting conditions, assuming the most unlikely arrangements possible.

The problem has an element of chance. The actual stopped time at a signal, with all things equal might well differ from day to day, since identical cyclical arrangements of arrivals will occur only rarely. On the average, it was assumed that the actual stopped time will be halfway between minimum and maximum. That assumption is expressed by Eq. 3 which was used to compute the average speeds for the speed-volume/capacity ratio curves.

$$\overline{S} = \frac{d(V)}{T(V) + (ST_{min} + ST_{max})/2}$$

in which,

$\overline{S}$ = average speed of all vehicles passing through the test section in an hour (mph);
d = test section length (miles);
V = volume per hour;
T = time to travel d; and
others as defined previously.

It can be demonstrated, however, that as the volume entering a street section increases, the percentage of arrivals at the signal or at the end of the queue during the red phase increases. (It is obvious that at low volumes, drivers can and do adjust speeds in order to arrive during the green phase as much as possible.) Some observations by CATS indicate that at signals with a 50-50 signal split the percentage of arrivals during the red phase may even rise above 50 percent as volume continues to increase. There is no apparent reason for the percentage to rise much above 50 percent, however.

The importance of the point is this—that, if there is a demonstrable relationship between the percentage of arrivals during the red phase and a volume to capacity index (for comparability of different street sections having different discharge rates), the actual stopped time would tend away from the halfway point between minimum and maximum. The effect of this tendency upon the calculated average speed, however, should be slight.

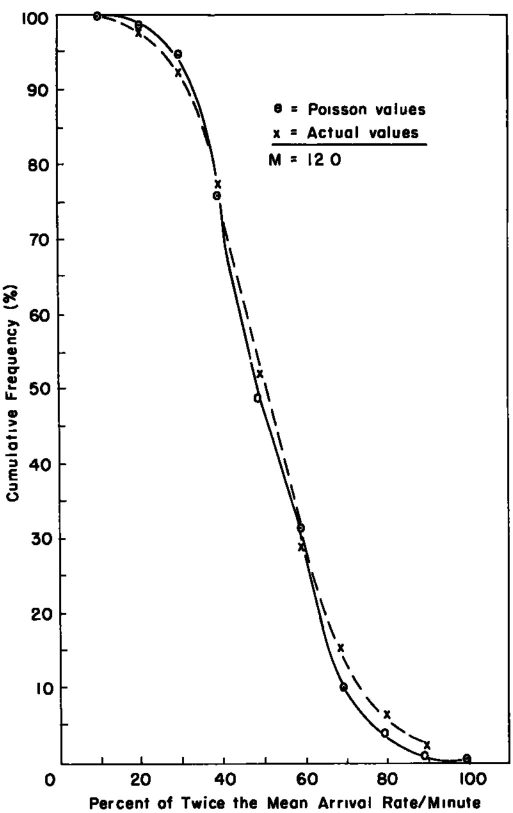

Figure 9. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

DERIVATION AND APPLICATION OF SPEED-VOLUME/CAPACITY RATIO CURVES

The application to actual route sections in the CATS arterial system required speed-volume curves in which speed could be solved for merely by the substitution of volume. Since the relation between volume and maximum discharge rate is implicit in this method of predicting average speeds, the speed-volume curves were converted to speed-volume/capacity ratio curves.. This conversion provided a common base for plotting the curves, that is, volume to capacity ratio, and made it possible to draw one curve for each speed range, yet account for route sections having different loads and different capacities. The following paragraphs discuss the derivation, simplification, and application of the required curves.

Derivation

The family of curves was obtained by by a combination of manual and machine calculations. This process yielded speed points which, when plotted against the volume/capacity ratios corresponding, produced the necessary preliminary curves. It was decided that speed values from Eq. 3 would be calculated for 108 curves; that is, a different curve for route section lengths of 0.5, 1.0, 1.5, and 2.0 miles; within this breakdown, a different curve for best attainable legal speeds of 20, 25, 30, 35, 40, 45, 50, 55, and 60 mph; and within this breakdown, a different curve for average maximum discharge rates of 600, 1,320, and 2,160 vph, assuming 50 percent green at the terminal signal. The latter capacity rates correspond to the capacity standards hypothesized by CATS for 2-, 4-, and 6-lane urban intersection approaches in intermediate type areas. These standards were the result of intersection, headway and starting reaction time surveys completed and analyzed by CATS.

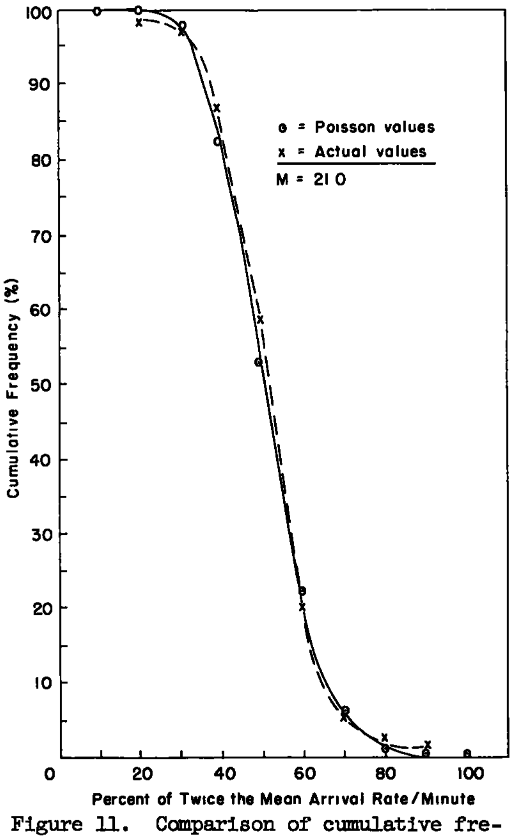

Figure 11. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

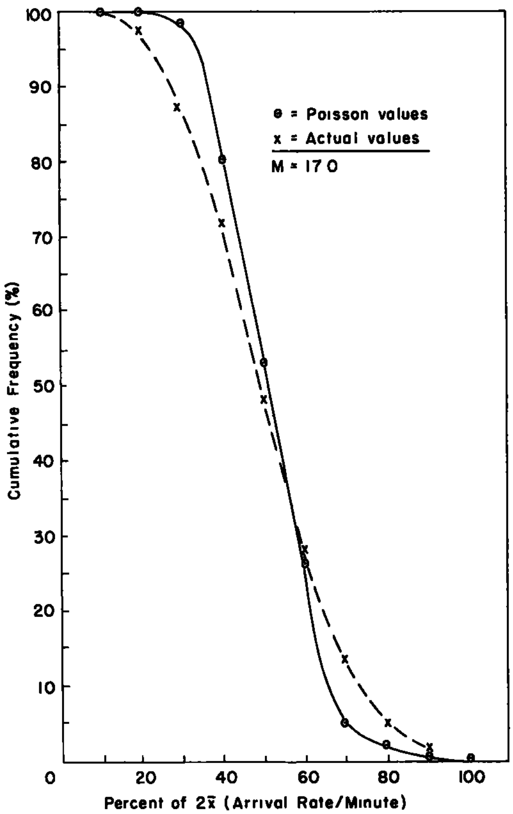

Figure 10. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

Six speed values were calculated for each curve at volume to capacity ratios of 50, 67, 83, 100, 117, and 138 percent. While more intermediate values could have been calculated at little additional cost, it was reasoned that 6 were sufficient to delineate accurate curves, since it was previously decided that the curves would have to be approximated later by straight lines. For purposes of illustration, the 9 curves for each best attainable legal speed through a 4-lane section 1.0 mile long are plotted in Figure 3. The curves are eye-fitted.

Simplification and Application

The application of 108 curves to matching CATS arterial street sections, however, presented a formidable machine problem. Simplification to a family of no more than 10-12 curves was highly desirable, and further analysis of the 108 curves proceeded with this in mind. Two important facts emerged. The first was that for a given section with all other things equal, increasing the section length from 0.5 to 2.0 miles shifted the speed points to the right, as shown in Figure 4. This was perfectly logical since vehicles might move at the best attainable legal speed up to the end of the queue, and the greater the section length, the greater the distance of unimpeded movement, generally.

The second important fact was, that all other things being equal, speed values for a 6-lane section will be slightly higher than for a 4-lane section, and the latter will be slightly higher than for a 2-lane section. This is demonstrated in Figure 5. The shift resulted from the fact that CATS capacity standards per unit of street width increase slightly as additional moving lanes are added. Preliminary releases of the revised "Highway Capacity Manual" show the same relationship.

These facts suggested that the 108 curves could be generalized by only 9 curves for which section length would be standardized at 0.5 mile and maximum discharge rate at 600 vph.

There were two reasons for choosing 0.5 mile as a standard—(1) the average section length of the 4,800 sections in the CATS system is roughly 0.5 mile; and (2) since deceleration and acceleration time losses are not accounted for by Eq. 3, the calculated speeds are overstated. Standardizing at 0.5 mile tends to compensate for this to some extent. Standardizing at 600 vph is an added compensation for the same bias.

The final family of eye-fitted curves, based on 9 free speeds, a section length of 0.5 mile, and an average maximum discharge rate of 600 vph, is shown in Figure 6. To facilitate machine application, the break point of all curves was taken at volume/capacity ratio = 60 percent. The lowest speed allowable was taken as 5 mph at volume/capacity ratio = 110 percent. They are reminiscent of the curves developed in a paper by Wardrop and Duff, titled "Factors Affecting Road Capacity." These are the curves to be used for the evaluation of the CATS arterial street assignment.

The reader may wonder how the volume can reach 110 percent of capacity. Obviously, the discharge of the signal cannot be greater than the maximum capacity. The volume referred to is the number of vehicles arriving at, and not necessarily discharging form, the intersection.

Briefly, the actual application might proceed as follows: during or after assignment, the volume assigned to any street is known, and may be compared to the street capacity to obtain the volume/capacity ratio. The appropriate curve, based upon the best attainable legal speed, is entered and the average speed, corres-

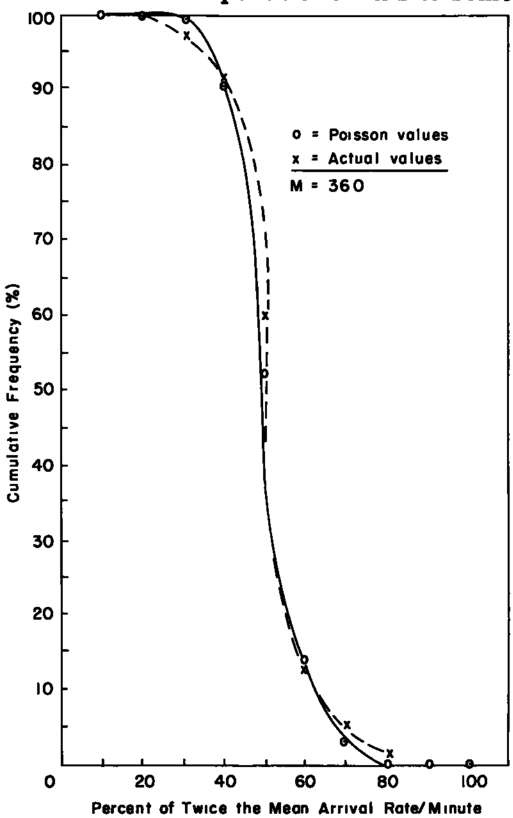

Figure 12. Comparison of cumulative frequency of actual arrivals per minute to Poisson derived arrivals per minute.

ponding to the assigned volume, determined. All this can and will be done mechanically.

SUMMARY

This report has explained the development of a series of curves relating speed to traffic volume for urban signalized arterials. The resulting curves show the relationship of speed to the ratio of volume to capacity.

The similarity of the distribution of traffic on urban streets to the Poisson distribution was first demonstrated. Then the Poisson distribution was used to generate arrival rates for various hypothetical locations and to calculate travel delays and starting time as the volume of traffic varied. Next, the average speed was calculated by adding the accumulative stopped time to the time to travel through a section of known length at very low traffic volume. This was done for streets with varying discharge rates and for various approach volumes.

This resulted in the development of a series of speed-volume curves. Since the relation of volume and capacity is closely interwoven, these curves were converted to speed-volume to capcity ratio curves. This conversion also provided a common base, (that is, volume to capacity ratio) for expressing all the curves.

This is a crude approach to the problem of defining the relationship of speed to volume. Many simplifying assumptions were needed to develop the curves which are presented in this report. However, the authors feel that this is a good simplified first step to the development of a rational theory explaining traffic flow.

There are many obvious applications of the speed-volume relationship in the field of urban traffic planning. For example, after a traffic assignment is made, it would be possible to estimate the average operating speed of all streets under the assigned loads. Thus a measure of the quality of service, which would be afforded at some future date with new planned facilities, could be determined. Also, it is possible to determine what volume would be allowable to obtain a reasonable minimum speed on urban streets.

These relationships would provide an excellent basis for a time or speed feedback in an assignment problem. For example, using assumed speeds or times for route sections, a traffic assignment is made. After the assignment is completed, it would be possible to determine the speed and thus the times obtainable with the assigned volumes through the use of the speed-volume to capacity curves. These times could be fed back into the computer and used as a basis for a reassignment. The second assignment would redistribute the traffic and a series of these assignments should eventually result in a balanced load for the network. In this way it would be possible to simulate, with some realism, the manner in which traffic would distribute itself in a transportation network.

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THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.