HIGHWAY RESEARCH BOARD

Bulletin 203

Travel Characteristics In Urban Areas

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Travel Characteristics In Urban Areas

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Travel Characteristics of Two San Diego Subdivision Developments

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An origin-destination study of two San Diego subdivision developments was made in an effort to develop relationships between land use and traffic generation, and to study the orientation of the generated traffic.

The smaller of these study subdivision developments contained 1,822 single family dwelling units at the time of the survey, and the larger contained 7,158 occupied dwelling units, of which 4,296 were single family, 1,838 were duplexes, and 1,024 were apartments. Both subdivisions had planned shopping areas which were partially developed at the time of the survey.

In addition to a home interview survey, a cordon line was established around each study area and 100 percent of the outbound non-residents were interviewed as were all of the outbound transit riders. A screen line check of 95.8 percent was obtained in the smaller subdivision, while an accuracy of 98.8 percent was obtained in the larger.

Vehicle ownership in both study areas was found to be 1.22 vehicles per dwelling unit. Trip generation data was developed per dwelling unit for 5-day, 7-day and weekend trip types by type dwelling unit. Intrazonal trips were related to area.

Weekday and weekend auto-truck trip purposes were studied and trip purpose time profiles developed.

The possibility of forecasting future trips using the a.m. peak period work trip and projecting by the relation of the work trip to all trips was investigated. The a.m. peak period work trips and the total of the work and related business trips of the two study subdivisions appeared to be stable, although the problem of sample size was noted.

Freeway usage was studied, as a further experiment in the accuracy of projecting the a.m. peak period volumes. It appears that the a.m. peak hour volume could be used to expand freeway type trips in areas similar in size to those studied when the trip length is under five or six miles.

The orientation of the generated trips, both auto-truck and transit, is shown by desire line charts and trip length distribution curves. The work trip was also studied in terms of its trip length distribution. Close relationships were observed between the two study subdivisions in the trip purpose analyses of trip length.

These studies developed useful trip generation data by type dwelling unit. The relation of trip generation and orientation to land use appeared in several of the analyses, thus suggesting that consistent relationships between land use and travel characteristics do exist.

● THE City of San Diego has experienced a population growth of from approximately 203,000 in 1940 to over half a million today. This has created a need to plan for sustained rapid growth. One of the essential elements of good street and highway transportation planning is the ability to make reasonable forecasts of future travel. It is believed that there is a need to relate the traffic generating characteristics and travel

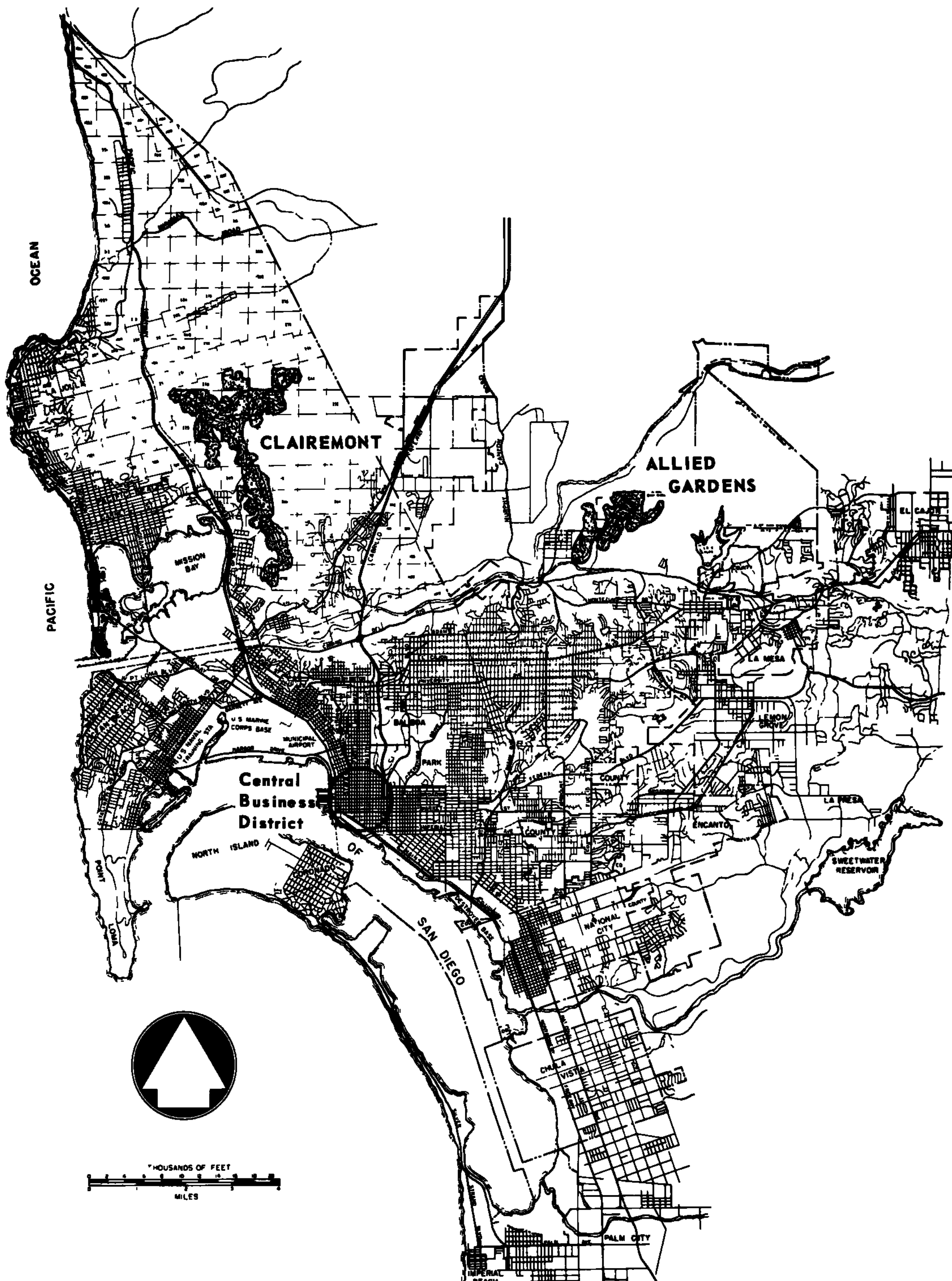

Figure 1. San Diego and vicinity, showing location of study areas.

patterns of various land uses to develop these forecasts of travel.

San Diego, covering 153.3 sq mi, is the central city of the metropolitan area of approximately 500 sq mi. Since January 1, 1957, there have been 295 new subdivisions filed with the City of San Diego. There has been a growing tendency in Southern California to build in large mass-production housing developments. These developments are generally well-planned and provide essential services for the residents of these planned communities. Thus, with large-scale housing development suddenly coming into being on formerly vacant land, it becomes increasingly important to be able to predict the impact of these developments on the traffic pattern of the metropolitan area. It is hoped that in San Diego in the near future it will be possible to estimate with reasonable accuracy the total origins to be expected, both auto-truck and transit, and to forecast their distribution when given an estimate of anticipated use of the land.

In 1952-53 a standard origin-destination survey was conducted in the San Diego metropolitan area by the Bureau of the Census for the California Division of Highways in cooperation with the U. S. Bureau of Public Roads. The results of this origin-destination survey and several important analyses have been reported in "San Diego Traffic Survey 1952-53" published by the California Division of Highways. In addition to the survey report, several tabulations and various other data have been made available to the City of San Diego. A number of analyses have been made of these data, but the individual dwelling unit and trip cards for the 1952-53 O-D have not been analyzed for trip purpose by selected geographical areas.

San Diego is one of the eight pilot cities selected to test the program of the National Committee on Urban Transportation. A study of travel desires and their relation to land use was an important part of the fact-gathering phase of the National Committee's program.

In an effort to develop relationships between land use and traffic generation and orientation, to contribute to the pilot city program, and to accumulate facts in areas which had been developed since the 1952-53 origin-destination study, it was decided to conduct an origin-destination study in two selected modern subdivisions during June and July 1956.

The Subdivisions

The two selected subdivision developments were Allied Gardens and Clairemont. These were selected for study because they were essentially homogeneous, were designed to modern standards, and have been developed since World War II. Both subdivisions represent typical middle income communities for the San Diego area and are approximately equidistant from the central business district. Allied Gardens was brushy hillside at the time of the 1952-53 O-D study, and only a small part of Clairemont was developed at that time. Both subdivisions could be considered to be planned developments, one completely developed by one concern, and the other developed by several large concerns. Planning for both of these subdivisions included the development of shopping areas designed to serve the planned population. Neither included any industrial uses nor had a high school at the time of the survey. Both included schools and provision for parks. Both areas were susceptible to a reasonably simple cordon line treatment, and both subdivisions were isolated to a considerable extent from the rest of the community. The two study areas represented the large-scale housing development anticipated in the future in the San Diego metropolitan area. The travel characteristics developed for these subdivisions can be assumed to apply to similar future developments.

The relation of Allied Gardens and Clairemont to the San Diego metropolitan area is shown by Figure 1. Allied Gardens is the smaller of the two subdivisions. Figure 2 is a land use map of Allied Gardens. Allied Gardens contained 1,822 single family dwelling units at the time of the survey and an estimated population of 6,930.

Figure 3 shows the land use in Clairemont. Clairemont contained a total of 7,158 occupied dwelling units at the time of the survey, of which 4,296 were single family, 1,838 were duplexes and 1,024 were apartments, and an estimated population of 27,775.

Both subdivisions had planned shopping areas. At the time of the study, 2.7 com-

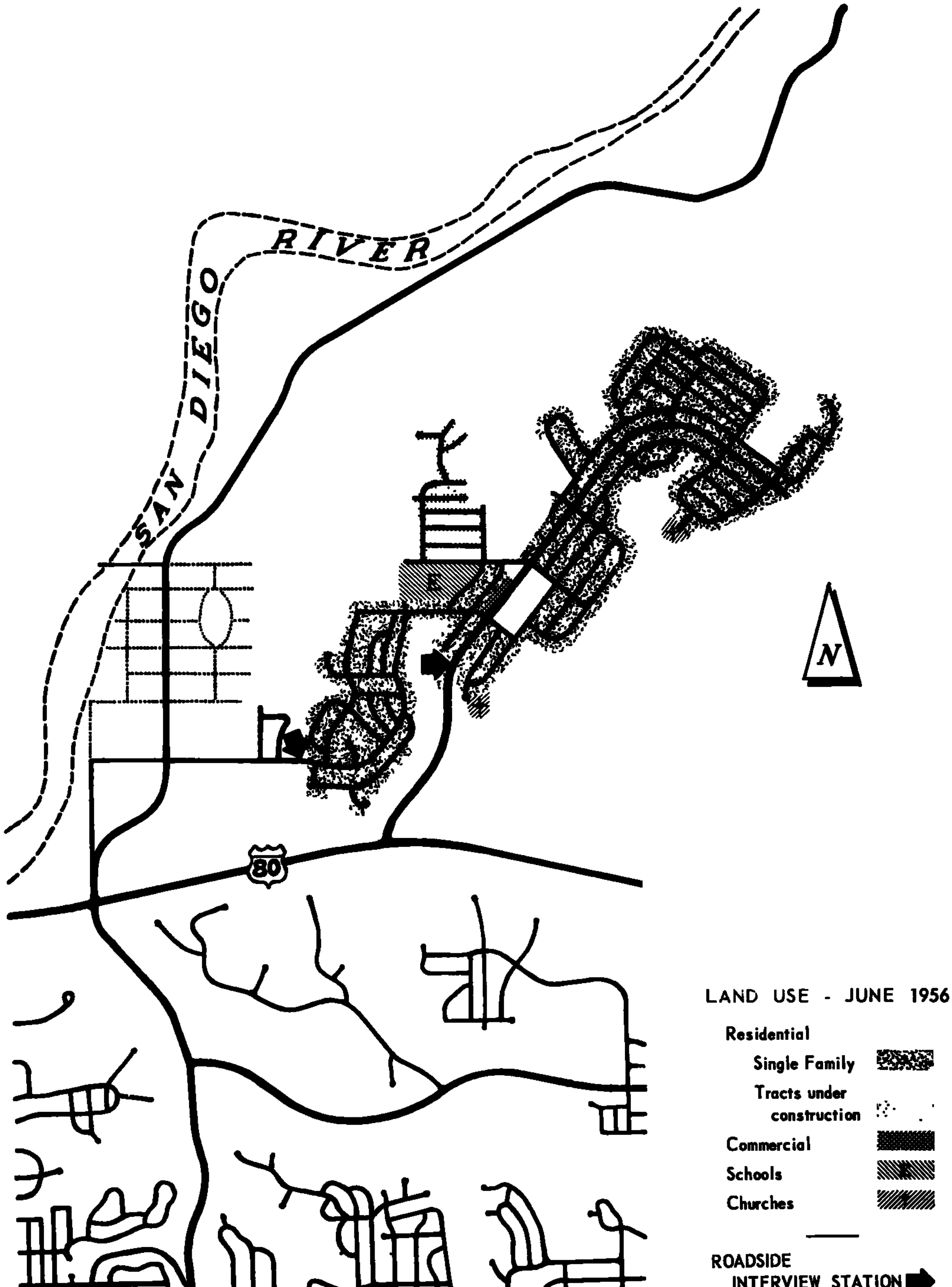

Figure 2. Allied Gardens, Origin-Destination Survey.

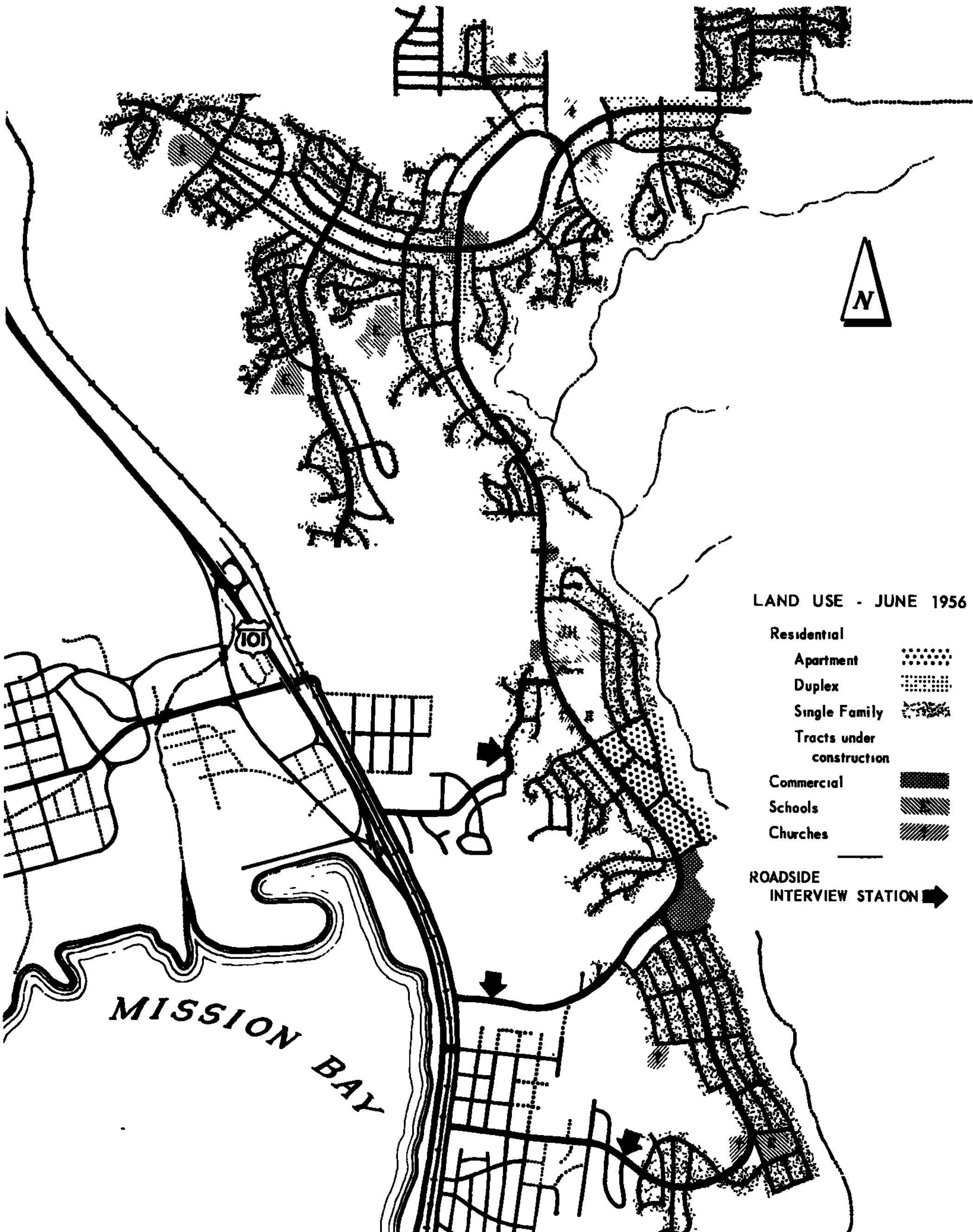

Figure 3. Clairemont, Origin-Destination Survey.

mercial acres were developed in Allied Gardens and 30.8 acres were developed in Clairemont. The shopping habits at Allied Gardens were studied in greater detail than Clairemont, as they were felt to be more isolable than the shopping areas of Clairemont.

Although neither of these modern, residential communities might be called completely balanced or completely developed communities, both of them represent a mature status of development in that all the essential functions of a neighborhood development were available. Selective shopping and many heavy goods were available in Clairemont, but such things as automobiles were not available. Both areas contributed to the land use balance then in existence in the metropolitan area.

Modern high standard major streets had been provided in both subdivisions. The city standard in both cases is four 12-ft travel lanes, two 8-ft parking lanes and a median. As is true with all new subdivisions in the City of San Diego, the subdivider provided high standard local residential streets with curbs and sidewalks.

Study Methods

The home interview origin-destination surveys used the standard California procedure which had been used during the 1952-53 origin-destination survey. The interview form was the identical form used for the 1952-53 origin-destination survey, with the exception that shopping was divided between shopping and convenience goods and the number of vehicles regularly garaged or parked at each dwelling unit was obtained. A 10 percent dwelling unit sample was taken at Allied Gardens and a 5 percent sample was obtained in Clairemont. The purpose of selecting a 10 percent sample of dwelling units in Allied Gardens was twofold; first, because of the relatively smaller size of the subdivision, and second, to compare the results of the 10 vs 5 percent sample sizes. The 1952-53 O-D was conducted on the basis of a 5 percent sample of dwelling units.

This origin-destination study was directed, designed, organized, conducted, and analyzed entirely by the City of San Diego. In an effort to maintain the best possible public relations, the owner's name and address of each selected sample dwelling unit was obtained from Water Department records. A letter signed by the City Manager was then sent to the owner of the dwelling unit explaining the purpose of the study and requesting his cooperation with the interviewer. The six interviewers were carefully trained and supervised, and thus, maximum accuracy was assured. The home interviewers coded each others interviews, thereby providing an important built in check. Table 1 shows the

TABLE 1

SUMMARY OF HOME INTERVIEW TRAVEL DAYS

Dwelling Unit Group	Completed Interviews by Travel Day							Total Travel Days for Which Information Was Obtained	Total Households Interviewed	Total Households in Dwelling Unit Group	Households Interviewed percent of total households
	1 Sunday	2 Monday	3 Tuesday	4 Wednesday	5 Thursday	6 Friday	7 Saturday				
1 Allied Gardens Single Family	24	26	33	35	31	30	29	208	184	1,822	10 10
2 Clairemont Apartments	5	14	13	6	6	7	5	56	51	1,024	4 98
3 Clairemont Duplexes	12	16	12	12	19	21	12	104	92	1,838	5 01
4 Clairemont Single Family (lower valuation)	23	33	17	16	25	16	24	154	131	2,623	4 99
5 Clairemont Single Family (higher valuation)	9	12	16	21	10	17	9	94	85	1,673	5 08
Total—All Clairemont Single Family	32	45	33	37	35	33	33	248	216	4,296	5 03
Total—All Clairemont Dwellings	49	75	58	55	60	61	50	408	359	7,158	5 02
Total—Allied Gardens and Clairemont	73	101	91	90	91	91	79	616	543	8,980	-

TABLE 2

CUSTOMERS BY TYPE ACTIVITY
ALLIED GARDENS BUSINESS DISTRICT

Type Activity	Number of Customers	
	Thursday 7-12-56	Saturday 7-14-56
Service Station	189	209
Radio-TV Shop	14	21
Laundromat	48	81
Medical/Dental Office	15	Not Open
Barber Shop	38	54
Beauty Shop	39	42
Market	1,200	2,000
Shoe Sales-Repair	24	37
Variety Store	265	328
Drug Store	401	436
Total Customers	2,233	3,208

TABLE 3

NUMBER OF CUSTOMERS BY HOUR
ALLIED GARDENS BUSINESS DISTRICT

Time	Drug Store Thursday 7-12-56	Drug Store Saturday 7-14-56	Variety Store Thursday 7-12-56	Variety Store Saturday 7-14-56
10-11 a.m.	37	40	25	36
11-12 a.m.	35	32	34	39
12- 1 p.m.	35	39	17	28
1- 2 p.m.	35	40	38	34
2- 3 p.m.	46	34	29	31
3- 4 p.m.	39	39	30	33
4- 5 p.m.	40	46	25	42
5- 6 p.m.	43	64	33	43
6- 7 p.m.	46	49	4[a]	2[a]
Total	356	383	235	288

[a] Variety store closes at 6:00 p.m.; drug store closes at 7 00 p.m.

Note: This count represents the number of persons who were considered by an observer outside the entrances to have transacted some sort of business in these stores. Compared to the number of customers reported by the manager of the variety store, this count represents 89 percent of the total number of customers reported by the manager on Thursday, and 88 percent of those reported by the manager on Saturday.

summary of travel days for which interviews were obtained by dwelling unit classification and study area.

Cordons were established around both areas and roadside interview stations were located on the entering roads—two for Allied Gardens and three stations at Clairemont. The roadside O-D interview study was designed to obtain data from a 100 percent of the outbound non-residents during a 16-hr period. A 100 percent sample of the outbound non-residents was obtained at all stations except one, Clairemont Drive, where 141 vehicles were passed during the peak hour. Clairemont Drive at that time carried an ADT of 18,340. Those vehicles that were not interviewed were classified and counted. A 100 percent classification count was made at the interview station during the 16 hours of study. Machine counts were conducted for 24 hours at all cordon stations during the study.

Careful field studies of the two study areas were made prior to the interviewing. During this field inventory the land use was recorded. In an effort to study the effect of economics on trip generation, the single family dwelling units in Clairemont were classified by dwelling unit valuation.

One of the underlying purposes of these origin-destination studies was to relate land use to trip generation and attraction. The attraction (drawing power) of a small residential neighborhood shopping center was studied by a customer count made at the Allied Gardens business district. Table 2 shows the customers by type activity for a typical weekday and a Saturday. Table 3 shows the attractiveness in terms of customers by time of day for two of the establishments.

The key-punching and machine analysis of the 543 home interviews and 3,682 roadside interviews was designed, supervised and carried out by the City of San Diego, using its own tabulating equipment.

The scope and accuracy of the studies are shown in Table 4. The very high accuracy indicated by the screen line checks is thought to be reasonable in view of the limited number of interviewers, their high caliber and the excellence of the supervision given in the field as well as the homogeneity of the two subdivisions.

Table 5 is a comparison of the results of the 5 and 10 percent sampling of dwelling units in Allied Gardens. The sample size of these studies is based on interviews for 7 days. This table compares various totals obtained by the two sample sizes as well as certain selected trip purposes and the screen line check. From this comparison it is concluded that a 5 percent sample size would have been adequate for over-all totals and the trip purpose analysis, but inadequate to determine travel patterns for Allied Gardens due to the serious variation in the number of interzonal transfers. Figure 4 demonstrates the significant difference in the number of interzonal transfers obtained by the two sample sizes. The importance of this is further emphasized by the relatively large size of Allied Gardens community. The

TABLE 4

SCOPE AND ACCURACY

Scope of Home Interview Survey	Allied Gardens	Clairemont
Total Dwelling Units	1,822	7,158
Seven-Day Sample Size	10%	5%
Dwelling Units Interviewed	184	359
Expanded Population	6,931	27,775
Expanded Weekday Auto-Truck Driver Trips	13,442	41,647
Expanded Total, 7-day trips, all modes	21,871	86,036
Accuracy—24-Hr Screen Line Check		
Expanded Weekday Auto-Truck Driver Trips Crossing Cordon	6,370	20,020
Non-Resident Auto-Truck Driver Trips Crossing Cordon	3,448	7,958
Total	9,818	27,978
Counted Cordon Volume	10,245	28,329
Percent Accounted for by Interviews	95.8%	98.8%

TABLE 5

COMPARISON OF 5 AND 10 PERCENT SAMPLES—ALLIED GARDENS

Item	5 Percent	10 Percent	Percent Difference
Totals			
Population	7,106	6,931	+ 2.5
Total 7-Day Trips, all modes	23,382	21,871	+ 6.9
Total 5-Day Auto-Truck Trips	13,261	13,442	- 1.4
Vehicle Inventory			
Cars	2,227	2,277	- 2.2
Trucks	101	109	- 7.3
Other	0	20	-100.0
Total	2,328	2,406	- 3.2
Screen Line Check	85.2%	95.8%	
Trip Purpose			
Percent of Work Trips	15.2	15.6	
Percent of Shopping Trips	11.0	11.8	
Subtotal Percent Work and Related Business Trips	36.5	35.4	
Subtotal Percent Vacation, Pleasure, Others	5.0	4.8	
Subtotal Percent Shopping, Medical, Dental Serve Passenger, etc.	58.4	59.7	
Travel Pattern			
Number of Interzonal Transfers 5-Day Auto-Truck Trips	266	451	- 41.0

analyses in the balance of this paper use the 10 percent sample data of Allied Gardens.

Travel Characteristics

Various travel characteristics of the two study subdivision developments have been summarized in the tables and figures of this report. Fortunately the automobile ownership of medium valuation single family dwelling units of both of the study areas was found to be similar, as was the combined ownership per dwelling unit of the two areas. Thus the elimination of this as a variable in the comparison between these two study areas is believed justified. The vehicle ownership of each area by type dwelling unit is given in Table 6. An interesting and expected rela-

TABLE 6

VEHICLES PER DWELLING UNIT BY TYPE OF DWELLING UNIT VEHICLES GARAGED AT DWELLING UNIT

Type Dwelling Unit	Automobiles	All Vehicles
Apartments—Clairemont	1.09	1.08
Duplexes—Clairemont	1.16	1.20
Single Family, medium valuation		
Clairemont	1.15	1.21
Allied Gardens	1.22	1.27
Single Family, high valuation		
Clairemont	1.39	1.42
All Types—Clairemont	1.20	1.24
Combined Allied Gardens and Clairemont	1.21	1.25

TABLE 7

RESIDENT TRIP GENERATION PER DWELLING UNIT IMPACT ON METROPOLITAN AREA

Trip Description	Area and Type Dwelling Unit						
	Allied Gardens	Clairemont					
	Single Family Medium Value	Single Family Medium Value	Single Family High Medium Value	Duplex	Apartment	Average	Combined Average
5-Day							
All	10.63	10.89	11.53	8.33	8.32	10.00	10.21
Auto Driver	6.96	5.83	6.74	4.45	4.82	5.54	6.01
Auto-Truck Driver	7.39	6.47	6.79	4.62	4.82	5.83	6.33
Auto-Truck Passenger	3.02	4.15	4.39	3.26	3.17	3.83	3.56
Mass Transit Passenger	0.20	0.28	0.33	0.41	0.30	0.33	0.29
7-Day							
All	10.61	11.90	12.21	8.42	8.34	10.59	10.58
Auto Driver	6.56	6.05	7.12	4.69	4.82	5.78	6.04
Auto-Truck Driver	7.14	6.70	7.21	4.85	4.82	6.08	6.44
Auto-Truck Passenger	3.29	4.99	4.69	3.24	3.27	4.23	3.92
Mass Transit Passenger	0.17	0.21	0.32	0.32	0.25	0.27	0.24
Saturday							
Auto-Truck Driver	7.93	6.29	8.00	6.83	4.40	6.54	7.05
Sunday							
Auto-Truck Driver	4.42	8.18	9.78	4.17	5.20	7.19	6.28

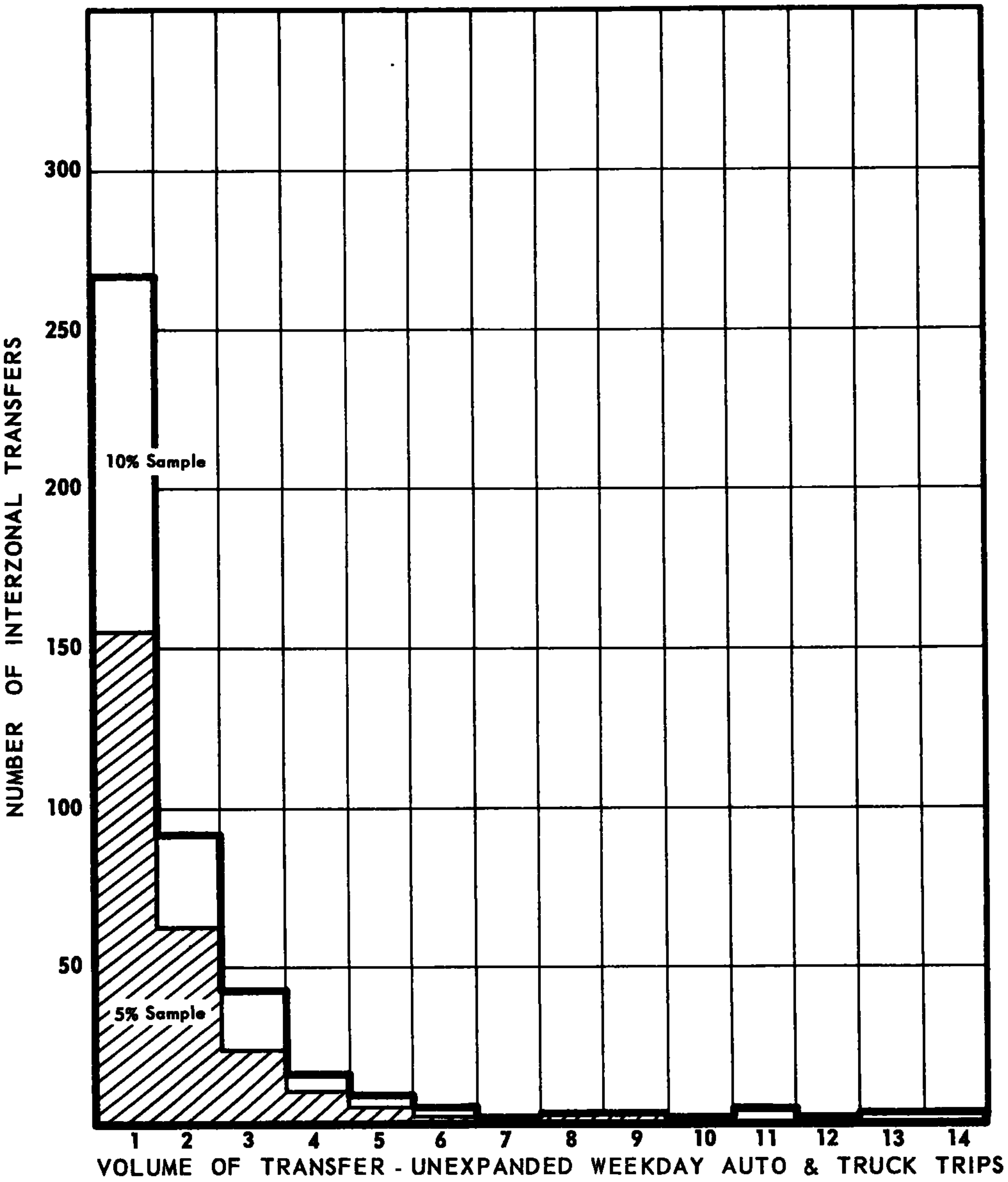

Figure 4. Comparison of 5 and 10 percent samples.

TABLE 8

RESIDENT TRIP GENERATION OF DRIVER TRIPS PER DWELLING UNIT

Trip Description	Allied Gardens	Clairemont					
	Single Family Medium Value	Single Family Medium Value	Single Family High Medium Value	Duplex	Apartment	Average	Combined Average
5-Day Auto							
All	6.96	5.83	6.74	4.45	4.82	5.54	6.01
One or both ends in area	4.33	4.46	4.78	3.70	3.66	4.25	4.24
One end at home	3.88	3.79	4.34	3.19	3.13	3.67	3.73
5-Day Auto-Truck							
All	7.39	6.47	6.79	4.62	4.82	5.83	6.33
One or both ends in area	4.39	4.77	4.78	3.76	3.66	4.37	4.37
One end at home	3.92	3.96	4.34	3.24	3.13	3.74	3.80

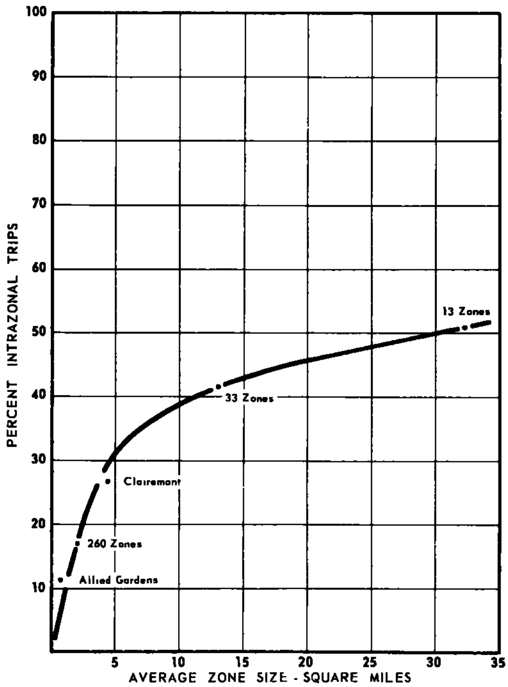

Figure 5. Auto and truck trips from 1952-53 San Diego Metropolitan Area O-D Study.

TABLE 9

WEEKDAY RESIDENTIAL AUTO-TRUCK ORIGIN GENERATION CALCULATION

Elements	Allied Gardens	Clairemont
Expanded Resident Trips		
One or Both Ends in Area	8,000	31,200
Expanded Resident Trips		
One End in Area (intra-area trips removed)	5,930	20,040
Percent Intra-Area Trips	11.9	26.7
Resident Origins	5,035	21,180
Resident Origins at Residences (Commerical origins removed)	4,378	18,700
Resident Origins at Residents (Screen line factor applied)	4,570	18,950
Non-Resident Origins at Residences (Commercial origins removed)	1,544	3,375
Residential Area Origins		
Total	6,114	22,325
Per Dwelling Unit	3.35	3.12
Per Person	0.87	0.80
Residential and Commercial Area Origins		
Total	6,951	25,409
Per Dwelling Unit	3.82	3.55
Per Person	0.99	0.91

tion between dwelling unit type and automobile ownership was found to exist.

Table 7 gives the trip generation per dwelling unit for 5-day, 7-day, and weekend trip types. This table represents the total resident generating impact of the study subdivisions on the entire metropolitan area regardless of location of trip ends. Table 8 reports the generation of the 5-day auto and 5-day auto-truck driver trips for the several types of dwelling unit classifications. Again, this represents the resident impact on the total metropolitan area. Tables 7 and 8 develop the relation-

TABLE 10

WEEKDAY AUTO-TRUCK TRIP PURPOSE PERCENTAGE DISTRIBUTION

Destination Purpose	Trip Purpose as Percent of Total						
	24-Hr 1952-53 O-D Summary	Allied Gardens			Clairemont		
		24-Hr	A.M. Peak Period	P.M. Peak Period	24-Hr	A.M. Peak Period	P.M. Peak Period
Work	15.3	15.6	55.2	8.6	16.3	58.0	3.5
Related Business	21.5	19.8	4.7	18.9	7.1	4.4	2.7
Subtotal	36.8	35.4	59.9	27.5	23.4	62.4	6.2
Medical and Dental	0.7	0.8	1.0	-	0.7	-	-
Shopping							
Convenience Goods	-	9.3	1.9	10.0	9.9	1.1	14.5
Shopping Goods	-	2.5	0	1.3	2.5	0	1.0
Total	7.9	11.8	1.9	11.3	12.4	1.1	15.5
Education, Civic and Religion	1.3	0.5	1.9	-	0.7	2.7	-
Eat Meal	1.7	2.0	1.0	1.8	2.7	2.2	1.6
Serve Passenger	10.4	11.6	24.8	12.2	13.6	24.6	19.3
Personal Business	5.1	6.4	1.0	5.4	6.6	1.1	6.5
Change Travel Mode	0.5	0.6	3.8	0.5	0.5	1.6	-
Home	28.6	26.0	3.8	37.8	31.7	3.3	45.6
Subtotal	56.2	59.7	39.2	69.0	68.9	36.6	88.5
Vacation	-	-	-	-	0.2	-	-
Pleasure	0.4	1.6	-	1.3	2.2	0.5	1.4
Others	6.4	3.2	1.0	2.3	5.2	0.5	3.8
Subtotal	6.8	4.8	1.0	3.6	7.6	1.0	5.2
Unknown	0.2	-	-	-	-	-	-
Total	100.0	99.9	100.1	100.1	99.9	100.0	99.9

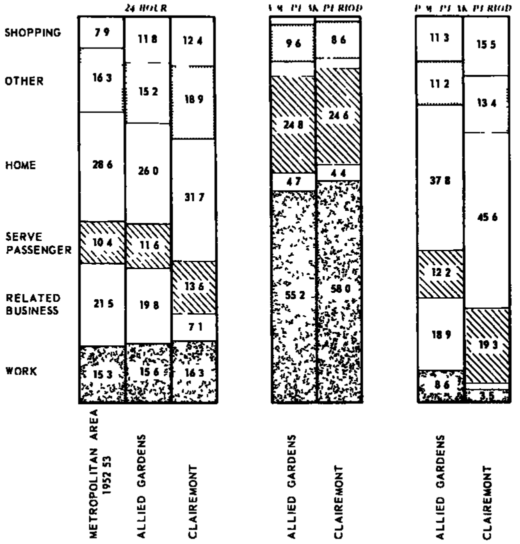

Figure 6. Weekday auto-truck trip purpose percentage distribution.

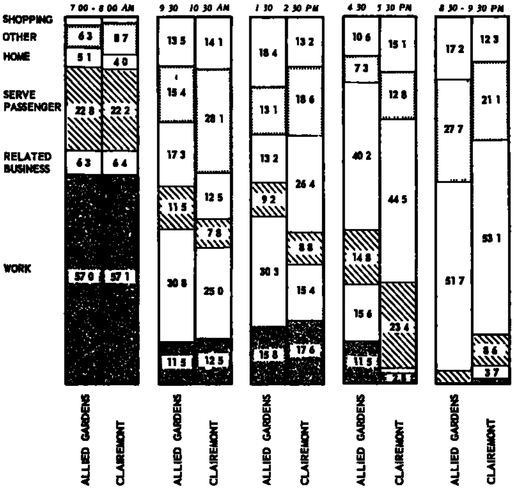

Figure 7. Weekday auto-truck trip purpose percentages by selected hours.

ships between auto driver and auto-truck driver trips. The various analyses that follow use the auto-truck driver trips to develop relationships as these are believed to be the desired end result.

It has been found in several studies that the effect of the intrazonal (intra-area) trip is significant and should be considered in the development of trip generation data. Figure 5 is a plot of the relationship between zone size and the percent of intrazonal trips. Allied Gardens and Clairemont are plotted as specific points to show their relationship to the metropolitan area curve. Table 9 indicates the calculations that are necessary to determine the weekday residential origins generated at a dwelling unit. Table 9 gives origins per dwelling unit for residential and for combined residential and commercial areas of the two subdivisions. Approximately 0.7 percent of the us-

TABLE 11

AVERAGE WEEKDAY AUTO-TRUCK TRIP PURPOSES BY SELECTED HOURS—ALLIED GARDENS

Destination Purpose	Interview Trips and Percent Distribution									
	7:00-8:00 a.m.		9.30-10.30 a.m.		1:30-2:30 p.m.		4:30-5:30 p.m.		8:30-9:30 p.m.	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Work	45	57.0	6	11.5	12	15.8	14	11.5	-	-
Related Business	5	6.3	16	30.8	23	30.3	19	15.6	-	-
Subtotal	50	63.3	22	42.3	35	46.1	33	27.0	-	-
Medical and Dental	1	1.3	2	3.8	1	1.3	-	-	-	-
Shopping										
Convenience Goods	2	2.5	5	9.6	10	13.2	11	9.0	5	17.2
Shopping Goods	-	-	2	3.8	4	5.3	2	1.6	-	-
Total	2	2.5	7	13.5	14	18.4	13	10.6	5	17.2
Education, Civic and Religion	1	1.3	-	-	-	-	-	-	-	-
Eat Meal	1	1.3	-	-	-	-	1	0.8	2	6.9
Serve Passenger	18	22.8	6	11.5	7	9.2	18	14.8	1	3.4
Personal Business	1	1.3	3	5.8	4	5.3	5	4.1	3	10.3
Change Travel Mode	1	1.3	-	-	-	-	-	-	-	-
Home	4	5.1	9	17.3	10	13.2	49	40.2	15	51.7
Subtotal	29	36.7	27	51.9	36	47.4	86	70.5	26	90.0
Vacation	-	-	-	-	-	-	-	-	-	-
Pleasure	-	-	-	-	1	1.3	1	0.8	1	3.4
Others (visit friends, etc.)	-	-	3	5.8	4	5.3	2	1.6	2	6.9
Subtotal	-	-	3	5.8	5	6.6	3	2.5	3	10.3
Total	79	100.0	52	100.0	76	100.1	122	100.0	29	100.3

able gross acres in Allied Gardens and 0.8 percent of the gross acres of Clairemont were in commercial uses at the time of the survey. It is interesting to note that 40.7 percent of the trips generated by Allied Gardens and 25.2 percent of the trips generated by Clairemont have both ends outside the respective areas. This is a function of zone size as is the intrazonal relationship.

One of the purposes of the study of these two subdivisions was to test the possibility of forecasting future trips using the a.m. peak period work trip and then expanding the projection by the relation of the work trip to all trips on a 24-hr basis. Table 10 gives the weekday auto-truck trip purpose in Allied Gardens and Clairemont for the 24-hr

TABLE 12

AVERAGE WEEKDAY AUTO-TRUCK TRIP PURPOSES BY SELECTED HOURS—CLAIREMONT

	Interview Trips and Percent Distribution									
Destination Purpose	7:00-8:00 a.m.		9:30-10:30 a.m.		1:30-2:30 p.m.		4:30-5:30 p.m.		8:30-9:30 p.m.	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Work	72	57.1	8	12.5	16	17.6	6	2.8	1	1.2
Related Business	8	6.4	16	25.0	14	15.4	3	1.4	3	3.7
Subtotal	80	63.5	24	37.5	30	33.0	9	4.1	4	4.9
Medical and Dental	-	-	5	7.8	2	2.2	-	-	-	-
Shopping										
Convenience Goods	2	1.6	6	9.4	9	9.9	31	14.2	8	9.9
Shopping Goods	-	-	3	4.7	3	3.3	2	0.9	2	2.5
Total	2	1.6	9	14.1	12	13.2	33	15.1	10	12.3
Education, Civic and Religion	4	3.2	-	-	-	-	-	-	-	-
Eat Meal	4	3.2	-	-	-	-	2	0.9	3	3.7
Serve Passenger	28	22.2	5	7.8	8	8.8	51	23.4	7	8.6
Personal Business	2	1.6	7	10.9	8	8.8	14	6.4	3	3.7
Change Travel Mode	-	-	-	-	-	-	-	-	1	1.2
Home	5	4.0	8	12.5	24	26.4	97	44.5	43	53.1
Subtotal	45	35.7	34	53.1	54	59.3	197	90.4	67	82.7
Vacation	-	-	1	1.6	-	-	-	-	-	-
Pleasure	1	0.8	2	3.1	3	3.3	4	1.8	3	3.7
Others (visit friends, etc.)	-	-	3	4.7	4	4.4	8	3.7	7	8.6
Subtotal	1	0.8	6	9.4	7	7.7	12	5.5	10	12.3
Total	126	100.0	64	100.0	91	100.0	218	100.0	81	99.9

TABLE 13

WEEKDAY VS WEEKEND AUTO-TRUCK TRIP PURPOSE PERCENTAGE DISTRIBUTION

	Trip Purpose by Percent of Total					
Destination Purpose	Allied Gardens			Clairemont		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
Work	15.6	7.9	5.7	16.3	9.5	5.2
Related Business	19.8	16.7	3.8	7.1	6.8	14.6
Subtotal	35.4	24.6	9.5	23.4	16.3	19.8
Medical and Dental	0.8	1.3	-	0.7	0.3	0.3
Shopping						
Convenience Goods	9.3	9.6	18.9	9.9	13.2	8.8
Shopping Goods	2.5	6.6	4.7	2.5	4.6	2.1
Total	11.8	16.2	23.6	12.4	17.8	10.9
Education, Civic and Religion	0.5	0.9	2.8	0.7	-	4.0
Eat Meal	2.0	3.5	4.7	2.7	4.0	1.4
Serve Passenger	11.6	11.4	8.5	13.6	13.2	11.2
Personal Business	6.4	7.9	3.8	6.6	7.4	6.0
Change Travel Mode	0.6	1.3	-	0.5	-	0.3
Home	26.0	23.3	28.3	31.7	30.7	30.4
Subtotal	59.7	65.8	71.7	68.9	73.4	64.5
Vacation	-	0.9	-	0.2	-	-
Pleasure	1.6	2.2	3.8	2.2	4.9	6.3
Others	3.2	6.6	15.1	5.2	5.5	9.5
Subtotal	4.8	9.7	18.9	7.6	10.4	15.8
Total	99.9	100.1	100.1	99.9	100.1	100.1

period and compares this to the 1952-53 O-D survey. Table 10 also shows the a. m. and p. m. peak period trip purpose in the two subdivisions. The data in Table 10 indicates a stability of the a. m. peak period work trip and the total of work and related business trips of the two study subdivisions. Figure 6 graphically presents a comparison of selected purposes. However, it should be borne carefully in mind that an orientation of the generated trips using a. m. peak period work trips would be based on a very weak percent of total 24-hr trips; even for areas as large as Allied Gardens and Clairemont. Tables 11 and 12 emphasize the trip purpose sample size problem. These tables indicate the destination purposes of trips reported for a typical weekday by residents for selected hours for Allied Gardens and Clairemont. Figure 7 summarizes the data contained in Tables 11 and 12.

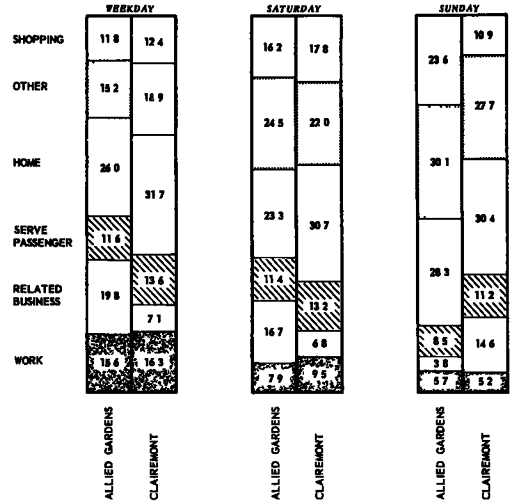

Figure 8. Weekday vs weekend auto-truck trip purpose percentage distribution.

Table 13 and Figure 8 compare the weekday and the weekend auto-truck trip purpose. Generally the expected daily trends are borne out, with shopping trips being highest on Saturday and work trips reducing on Saturday and reaching the lowest percent on Sunday. It is interesting to note, however, that there seems to be a considerable amount of shopping at Allied Gardens on Sunday as compared to Clairemont. This could possibly be due to sampling error.

The distribution or orientation of the generated trips is really the significant problem of forecasting future travel. The ability to determine a close approximation of the resident generated origins is within reach. The pattern of the Allied Gardens resident auto-truck desire lines is shown in Figure 9. These desire lines were plotted per thousand dwelling units in order to make them comparable to the Clairemont auto-truck pattern as well as the transit patterns. Figure 10 shows the Clairemont pattern of resident auto-truck desire lines per thousand dwelling units.

The orientation pattern is simply demonstrated by studying the straight line trip length distribution. The trip length distribution for the metropolitan area in 1952-53 is given in Figure 11. Figure 11 also includes the trip length distribution of all auto-truck trips with one end in Allied Gardens or Clairemont and for work trips with one end in the respective area. The close relationship between work trips generated in one area or the other and between all trips generated in the two study areas is quite encouraging. A study of these curves clearly indicates that there are fewer short all-purpose trips from outlying subdivisions than there are for the whole metropolitan area. The trip length distribution of the auto-truck trips with one end in the area comparing the convenience shopping to the shopping goods trips of Allied Gardens and Clairemont is shown in Figure 12. Again the trip purpose relationships between the two areas appear to be good.

The trip length cumulative curves developed in Figures 11 and 12 were drawn by connecting actual point plots. Smooth curve relationships can be interpreted from these data and are believed to exist. Certain characteristics of the presented trip length distribution curves appear to be satisfactorily explained by existing conditions and therefore data from additional areas will be required in order to develop these smooth curves. Figures 13 and 14 present the trip destination purpose family of curves of the major purposes selected for Allied Gardens and Clairemont respectively. Related business trips have been plotted as two curves for each area. One plots related business trips with one end in the area and the other plots trips with neither end

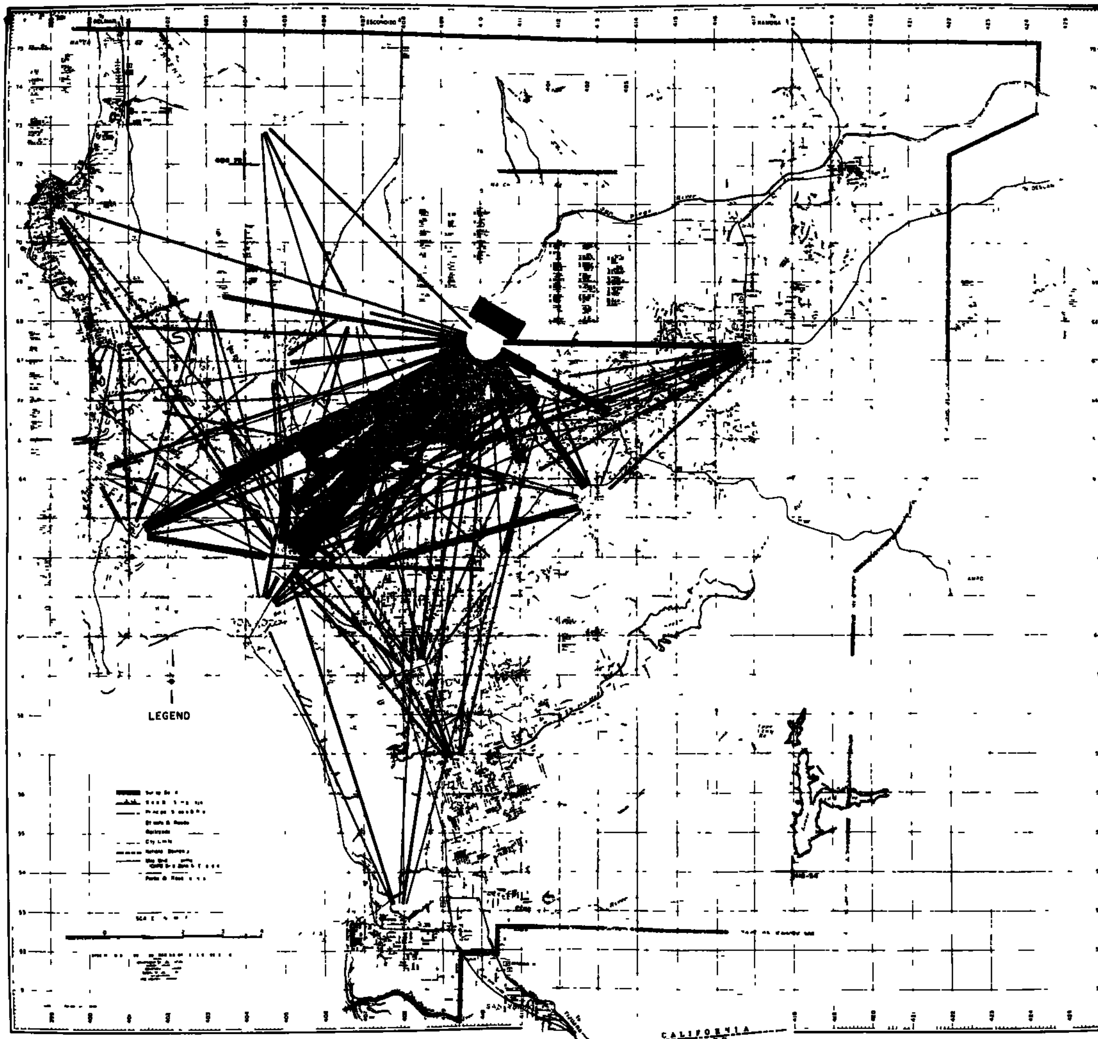

Figure 9. Allied Gardens auto and truck trip desire lines per 1,000 dwelling units, June-July 1956.

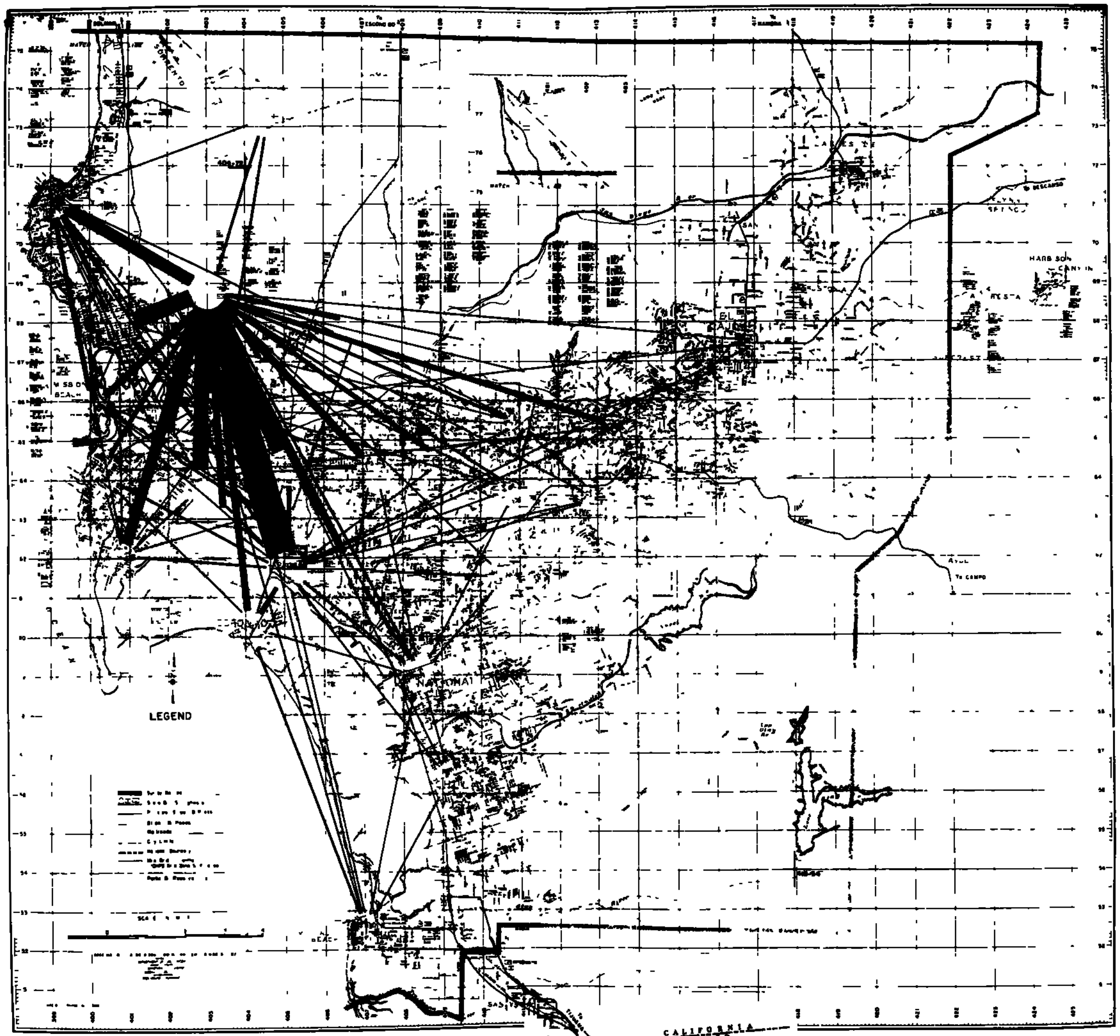

Figure 10. Clairemont auto and truck trip desire lines per 1,000 dwelling units, June-July 1956.

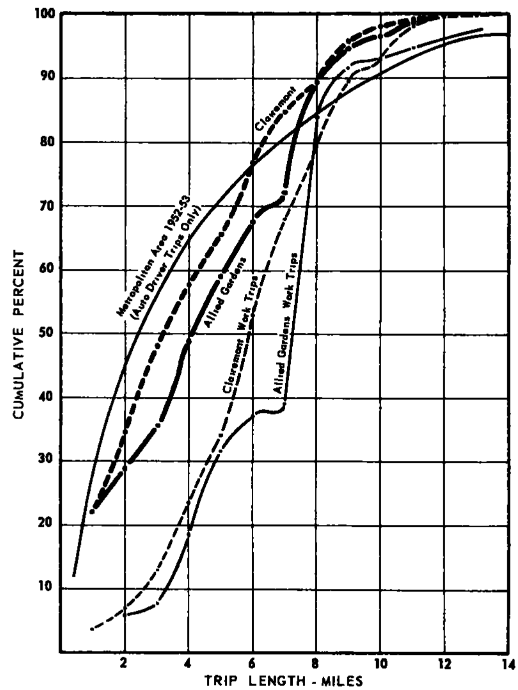

Figure 11. Cumulative percentage distribution of trip length.

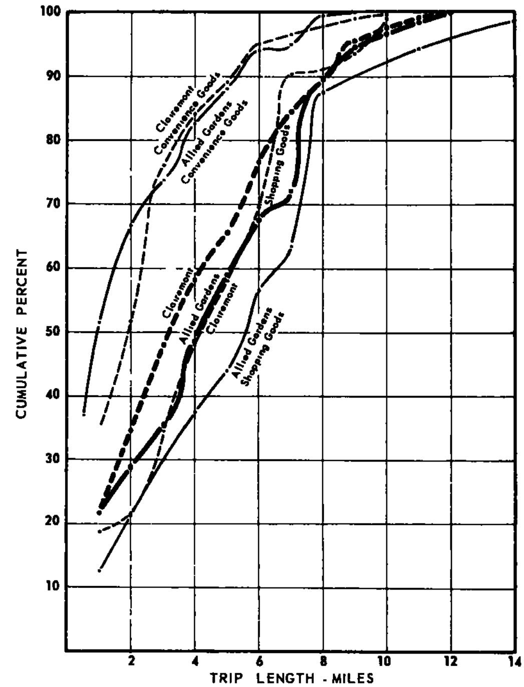

Figure 12. Cumulative percentage distribution of trip length.

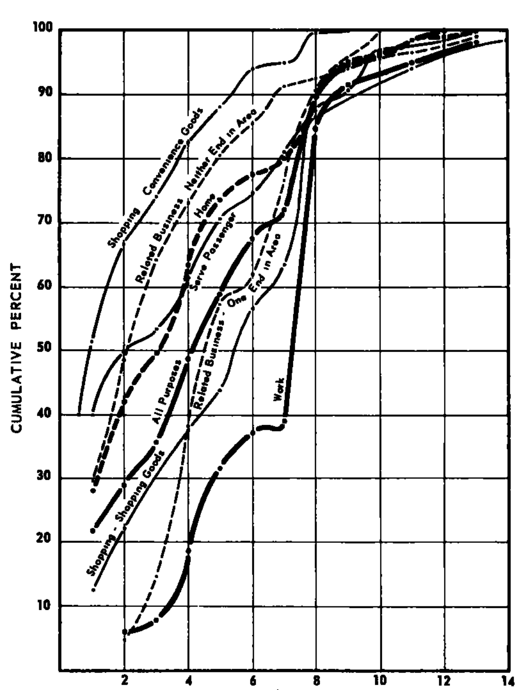

Figure 13. Cumulative trip length percentage distribution of selected destination purpose auto-truck trips, Allied Gardens.

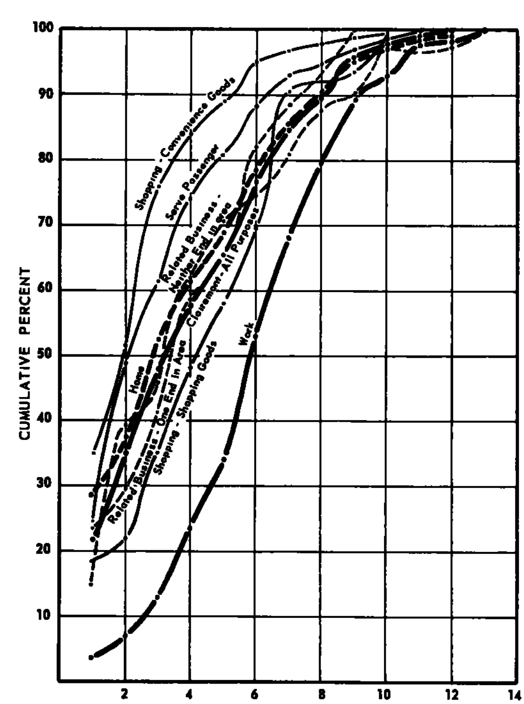

Figure 14. Cumulative trip length percentage distribution of selected destination purpose auto-truck trips, Clairemont.

in the study area. It is interesting to note that the related business trips form the only significant difference in the pattern of the two families of curves.

Southern California has developed in the age of the motor vehicle; consequently, primary attention is focused on the freeways and major streets and highways and their development. However, throughout the San Diego Metropolitan Area Transportation Study an effort has been made to keep the role of transit in proper perspective. Table 14 contains the weekday mode of travel distribution of the two study areas.

TABLE 14

WEEKDAY TRIP 24-HOUR VOLUME BY MODE

Mode of Travel	Allied Gardens		Clairemont	
	Number	Percent	Number	Percent
Auto-Truck Driver Trips	10,245	98.2	28,329	95.9
Bus Passenger Trips	202	1.8	1,206	4.1
Total Trips[a]	10,447	100.0	29,535	100.0

[a] Excludes auto-truck passenger trips.

Figure 15 presents the transit desire lines per thousand dwelling units for Allied Gardens and Clairemont. The desire lines clearly indicate some relation between the level of service and the use of transit exists. Clairemont has direct service to the major employment areas as well as downtown while Allied Gardens requires at least one transfer to reach similar destinations. Efforts are continuing to more empirically define the complex but important relationships between level of service and transit use. Figure 16 contains the trip length distribution of the metropolitan area 1952-53 mass

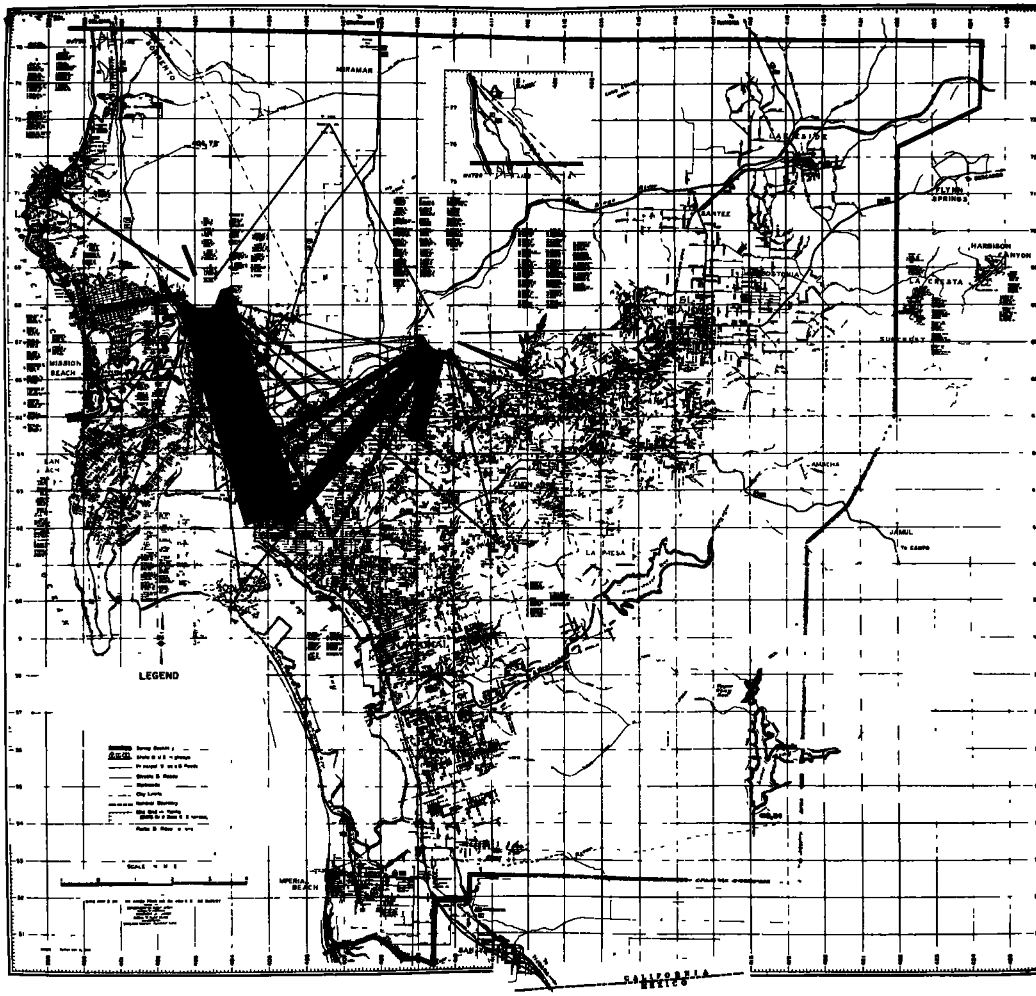

Figure 15. Outbound bus passenger desire lines per 1,000 dwelling units.

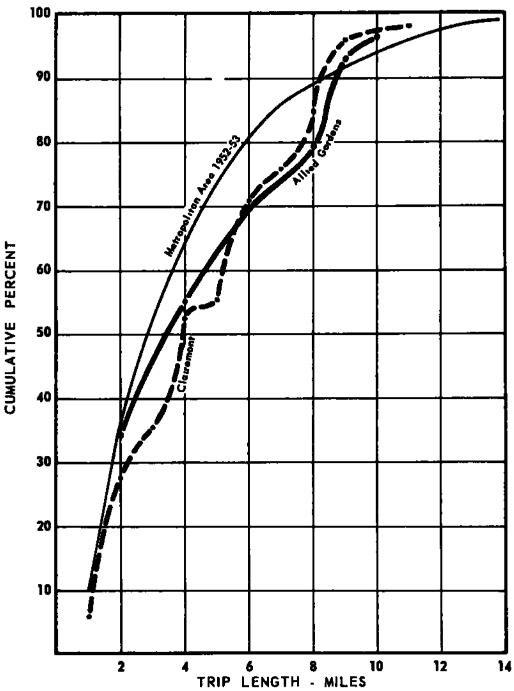

Figure 16. Cumulative percentage distribution of trip length, mass transit passengers.

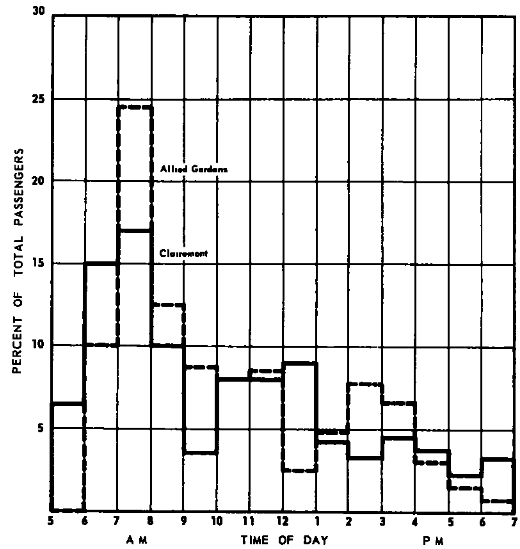

Figure 17. Percentage-time distribution of outbound bus passengers, two-day average, June-July 1956.

transit trips and the mass transit trips of Allied Gardens and Clairemont. The close relation of the trip length curves of the two study areas is the more interesting because of the wide variance in the transit level of service. The percentage time of day distribution of outbound bus passengers for the two study areas is compared in Figure 17.

Freeway usage by residents of the two subdivisions was coded during the interviews. Table 15 summarizes the actual freeway use and incorporates a further experiment in the accuracy of projecting from the a. m. peak hour volumes. The sample size, as well as the expansion factor, play an important part in the accuracy of the expansion.

TABLE 15

ACTUAL FREEWAY USAGE VS EXPANDED PEAK HOUR USAGE
ALLIED GARDENS-CLAIREMONT O-D SURVEY

Freeway-Expressway Section	A. M. Peak Hour Volume	Expanded 24-Hr Volume	Actual 24-Hr Volume	Percent Difference	Distance in Miles Centroid to Center	
					Allied Gardens	Clairemont
Pacific Highway (US 101) - US 80 to North City Limits	48	525	471	11.5	8	1
Mission Valley Road (US 80) - US 101 to US 395	27	295	279	5.7	6	4
Mission Valley Road (US 80) - US 395 to Fairmount	35	383	352	9.9	3	5
Alvarado Canyon Road (US 80) - Fairmount to Fletcher Parkway	32	350	359	- 2.5	1	8
El Cajon Boulevard (US 80) - Fletcher Parkway to Chase	3	33	34	3.1	4	12
Cabrillo Freeway (US 395) - Ash to US 80	21	230	229	0.4	6	5
Cabrillo Freeway (US 395) - US 80 to North City Limits	4	44	37	18.9	4	3
Wabash Avenue - Harbor to University	3	33	34	- 2.9	6	8
Montgomery Freeway (US 101) - 8th St., National City to Border	2	22	33	-33.3	10	12
Fletcher Parkway - US 80 to Lake Murray Blvd.	2	22	24	- 8.3	4	11
Total	105	1,937	1,850	4.7		

A third important variable, which relates to sample size, is the distance from the origin of the trip to the particular freeway or expressway section. Table 15 indicates that generally, freeway usage could be estimated with reasonable accuracy when expanding on the a.m. peak hour volume, particularly when the trip is under 5 or 6 miles in length.

SUMMARY

These studies of the travel characteristics of two San Diego subdivision developments have furnished accurate data on trip generation and dwelling unit origin generation. The trip generation data by type of dwelling unit appears to be significantly different and is helpful in developing trip origins. The trip origin calculation furnishes a sound basis for differentiating between the resident generated origins and the total auto-truck origins from all parts of the metropolitan area to be expected in a typical subdivision.

The general close similarity of the 24-hr trip destination purpose of the auto-truck trips between the metropolitan O-D study and the two specific study areas is encouraging and again suggests that consistent relationships between land use and trip generation do exist. The trip destination purpose analysis has given a clear 24-hr picture and an indication of the time profile of trip purpose to be expected. Trip purpose projections would appear to be generally on a weak statistical base, except for a.m. peak hour or peak period work trips or combined work and related business trips. This is particularly significant in view of the relatively large size of the two study developments. The trip length relation by trip purpose between the two study areas is borne out in several of the figures presented and is useful for the orientation of generated trips. Thus, it is concluded that there is a relationship between trip generation and orientation, and land use.

Several of the relationships developed from this intensive study of two subdivision developments in San Diego have been used in conjunction with the traffic generator study to make a forecast of future year origins in each of 234 traffic assignment zones within the metropolitan transportation study area. The development of future (horizon) year origins was based on the land use and population estimates of the city and county planning departments. The origins were summated by residential, commercial, industrial, major institutional, parks and recreational, and military uses. Future year trips for a population of 2.3 million are now being distributed over a study system of freeways, expressways, and major streets and highways by the California Division of Highways.

There is a need for further study to develop additional traffic generator data, particularly in the commercial and industrial uses. Much still must be done to develop empirical distribution relationships between land use and travel patterns in order to orient the generated trips. As the federal aid highway program reaches high gear it is particularly important to be able to apply soundly developed relationships between travel and land use to urban freeway and major street planning.

Factors Affecting Trip Generation of Residential Land-Use Areas

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The present and potential trip-generating power of urban residential areas can be estimated with a reasonable degree of accuracy, dependent upon the availability and reliability of certain related information.

The major factors affecting trips by residents of an area are population and automobile ownership. With data normally developed from a home-interview-type origin and destination survey it is possible either to up-date the resident trip information or, with slightly less reliability, to forecast the trips for some future date.

It was found that the total number of trip ends in a residential area is approximately equal to the number of trips made by residents of that area between all origins and destinations. Therefore, any methods for estimating residents trips are equally applicable to estimates of total trip ends on residential land. As a corollary, the number of trips to non-residential land in an urban area can be estimated if the number of trips made by residents of the entire urban area is known.

Generally, about 80 percent of all trips made by residents of a residential area begin or end at home. Also approximately 80 percent of the total trip ends on residential land, by residents and non-residents, are "home" oriented. These proportions are greater in areas where car ownership and economic status are lower, and where population density is higher. They do not vary appreciably with distance from the central business district.

These findings are all based upon analyses of data from the two home-interview-type origin and destination traffic surveys made in the Washington, D.C., metropolitan area in 1948 and 1955. All of the results pertain to the Washington area during the time interval studied, but it may reasonably be assumed that certain aspects of the findings and methodology will be applicable elsewhere.

● COMPREHENSIVE home-interview origin and destination studies have been made in well over 100 metropolitan areas. The existing pattern of travel by different means of transportation in these areas has been developed with considerable accuracy. This information has been invaluable in determining the present need for highways and transit facilities but, in itself, does not give the answer to future needs, which must be the basis for intelligent planning.

One of the basic keys to forecasting future transportation needs is the establishment of the relationships between travel and the type, intensity, and interrelationship of land uses. When these relationships have been established and trends observed, it will be possible to determine more accurately in advance the transportation needs that will exist when anticipated urban development has taken place.

Data from a number of surveys have been analyzed to develop factors for estimating the number of trips attracted to and generated by land-use developments of different kinds, size, and intensity. These related to specific places and times. Information on trends is comparatively meager, repeat studies having been completed in only a very few of the metropolitan areas. It has not, therefore, been possible to establish relations which will permit the accurate pre-determination of the number of trip ends to be expected in different areas under conditions anticipated for some time in the future, these being dependent upon the stability of a number of factors.

In 1948 a home-interview type of origin and destination survey was in the Washington, D.C., area. A repeat study was made in 1955. In the earlier survey a 5 percent sample was obtained by interviewing the residents of one of every 20 dwelling units. In the latter survey, the sample rate was 1 in 30 in the District of Columbia and 1 in 10 in the Maryland and Virginia suburban areas. These two surveys give a basis for a study of factors and trends relating to urban travel habits, and several research projects have been carried out with this objective.

This paper is concerned with the evaluation of methods for estimating the potential generation and production of person trips in urban residential developments. Another paper entitled "Evaluating Trip Forecasting Methods with an Electronic Computer" by Brokke and Mertz of the Bureau of Public Roads is concerned with the evaluation of methods of estimating the distribution of zone-to-zone trip movements resulting from zone growth.

There are many factors, other than size, that could be expected to affect the potential generation and production of person trips in urban residential developments. This report presents the results of an analysis of the effect that differences in population, car ownership, income per household, distance from the central business district, and population per net residential acre had on the number of person trips attracted to and generated by residential land. These factors were selected because it has been possible to establish measures that are free from personal bias and because it seems that they constitute a logical premise on which to begin an analysis of total trips generated by residential land-use areas.

Because the summarization of the 1955 data has not progressed far enough to permit a study by mode of travel, the current analysis is confined to total person trips by all modes of travel to and from residential land. It does not include pedestrian trips or trips by taxi and truck operators in the course of their daily work.

SOURCES OF INFORMATION

The trip data obtained from the Washington transportation surveys of 1948 and 1955 reflect total person trips for an average weekday of the respective survey periods. Data on population, car ownership, and distance from the central business district were also obtained from these surveys. The 1955 income information was obtained from the National Capital Regional Planning Council.

Residential acreage figures were developed jointly by the staffs of the Washington Metropolitan Area Transportation Study which made the 1955 survey and the National Capital Regional Planning Council. The figures developed were net residential acres. Streets and all non-residential land uses were excluded.

This report combines the results of a number of studies based upon travel data obtained from the two Washington transportation surveys. The basic data were summarized by groupings best suited for the objectives under consideration. For example, one very limited study utilized data for only 10 residential areas. A subsequent study was confined to the District of Columbia for which data on family income and population density were available by census tracts. Another study was based, in part, on the analysis of 118 subzones throughout the survey area that could be classed as purely residential and, in part, on 77 of the 118 subzones grouped into 48 residential areas each of which had 1,000 or more trip origins. Tests were also made using 56 of the 118 subzones grouped into 35 residential areas each of which had 2,000 or more trip origins. Finally, an analysis was made of trips by the residents of 200 zones selected so that data from the surveys would be comparable. These zones contained 96 percent of the population resident within the 1948 traffic study cordon and 93 percent of the persons living within the 1955 cordon.

FINDINGS

"Home" Trips as a Measure of Total Trip Ends on Residential Land

Any study of residential land-use trip generation must take into account the number of trip origins and trip destinations (trip ends) in a particular residential area, and the number of trips made by the residents of that area (trip production).

The present study of residential land-use trip generation and residents trip produc-

TABLE 1

RESIDENTS AVERAGE WEEKDAY TRIPS—WASHINGTON, D C, METROPOLITAN AREA, 1948

Residential Areas Studied	1 Massachusetts Avenue Park, D C	2 Wesley Heights and Spring Valley, D C	3 American University Park, D C	4 Beverly Hills, Braddock Heights, and Del Ray, Va	5 Fairlington and Parkfairfax, Va	6 Brightwood Area, D C	7 U. S. Soldiers' Home Area, D C	8 Shirley Homes, Va	9 Central City Area, D C	10 Southwest Area, D C	Totals: Selected areas	Totals: Metropolitan area
Location												
Travel distance from CBD, mi	3.29	5.29	5.71	7.43	6.86	5.29	2.71	5.71	1.14	1.14		
1950 average peak-hour driving time from CBD, min	12	16	18	17	15	18	12	13	6	7		
Residential Area Characteristics												
Predominant residence type	Single family detached	Single family detached	Single family detached [b]	Single family detached [b]	Garden type apartments	Two-family semi-detached and apartments	Multi-family apartments and row houses	Government low rent row houses [b]	Row houses	Single family detached and row houses		
Economic class [a]	Very high	Very high and upper high	High	Above average	Above average	Above average	Below average	Below average	Below average	Low and very low		
Dwelling units	158	712	2,375	1,426	4,826	2,497	2,101	1,352	3,270	6,596	25,313	336,181
Passenger cars owned	180	1,201	2,039	1,447	3,833	2,209	1,404	686	582	1,975	15,556	203,464
Population	518	2,896	7,975	5,176	15,658	9,354	6,913	4,805	10,977	28,657	92,929	1,109,860
Persons per dwelling unit	3.28	4.07	3.36	3.63	3.24	3.75	3.29	3.55	3.36	4.34	3.67	3.30
Passenger cars owned per dwelling unit	1.14	1.69	0.86	1.01	0.79	0.88	0.67	0.51	0.18	0.30	0.61	0.61
Auto driver trips per passenger car	2.55	3.83	4.20	4.84	4.63	3.77	2.67	4.21	1.95	1.98	3.75	3.10
Residents Trips per Dwelling Unit by Purpose—All Destinations—All Modes												
Work	1.02	2.42	1.32	1.49	1.36	1.95	1.62	1.06	1.23	1.21	1.40	1.32
Business	0.87	0.51	0.55	0.33	0.12	0.30	0.14	0.08	0.16	0.14	0.22	0.20
Medical and dental	-	0.07	0.06	0.03	0.10	0.06	0.09	0.03	0.04	0.03	0.06	0.05
School	0.15	0.36	0.25	0.34	0.33	0.24	0.12	0.09	0.03	0.08	0.17	0.12
Social and recreation	0.58	1.98	1.48	0.99	1.00	0.91	0.53	0.74	0.17	0.22	0.70	0.62
Change travel mode	0.58	0.20	0.08	0.11	0.09	0.15	0.01	0.06	0.01	0.003	0.06	0.07
Eat meal	0.15	0.48	0.13	0.13	0.15	0.18	0.10	0.11	0.01	0.02	0.10	0.09
Shop	0.58	0.82	0.75	0.93	0.90	0.80	0.28	0.63	0.08	0.11	0.50	0.33
Serve passenger	0.30	0.58	0.48	0.96	0.52	0.29	0.11	0.31	0.01	0.02	0.28	0.19
Home	2.17	4.60	3.23	3.31	2.97	2.75	2.45	2.12	1.54	1.59	2.40	2.13
Total trips	6.40	12.02	8.33	8.62	7.54	7.63	5.45	5.23	3.28	3.43	5.89	5.12
Residents Trips per Dwelling Unit by Mode of Travel—All Destinations												
Auto driver	2.90	6.45	3.60	4.91	3.68	3.34	1.78	2.14	0.35	0.59	2.31	1.88
Auto and taxi passenger	1.75	3.36	2.89	2.25	2.22	1.57	1.11	1.52	0.47	0.40	1.42	1.22
Total auto trips	4.65	9.81	6.49	7.16	5.90	4.91	2.89	3.66	0.82	0.99	3.73	3.10
Mass transit	1.75	2.21	1.84	1.46	1.64	2.72	2.56	1.57	2.46	2.44	2.16	2.02

Economic Class [a]	1949 Estimated Income
Very high	$10,200 and over
Upper high	8,500 - 10,199
High	6,800 - 8,499
Above average	5,100 - 6,799
Below average	3,825 - 5,099
Low	2,550 - 3,824
Very low	Under 2,550

[a] Source for District of Columbia Subdivisions Economic Development Department, Washington, D C, Board of Trade, June 1954
Virginia Subdivisions (4, 5, and 8) estimated on the basis of comparable rentals, housing values, and income, reported by 1950 Census of Population and Housing

[b] Includes small number of apartment units

tion was started several years ago with an analysis of relationships of residents trips and other factors in 10 areas of varying type and income, utilizing data from the 1948 Washington transportation survey and other sources (Table 1). It was initially apparent from the developed data that residents trip production generally increased with income, except for the highest income area. It was equally apparent that the number of residents total trips varied directly with the number of passenger cars owned per dwelling unit.

To establish the degree of reliability of these findings and to evaluate the contributing influence of these and other variables on residents trip production, a series of statistical analyses was undertaken, based on 95 census tracts in Washington, D.C. The results of these studies were valuable in that they established statistically the possibility of estimating with a relatively high degree of reliability residents daily trip production.

One of the most important by-products of the analysis of the 10 residential areas was the apparent value of the study as a means of estimating traffic growth for urban redevelopment projects. For example, Area 10, the southwest area of Washington, is such an urban redevelopment area. Redevelopment plans call for the construction of apartments and row houses in the residential portion of the area. If it is assumed that data developed for Area 7, an apartment and row house area, would be representative of the redevelopment area when completed, then auto trips per dwelling unit will increase three times, while transit travel will remain relatively constant. This general method of estimating trips to a given land use should be of value, particularly to the planning and design of redevelopment projects as related to improved highway facilities.

TABLE 2

BASIC DATA FOR 118 SELECTED RESIDENTIAL SUBZONES IN THE 1955 WASHINGTON, D.C., SURVEY AREA, GROUPED BY RINGS

Rings[a]	Number of							
	Subzones	Interviews	Persons	Dwelling Units	Cars	Net Residential Acres	Residents Trips[b]	Cars per 100 Persons
2	2	46	4,689	1,820	1,182	9.5	7,574	25.2
3	3	42	4,603	1,602	881	141.8	6,853	19.1
4	16	282	17,987	6,412	5,251	487.4	32,988	29.2
5	30	379	27,014	8,817	9,305	956.3	56,973	34.4
6	25	348	18,584	5,742	6,480	782.5	39,636	34.9
7	16	454	17,735	5,190	6,242	1,041.2	39,481	35.2
8	12	279	10,727	3,007	3,657	536.8	23,386	34.1
9	12	229	9,407	2,527	3,278	1,259.2	20,793	34.8
10	2	68	3,086	798	962	215.9	6,185	31.2
Total	118	2,127	113,832	35,915	37,238	5,430.6	233,869	32.7

[a] Distance of residence from the central business district (mi). None of the selected subzones were in Rings 1, 11, 12, or 13.
[b] On an average weekday in 1955.

TABLE 3

EFFECT OF DISTANCE FROM THE CENTRAL BUSINESS DISTRICT ON THE "FROM" PURPOSE DISTRIBUTION OF PERSON TRIPS ORIGINATING ON RESIDENTIAL LAND IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955[a]

Rings[b]	Distribution of Trips from[c]							
	Work (percent)	Personal Business (percent)	Serve Passenger (percent)	Change Mode of Travel (percent)	Social and Recreation (percent)	Medical, Dental, and Eat (percent)	Home (percent)	Total Number of Trips (= 100 percent)
2	2.2	1.0	2.6	0.7	5.4	-	88.1	3,672
3	4.5	4.2	2.1	-	1.5	-	87.7	3,610
4	8.2	2.0	4.4	0.5	4.8	0.6	79.5	16,598
5	4.5	2.0	5.0	0.3	7.5	0.7	80.0	28,076
6	5.8	1.3	4.7	1.5	4.6	1.3	80.8	19,684
7	4.8	2.7	4.7	0.7	5.4	0.8	80.9	18,854
8	3.8	2.0	5.3	1.0	4.8	0.3	82.8	11,263
9	5.6	2.4	4.4	0.4	5.3	0.3	81.6	9,812
10	2.8	3.9	6.1	-	0.5	0.9	85.8	2,550
Total	5.2	2.1	4.7	0.7	5.4	0.7	81.2	114,119

[a] Based on study of 118 selected residential subzones.
[b] Distance of residence from central business district (mi). None of the selected subzones were in Rings 1, 11, 12, or 13.
[c] Trips from shopping and school were not included, because they were probably the result of small amounts of non-residential land use.

The 10-area study provided an insight into residents total trip production, but as most of the areas studied included other than residential land uses, it was not possible from available data to determine definitely the actual trip generation of the residential land.

To provide accurate data for such an analysis, 118 purely residential subzones (unless otherwise specified, all subsequent references to residential areas refer to areas entirely residential) of the 1955 Washington transportation survey were selected. These subzones represented 7.6 percent of the total number of subzones in the survey area, and 113,832 persons, or 7.2 percent of the total area population, lived in these subzones. The basic data, including trip information, for these residential subzones were summarized by annular areas (rings) at varying distance from the central business district (Table 2).

In the home-interview surveys, trip purpose was designated as purpose "from" and purpose "to"; for example, from home to work and from work to shopping. For trips having one end in a given area, the number "from" a specific purpose generally equals the number "to" that purpose. For example, for each trip to work at a specific location, there is a corresponding trip from work. Correspondingly, there would be an equal number of trips "to home" as "from home" in the 118 residential subzones studied.

The average percentage trip-purpose distribution as affected by distance from the central business district is shown in Table 3. Trips from home constituted 81.2 percent of all the person trips with origins in the studied subzones, and consequently "home oriented" trips constituted the same percentage of all trips beginning and ending in these residential subzones. (From a study of trips to 210 residential blocks in the Detroit, Mich., area, it was found that 73.3 percent of the incoming trips were to home. From a study of trips to 35 residential zones in the 1948 Washington, D.C., survey area, it was found that 80 percent of all incoming trips were to home.) This is an average figure and does not reflect any variations which might be due to economic, geographic, and demographic factors.

The data in Table 3 also show that the percentage of trips which originated within these residential subzones "from home" did not vary appreciably as distance from the central business district increased. The higher percentage of "from home" trips shown for Rings 2, 3, and 10, compared to the other rings, may not be significant, as the number of interviews in these rings was comparatively small (Table 2). This variation from the pattern is reflected in the instability of trip purpose in these rings.

As distance from the central business district was not an influencing factor in the

TABLE 4

EFFECT OF FAMILY INCOME ON THE PURPOSE DISTRIBUTION OF PERSON TRIPS ORIGINATING ON RESIDENTIAL LAND IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955[a]

Income Group[b]	Distribution of Trips from							
	Work (percent)	Personal Business (percent)	Serve Passenger (percent)	Change Mode of Travel (percent)	Social and Recreation (percent)	Medical, Dental, and Eat (percent)	Home (percent)	Number of Trips (= 100 percent)
2	2.5	-	-	-	7.5	-	90.0	2,040
3	4.6	1.7	4.5	0.5	4.5	0.6	83.6	39,560
4	4.5	2.7	4.0	0.8	5.5	0.6	81.9	43,671
5	7.4	1.9	6.3	0.8	6.1	1.1	76.4	28,848
Total	5.2	2.1	4.7	0.7	5.4	0.7	81.2	114,119

[a] Based on study of 118 selected residential subzones.
[b] The assignment of an income group rating to each area was made by the National Capital Regional Planning Council. The assignment was based on an analysis of average (median) family incomes which were developed for each area with the aid of local planning commissions, using 1950 census data and income statistics reported by the Washington Evening Star Consumer Survey of 1955-1956. The groups are as follows:

Income Group	1955 Family Income	
1	$ 1 - 2,499	(None of the selected subzones were in this group.)
2	2,500 - 4,499	
3	4,500 - 6,999	
4	7,000 - 9,999	
5	10,000 - over	

proportion of residential-area trips having "home" as a trip purpose, an analysis was made of the effect of variation in family incomes on these "home" oriented trips. The results of grouping the 118 residential subzones into 5 categories of income are shown in Table 4. The data indicate that the percentage of total trips originating on residential land which were "from home" decreased as family income increased. Although a variety of inferences could be drawn from the data, including the apparent and reasonable increase in work opportunities at homes in the highest income group areas, there are several factors left unexplained by the data. A further classification of income of over $10,000 might help to clarify the trend.

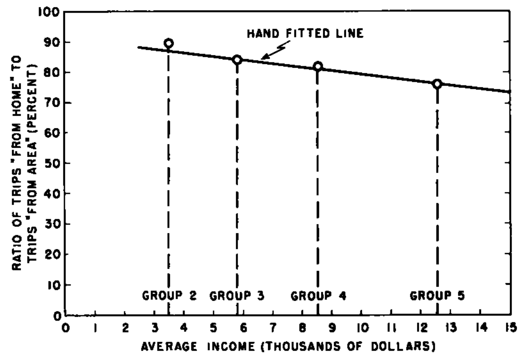

Figure 1. Income related to proportion of trip origins from home in 1955.

To obtain factors by which total trips originating in residential areas could be estimated, the proportion of trips "from home" to the total trips originating in the 118 residential subzones was plotted in relation to income (Fig. 1). By smoothing out the irregularities in the plotted data with a hand fitted line, the percentages of "from home" trips for each income group were slightly modified and expansion factors were developed as follows:

Income Group	Family Income	"From Home" Trips / Area Trip Origins	Trip Expansion Factors
	($1,000)	(percent)	(100.0/Column 3)
2	2.5 - 4.4	87.2	1.15
3	4.5 - 6.9	84.5	1.18
4	7.0 - 9.9	81.2	1.23
5	10.0 and over	76.4	1.31
Average		81.2	1.23

Prior to testing the adequacy of these trip expansion factors to duplicate total trips originating in the residential areas (from all purposes), those subzones which had less than 1,000 trip origins were eliminated, or where possible, combined, to provide greater stability to the data. This resulted in a total of 48 purely residential areas composed of 77 of the original 118 subzones, either individually or in combination, being used to test the above expansion factors.

The "from home" trips for each of the 48 areas were multiplied by (a) the applicable income group expansion factor and (b) by the average factor of 1.23, derived from the finding that an average of 81.2 percent of trip origins in residential areas were "from home" purpose. The results of these expansions compared to actual trip origins are shown in Table 5.

From a detailed study of data presented in Table 5, it appears that factoring by income groups improves the accuracy of estimating trip origins slightly over using an average factor. Two-thirds of the estimates were within ± 8 percent of the actual values when using income factors, as compared to ± 9 percent when using the average factor. The maximum error was + 19 percent when factored by income, and the maximum error was - 21 percent when using an over-all expansion factor. In appraising these results, it should be remembered that the comparisons were made for individual subzones, and that the basic trip data for any one subzone could have an appreciable error. Additional detailed study shows that the error decreases as trip volumes increase, when using either income factors or the average factor to expand "from home" trips.

From the foregoing, the conclusion may be drawn that if the number of "home" trips from any residential area is known, the total trips generated by that area can be estimated with an acceptable degree of reliability. Thus, trips generated by the residential land in any zone can be assigned to that land.

Now that trips can be assigned to residential land, it should be possible to relate these known values to the various characteristics of the residential area. It has been shown that the proportion of trips originating in residential areas that are "from home" tends to decrease as income increases. There are, however, other influencing factors which must be considered. To determine the effect that car ownership and population density had on the percentage of "from home" trips, correlations between each of the above independent variables and the percentage of "from home" trips were made for these same residential areas (Table 6). The results of these analyses are presented

TABLE 5

COMPARISON OF TOTAL NUMBER OF TRIPS ORIGINATING IN 48 RESIDENTIAL AREAS IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955 WITH THE NUMBER ESTIMATED BY APPLICATION OF FACTORS TO "FROM HOME" TRIPS

Subzones	Income Group[a]	From-Home Trips	Total Trips Originating in Area	From-Home Trips Times Income Group Factor[b]	Percent Difference	From-Home Trips Times Average Factor[c]	Percent Difference
4144	2	1,161	1,334	1,335	-	1,428	7
1712-3	3	1,238	1,787	1,461	-18	1,522	-15
3143	3	2,076	2,338	2,449	5	2,553	9
3312	3	931	1,069	1,098	3	1,145	7
4752	3	1,586	1,830	1,871	2	1,950	7
4861	3	1,238	1,427	1,461	2	1,522	7
5143	3	1,852	2,006	2,185	9	2,278	14
5314	3	1,795	2,393	2,118	-11	2,208	-8
5325	3	1,089	1,395	1,285	-8	1,339	-4
5653	3	1,389	1,581	1,639	4	1,708	8
5741	3	1,201	1,318	1,417	8	1,477	12
6353	3	1,780	2,107	2,100	-	2,189	4
6469	3	1,790	2,097	2,112	1	2,202	5
6611-2-3	3	3,017	3,475	3,560	2	3,711	7
7825	3	1,101	1,244	1,299	4	1,354	9
7872-4	3	1,369	1,638	1,615	-1	1,683	3
8732	3	2,497	3,106	2,946	-5	3,071	-1
1331	4	1,102	1,195	1,355	13	1,355	13
1622-3	4	2,774	3,143	3,412	8	3,412	8
2245	4	1,079	1,117	1,327	19	1,327	19
2325	4	785	1,022	965	-6	965	-6
2333-4	4	1,040	1,365	1,279	-6	1,279	-6
2622-3	4	2,473	2,955	3,042	19	3,042	19
2643	4	890	1,055	1,094	4	1,094	4
2872	4	1,431	1,730	1,760	2	1,760	2
3434-6-7	4	1,547	1,832	1,902	4	1,902	4
3444	4	1,217	1,493	1,497	-	1,497	-
3524-6	4	1,890	2,325	2,325	-	2,325	-
3581-2	4	1,196	1,736	1,471	-15	1,471	-15
6476	4	1,194	1,487	1,468	-1	1,468	-1
7311-3	4	2,649	3,111	3,258	5	3,258	5
7452	4	1,265	1,403	1,556	11	1,556	11
7842-6-7	4	2,784	3,614	3,424	-5	3,424	-5
7911	4	784	1,098	964	-12	964	-12
8242-3	4	3,605	4,277	4,434	4	4,434	4
8426	4	913	1,247	1,122	-10	1,122	-10
1164	5	1,730	2,690	2,266	-16	2,127	-21
1322-3-5	5	1,737	2,146	2,275	6	2,136	1
2341-2-3	5	1,578	2,280	2,067	-9	1,941	-15
2421-5-7	5	1,822	2,551	2,387	-6	2,241	-12
2512	5	1,248	1,736	1,634	-6	1,535	-12
2521-2-3-5-6-7-8	5	3,077	3,900	4,031	3	3,785	-3
2531-5-6	5	1,997	2,465	2,616	6	2,456	-
2613	5	1,019	1,136	1,334	17	1,253	10
2732	5	714	1,098	935	-15	878	-20
2743	5	1,597	2,128	2,092	-2	1,964	-8
2851	5	1,241	1,411	1,625	15	1,526	8
8343	5	984	1,431	1,289	-10	1,210	-15

[a] See Footnote b on Table 4.

[b] Factor to expand home trips to total trips for each income group:

Income Group	Factor
2	1.15
3	1.18
4	1.23
5	1.31

[c] Average factor to expand home trips to total trips = 1.23.

TABLE 6

RESIDENTIAL CHARACTERISTICS OF 48 SELECTED RESIDENTIAL AREAS IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955

Subzones	Cars per 100 Persons (number)	Persons per Residential Acre (number)	Trips from Home/Trips from Area (percent)	Trips to and from Home/Trips by Residents (percent)	Trips per Resident (number)
3434-6-7	14	81	84	92	1.2
3312	17	86	87	93	1.8
4144	20	184	87	94	1.0
5143	21	144	92	95	1.3
6353	23	97	84	84	1.5
3444	26	92	82	95	1.5
2421-5-7	27	21	71	78	1.9
5314	27	73	75	80	1.6
5325	27	52	78	91	1.5
5741	27	26	91	81	1.9
2512	29	49	72	76	2.5
5653	29	24	88	86	1.5
2245	30	45	97	82	2.5
6611-2-3	30	30	87	80	1.7
7825	30	61	88	93	1.8
8242-3	30	23	84	72	2 6
3143	31	286	89	81	2.2
4752	31	32	87	83	2.3
8426	31	13	73	81	2.0
3524-6	32	77	81	79	1.6
7872-4	32	11	84	82	2.2
8732	32	5	80	79	2.3
4861	33	50	87	88	1.6
6476	33	64	80	68	2.4
7311-3	33	28	85	55	2.7
1164	34	38	64	82	2.0
1622-3	34	14	88	82	2.5
2613	34	16	90	82	2.3
2872	34	12	83	71	1.9
6469	34	57	85	69	2.5
7452	34	64	90	94	1.8
2743	35	18	75	80	2.8
1712-3	36	12	69	76	2.8
2341-2-3	36	27	69	77	2.0
1331	37	29	92	68	2.8
2333-4	37	31	76	73	2.6
2643	37	31	84	78	2.2
2851	37	5	88	74	2.5
3581-2	37	29	69	80	2.0
8343	41	21	69	80	2.4
2521-2-3-5-6-7-8	42	20	79	74	3.2
2531-5-6	42	33	81	82	2.6
7842-6-7	42	17	77	89	2.1
7911	42	8	71	76	2.2
2325	45	45	77	88	2.9
1322-3-5	46	10	81	78	2.7
2622-3	46	65	84	80	2.4
2732	49	14	65	70	2.7

in Figures 2 and 3. Regression equations were fitted to the points by the method of least squares. Although these points do not exhibit a marked trend, especially those in Figure 3, related studies have shown a measurable relationship between trips and both car ownership and population density. It is believed that the sampling variability may have somewhat obscured the relationships in this case, but that these relationships should not be ignored.

Since for a given area the trips "to home" are generally about equal to the trips "from home," then 81.2 percent of all trips to and from the selected residential areas are "home" oriented. In effect, this means that on an average 81.2 percent of all trips to and from residential areas in the Washington area are made by the residents of those areas. The percentage varies with income, car ownership, and population density.

In summary, the total number of trip ends in any residential area can be determined, if the number of trips "to home" and "from home" is known, by expanding the "home" trip volumes by income, car ownership, or population density factors. An attempt will now be made to develop methods for estimating trip ends on residential land from a knowledge of total residents trips to all origins and destinations.

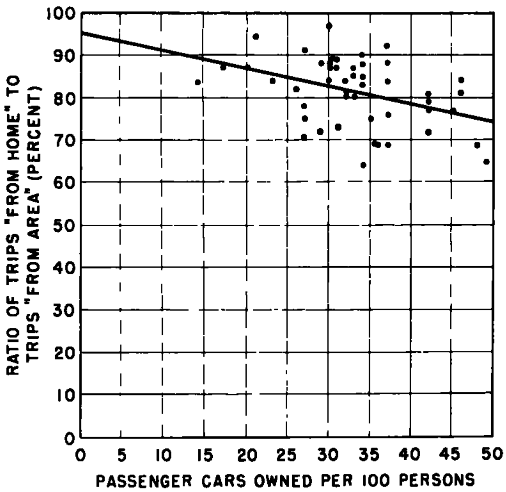

Figure 2. Car ownership related to proportion of trip origins from home in 1955.

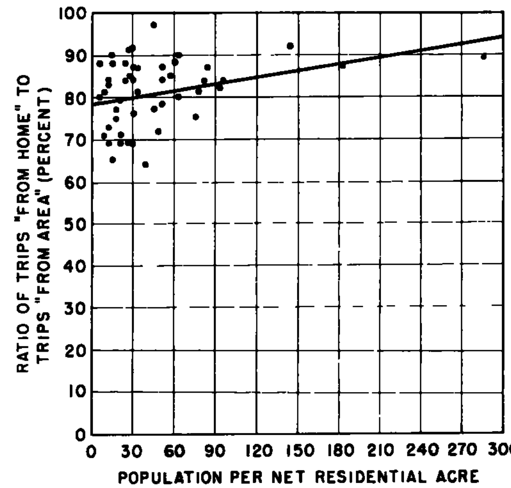

Figure 3. Population density related to proportion of trip origins from home in 1955.

Residents Trips Between All Origins and Destinations as a Measure of Total Trip Ends on Residential Land

An analysis of the data developed by the Washington transportation studies of 1948 and 1955 showed that 84 percent of all the residents internal area trips began or ended "at home" in each of the two years studied. (A study of travel patterns in 50 cities showed that an average of 82 percent of the total trips by residents had either their origin or destination at home. The range was from about 70 to 92 percent.) The percentages of residents trips which were made to and from home were computed for 48 selected purely residential areas (Table 6). Table 7 presents the percentages for 118 subzones grouped by income and distance from the central business district. Correlations were made between these percentages and the previously mentioned independent variables. The results of these analyses are presented in Figures 4 through 6, and show that the percentage of residents trips that started or ended at home tends to decrease as either income or car ownership increases, but appears to increase as population density increases. These patterns, it should be noted, have approximately the same relationship that the percentage of "from home" trips to total trips originating in a residential area had to the variables.

It may be concluded, therefore, that the ratio of "home" trips to total residents trips is related to the ratio of "home" trips to total trip ends. It follows then that the total number of trips by the residents of an area should be a useful index for estimating the total number of trip ends attributable to the residential land use in that area, by both residents and non-residents.

The factors to convert residents trips to residential land-use trip ends were

TABLE 7

EFFECT OF FAMILY INCOME AND DISTANCE FROM THE CENTRAL BUSINESS DISTRICT ON THE PERCENTAGE OF RESIDENTS TRIPS THAT WERE TO AND FROM HOME IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955[a]

Variables	Number of Trips		Percent of Residents Trips to and from Home
	To and from Home	By Residents	
Income Group[b]			
2	3,670	4,071	90.1
3	66,138	82,212	80.4
4	71,558	90,280	79.3
5	44,082	57,306	76.9
Ring[c]			
2	6,474	7,574	85.5
3	6,334	6,853	92.4
4	26,398	32,988	80.0
5	44,898	56,973	78.8
6	31,794	39,636	80.2
7	30,492	39,481	77.2
8	18,662	23,386	79.8
9	16,022	20,793	77.1
10	4,374	6,185	70.7
Total	185,448	233,869	79.3

[a] Based on study of 118 selected residential subzones.
[b] See Footnote b on Table 4.
[c] Distance of residence from central business district (miles). None of the selected subzones were in Rings 1, 11, 12 or 13.

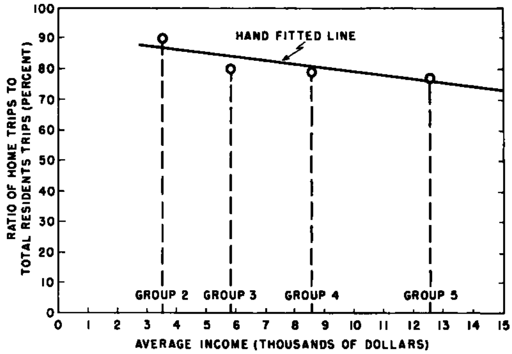

Figure 4. Income related to proportion of residents trips both to and from home in 1955.

developed for each of the selected independent variables (Table 8). As these conversion factors do not vary appreciably with any of the independent variables, a conversion factor of 1.0 was used. As previously indicated, this means that the total number of trip ends in a residential area is equal to the total number of trips made by the residents of the area between all origins and destinations.

The number of trip ends were then estimated from residents trips, using the factor of 1.0, and compared with the actual number of trip ends, as determined from the transportation survey, in 35 purely residential areas which had 2,000 or more trip ends and in which residents of 20 or more sample dwelling units were interviewed (Table 9). This comparison shows that in 3 out of 4 cases, the estimated number of trip ends was within 10 percent of the survey results. Part of the error that does exist is undoubtedly due to the small size of the areas studied, and part is due to the use of only one conversion factor.

It may be concluded, therefore, that the total number of trip ends attributable to the residential land use in an area can be estimated with an acceptable degree of accuracy from the total number of trips made by the residents of that area. The problem now is how best to determine residents trips.

Residents Trip Production. A previous analysis based on travel data obtained from the 1948 Washington metropolitan transportation study determined the influencing effect of each of four variables, individually and combined, on the number of trips made by the residents of 95 census tracts in the District of Columbia.[1] These variables were distance from the central business district, income, car ownership, and population density. A technique known as "analysis or partition of the variance" was employed to estimate the significance of each of the independent variables. It was established in

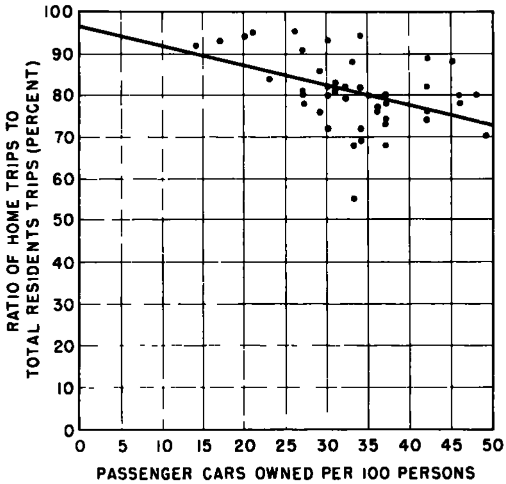

Figure 5. Car ownership related to proportion of residents trips both to and from home in 1955.

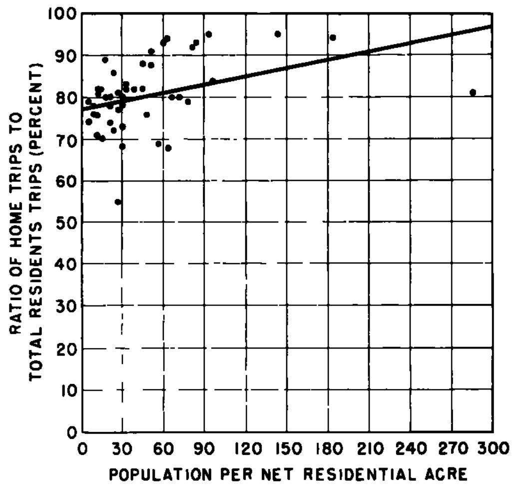

Figure 6. Population density related to proportion of residents trips both to and from home in 1955.

[1] Mertz, William L., and Hamner, Lamelle B., "A Study of Factors Related to Urban Travel." Public Roads, Vol. 29, No. 7 (April 1957).

TABLE 8

CONVERSION FACTORS FOR ESTIMATING TOTAL NUMBER OF TRIP ENDS IN RESIDENTIAL AREAS IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955

Independent Variables	Trip Ends at Home as a Percentage of Total Trip Ends in an Area (percent)	Residents Trips to and from Home as as Percentage of Their Total Trips (percent)	Factors to Convert Total Residents Trips to Total Trip Ends in a Residential Area (factor)
Rings[a]			
2	88.1	85.5	0.97
3	87.7	92.4	1.05
4	79.5	80.0	1.01
5	80.0	78.8	0.98
6	80.8	80 2	0.99
7	80.9	77.2	0.95
8	82.8	79.8	0.96
9	81.6	77 1	0.94
10	85.8	70.7	0.82
Income Group[b]			
2	90.0	90.1	1.00
3	83.6	80.4	0.96
4	81.9	79 3	0.97
5	76.4	76 9	1.01
Car Ownership[c]			
5	92.6	93.7	1.01
10	90.6	91 4	1.01
15	88.6	89.1	1.01
20	86.5	86.7	1.00
25	84.5	84.4	1.00
30	82.5	82.1	1.00
35	80.4	79.8	0.99
40	78.4	77.4	0 99
45	76 4	75.1	0.98
50	74.4	72.8	0.98
Population Density[d]			
30	80 3	79 5	0 99
60	81 8	81.4	1.00
90	83 3	83.3	1.00
120	84.7	85.2	1.01
150	86 2	87.1	1.01
180	87 7	89.0	1.01
210	89.9	90 9	1.02
240	90 6	92 8	1.02
270	92 1	94.7	1.03
300	93 6	96 5	1.03

[a] Distance from the central business district (miles). None of the selected subzones were in Rings 1, 11, 12, or 13

[b] See Footnote b in Table 3

[c] Passenger cars owned per 100 persons

[d] Persons per residential acre.

this study that the use of all four variables combined did not significantly increase the accuracy of predicting trips over that which was obtained using only automobile ownership and population density combined. Furthermore, automobile ownership was found to be the most reliable single predictor with very little additional accuracy gained by combining it with population density.

Assuming that car ownership remained the most reliable single indicator of residents trips, the 1955 data on trips per person were correlated with cars owned per 100 persons to determine an estimating equation for residents total trips. Total residents trip production and information concerning car ownership are obtainable for any area where a home-interview traffic study has been made and not just those areas which are purely residential. This correlation was based on 200 areas or "zones" for which the required information was available from both the 1948 and 1955 Washington surveys. The estimating regression equation was $Y = 0.6 + 0.04\ X$, where Y equals trips per person, and X equals passenger cars owned per 100 persons. The correlation coefficient is +0.71 and the standard error of estimate is 0.39 trips per person.

Using the above equation and the conversion factor developed in a previous section of this report (residents trips/trip ends = 1.0), the residents trips and, consequently, the residential trip ends were estimated for each of the 35 residential areas listed in Table 9. The estimated trip ends were compared with the actual survey values to test the accuracy for prediction purposes. Twenty-five, or 71 percent of the estimates were within ± 15 percent of the actual survey values and 88 percent were within ± 25 percent. The average error was 14.5 percent.

An intensive study of those areas with an extremely high percent of error might result in a reasonable explanation of the differences. Once again, it should be remembered that these comparisons refer to relatively small areas and the so-called actual number of residents trips is subject to error due to sample variability inherent in the basic survey.

Therefore, it is also possible to estimate, with a fair degree of accuracy, the trip ends of the residential portion of an area if the population and car ownership for that area are known. It must be pointed out, however, that these estimates are based upon a particular over-all citywide relationship between residents trips per person and car ownership.

Residents Trips as a Measure of Non-Residential Trip Ends. If, as has been shown, the number of residents trips provides a useful basis for estimating total trip ends in residential areas, it is reasonable to test its application as a measure of non-residential trip ends. Obviously, the difference betweeen total trip ends in an urban area and trip ends on residential land could be assigned to non-residential land. But, it has not been practicable to isolate each parcel of residential land to determine the trips generated thereby.

However, in this study the total number of home trips is known, and these must have been generated by residential land. It can be assumed then, that these "home" trips will represent the same proportion of total trips to all residential land as the "home" trips in the 118 selected (purely residential) subzones are to the total trips destined to these areas. In this manner, it was found that 19 percent of the trips destined to residential land were other than "to home." Also, since 58 percent of all trips in the metropolitan area were for other than "to home" purposes, it follows that 19 percent of 58 or 11 percent of all trips are generated by residential land for a purpose other than "to home." This means a total of 53 percent (42 + 11) of all trip ends are on residential land and the remaining 47 percent are on non-residential types of land. A comparison of these results with the 1948 Washington data and with that for 50 cities, similarly developed, and with data from Detroit gave the following percentage distribution of internal trip ends by land use:

Land Use	Washington Study Area		Detroit, Mich.	50 Cities
	1948	1955		
Residential				
Home	42	42	39	41
Other	11	11	14	11
Non-Residential	47	47	47	48
Total	100	100	100	100

Stability of the Relationship Between Residents Trips per Person and Car Ownership. To determine the stability of the relationship between residents trips per person and car ownership, an additional correlation between the two variables was made for the same 200 areas using data developed from the 1948 Washington area transportation survey (Fig. 8). A com-

TABLE 9

COMPARISON OF ESTIMATED TRIP ENDS AND ACTUAL TRIP ENDS IN 35 RESIDENTIAL AREAS IN THE WASHINGTON, D.C., SURVEY AREA ON AN AVERAGE WEEKDAY IN 1955

Subzones	Number of: Miles from the Central Business District	Home Interviews	Estimated Trip Ends[a]	Actual Trip Ends[b]	Percent Difference
3134	2	29	5,106	4,676	9.2
5143	3	24	3,903	4,012	-2.7
1164	4	31	4,220	5,380	-21.6
2421-5-7	4	25	4,650	5,102	-8.8
3434-6-7	4	24	3,359	3,664	-8.3
5314	4	30	4,468	4,786	-6.6
7311-3	4	124	6,365	6,222	2.3
3524-6	5	26	4,779	4,650	2.8
6353	5	20	4,234	4,214	0.5
6469	5	21	5,174	4,194	23.4
7825	5	55	2,367	2,488	-4 9
7842-6-7	5	96	6,248	7,228	-13.6
2512	6	20	3,297	3,472	-5.0
2521-2-3-5-6-7-8	6	25	8,300	7,800	6.4
2613	6	30	2,485	2,272	9.4
6611-2-3	6	107	7,578	6,950	9.0
7452	6	47	2,689	2,806	-4.2
8343	6	24	2,460	2,862	-14.0
1622-3	7	60	6,770	6,286	7 7
2622-3	7	104	6,177	5,910	4.5
2732	7	21	2,037	2,196	-7.2
2743	7	39	3,996	4,256	-6.1
7872-4	7	37	3,350	3,276	2.2
8242-3	7	86	10,024	8,554	17.2
8426	7	26	2,244	2,494	-10 0
1712-3	8	31	3,253	3,574	-9.0
2643	8	32	2,290	2,110	8.5
4752	8	37	3,807	3,660	4.0
4861	8	45	2,824	2,854	-1.0
5741	8	32	2,965	2,636	12.5
2851	9	33	3,355	2,822	18.9
5653	9	48	3,242	3,162	2.5
7911	9	22	2,060	2,196	-6 2
8732	9	67	6,347	6,212	2.2
2872	10	48	4,041	3,460	16.8

[a] Estimated trip ends = residents trips times 1.

[b] As determined by 1955 survey study.

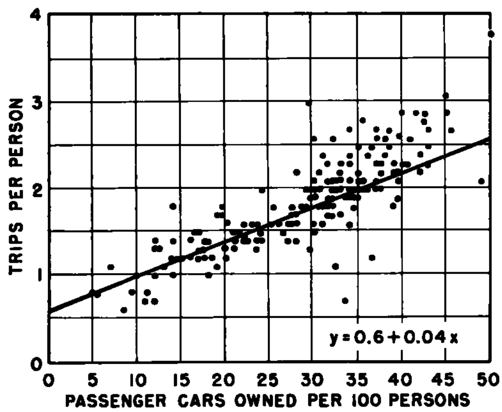

Figure 7. Trips per person related to car ownership in 1955.

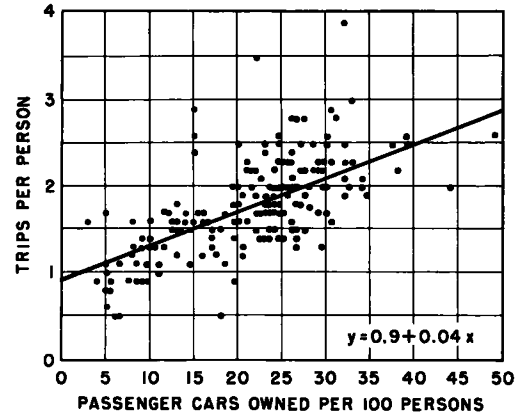

Figure 8. Trips per person related to car ownership in 1948.

parison of the regression line in this figure and the regression line based on 1955 data (Fig. 7) is shown in Figure 9. A study of these two lines indicates that the relationship between trips and car ownership has not been stable, but has experienced a measurable shift during the 7-yr period. The only difference between the two lines is the value of the constant (0.9 for 1948 and 0.6 for 1955) where the regression line intersects the Y axis. Statistical tests ("t") showed that the difference between these two constants was highly significant and could not be accounted for by sampling variability. Measures obtained from the analyses are as follows:

Year	Correlation Coefficient	Standard Error of Estimate (trips per person)	Average Trips per Person ($\bar{y}$)	Average Car Ownership ($\bar{x}$) = cars per 100 persons	Estimating Equations
1948	+0.67	0.41	1.7	21.2	Y = 0.9 + 0.04X
1955	+0.71	0.39	1.8	28.7	Y = 0.6 + 0.04X

Further analysis of the characteristics and relationship of the regression lines gives an insight into the reasons for the shift. The fact that the slope of the regression lines (0.04) remained the same during the interval between the study periods is of particular importance. Equally important is the fact that, although the average car ownership increased from 21.2 to 28.7 cars per 100 persons, an increase of 35 percent, the average number of trips per person remained relatively constant. The explanation, therefore, for the shift in the regression lines appears to be the increase in car ownership. This, in effect, means that during the 7-yr interval the numerical relationship between the two variables changed due to the increase in car ownership in 1955, but the relative association between the two variables, as indicated by the correlation coefficients, remained almost constant.

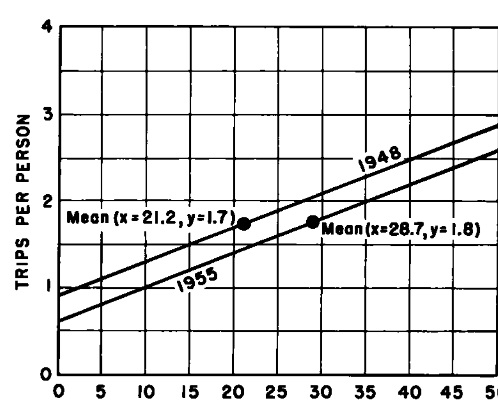

Figure 9. Comparison of the relationships between trips per person and car ownership in 1948 and 1955.

If these relationships are valid and the

TABLE 10

INDICES FOR ESTIMATING THE TOTAL NUMBER OF TRIPS TO AND FROM RESIDENTIAL SUBDIVISIONS OF THE WASHINGTON, D.C., SURVEY AREA[a]

In Each Subdivision of Area	Number of Passenger Cars Owned per 100 Persons — In Entire Survey Area										
	20	21	22	23	24	25	26	27	28	29	30
	Trips per Person										
5	1.20	1.16	1.12	1.08	1.04	1.00	0.96	0.92	0.88	0.84	0.80
10	1.40	1.36	1.32	1.28	1.24	1.20	1.16	1.12	1.08	1.04	1.00
15	1.60	1.56	1.52	1.48	1.44	1.40	1.36	1.32	1.28	1.24	1.20
20	1.80	1.76	1.72	1.68	1.64	1.60	1.56	1.52	1.48	1.44	1.40
25	2.00	1.96	1.92	1.88	1.84	1.80	1.76	1.72	1.68	1.64	1.60
30	2.20	2.16	2.12	2.08	2.04	2.00	1.96	1.92	1.88	1.84	1.80
35	2.40	2.36	2.32	2.28	2.24	2.20	2.16	2.12	2.08	2.04	2.00
40	2.60	2.56	2.52	2.48	2.44	2.40	2.36	2.32	2.28	2.24	2.20
45	2.80	2.76	2.72	2.68	2.64	2.60	2.56	2.52	2.48	2.44	2.40
50	3.00	2.96	2.92	2.88	2.84	2.80	2.76	2.72	2.68	2.64	2.60

[a] Determined from correlation of trips per person and car ownership in the Washington, D.C., survey area—1948 and 1955. To compute trips multiply population of each subdivision by appropriate index.

trend is assumed to be consistent in the future, then it should be possible to forecast residents trip production and residential land-use trip generation in the Washington area for any future year, provided that population and car ownership for that year are known or can be accurately forecasted. In fact, estimates could be readily obtained from the indices developed in Table 10, which may be taken from a family of regression curves assuming a constant average trips per person and a uniform slope, similar to those in Figure 9. The use of this table would require estimates of the citywide average car ownership for the future year plus estimates of car ownership for each zone or area for which potential trip data are desired.

Residents trip production for 1955 for each of the previously mentioned 200 areas was estimated by the indices in Table 10. The estimated trips were correlated with the actual trips as found in the survey (Fig. 10). It is readily apparent that the degree of association between the estimated and actual trips is very high. The square of the correlation coefficient (+ 0.98) indicates that the change in car ownership and change in population over the 7-yr period explained 96 percent of the variation in trip production (residents trips) and residential land trip generation for 1955. Two-thirds of the estimated values were within ± 15 percent of the survey results.

In the event car-ownership data are not available or are too difficult to develop, one

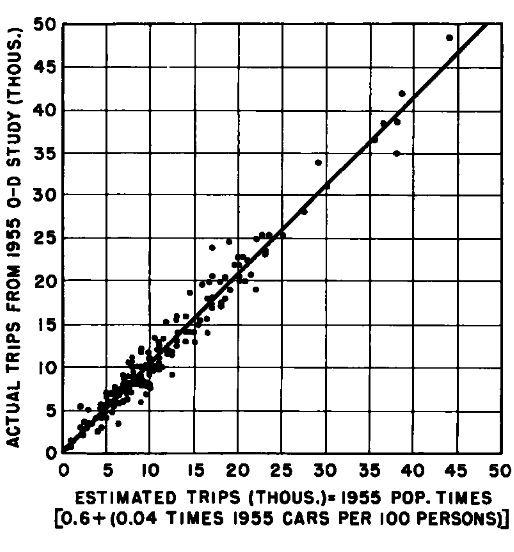

Figure 10. Actual trips related to trips estimated from relationship between trips per person and car ownership.

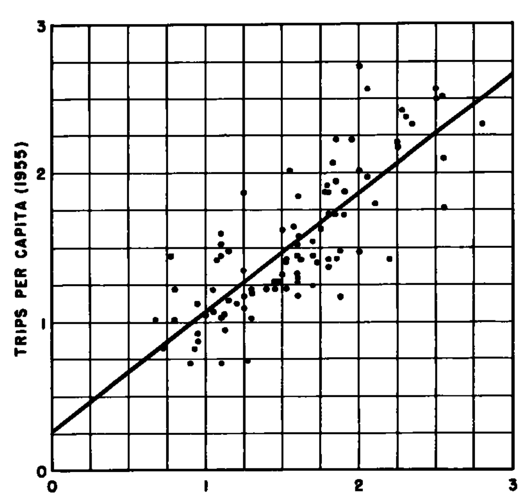

Figure 11. Trips per capita in 1955 related to trips per capita in 1948.

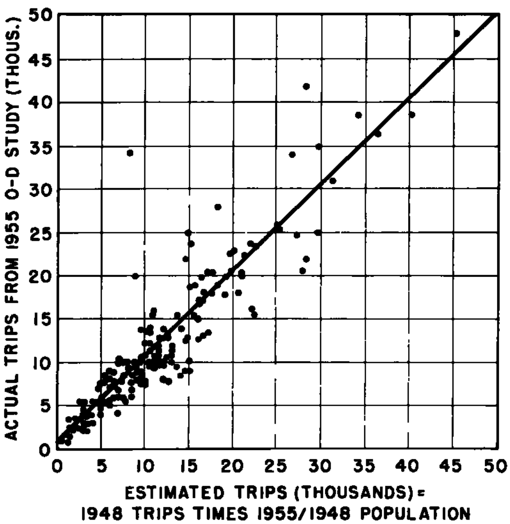

Figure 12. Actual trips related to trips estimated from change in population.

or more of the other previously mentioned independent variables could be substituted for car ownership with, of course, a probable decrease in predictability.[2]

Stability of Residents Daily Trip Production. To forecast accurately residents trip production and residential area trip generation by the method just described would require accurate estimates of population, as well as one or more factors related to trip production and generation, such as auto ownership and income, for each zone or area for which trip forecasts are desired. Admittedly, this process could prove to be more difficult and results perhaps not as satisfactory as those obtained from estimates derived from only one independent variable.

The previous comparison between 1948 and 1955 data showed that the average trips per person remained almost constant during the 7-yr period. Assuming that this consistency is not just a happy balance of plus and minus values, but rather the result of a consistency in the individual figures which comprise this average, then a second and easier method for projecting trip production and residential land trip generation to future years will be available.

To test this consistency or stability of residents daily trip production, trips per person in 1948 were compared to trips per person in 1955 for 95 census tracts in the District of Columbia (Fig. 11). The correlation coefficient is + 0.80. This means that the same factors that affected persons trips in 1948 were still applicable in 1955. Therefore, it can tentatively be assumed that residents trip production in any desired area for which prior survey results are available can be forecasted by multiplying trips per person for the base year by population of the area for any future year.

Residents trips for 1955 for each of the previously mentioned 200 areas were estimated in this manner, using 1948 trip data as the base. A comparison between the estimated and actual survey values is shown in Figure 12. The results of this analysis show that two-thirds of the estimated values were within ± 25 percent of the actual values (see Method 2 in Table 11) and the correlation coefficient was + 0.94. In other words, this means that the change in population alone was 88 percent effective in explaining the 1955 residents trip production and, consequently, residential land-use trip generation.

Increase in Cars Owned as an Indicator of Potential Trips. To measure the effect of cars owned, alone, as a predicting

TABLE 11

COMPARISON OF THREE METHODS FOR ESTIMATING 1955 RESIDENTS TRIPS FOR 200 AREAS IN THE WASHINGTON, D.C., SURVEY AREA

Maximum Error (percent)	Methods of Estimating		
	Method 1[a]	Method 2[b]	Method 3[c]
±	(percent of estimates)	(percent of estimates)	(percent of estimates)
5	30.9	18.5	7.8
10	51.0	39.5	15.7
15	67 2	54.5	26.2
20	79.4	63.5	33.0
25	88.7	68.5	40.3
30	91.2	78.0	47.6
35	92.2	86.0	53 9
40	94.1	88.0	57.6
45	95.6	91.0	63.9
50	96.6	93.5	68 6
55	97.1	95.0	71.2
60	97.1	95.0	75.4
65	97.1	96.5	79.1
70	98.0	97.0	82.2
75	98.0	98.5	85.9
80	98.5	98.5	87.4
85	98.5	98.5	88.0
90	98.5	98 5	89.0
95	98.5	99.0	89.5
100	98.5	99 0	92.1
Average error	± 15 4	± 20.9	± 50.3

[a] Estimating equation = 1955 pop. [0.6 + (0.04 times 1955 cars per 100 persons)]
[b] Estimating equation = 1948 trips times 1955 pop./1948 pop
[c] Estimating equation = 1948 trips times 1955 cars/1948 cars.

[2] See Footnote 1 on page 29.

variable for estimating 1955 residents trip production and residential land-use trip generation, 1948 trips for the 200 areas were multiplied by the ratio of 1955 cars owned to 1948 cars owned. The analysis revealed that this method of estimating residents trips was not nearly as effective as the two previous methods described. In this case the correlation coefficient was +0.88. Data in Table 11 and Figure 13 compare the accuracy of three methods developed for estimating 1955 residents trips and residential trip generation for the 200 areas studied.

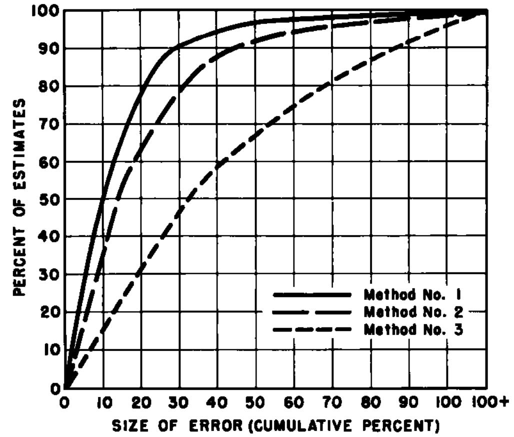

Figure 13. Comparison of three methods for estimating residents trips.

Estimating Future Traffic Potential of Residential Areas. Assuming that the travel patterns of the Washington metropolitan area are not unlike the travel patterns of other cities, the following methods and procedures have been developed for estimating with a fair degree of accuracy total residents trips for any area. As the factor to convert residents trips to trip ends on residential land was found to be approximately equal to 1.0, these methods will also give the trip generation due to any residential portion of the study area.

Method 1

Using the tabular data from an origin and destination study

1. Compute the residents trips per person for each zone in the area for which population and trip data are given.
2. Compute car ownership (passenger cars owned per 100 persons) for each zone.
3. Letting x = cars per 100 persons, y = trips per person, and n = number of zones, solve the following simultaneous equations for a and b:

$$\Sigma y = an + b\,\Sigma x$$

$$\Sigma xy = a\Sigma x + b\Sigma x^2$$

4. Determine estimating equation

$$y = a + bx$$

This equation provides an estimate of the trips per person corresponding to the car ownership in a particular area for an over-all citywide car ownership ($\Sigma x/n$) existing at the time of the survey. To apply this relationship to a future time, it is necessary to compute the parallel curve for an over-all car ownership estimated for the future data ($\Sigma x'/n$). This is done by assuming "y" and "b" remain constant and solving for the new "a" in the following equation:

$$\bar{y} = a' + b\bar{x}'$$

The trips per person for each area can then be calculated by substituting in the new equation ($y = a' + bx'$) for each estimated value of car ownership in the study areas. If desired, an index table similar to Table 10 could be prepared.

Although this has not been tested, instead of using car ownership data, it should be possible to utilize these techniques by substituting population density, income, distance from the central business district, or a combination of these variables.

Method 2

Using the tabular data from an origin and destination study

1. Compute the ratio of residents trips per person for each zone in the area.

2. Estimate the future population of each zone.
3. Multiply 1 times 2 for each respective zone.
4. In zones for which prior trip data are not available, estimates can be made by comparison with zones having similar characteristics.

Method 3

Using the tabular data from an origin and destination study

1. Determine the number of trips and the cars owned for each zone in the area.
2. Estimate the future cars owned in each zone.
3. Multiply the number of trips by the ratio of future to present cars owned.

The application of the most desirable method of estimating the potential trip generation in residential areas is dependent upon the availability and reliability of correlative data. For instance, although the first method appears to be the best, it must be pointed out that its accuracy depends upon the reliability of the estimated population and car ownership data. In the example above, the number of persons and the number of cars were known from origin and destination surveys. However, to forecast residential trips for a future period, the population and car ownership information is not available and must be estimated. Since the car ownership estimates are likely to be less accurate than population forecasts, Method 2, utilizing population data alone, may well be more accurate to forecast future trips.

CONCLUSIONS

1. Primarily the results of this study emphasize the fact that traffic is a phenomenon of human behavior. It is with people (and their daily travel) that there should be most concern.

2. The results of the analysis indicate means of estimating residents trips and trip ends on residential land with a reasonable degree of statistical accuracy. It appears desirable to ascertain and develop additional factors by which the accuracy of the technique could be greatly improved in each specific zone.

It would also be desirable to continue these studies, where possible, over a longer period of time to determine whether factors such as trips per person remain constant beyond a 7-yr interval. In addition, similar studies are needed in other urban areas of different sizes and with different travel characteristics, for instance, where mass transit is much less prevalent or negligible.

3. It has been shown that the use of population data as estimating factors would provide reasonable estimates of total trip ends on residential land by all modes of travel combined. However, to implement the design of transport facilities, estimates must be made of auto-driver trips, mass-transit trips, and trips by all other modes of travel, separately. It would seem necessary, therefore, to determine the degree of car ownership as a means of making these separate estimates for particular modes of travel.

4. Recognizing that a variable such as automobile ownership may only be a transient predictor of person trips, it still presents at this time rather impressive possibilities for improving traffic estimates, when known. In this regard, it is strongly urged that automobile ownership or registration records be established within urban and metropolitan areas on a basis of statistical areas, such as census tracts, police precincts, postal zones, school districts, or origin and destination zonal areas. Such a system would also enable the use of license tags in traffic analyses and many other studies, such as those connected with civil defense and market research.

Forecasting Peak Hours of Travel

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Urban transportation planning calls for an accurate forecast of peak hour traffic patterns. Evidence presented in this paper indicates that because of the wide disparity in the ratio of the peak hour to the average daily traffic and in the directional distribution of traffic found on urban streets, existing techniques for forecasting peak hour travel from origin and destination data should be revised.

In line with the results from eight cities a technique has been developed which should be sensitive to these variations in peak-hour travel. The technique calls for the application of a mathematical model and certain revision in existing O-D procedure.

● A KNOWLEDGE of the characteristics of peak-hour traffic is fundamental to the planning, design and operation of urban transportation systems. In the planning phase it is essential to be able to forecast peak-hour volumes so that transportation facilities can be designed to accommodate these needs. Such data are necessary to evaluate the proper role of highway and transit services in handling travel desires.

The magnitude of the peak-hour traffic, and the direction of it are both important in determining lane requirements of freeways and arterial streets as well as ramp locations. Certainly a knowledge of peak-hour travel patterns is basic for the development of sound operational improvements. In the city planning field, knowledge of peak hour patterns with respect to volume and direction of traffic is very valuable in shaping land use plans.

In the past, forecasts of peak-hour travel that have been based on O-D data have been determined by taking a percentage of the estimated 24-hr pattern. The reason that the peak hour was not analyzed separately was that it was feared that such an analysis would be plagued with many statistical problems. In effect, it would be dealing with only ⅒ of the trips related to the 24-hr pattern. Recent information on the characteristics of urban travel seem to raise serious questions about this approach.

PEAK-HOUR TRAVEL VARIES

In Cincinnati where several year-round counting stations were recently established, it was found that the ratio of peak hour traffic to average daily traffic varied as much as 100 percent between locations. (1) (See Fig. 1.) The highest portions were observed on arterial streets feeding primarily residential areas. In Portland, Oregon, it was found that the peak hours on some of the one-way streets in downtown area where there were capacity deficiencies ran as low as 6 percent. (2) In Baltimore a radial arterial street which ran through an industrial area had a balance in the direction of flow traffic, while another radial arterial street located in a residential area had a marked unbalance in the flow of traffic. (3) Traffic across a screen in Baltimore (Table 1) gave substantially the same results found in Cincinnati. The variation seemed to be keyed to land use difference.

Another example of such variations is the traffic crossing the Anacostia and Potomac Rivers in Washington, D.C. In this case the peak hour traffic observed on the bridges crossing these rivers was between 7 and 13 percent of the average daily traffic. The peak directional flow ranged from 4.5 to 9 percent of the average daily traffic. On one bridge 9 percent of the average daily traffic occurred in the outbound direction during the evening rush hour, while inbound it amounted to only 2 percent of the average. (4) This very unbalanced condition was related primarily to land use. The land on one side of the bridge was limited to residential development.

PEAK RELATED TO CAPACITY AND LAND USE

In light of these observations it would appear that peak hour travel was largely influenced by two factors: (a) capacity of the transportation system, and (b) land use factors.

There are cases in which the limited capacity of a street or highway has affected the hourly pattern of traffic. One of the most notable examples is the Holland Tunnel where there is little variation between various hours of the day. Drivers and truckers have adjusted their travel habits to conform to the available capacity of the tunnel. In other cases the overflow during the peak hour of traffic on an arterial street is found on adjacent local streets.

It is also known that if capacity is added to transportation facilities there is a tendency to accentuate the peak. For example, with the completion of the subway in Toronto it was found that 10,000 more people were traveling in the peak hour than during the year before though there was little increase in the daily traffic. (5)

Land use affects traffic patterns in two ways—trip production during the peak hour and orientation of trips during the same period. For example (Fig. 2), land uses have different patterns of trip production during the peak hour. (6) In the core of the downtown area in Washington, about 23 percent of the daily trips leaving the area occurred during the peak hour. However, in some of the important areas adjacent to this core it was found that this percentage ran as high as 36 percent.

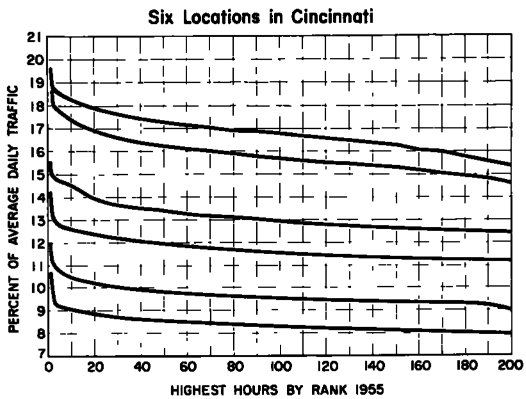

Figure 1. Variation in Peak Hour Vs. Average Daily Traffic. (1)

TABLE 1

PEAK HOUR TRAFFIC CHARACTERISTICS FOR SCREEN LINE IN BALTIMORE 1957

Crossings	24-hr Volumes 2-way	Peak Hour A.M. East No.	A.M. 1-way %	A.M. 2-way No.	A.M. 2-way %	P.M. West No.	P.M. 1-way %	P.M. 2-way No.	P.M. 2-way %	% by Direct P.M. 1-way 2-way
Kelley Ave.	10132	732	7.2	1148	11.4	665	6.6	1020	10 2	65
Belvedere	13622	855	6.2	1410	10.3	815	6.0	1482	10.8	55
Cold Spring	13697	540	3.9	998	7.3	750	5.5	1273	9.3	59
41st St.	13845	538	3 9	1194	8.6	593	4.3	1179	8.5	50
Union Ave.	3476	43	1.3	225	6.5	234	6.8	344	10.0	68
Wyman	8003	529	6.6	928	11 6	625	7.8	1192	14.8	52
29th St.	22278	1037	4.7	1691	7.6	1016	4.6	2354	10.6	43
North Ave.	31937	957	3.0	1801	5.7	1333	4.2	2302	7 2	59
Howard St.	23020	813	3 5	1736	7.5	600	2.6	2179	9 4	28
Maryland[1]	19003	-	-	2797	14.6	966	5.1	966	5.1	-
Charles[1]	28707	1414	4.9	1414	4.9	-	-	2869	10.0	-
St. Paul[1]	27741	-	-	3009	10.8	1612	5.8	1612	5.8	-
Guilford[1]	15465	869	5.6	869	5 6	-	-	2290	14.7	-
Preston	13725	504	3.7	947	6.9	669	4.9	1092	8.0	61
Biddle	4575	183	4.0	421	9.2	346	7.6	562	12.2	62
Chase	3988	147	3.6	241	6.0	178	4.6	445	11.2	41
Eager	2165	33	1 5	175	8.1	195	9.0	288	13.3	68
Madison[1]	7790	631	8.1	631	8 1	-	-	854	11.0	-
Monument[1]	10708	-	-	955	8.9	1154	10.7	1154	10.7	-
Hillen	11484	265	2.3	990	8.6	414	3.6	995	8.6	42
Gay	13606	334	2.4	1152	8.5	416	3.0	916	6.7	45
Lexington	2852	168	5.9	255	9.0	206	7.2	426	14.8	48
Fayette	23129	741	3 2	1825	7.9	1153	5.0	2146	9.3	54
Baltimore	15539	543	3.5	980	6.3	645	4.1	1378	8.9	46
Lombard	6209	151	2.4	465	7.5	363	5.8	527	8.5	68
Pratt	44583	1474	3.3	3152	7.1	1896	4.2	3605	8.1	52
	391,279							35,450	9 1	

[1] One-way

Such a variation would have a significant bearing upon the location and frequency of ramps and the number of freeway lanes needed to serve this area. If a straight percentage had been taken of average daily traffic, the number of freeway lanes that would be needed to serve Zone 1 (Table 2) would have been under-estimated by two lanes, since most of the travel in and out of the zone undoubtedly would be on the freeway planned to traverse this section.

Similarly, the pattern of trips will vary during different hours of the day. Figure 3 shows that the peak of shopping trips occur largely in the downtown area in the morning, while the peak for suburban shopping occurs during the evening rush hour. (7) Such variations are of importance in planning and design of a freeway and arterial street system. In the downtown area the shopping trips have little impact upon peak traffic demands, while in the suburban area they complicate the issue in that they occur at the same time as the heavy work movement.

Thus, it would appear that peak hour patterns in urban areas are related to three factors: (a) orientation of trips during peak hours, (b) trip production of land uses during peak hours and (c) capacity of transportation facilities.

It would probably be fairly easy to get agreement on such a general thesis but the problem is to apply it in the analysis of origin and destination data.

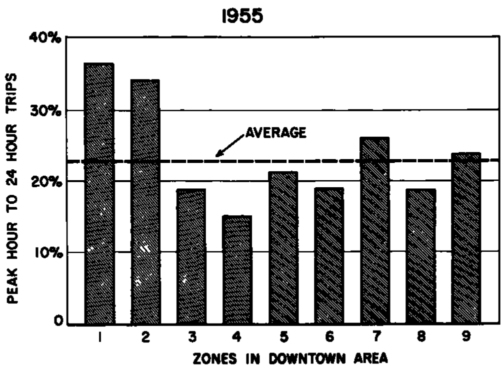

Figure 2. Variation in Peak Hour Traffic Generations for Zones in Downtown Washington. (6)

TRAFFIC MODEL

To overcome the sampling problem in determining the orientation of trips during the peak hour, the development of some suitable mathematical model offers the best prospect. Though there are many types of models that might be considered, the gravity model in light of past research seems to have the most advantages. This model adapts Newton's Law of Gravity to traffic behavior. It says, in effect, that the number of trips produced by any zone will be at-

TABLE 2

COMPARISON OF NUMBER OF TRIPS LEAVING DOWNTOWN WASHINGTON DURING A 24-HR INTERVAL WITH PEAK HOUR[a]

Downtown Zones	Reported Trips in 24 hr	Reported Trips During Peak Hr	Estimated Peak (23.0 % of 24 hr)	Difference between Estimate of Reported Peak	Percent Reported Peak of 24 hr
01	21984	8006	50500	+ 2956	36.5
02	8257	2827	1900	+ 927	34.3
03	19494	3669	4500	- 831	18.8
04	11236	1719	2580	- 861	15.3
05 (core)	35378	7587	8100	- 613	21.4
06	28220	5394	6500	- 1106	19.0
07	19747	4855	4300	+ 555	26.0
08	29980	5642	6850	- 1208	18.8
09	5949	1421	1340	+ 81	23.8
	179245	41120	40910		23.0

[a] Source: ref (6).

tracted by other zones in the area in direct proportion to their size, and indirectly in proportion to the length of the trips. (8) This gravity model can be expressed in the following formula in which M denotes the size of the zone in some appropriate unit, D represents the length of trip, and X is the exponent which is determined empirically:

$$T_{1-2} = (T_1)\,\frac{\dfrac{M_2}{D_{1-2}^{X}}}{\dfrac{M_2}{D_{1-2}^{X}} + \dfrac{M_3}{D_{1-3}^{X}} + \ldots \dfrac{M_n}{D_{1-n}^{X}}}$$

The gravity model can be applied in two general ways to traffic problems. The first is to use a single model for all trips. The other is to develop separate models for each trip purpose or group of purposes.

In applying the gravity model to peak hour patterns it is necessary to use the trip purpose model, since the all-trip model would not indicate direction. The trip purpose model has certain other advantages in that it defines the impact of land use patterns on traffic patterns more effectively.

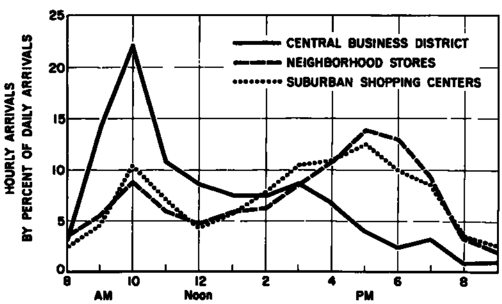

Figure 3. Arrival Pattern of Shopping Trips in Houston. (7)

Table 3 shows the percentage of purposes of trips that occur during the peak hour. This figure is based upon a special study made in San Diego of a suburban area well served by freeways. This table has certain other modifications which are usually not made in such tabulations. Trips made to serve passengers, stops at a grocery store on the way home, or other side trips were not considered in this analysis—only basic traffic desires. This means that most of the trips were from home to their main destination and return. However, in addition to this there were a certain number of trips made by salesmen, etc., which were not involved with residential areas at all. These were considered separately and have been indicated as non-residential trips.

On the basis of this tabulation it is clear that the work trip is very important in fore-

TABLE 3

RELATIONSHIP BETWEEN STREET USE AND TRIP PURPOSE
SAN DIEGO, CALIFORNIA - 1956 [a]

Trip Purpose	24 Hour Pattern Used Freeway (%)	24 Hour Pattern Other Streets (%)	Peak Hour Pattern Used Freeway (%)	Peak Hour Pattern Other Streets (%)
Work	61	31	82	40
Shopping				
Convenience goods	2	30	-	50
Shopping goods	5	10	-	-
Social & recreational	23	4	13	-
Other	4	15	-	-
Non-residential	5	10	5	10
Total	100	100	100	100

[a] Source: ref. (16).

casting peak hours of travel. It will probably account for about 80 percent of the freeway usage during the peak hours. Therefore, it is vital to develop a model which is accurate for such travel. Over a period of several years the author has examined origin and destination of work trips in six American cities, and the investigations indicate that the gravity model can be used effectively in forecasting traffic. Research conducted in Detroit and Toronto also verified these findings. (9)

Figure 4 shows the close similarity in work trip patterns based upon a sample of O-D data obtained for South Bend, Oklahoma City, and Fort Wayne. (10) This figure depicts the ratio between probable zonal interchanges and observed interchanges for movements of varying lengths. Distance was expressed in terms of auto travel time during the peak hour between zones.

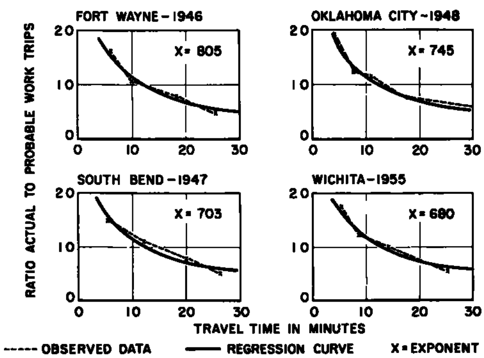

Figure 4. Comparison of Work Travel in Various Cities. (10)

To insure statistical stability, data were grouped by travel time as shown by the points on the chart. The exponents which were determined by the least-square method range between 0.6 and 0.8. Tests in Baltimore and Philadelphia also gave similar results (Baltimore, 0.647 and Philadelphia, 0.805). (11) Recognizing that such range in the exponent would have less than a 10 percent variation in trip estimate for most interzonal movements, and furthermore that much of the travel time data used was weak (usually based on estimates of the traffic engineers), the correlation between cities is significant.

In addition, studies were made for Baltimore and Wichita to see if these exponents varied for residential areas at different distances from the central business district. In both instances the analysis revealed that the exponents range was between 0.65 and 0.85. (In determining the exponent the travel time related to the mode of travel was used—transit users and auto drivers were studied separately.) Furthermore, there

TABLE 4

COMPARISON OF ZONE TO ZONE MOVEMENT DETERMINED BY HOME INTERVIEW METHOD OF DIFFERENT SAMPLE SIZES WITH THE GRAVITY MODEL [a]

CINCINNATI, OHIO

Zone to Zone Movement	Theoretical Trips	Percent						
		100	20	12½	10	8⅓	6⅔	5
573-103	11	11	20	-	-	24	-	42
112	14	16	30	42	-	-	-	-
113	19	22	15	25	10	-	30	42
150	24	18	25	25	42	12	30	-
153	7	6	7	25	21	-	-	-
506-103	23	25	31	16	31	-	15	-
112	27	26	21	16	-	-	31	-
113	28	35	26	56	21	49	-	83
130	19	14	10	33	51	24	-	-
135	7	13	21	-	-	-	-	-
144	19	13	-	16	10	24	-	42
150	12	7	10	-	-	-	-	-
153	5	8	10	-	20	-	31	-

[a] Source: ref. (12).

was no consistent relationship between these slight variations in the size of the exponent and the location of the residential area. Such findings would seem to indicate that urban work trips patterns are substantially the same throughout the country.

The correlation coefficients associated with these various curves were usually in the 90's, but such indices cannot be used to determine the accuracy of zone-to-zone interchange since the interzonal movement had been grouped. However, to obtain an indication of the statistical reliability of these curves, chi-square tests were made for Wichita and Oklahoma City. The probability level for Wichita was over 50 percent and for Oklahoma City over 40 percent, thus further substantiating the validity of the use of the gravity model.

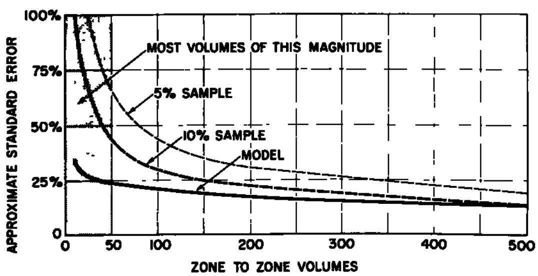

Figure 5. Comparison of Error Related to Sampling and Traffic Model. (12, 13)

Although these statistical tests were satisfactory they do not give an estimate of the error which is inherent to the model itself. Unfortunately, such estimates are difficult to derive without 100 percent observations.

In one of the few areas where such data were available, an attempt was made to establish the error. This was based upon a special study made by the Ohio State Highway Department of two zones in Cincinnati. (12) The results that would be obtained by different sample sizes are compared with the model in Table 3. This table clearly shows that good results were obtained by the gravity model—in fact, considerably better than you could get from a 20 percent sample. The standard deviation from zonal interchanges of 10 to 20 trips was about 25 percent. Because of the characteristics of the sample it is believed that this deviation is somewhat below the normal that would be found for this traffic movement, but it does give the general size of the error related to the model.

Another appraisal in Philadelphia was made for interzonal movements exceeding 1,000 trips a day. (13) There it was found that the standard error was about 15 percent, if it is assumed that all the error was related to the model. (The exponential curve gave slightly better results than the hyperbolic curve test by Lapin.) In Baltimore a check was made of traffic crossing a screen line running through the heart of the city. In that case the error was only 5 percent. However, the trips crossing this screen line were 100,000. (11)

In light of these observations it would appear that as the number of trips between zones increased, the percentage error associated with the model would decrease somewhat as shown by Figure 5. This figure also compares the error of the model with normal sampling errors. Obviously, the model gives better answers for daily zone-to-zone interchanges which are less than 500 for both 5 and 10 percent sample.

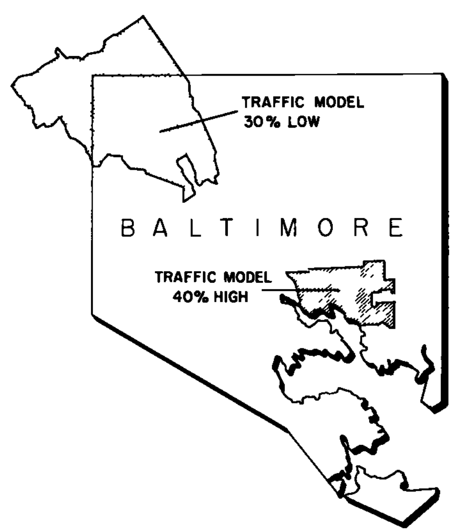

Figure 6. Residential Areas Where Observed Travel to Downtown Baltimore Varied from Traffic Model. (11)

And what is probably of more importance is that the model gives much better results for zone volumes less than 50. In most origin-and-destination studies these volumes constitute the bulk of the traffic. For example, in the 1948 Washington study more than 90 percent of all the trips were made between zones having such volumes. (14)

These tests as to relative error of the model apply to the 24-hr pattern of the work trip. Unfortunately, there were no data available to make such tests for peak hour conditions but it would appear that if adjustments are made for trip production throughout the peak hour the error of the model would be about the same as that shown by Figure 5. Certainly the sampling error would greatly increase for peak hour travel thereby leaving the model as probably the only practical alternative.

In applying the gravity model in these 6 cities the work trips were brought into balance. That is, if in applying the model too many trips were allocated to a particular employment center, they were adjusted to conform to the known number of trips made to the center. This was achieved by multiplying all trips to the center by an appropriate adjustment factor. In many instances this balance procedure improved the results of the model.

The only modification made in applying the model was for trips to the downtown area. This was done to adjust for differences in relationship between homes and employment for different social, economic, and occupational classes. From experiences in these cities it would appear that this correction is only necessary for trips to the downtown area.

It appears from these studies that correction for these differences is more important in the older Eastern cities, where there has been a considerable amount of colonization of various social and economic classes. Therefore it is recommended that in developing a model for such cities appropriate tests be made to determine the weight that should be given to these characteristics. This can be achieved by analyzing the O-D data on a district basis (groups of zones) and by studying the difference between the work trip patterns determined by the model and those observed for such districts.

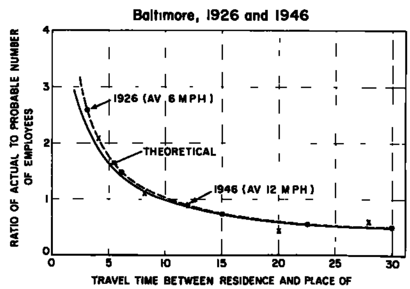

Figure 7. Comparison of Residence and Place of Employment. (15)

The correction that was made for downtown trips was quite simple. It involved the determination of just how much the gravity model was off with respect to trips to the downtown area. Figure 6 gives the important areas in Baltimore which did not conform to the model and the percentage by which these areas were in variance with the model. (11) Taking account of the social and economic characteristics of these areas, projections can be made to show where such areas will occur in the future.

Though the gravity model is quite adequate for evaluating existing traffic patterns, the question is, can it be used for evaluating future patterns? The answer seems to be yes. In Baltimore such a model proved itself in 1926 and again in 1946 (Fig. 7). The exponent of the gravity model was 0.605 in 1926 and 0.645 in 1946, a remarkable correlation. (15)

In applying the gravity model in both of these cases the travel time for the particular era was used. In 1926 the average travel speed during the peak hour was 6 mph; in 1946 it was about 12 mph. This assumes that the work trips in 1926 were largely oriented to transit; in 1946, to the automobile.

Hence, the gravity model probably can be used effectively in forecasting traffic changes that will occur with improvements in transportation services. It can, in other words, estimate generated traffic.

This particular Baltimore study provides a glimpse of what the future may have in store. The doubling of speeds between 1926 and 1946 increased the average length of work trips by 50 percent. Therefore, it is probably not unrealistic to expect comparable increases in trip length it cities double travel speeds with the construction of freeway systems.

To repeat, then, the gravity model, if adjusted for local conditions, can be used effectively in forecasting work trips during the peak hour. Other trips for other purposes which may occur during this period may be predicted by similar techniques. The exponents can be determined by appropriate analysis of origin and destination data. It is recognized that estimates for these other types of trips may not be as accurate as those obtained for work trips, but their significance during the peak hour is rather small and therefore such inaccuracies will not have much impact on the estimated peak-hour pattern.

TRIP PRODUCTION

To reveal variations in peak hour production of trips for different land uses, special analyses should be made of O-D data. This can be readily done if trips are related to land use, as has recently been done in St. Louis and Chicago studies. Land use categories should probably conform to the traditional breakdown of land uses—residential, commercial, industrial, etc.

In addition, production of trips for various purposes during the peak hour should also be established for different land uses. The categories of trip purposes should be held to a minimum and should correspond to those used in the traffic model. Furthermore, it might be advisable to make comparable studies for major traffic generators like the central business district.

Development of such data from home interview O-D surveys would certainly be helpful in understanding the nature of peak hour travel.

CAPACITY EVALUATION

To determine the impact that capacity is having on travel habits an attempt should be made to evaluate the differences in travel patterns for various types of land uses under varying degrees of traffic congestion. Such a comparison should indicate what adjustment in the production and correlation of peak hour travel will come about with changes in traffic conditions.

To measure the impact capacity is having on street usage, an urban transportation study should assign traffic to a complete highway network. This is a difficult problem since it involves many so-called "feed-back" adjustments. Such adjustments are necessary because travel patterns change with variations in travel speeds which in turn vary with fluctuations in traffic volumes. At the present time there is no mathematical method devised which is dynamic enough to adjust for such variations in speed and volumes on a network basis.

But even if such a method were available there are still other problems related to lower volume streets (arterial streets in larger cities and collector streets in smaller communities). For example, work done by the Ohio State Highway Department indicates that the home interview type or origin and destination surveys miss from 1 to 2 trips per dwelling unit. (12) Many of these trips may in fact be stops enroute, but such stops may be important in arterial street assignment. Beside these errors, the limitations of predicting the behavior of small volumes of traffic are a handicap.

However, despite these difficulties of assigning trips to a highway network some sort of assignment should be made to a freeway and an evaluation taken of the arterial streets.

The first step should be that of assigning traffic to freeways. This can be carried out by several of the methods that are now employed, if estimates of travel speed on the various highways are made.

To carry out the second phase a separate evaluation should be made of the trips that will use the arterial streets. This might be done by allotting these trips to districts (groups of zones) through which they are made. Then the relationship between speed and volume should be determined for streets within these districts. With such data, travel speeds through these districts can be estimated in light of anticipated volumes. Travel speed estimates should then be checked with original assumptions on speeds.

If these speeds are at variance, adjustments in assignment procedure should be made and the new assigned values should be studied again to determine the effect they will have on travel speeds. If this process is repeated enough a balance between the speed and volume relationships can be obtained for the highway system, thereby giving an effective forecast of the use of the highway network.

KEEPING IT UP TO DATE

Another point that should be stressed with regard to traffic models is that traffic pattern forecasts should be checked periodically to verify their accuracy. This can be done by establishing screen lines over which traffic is counted annually. With the development of land use models by the city planning agency, it is hoped that both land use and traffic models can be tested periodically and adjusted accordingly.

If the projection technique that has been described is to be employed, it is apparent that certain changes should be made in the sample design and the standard interview form used in obtaining trip information. For example, the sample design should be such as to test the model. This may call for a very small over-all sample to obtain general patterns of traffic movement and a series of cluster samples to measure the variation travel characteristics of different social and economic groups.

In obtaining data on trips it may be advisable to depart from the standard classification of trips. For example, a trip to work on which one picks up two passengers might be designated as only one trip. Stops enroute to pick up passengers might be designated as secondary trips.

The general technique which has been suggested for forecasting peak hour traffic patterns may seem rather involved at first glance. However, studying it closely, it is not much more complex than the present method. The main difference is that instead of applying a growth factor a traffic model is used. The traffic model technique need not be too time consuming or expensive, since it can be readily programmed for electronic computers.

On the other hand, determination of peak production of trips for various land uses and the analysis outlined are quite similar to what is being done today.

In short, the main advantage of this new method is that it gives better forecasts of peak hour travel in that it establishes the magnitude and directional characteristics of traffic throughout the urban area.

CONCLUSION

1. The wide disparity in the ratio of the peak hour to the average daily traffic and in the directional distribution found on urban streets today indicates that existing techniques of forecasting peak hour travel from O-D data need to be revised particularly for critical traffic areas like the central business districts.

2. Since peak-hour traffic patterns are related to (a) orientation of trips during the peak hour, (b) trip production of land use during the peak hour, and (c) capacity of transportation facilities, it is essential that these factors be taken into consideration in projection procedures.

3. Results from this study indicate that the gravity model can be used to obtain accurate forecasts of the orientation of trips during the peak hour. Trip production of land use during the peak hour can be developed by techniques already in use and the capacity of transportation facilities can be approximated with certain adjustments in existing procedures.

4. Since this technique for forecasting traffic considers change in travel time it can be used to estimate the impact that adjustments in transportation service will have on travel patterns. A good dynamic test of this technique would be to see if it can effectively forecast traffic generation.

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Transportation Usage Study

WILLIAM J. MORTIMER, Superintendent, Traffic Engineering Division, Illinois Highway Department.

OBJECTIVES

●THE MAIN objective of this study was to secure information to aid in the assignment of traffic to arterial streets, expressways, and to mass transportation facilities. This study was designed to probe directly into the attitudes and personal reasons involved in the choice of mode of travel.

People making trips (other than walking) can be divided into three broad categories: (a) those who must use some form of mass transit; (b) those who must use an automobile; and (c) those who have a choice of using either an automobile or some form of mass transit. Knowledge of the characteristics of group (c) is of great value for traffic assignment purposes. When changes are made in available facilities, this group tends to redistribute itself over the various forms of mass transit and auto transportation. This redistribution can best be explained in terms of the personal reasons involved in the choice of mode of travel.

THE SAMPLE

Usable data was obtained from interviews of nearly 2,000 households in Cook County, Ill. as the general sample for the Transportation Usage Study. Each adult member (16 years of age and older) of every household was personally interviewed. In addition to the general sample, six cluster areas were selected for blanket coverage (minimum of 100 household interviews per cluster). These areas were chosen on the basis of such factors as income level, available mass transit facilities, and distance from the central business district (CBD) of Chicago.

THE INTERVIEW

The interview consisted of basic household data, and for each person interviewed, data pertaining to work trips, trips to the downtown area of Chicago (other than for work), and trips for the purpose of shopping. This discussion will be limited to that portion of the study dealing with work trips.

WORK TRIPS

Mode of Travel

Nearly 4,200 adults were interviewed, of which over 2,300 reported making one or more work trips during an average week. Figure 1 shows the modes of travel used to reach work destinations in the Chicago CBD and in outlying areas. The left side represents those trips to the Chicago CBD, and the right side portrays trips to outlying areas. The number of trips made by each of the major modes of travel is shown by a bar graph. The respective percentage associated with each mode of travel is also indicated. The sharp differences in mode of travel to the CBD as opposed to mode of travel to the outlying areas is apparent. Automobile trips account for 29 percent of the work trips to the CBD but account for 64 percent of trips to outlying areas. All forms of mass transit except the Chicago Transit Authority (CTA) bus show large percentage drops in usage for trips outside of the CBD as compared to trips within the CBD. These relationships were also found to hold generally in the five cluster areas. However, cluster No. 2, an above average income area, showed a higher than average percentage of automobile trips both to the CBD and to the outlying areas.

Reasons for Choice of Mode of Travel

The significant reasons given for choice of mode of travel are shown in Figure 2 for the general sample. As in Figure 1, the left side portrays trips to the Chicago CBD

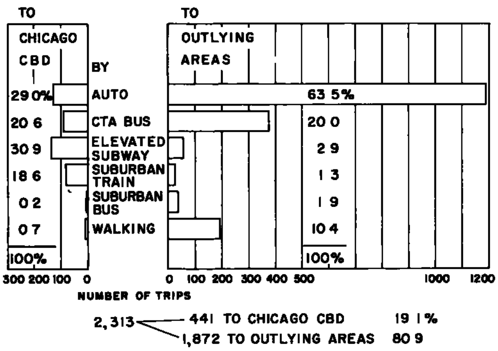

Figure 1. Mode of Travel for Work Trips, General Sample.

while the right side shows trips to outlying areas. The number of persons giving each of the indicated reasons is shown by the respective bar graphs. The white bar graphs represent automobile trips, and the black represent trips made by mass transportation facilities. The reason most frequently given was "less time required." This was true of trips made by transit as well as trips made by automobile. The next most important reason seems to be comfort, although when automobile and transit are considered separately it can be seen that comfort plays only a minor role in the selection of transit as a mode of travel. The cost factor ranks high for the transit users, and is important because of its absence for the automobile users.

In about 37 percent of the automobile trips to the CBD either the car is necessary for business purposes or there is no other reasonable means available. The other 63 percent might be induced to switch to some form of mass transit if the time and comfort factors could be altered to make the transit facilities more attractive. This is not an unreasonable approach for trips to the CBD. However, with the advent of the comprehensive expressway system, automobile travel to the CBD will be on a much more competitive basis with transit facilities with respect to both time and comfort factors. This might easily lead to a drop in the percentage of transit trips to the CBD.

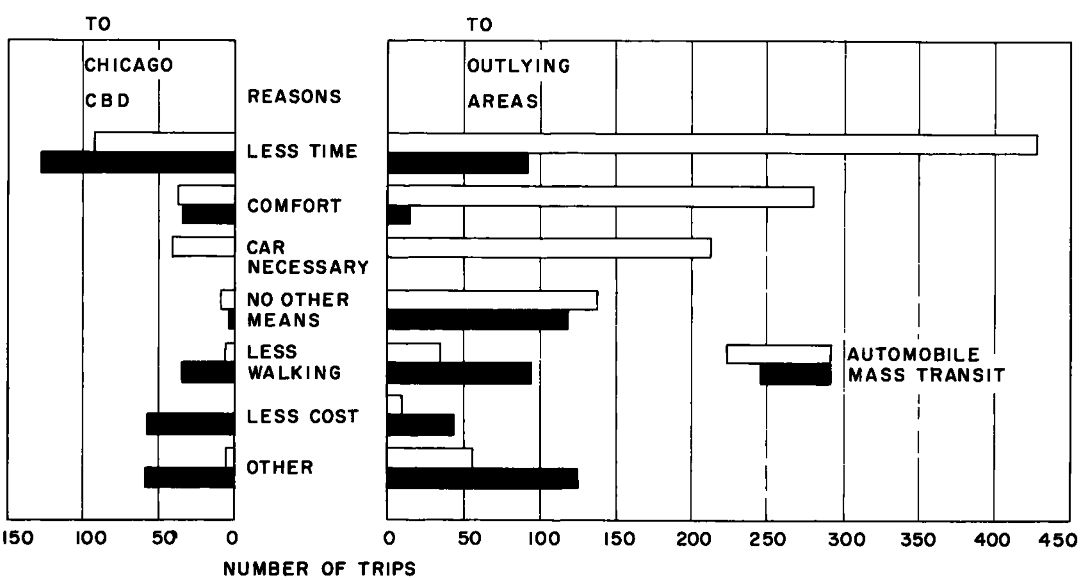

Figure 2. Reasons for Choice of Mode of Travel for Work Trips, General Sample.

The transit companies are faced with even more difficult problems for trips with destinations other than to the CBD. Many of these trips involve one or more transfers so that automobile travel has an even greater time advantage than for trips to the CBD. The bulk of those who could shift from automobile to some form of mass transit are made up of the "time" and "comfort" groups so that a satisfactory solution for the transit companies (with respect to trips to the outlying areas) seems remote.

Assignment Curves

Assignment curves have been constructed which relate the percentage of transit trips to several pertinent variables. These are (a) the time ratio, (b) the cost ratio, (c) the time required for the trip, and (d) the annual household income.

Figure 3 shows the relationship between the percentage of transit trips and the time ratio (defined to be the time required to make a trip by transit divided by the time to make the same trip by automobile). The time referred to is the time for the entire trip, from point of origin to point of destination. This curve is based on data from over 1,200 trips to the Chicago CBD and to outlying areas, for which each person had a choice between making the trip by transit and making it by automobile.

When the time by transit is one-half that of the time by automobile (time ratio = 0.5) almost all trips are made by transit facilities; when the time by transit is equal to the time by automobile (T.R. = 1.0) about 40 percent of the trips are made by transit; and when the time by transit is twice that of the time by automobile (T.R. = 2.0) only about 10 percent of the trips are made by transit.

Figure 4 relates the percentage of transit trips to the cost ratio (defined to be the cost of making a trip by transit divided by the cost of making the same trip by automobile). For automobile travel, this cost includes operation and parking costs. The curve indicates that when the cost by transit is one-tenth that of the cost by automobile about 60 percent of the trips are made by transit; when the cost by transit is one-half that of the cost by automobile, 15 percent of the trips are by transit; and when the cost by transit is equal to the cost by automobile only about 5 percent of the trips are by transit. This curve is based on the same data as that for Figure 3.

Figure 5 indicates the relationship between the time required for trips and the percentage of trips made by transit facilities. It is limited to those trips to the Chicago CBD.

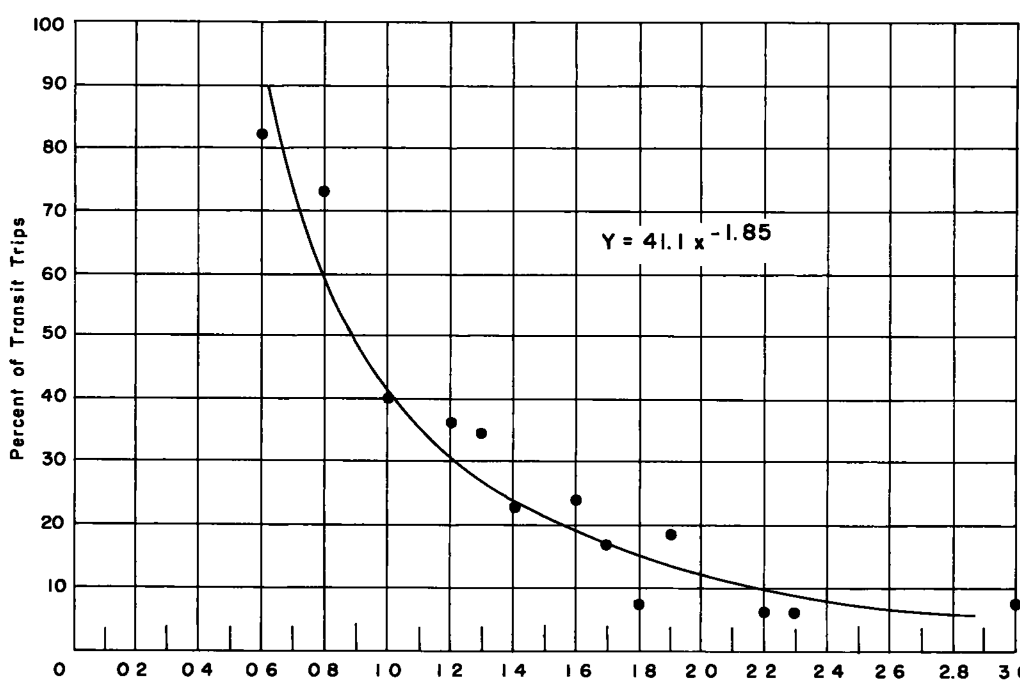

Figure 3. Transit Assignment, Chicago CBD and Outlying Areas.

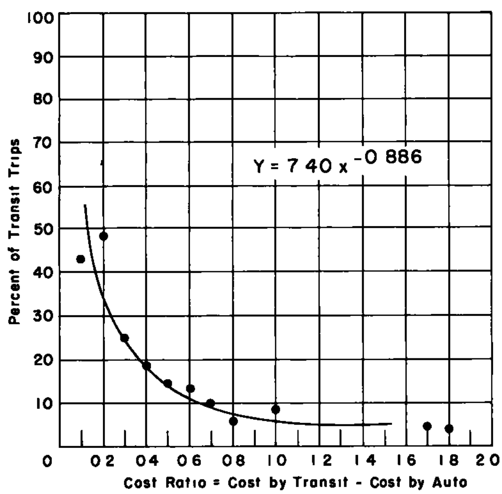

Figure 4. Transit Assignment, Chicago CBD and Outlying Areas.

Of all trips requiring 15 minutes about 60 percent are made by transit; of those trips requiring 45 minutes, 75 percent are by transit; and of those taking 75 minutes, 90 percent are by transit. The transit facilities seem to increase in relative attractiveness as the time required for the trips increases.

The curve in Figure 6 relates transit usage to household income. It is limited to trips with destinations other than to the CBD. Transit usage is very high for the extremely low income groups; it drops very sharply until the income level is about $4,500 per year, and then transit usage tapers to a gradual decrease with increase in income.

All of the assignment curves shown were determined by regression analysis, and all four variables were highly correlated with the percentage of trips made by mass transit (correlation coefficients greater than 0.90).

Comfort

Several factors closely related to comfort were isolated and tested for statistical significance. These factors were (a) possession of a seat for the transit riders,

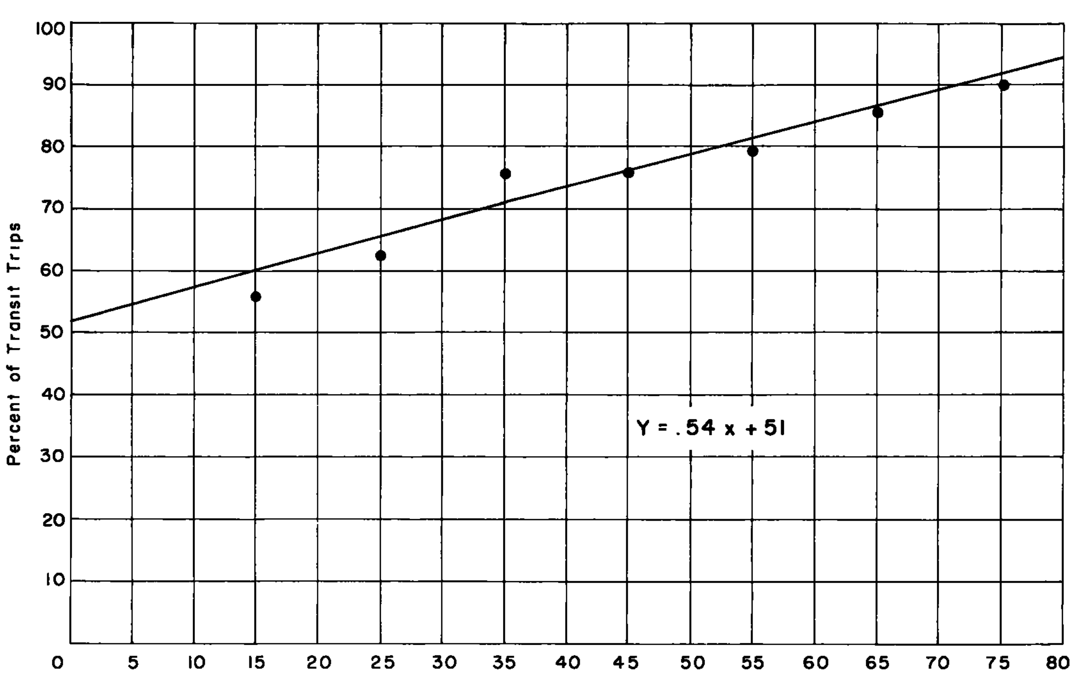

Figure 5. Transit Assignment, Chicago CBD Only.

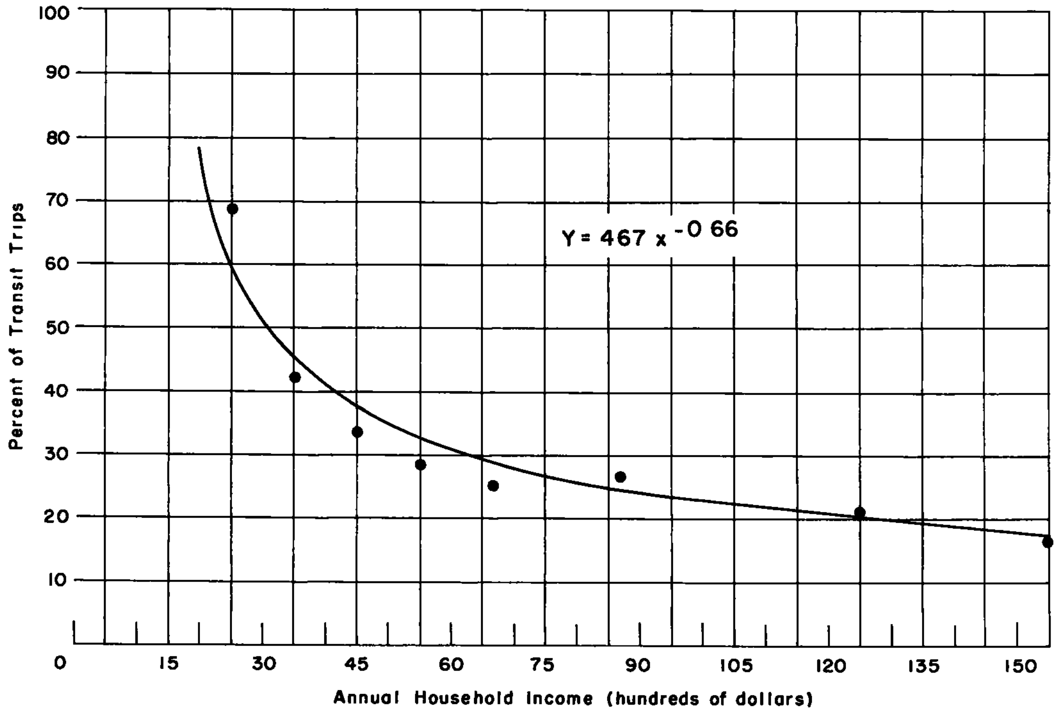

Figure 6. Transit Assignment, Outlying Areas Only.

(b) necessity of making a transfer, and (c) the amount of walking required. The significance tests were done on two groups of transit users: (a) those who could have made their trips by automobile, and (b) those who could not have made their trips by automobile. For each of these two groups, the percentage not having seats was determined. These two percentages were tested and the difference found to be statistically significant. The group that could have used an automobile had a substantially lower percentage of persons without seats. For each of the same two groups, the percentage making transfers was determined. The group who could have used an automobile had a significantly lower percentage of persons making transfers. The total number of blocks walked (origin end of trip plus destination end of trip) was tested in the same manner, but found not to differ between the two groups.

SUMMARY

Mode of Travel

Over two-thirds of the trips to the Chicago CBD were made by mass transportation facilities. For trips to areas other than the CBD, about two-thirds were made by automobile.

Reasons for Choice of Mode of Travel

Time. Both the absolute time required for making a trip, and the relative time between transit and automobile travel for the trip were shown to have a substantial influence on the choice of mode of travel.

Cost. The relative cost between transit and automobile travel was shown to be an influencing factor in selection of mode of travel. For trips to outlying areas household income was shown to be inversely related to transit usage.

Comfort. Not having a seat and the necessity of making a transfer were both shown to have a statistically significant influence on the group who have a choice between making a trip by automobile and making it by mass transportation facilities. The number of blocks walked had no apparent influence on this group.

Evaluating Trip Forecasting Methods with an Electronic Computer

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In forecasting future trip distribution from the existing pattern, the average factor method, the Detroit method, and the Fratar method are equally accurate if each method is carried through a sufficient number of successive iterations. In all cases tested, the second approximation of the Fratar method was of maximum accuracy while four or more approximations were usually required with the other two methods.

The results of the test emphasized the fact that the majority of the trips within a metropolitan area consist of a very large number of small-volume zone-to-zone movements, where the zones are of normal size. With sampling rates used these individual small-volume movements are not accurately determined. The accumulation of the small-volume movements into volumes associated with ramps, streets, and expressways, should result in acceptable accuracy as calculated by statistical formulas, but this will have to be definitely established by additional research.

The advantage of using an electronic computer on research projects of this type can hardly be overestimated, notwithstanding the difficulty and time consumed in preparing the program. In this series of tests, the speed and accuracy of the computer permitted the attainment of results in hours instead of years after the program had been completed, without a single error attributable to the computer.

● HOME-INTERVIEW origin and destination studies were made in the Washington, D.C. area in 1948 and in 1955. In the earlier study a 5-percent sample was obtained by interviewing the residents of one of every 20 dwelling units. In the 1955 study, the sample rate was 1 in 30 in the District of Columbia and 1 in 10 elsewhere within the area.

These two surveys offered, for the first time, an opportunity to study the changes occurring over a period of several years in a metropolitan area in the pattern of trips, that is, the differences in the numbers of trips between the same origins and destinations. They also provided data that could be used to evaluate methods of forecasting future trip volumes.

TRIP FORECASTING ELEMENTS

Two basic elements are involved in the forecasting of trips. One is the increase in the number of trip origins and destinations in a particular part of the city such as a zone. For brevity the number of trip origins and destinations combined have been labeled trip ends. Thus, for example, 2 trips originating in a zone and 3 trips destined to it would be counted as 5 trip ends. Therefore, if only the trips made wholly within an area are considered, the total number of trip ends in the area is exactly twice the number of trips.

The ratio of the future trip ends expected in a particular zone to the present trip ends in the zone is called the growth factor for that zone. Much work has been and is being done in this field to determine the best method of arriving at the proper growth factor. Up to now, however, forecasts, so far as total trip ends are concerned, are dependent to some extent on personal judgment. In order to eliminate this variable, and isolate the elements being studied, the growth factors were calculated for each zone by taking the ratio of the reported trip ends in each zone in 1955 to the reported trip ends in each zone in 1948. Thus any variability in predicting growth factors will not affect this study of forecasting methods.

The other basic element involved in forecasting zone-to-zone movements is the application of the growth factors of the two terminal zones in predicting the number of future trips between them. Various mathematical formulas have been developed with that end in view. It is the purpose of this study to evaluate the accuracy of these methods and the formulas used therein. Certain other methods of trip forecasting, based on population distribution, trip-attraction distribution, and distance or travel time, directly predict the number of zone-to-zone trips, but as these methods are still in the process of development they will not be further discussed.

CHARACTERISTICS OF THE AREA

One problem that had to be resolved in beginning the test was that the area covered in the 1948 Washington survey was somewhat smaller than that of the 1955 survey, and the extent and identifying numbers of many of the zones had been changed. The first step was to reconcile these differences by rezoning the metropolitan area into 254 zones and to determine both the 1948 and 1955 volumes of trips into and out of these zones.

The 254 zones covered in area which contained 96 percent of the population that lived within the 1948 cordon and 93 percent of that living within the 1955 cordon.

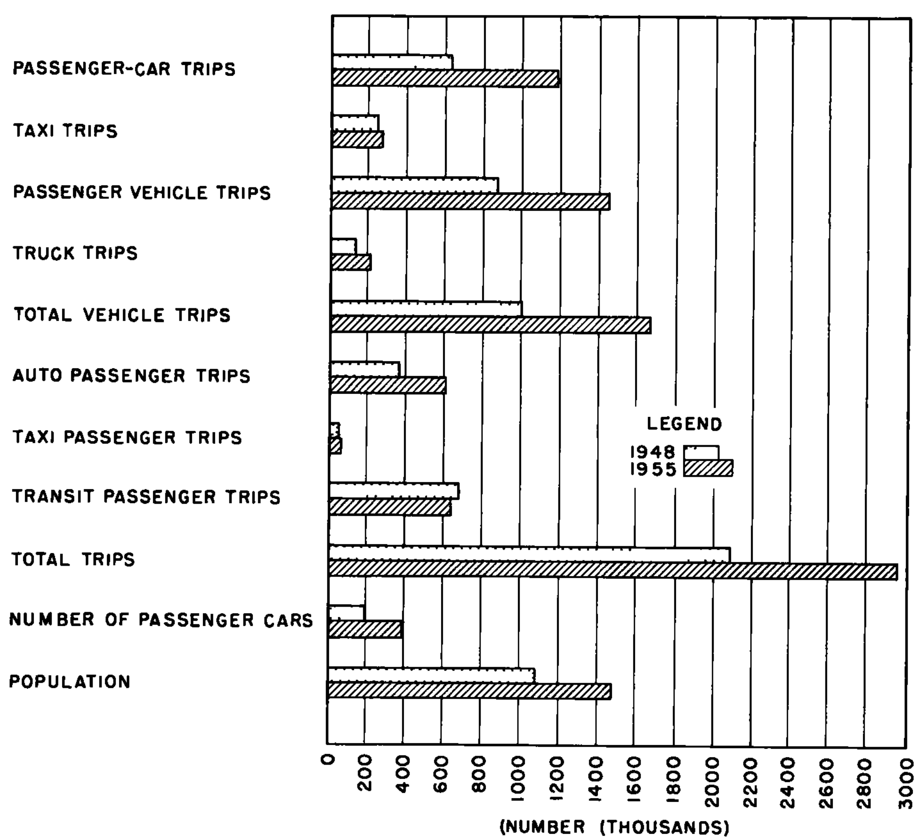

Figure 1. Area within the 1948 cordon, Washington, D. C. Number of trips, cars and transportation 1948-1955.

Most of the external cordon stations in 1955 were placed at different locations from those in 1948, and therefore the trips crossing the cordon, called "external" trips, are omitted from the study, the two surveys not being comparable in regard to this class of trip.

Within the 254 zones the population increased 38 percent during the 7-year interval while the number of trips by persons increased 42 percent. (In this paper "trips by persons" includes trips by drivers of automobiles, taxis and trucks and by passengers in automobiles, taxis and mass transit vehicles. Walking trips and the small number of trips by passengers in trucks are not included.) This represents a small increase in trips per person from 1.95 to 2.00. During the same interval the number of passenger cars owned by residents almost doubled, increasing 96 percent, and the number of

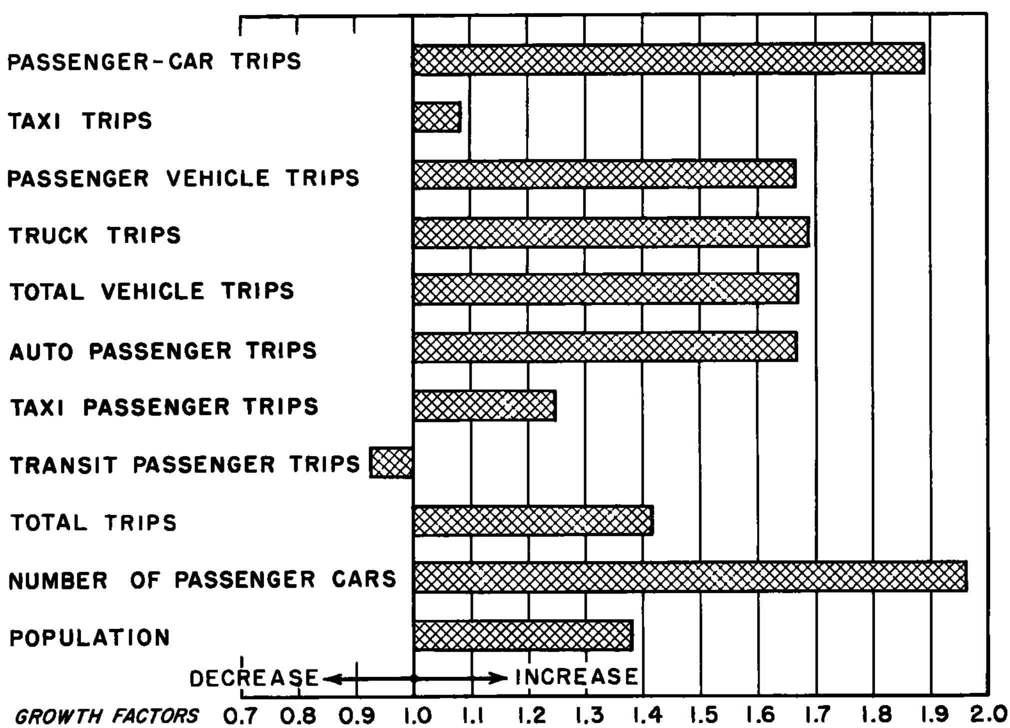

Figure 2. Area within the 1948 cordon, Washington, D. C. Change from 1948 to 1955.

trips made by these passenger cars went up 89 percent. This represents a small decrease in the numer of passenger-car trips per passenger car from 3.15 to 3.05. These figures seem to indicate that the number of car trips increases roughly in proportion to the increase in the number of cars, and total person trips increase about as population does in the Washington area.

The number of trips by various vehicle types and modes of transportation together with the population and passenger-car ownership are shown in Figure 1. The growth factors resulting from the changes between 1948 and 1955 are shown in Figure 2.

The increase of 89 percent in the number of passenger-car trips during the 7-year interval is rather high. It represents an average increase of almost 13 percent annually on a straight-line basis or about 9.5 percent if compounded annually.

This high rate of increase in the Washington area, however, has the advantage of providing growth factors that are somewhat similar to the growth factors that have been forecast for about 25 years in some of the larger cities. For example, the growth factors for total vehicle trips as measured in Washington and those predicted for Detroit and Cleveland are shown in the following table:

Item	Washington	Detroit	Cleveland
Period covered	1948 to 1955	1953 to 1980	1952 to 1975
Over-all growth	1.66	1.67	1.79
Percent of zones with growth factors:			
Less than 1.00	5	2	1
1.00 - 1.49	38	64	54
1.50 - 1.99	25	9	17
2.00 - 2.99	18	9	8
3.00 - 4.99	9	8	15
5.00 - 9.99	3	6	5
Over 10.00	2	2	0

Thus, although the test of the forecasting methods is confined to the growth of Washington from 1948 to 1955, the actual growth factors are not entirely dissimilar to forecasts into the future for Detroit and Cleveland although the latter two are for longer periods of time.

In this study, the passenger-car trips and taxi trips were combined into one category of passenger-vehicle trips The over-all growth factor for these trips was 1.67. As for individual zones, about 6 percent had fewer trip ends in 1955 than in 1948, and 50 percent had a growth factor smaller than 1.55. A more detailed distribution of the individual zone growth factors is as follows:

Growth Factor	Percent of Zones
Less than 1.00	6
1.00 to 1.50	40
1.50 to 2.00	23
2.00 to 3.00	19
3.00 to 5.00	7
5.00 to 10.00	2
Over 10.00	3

METHODS OF FORECASTING TRIPS

The 1948 zone-to-zone trips were expanded to 1955 by various formulas and the predicted values compared with those obtained in the 1955 sample. The actual methods are described as follows:

T_{ij} = Observed 1955 trips between zone i and j

$T_{ij'}$ = Calculated 1955 trips between zone i and zone j

T_{i-j}' = Calculated 1955 trips from zone i to zone j

T_{j-i}' = Calculated 1955 trips from zone j to zone i

t_{ij} = Observed 1948 trips between zone i and zone j

T_i = Summation of observed 1955 trip ends in zone i

t_i = Summation of observed 1948 trip ends in zone i

F_i = Growth factor for zone i $= \frac{T_i}{t_i}$

T = Summation of 1955 trip ends in entire area

t = Summation of 1948 trip ends in entire area

F = Growth factor for entire area $= \frac{T}{t}$

t_{ix} = 1948 trips between zone i and each of all other zones designated as zone x

F_x = Growth factor for zone x

Uniform Factor Method

The most simple method of expanding trips is to compute a single factor for the entire area and use it to multiply all zone-to-zone trips. This particular method is seldom used now, but because of its wide use in the past it was evaluated. Mathematically the expansion formula is as follows:

$$T_{ij}' = t_{ij}\ F$$

There is no possibility of successive approximations with this method, such as those used in the methods subsequently described.

Average Factor Method

In this method each of the 1948 zone-to-zone movements is multiplied by the average of the growth factors for the two zones involved as follows:

$$T_{ij}' = t_{ij} \frac{(F_i + F_j)}{2}$$

After the trips from one zone (i) to all other zones have been computed by this method, the sum of all trip ends in that zone as determined from this calculation (T_i') will probably not equal the actual 1955 trip ends in that zone (T_i). This discrepancy can be eliminated by a series of iterations producing successively closer approximations, as follows:

Let F_i' equal the factor needed to bring the calculated number of trip ends (T_i') to actual number (T_i) or $F_i' = T_i/T_i'$, and similarly $F_j' = T_j/T_j'$

Then for the second approximation, $$T_{ij}'' = T_{ij}' \frac{(F_i' + F_j')}{2}$$

Similarly for a third approximation, $$T_{ij}''' = T_{ij}'' \frac{(F_i'' + F_j'')}{2}$$

The process can be repeated until the F factors for a new iteration equal the limiting value of 1.00.

One of the inherent disadvantages of the average factor method is that the calculated trips into zones with higher-than-average growth factors generally total less than the predicted number of trips. Conversely the calculated trips into zones with lower-than-average growth factors total more than the predicted total of trips. This systematic bias of the predicted values could result in an inordinate number of approximations and may affect the accuracy of the method.

Detroit Method

A method to alleviate this difficulty was developed by Carroll's staff for the Detroit study. In this method they assumed that the trips from zone i will increase as predicted by F_i and will be attracted to zone j in the proportion $\frac{F_j}{F}$. The predicted trips from zone i to zone j can then be calculated as follows:

$$T_{i-j}' = t_{i-j} \frac{(F_i \cdot F_j)}{F}$$

Similarly the trips from zone j can be considered as increasing as predicted by F_j and will be attracted to zone i in the proportion $\frac{F_i}{F}$.

The predicted trips from zone j to zone i can then be calculated as follows:

$$T_{j-i}' = t_{j-i} \frac{(F_j \cdot F_i)}{F}$$

Therefore the number of trips between zone i and zone j is equal to the sum of the trips from i to j and from j to i or

$$T_{ij}' = T_{i-j}' + T_{j-i}'$$

or

$$T_{ij}' = t_{i-j} \frac{(F_i \cdot F_j)}{F} + t_{j-i} \frac{(F_j \cdot F_i)}{F}$$

$$= (t_{i-j} + t_{j-i}) \frac{(F_i \cdot F_j)}{F}$$

$$= t_{ij} \frac{(F_i \cdot F_j)}{F}$$

As in the case of the average factor method the calculated trip ends in a particular zone will probably not equal the predicted trip ends in that zone. Therefore new F factors can be determined as follows:

$$F_i' = \frac{T_i}{T_i'}$$

$$F_j' = \frac{T_j}{T_j'}$$

and a second approximation can be calculated as follows:

$$T_{ij}'' = T_{ij}' \frac{(F_i' \cdot F_j')}{F'}$$

This same procedure can be used to calculate a third and subsequent approximations until the new F factors equal the limiting value of 1.00.

Fratar Method

The first method in which the iterative process was used in predicting future trips was developed by Thomas J. Fratar in connection with the forecast for Cleveland, Ohio. Fratar considers that the distribution of the trips from any zone i is proportional to the present movements out of zone i modified by the growth factor of the zone to which these trips are attracted. The volume of the trips, however, is determined by the expansion factor of zone i.

If the trips between zones i and j, as calculated by considering all trips from zone i are represented by the symbol $T_{ij(i)}'$ and those as calculated by considering all of the trips from zone j by the symbol $T_{ij(j)}'$, then

$$T_{ij(i)}' = t_{ij} \cdot F_j \cdot \frac{\Sigma (t_{ix} \cdot F_i)}{\Sigma (t_{ix} \cdot F_x)} \qquad (1)$$

Noting that $\Sigma t_{ix} \cdot F_i$ can also be written as $F_i \cdot \Sigma t_{ix}$ then Eq. 1 can be written as

$$T_{ij(i)}' = t_{ij} \cdot F_j \cdot F_i \cdot \frac{\Sigma t_{ix}}{\Sigma (t_{ix} \cdot F_x)} \qquad (2)$$

The last term in Eq. 2 basically represents the reciprocal of the average attracting pull of all other zones on i. It has been labeled the "Location" or "L" factor since it is somewhat dependent on the location of the zone with respect to all other zones. Thus since

$$\frac{\Sigma t_{ix}}{\Sigma(t_{ix} \cdot F_x)} = L_i \qquad (3)$$

Eq. 2 can be rewritten as

$$T_{ij(i)}' = t_{ij} \cdot F_j \cdot F_i \cdot L_i \qquad (4)$$

Then for all trips from zone j, it can similarly be shown that

$$T_{ij(j)}' = t_{ij} \cdot F_i \cdot F_j \cdot L_j \qquad (5)$$

Thus the trips between zone i and zone j have been computed twice—once for all trips out of zone i and once for all trips out of zone j. The most probable value is an average of the two computations or

$$T_{ij}' = \frac{T_{ij(i)}' + T_{ij(j)}'}{2} \qquad (6)$$

Substituting the identities from Eqs. 4 and 5 into Eq. 6 and factoring out the common terms, the final equation is developed

$$T_{ij}' = t_{ij} \cdot F_i \cdot F_j \cdot \frac{(L_i + L_j)}{2} \qquad (7)$$

After all the zone-to-zone trips have been computed by this formula, the calculated trip ends in a particular zone will probably not agree with the predicted trip ends in that zone. Therefore new factors can be calculated as follows:

$$F_i' = \frac{T_i}{T_i'}$$

$$F_j' = \frac{T_j}{T_j'}$$

$$L_i' = \frac{\Sigma T_{ix}'}{\Sigma T_{ix}' \cdot F_x'}$$

$$L_j' = \frac{\Sigma T_{jx}'}{\Sigma T_{jx}' \cdot F_x'}$$

A second approximation can then be calculated as follows:

$$T_{ij}'' = T_{ij}' \cdot F_i' \cdot F_j' \cdot \frac{(L_i' + L_j')}{2}$$

The same procedure can be used for subsequent approximations until the new F factors equal the limiting value of 1.00.

THE PROBLEM OF EVALUATION

With the Washington area divided into 254 zones, the number of possible zone-to-zone movements is $\frac{N(N+1)}{2} = 32,385$. (Zone-to-zone movements as used in this article also include intrazone movements.) It was expected that some of the zone-to-zone movements would be zero in 1948 and 1955 and would not need to be computed. However, it was estimated conservatively that perhaps 30,000 of the 1948 zone-to-zone movements would require expansion to 1955.

To determine whether the accuracy of the prediction was influenced by vehicle type or mode of transportation, the trips were separated by mode of travel into six categories: passenger-vehicle trips, truck trips, total vehicle trips, transit-passenger trips, auto-passenger trips, and total trips by persons; and each group was expanded separately.

Expanding each of the 30,000 zone-to-zone trips made in 1948 would be almost meaningless unless some method of summarizing the comparison to the 1955 survey movements had been determined. The most obvious answer to this problem was to subtract the computed number of trips from the reported number of 1955 trips, square the difference and accumulate the result. The sum of the differences squared could then be used to calculate the root-mean-square error of the number of trips as expanded from the 1948 data.

This summary, however, had a serious disadvantage in that the actual volume of zone-to-zone trips varies from zero to several thousand. A root-mean-square error could be inordinately affected by the relatively few large movements. Similarly, if the difference were converted to a percentage of the 1955 actual movement and the root-mean-square of the percentage computed, the result could be as greatly affected by the small movements that probably lack sufficient stability to provide meaningful information. It was therefore decided to stratify the 1948 movements by volume classes, thus: by volumes of tens to 100, by volumes of hundreds to 1,000, and all volumes over 1,000. The numerical root-mean-square error was then computed for each volume class and the percentage error for the class was obtained from the ratio of the numerical root-mean-square to the average 1955 volume. The proportion of all 1955 volumes in each volume class was then determined and each of the percentage errors was weighted by the proper proportion to obtain the over-all percentage error.

The over-all percentage error as described above was regarded as the proper measure to evaluate the various predictive formulas. In addition, the accuracy of larger movements could be measured by an extrapolative process in which the number of average zone-to-zone movements required to make up a larger volume was determined and the basic error was divided by the square root of the number of movements required.

In addition to the computation described above, it was desirable to know the root-mean-square error for each of the zones so that the error can be related to the growth factor of the individual zones. Therefore, the difference between the expanded 1948 and the 1955 movements squared was accumulated for each of the zones. It was considered likely that from this computation any inordinate error found in a particular zone could be recognized.

As has been previously explained, it is possible to carry the average factor method, the Detroit method, and the Fratar method through a number of iterations to produce successively closer approximations. To be reasonably certain that this process was continued a sufficient number of times, it was decided to calculate 10 successive approximations by each method.

NEED FOR AN ELECTRONIC COMPUTER

It has been estimated that roughly 25 million computations would be required for this test. On the very optimistic basis that one computation can be completed in 10 seconds, using ordinary desk calculators, the project would require some 30 man-years for completion. Clearly this is not feasible. However, with electronic computers, the time required can be reduced enormously.

The three methods that use iterations are similar in that the input for the first calculation is made up of the original data, the output of this calculation and each successive iteration becomes the input of the next iteration and so on until 10 calculations have been made if necessary for satisfactory closure. In addition each iteration of the Fratar method requires two passes of the input—one to determine the L factor and one to make the required expansion. Thus, the 30,000 zone-to-zone movements have to be processed 42 times, including the one pass of the data required to obtain the original growth factors.

In deciding upon the particular type of computer to be used, the first problem was to decide whether to use one with card input and output, or one with tape. The card type would require about 200 hours of computer time provided sufficient memory were available. With tape, only about 10 hours of computer time, or less would be required, again assuming sufficient memory, so obviously the tape-using type was preferable. In the actual test, 30 hours of computer time were used principally due to additional tests on larger zone groupings.

COMPUTER CHARACTERISTICS

Computer problems in general fall into two categories—data-processing problems and computation problems. For instance, a problem of testing forecasting methods, requires a great deal of input and output but rather simple internal operations and is properly classified as a data-processing problem. On the other hand computing such things as log tables or trigonometric functions requires much computation but very little input and output.

The problem then was to select a machine designed to process data with good "read and write" characteristics and with a large memory. Part-time use of an IBM 705 machine which met all these requirements very well was arranged. The machine had a core memory of 40,000 characters. The memory capacity of computers is sometimes reported in "characters" and sometimes in "words." In computer terminology, a "character" may be a digit, a letter or a symbol, while a "word" consists of a group of characters. In some computers the work is of a constant length and in other computers the word length may be varied at the option of the programer. The computer used was a variable-word-length machine and the core-memory capacity is therefore given in characters rather than words.

The machine was equipped with two tape-record coordinators, more commonly referred to as buffers. The purpose of the buffers is to shorten the reading and writing time. Each buffer has a core storage capacity of 1,024 characters. The buffers are loaded from the tape units, and when the computer requires more data it obtains it at electronic speed from the buffer. As soon as the buffer is called upon for data, the tape unit feeding it begins to accelerate, so that by the time the buffer is empty the tape unit has begun to refill it with the next record to be processed. The same process works essentially in reverse for output. Thus the machine can go on with other work while records are being fed into and out of the buffers.

The 1,024-character capacity of the buffers also allows a number of card records to be grouped so that when the buffer calls on the tape units for data, one tape record can receive information from a number of cards without exceeding the buffer capacity. The program for this study was designed to have the machine read or write the equivalent of 24 cards of information per reading or writing cycle. As it turned out in production, the computer took a longer time to process the data on the 24 cards than was required to fill or empty the buffers so that the machine never had to wait for data, and all reading or writing time was essentially "free."

The 705 is a decimal machine, meaning that the entire content of memory is in condition always to be printed out as alpha-numeric information directly without conversion from binary to decimal. The machine performs internal operations at an average rate of 8,300 per second.

PREPARATION OF PROGRAM

This was the first large scale electronic computer project done by the Bureau of Public Roads, therefore, the services of the Bureau of Standards Computer Laboratory were retained to aid in the selection of the machine and in the preparation of the program. Their wide experience in this field has proven invaluable in the completion of this work.

In programing the problem the first difficulty was one of memory space, in spite of the large amount available. It was necessary to overlap the program and resort to external tape storage. Even so it was necessary to split the problem into two parts. All of the vehicle types (passenger cars, trucks, and total vehicles) were handled in the first run. The second run processed the person trips: auto passengers, transit passengers, and total persons. The same basic program was used for both runs, however.

It was necessary to prepare a preliminary program in order to group the single card records into groups of 24, which is the maximum number of cards within buffer capacity, and to separate them into vehicle or person categories. Included in this preliminary program was an editing routine, a volume-classification routine, and a check-sum routine. The editing routine rejected any cards with alphabetic information, for example, over-punches and inconsistent zone numbers. The volume classification routine classified the 1948 volumes of trips into 20 volume classes. The check-sum routine summed all the volumes by modes and zones and compared the totals with a 254-card summary deck prepared independently. The preliminary program also permitted the preparation of the main program while the input data were being compiled. Any changes in the arrangement of the data taken from the cards could be taken care of in the first program without affecting the main program.

The program was designed to have all the final output written on tape for subsequent printing. It was found that the machine would be slowed down a great deal if a printer were connected "on line." As originally designed, there was one line of printed information for each of 20 volume classes times 6 modes of travel, one line for each of 254 zones times 6 modes, and one line for each over-all citywide volume for each of the 6 modes. For all of the methods tested, with their iteration, this amounted to 52,800 printed lines, or almost 1,760 pages—a real data-processing problem.

TEST RESULTS

The initial run of the computer was made for vehicle trips by passenger cars, trucks, and total vehicles. The 1948 zone-to-zone movements were projected to 1955 by a uniform factor, by the average factor method, by the Detroit method, and by the Fratar method. These projected or "forecasted" results were compared with the measured 1955 volumes and the differences were squared, accumulated, and used to compute a root-mean-square error for the average movement, for the various volume classes and for the individual zones.

These results are shown in Table 1 for the three types of vehicle trips. So far as number of trips is concerned, the errors are not large, considering that the sample was as small as 1 in 30 for an important part of the data, and in no case larger than 1 in 10. On a percentage basis, however, the errors are very large.

When the results of the first computer run became available, the question immediately arose whether the errors were primarily attributable to the forecasting methods being tested or to the preponderance of low-volume zone-to-zone movements, which are known to lack accuracy or stability at the sample rates used.

This problem was attacked by two methods. One was by a systematic enlargement of the zones to increase the volume of the zone-to-zone movements and then testing these larger volumes through the computer program. The other method was to determine the percentage distribution of the zone-to-zone trip volumes within the city and by statistical techniques to determine the accuracy that might be expected in the original trip expansion. If the 1948 zone-to-zone trip volumes as expanded from the sample were unreliable, the error would be carried on into the forecast data, and if the 1955 expanded volumes were also unreliable, the result could be to compound the effect of the errors due to sample variability in comparing the forecasts with the 1955 data.

Enlarging Zones

Inasmuch as zone boundaries are chosen from land-use and geographic features, the number of trip ends in each zone is not uniform. In this study the variability was intensified by the fact that the area had to be rezoned so that it would be identical in both years, and the trip ends in the individual zones vary over wide limits. For example the number of 1948 passenger-vehicle trip ends averaged 6,900 per zone but varied from as little as 193 to as much as 59,870. As the initial step, therefore, adjacent zones were combined until each zone group had a minimum of 10,000 passenger-vehicle trip ends in 1948. To minimize the effect of sample variability on the errors, this procedure was repeated to accumulate a minimum of 20,000 trip ends per zone group, and again to accumulate a minimum of 30,000 trip ends per group, then to divide the entire area into 7 groups and finally into 2 groups.

TABLE 1

ROOT-MEAN-SQUARE ERROR IN THE NUMBER OF ZONE-TO-ZONE TRIPS FORECASTED FOR 1955 FROM 1948 DATA, COMPARED TO 1955 SURVEY RESULTS, EXPRESSED IN NUMBER OF TRIPS AND PERCENTAGE

Approximation Number	Numerical RMS Error Uniform Factor	Average Factor	Detroit	Fratar	Percent RMS Error[1] Uniform Factor	Average Factor	Detroit	Fratar
				Passenger Cars[2]				
1	165	133	234	140	151	136	192	140
2		132	129	131		136	133	134
3		133	148	132		136	143	134
4		134	129	132		137	133	135
5		134	136	132		137	137	135
6		135	131	132		138	134	135
7		135	133	132		138	135	135
				Trucks[2]				
1	18	57	59	55	163	160	172	162
2		55	58	55		160	161	161
3		55	55	55		161	163	161
4		55	56	55		162	161	161
5		55	55	55		162	162	161
6		55	55	55		162	161	161
7		56	55	55		162	162	161
				Total Vehicles[2]				
1	174	137	229	138	141	124	175	125
2		133	131	130		122	120	120
3		133	144	131		121	128	121
4		133	129	131		122	119	121
5		133	134	131		122	122	121
6		133	130	131		122	120	121
7		133	132	131		122	121	121

[1] Calculated by determining the error in the various volume groups and weighting the error in each group in proportion to the percentage of all trips in that group.
[2] Calculated on the basis of number of zone-to-zone movements that had more than 0 trips in either 1948 or 1955.
Passenger cars average zone-to-zone volume = 84,
Trucks average zone-to-zone volume = 28;
Total vehicles average zone-to-zone volume = 90.

The number of zones in these successive groupings, the number of 1948 passenger-car trip ends in the average zone, and the average number of area-to-area trips are as follows:

Number of Areas	Number of Trip Ends Per Area Minimum	Average	Number of Area-to-Area Possibilities	Average Number of Area-to-Area Trips
254 zones	193	6,900	32,385	27
122 groups	10,000	14,400	7,503	116
66 groups	20,000	26,600	2,211	394
49 groups	30,000	35,800	1,225	711
7 groups	214,305	250,000	28	31,092
2 groups	731,000	870,000	3	290,192

Test Results of Enlarged Zones

The results of tests of each forecasting procedure for the various zone groupings are shown in Table 2. The average-factor method, the Detroit method, and the Fratar method each reach essentially the same minimum error although the Fratar method reaches this minimum in the second approximation, whereas more iterations are generally required for the other methods.

The minimum percentage error, by any of the methods tested after any number of iterations, for the various zone groups and the average number of area-to-area passenger-car trips were as follows:

Number of Areas	1948 Average Number of Area-to-Area Trips	Minimum Percent Error
254 zones	27	133
122 groups	116	70
66 groups	394	41
49 groups	711	34
7 groups	31,092	14
2 groups	290,192	11

In the case of the 2-group division a second test was made by dividing the area with a line roughly at right angles to the first. The minimum percent error for this second grouping was the same as that for the first, to the nearest percent (11 percent).

TABLE 2

ROOT-MEAN-SQUARE ERROR OF THE FORECASTED 1955 PASSENGER CAR TRIPS FOR THE 254 ZONES AND FOR DIFFERENT ZONE GROUPINGS

Approximation Number	254 Zones Error in Trips Number	254 Zones Error in Trips Percent[1]	122 Groups Error in Trips Number	122 Groups Error in Trips Percent[1]	66 Groups Error in Trips Number	66 Groups Error in Trips Percent[1]	49 Groups Error in Trips Number	49 Groups Error in Trips Percent[1]	7 Groups Error in Trips Number	7 Groups Error in Trips Percent[1]
					Uniform Factor Method					
	165	151	415	98	499	57	747	49	19,641	38
					Average Factor Method					
1	133	136	244	77	458	49	655	42	10,180	20
2	132	136	204	72	364	44	542	37	8,300	16
3	133	136	196	71	344	43	517	36	7,810	15
4	134	137	194	71	338	42	509	35	7,690	15
5	134	137	193	71	337	42	507	35	7,540[2]	15
6	135	138	193	71	336	42	506	35		
7	135	138	193	71	336	42	506	35		
					Detroit Method					
1	234	192	388	89	720	64	871	51	10,300	20
2	129	133	228	74	396	46	543	37	8,960	17
3	148	143	299	74	344	42	504	35	7,700	15
4	129	133	194	70	337	42	484	34	7,510	15
5	136	137	196	70	320	41	478	34	7,500	15
6	131	134	189	70	326	41	480	34	7,570	15
7	133	135	190	70	319	41	476	34	7,480	14
					Fratar Method					
1	140	140	205	71	339	42	498	35	7,360	14
2	131	134	188	70	322	41	480	34	7,460[2]	14
3	132	134	188	70	322	41	478	34		
4	132	135	188	70	321	41	479	34		
5	132	135	188	70	322	41	478	34		

[1] A weighted percent error obtained by determining the percent error in each volume class and weighting this error by the proportion of trips in that volume class. Not applicable for the 7 zone group because all volumes were in the largest volume class.
[2] No further iterations required because new F factor for all zones was 1.00.

The relationship between average area-to-area trip volume and the minimum percent error is shown in Figure 3. As the minimum error for the three iterative methods is about the same, the chart can be considered as applicable to any one of them. This chart is difficult to interpret because part of the error is due to sample variability and part is due to the projection method being tested. Differences in sampling rate introduce a further complication. In the 1948 survey the sampling ratio was 1:20 throughout the area, while in the 1955 survey it was 1:30 for the District of Columbia and 1:10 for the Maryland and Virginia suburbs. However, the curve should give some indication of the error to be expected in using any of the three iterative methods where the sampling rate is about the same as the average for the two Washington surveys, that is, about 5 percent.

The shape of the curve suggests that it will level off at about 10 percent. In other words an error of about 10 percent seems to be inherent in the methods tested, regardless of size of sample or areas.

Rate of Closure. A measure of the efficiency of the various forecasting methods is the rapidity with which the individual zone growth factors converge toward the limiting F factor of 1.00 in successive iterations. The difference between the computed F factor at the end of an iteration and 1.00 is the factor residual error that remains in the individual zones.

The factor residual error for the 254 zones is shown in the following tabulation for the various iterations of the three methods. The first column indicates the method and the second column indicates the approximation number. The third column shows the percent of the zones that have no residual error (new F factor = 1.00) at the end of the approximation shown in the second column. The fourth column indicates the percent of zones with a residual error less than 0.01 (new F factor between 0.99 and 1.01). The next four columns similarly show the percent of zones with residual errors less than 0.02, 0.03, 0.05, and 0.10. The last column shows the percent of zones with residual errors greater than 0.10 (new F factor less than 0.90 or more than 1.10).

Method	Approximation No.	Percent of zones with a factor residual error of—						
		0.00	Less than 0.01	Less than 0.02	Less than 0.03	Less than 0.05	Less than 0.10	0.10 and over
Average factor	1	1	8	11	17	26	47	53
	2	6	15	24	35	50	75	25
	3	10	30	44	55	77	93	7
	4	19	47	71	84	98	99	1
	5	33	70	88	93	98	99	1
	6	49	84	92	94	98	100	0
	7	64	92	97	99	100	100	0
Detroit	1	2	4	9	14	23	44	56
	2	1	3	11	15	22	57	43
	3	4	13	25	37	63	95	5
	4	5	18	38	58	95	98	2
	5	10	36	68	93	98	99	1
	6	16	62	95	97	98	100	0
	7	28	85	98	99	100	100	0
	8	37	96	99	100	100	100	0
Fratar	1	6	20	33	54	68	79	21
	2	60	97	100	100	100	100	0
	3	98	100	100	100	100	100	0
	4	99	100	100	100	100	100	0

As can be seen from this table the Fratar method is extremely efficient in its rate of closure. Since the F factor must be obtained for each new iteration and since these new F factors may be easily summarized, it is suggested that they be used to indicate the desirability for additional iterations.

Number of Iterations Required. From the tests that have been run, the minimum root-mean-square error has always been reached in the second approximation by the Fratar method. By the other methods, however, this minimum error may not be reached until the fourth or fifth approximation. There is also a possibility that an unusual set of growth factors will develop that will not close as rapidly as those occurring in the test data.

Considering the division of the Washington, D.C., area into 49 zone groups with a minimum of 30,000 passenger-car trip ends per group, the factor residual error was accumulated for all groups at the end of each iteration. The accumulated residual error was then divided by the number of groups to obtain the average residual error per group. This average residual error was then related to the RMS error already computed for each approximation. The following table indicates the results:

Approximation No.	Average Factor		Detroit		Fratar	
	Average residual error	RMS error	Average residual error	RMS error	Average residual error	RMS error
		(percent)		(percent)		(percent)
1	0.084	42	0.123	51	0.035	35
2	0.034	37	0.070	37	0.003	34
3	0.014	36	0.032	35	0.001	34
4	0.007	35	0.022	34	[1]	34
5	0.003	35	0.014	34	[1]	34

[1] Less than 0.001

To be reasonably certain that greater accuracy cannot be obtained with additional iterations, it is suggested that iterations be continued until the average residual error per zone is less than 0.01.

The computer time required for each method, however, is not uniform but is approximately related to the complexity of the method. During the test, the computer time as recorded for each iteration of each method and adjusted proportionately to a common base of 10,000 zone-to-zone movements is as follows:

TABLE 3

PERCENT ROOT-MEAN-SQUARE ERROR BY VOLUME CLASS OF ZONE-TO-ZONE MOVEMENTS—PASSENGER VEHICLES

1948 Volume Class	254 Zones	122 Zone Groups	66 Groups	49 Zone Groups
20-29[1]	195.0	121.0	95.6	106.1
30-39	222.1	101.4	86.7	83.4
40-49	279.7	118.1	81.5	73.4
50-59	141.0	96.3	82.3	89.4
60-69	139.9	107.5	92.6	89.7
70-79	108.4	74.2	78.2	76.2
80-89	154.3	95.2	94.9	54.4
90-99	128.2	83.0	54.8	73.2
100-199	133.4	93.3	64.8	64.8
200-299	80.5	69.7	58.6	52.1
300-399	60.7	64.0	56.0	43.8
400-499	54.9	56.6	50.9	38.4
500-599	42.6	42.3	45.9	44.1
600-699	51.2	40.6	46.7	48.6
700-799	88.8	41.1	31.1	26.5
800-899	38.9	26.5	57.2	31.6
900-999	18.4	21.4	33.1	38.4
Over-1,000	28.6	27.5	21.2	25.3

[1] Because of home interview sampling ratio of 1.20 in 1948, errors for volume classes below 20 cannot be accurately appraised.

Computer time per iteration of 10,000 area-to-area movements:

Average factor method - 6 minutes
Detroit method - 9½ minutes
Fratar method - 12 minutes

From this, the computer time required for the average factor method is half that required for the Fratar method. These times, however, include the computer time needed to develop and store the various statistical measures. In an ordinary forecasting procedure these measures would not be required and the above times would be reduced by a constant but indeterminate amount. The average factor method should therefore require something less than half the time per iteration required by the Fratar method.

Since the RMS error for the average factor method at the end of four approximations is about equal to the RMS error for the Fratar method at the end of two approximations, the over-all computer time required for equal RMS accuracy is about the same. However, the rate of closure of the Fratar method is more than twice as rapid as the average factor method and it would therefore appear to be the preferred method.

Percent RMS Error for Accumulated Volumes

The data presented thus far have to do only with the error for the area-to-area volumes. As has been shown, the average volume between zones of the size ordinarily used is relatively small and the percent root-mean-square error is, roughly speaking, correspondingly large.

In actual practice, the individual zone-to-zone volumes are assigned to the highway network and, therefore, each portion of the highway network represents an accumulation of zone-to-zone volumes. The volumes assigned to the highway network are our primary concern. The errors to be expected in such accumulated volumes can only be determined from actual tests and these have not yet been made. However, some indication of the magnitude of the errors to be expected can be obtained from purely theoretical considerations.

From a statistical standpoint, if the percent error of an average zone-to-zone volume is X, the percent error of a group of average zone-to-zone volumes is $\frac{X}{\sqrt{N}}$ where N is the number of individual zone-to-zone movements in the group. By dividing 10,000 by the average zone-to-zone volume for each of the zone groupings, the number of zone-to-zone movements (N) required to accumulate to a volume of 10,000 can be determined and the percent RMS error of the group can therefore be calculated.

The above relationship holds true only if the mean error of the group is zero. If the movements, however, are heavily weighted by trips from an individual zone, as they would be in the case of ramp volumes, the factor residual error (as previously explained) may be appreciable in the early iterations.

For example, if the trips on a ramp are essentially from two zones and these two zones have an average F factor for the next iteration of 1.30, the summation of trips into and out of the zones at the end of the present iteration are too low. The total number of trips for a group of zone-to-zone movements from these zones, therefore, will have a tendency to approach a volume which should be increased by 30 percent. To take this error into account, the root-mean-square of the residual errors was determined for each iteration of each method. The number of zones required to provide a volume of 10,000 was determined and the root-mean-square residual error was added to the RMS error for individual zone-to-zone movements by taking the square root of the sum of the squares of the two errors to determine the total error. The results of this test are shown in Figure 4.

Assuming that this chart has some validity with reference to the problem, it indicates that the error for a volume of 10,000 trips is within acceptable limits and that it does not make too much difference what size zone group is used although a minimum error was obtained for the zone grouping which had 10,000 trip ends per group. Manifestly, however, this conclusion is dependent, to a substantial degree, on statistical inference and should be subjected to an actual test before it can be fully accepted.

Distribution of Zone-to-Zone Volumes

Even though the accumulated volumes of 10,000 or more apparently will have errors of rather modest proportions, it is desirable to inquire into the reasons for the inaccuracies of the movements between zones as they were originally planned and subsequently enlarged.

The test program was set up to count the number of zone-to-zone movements in each of several 1948 volume classes as previously described. This procedure was followed for the original 254 zones and for the subsequent groupings to 122 areas, 66 areas, and 49 areas.

The results of this test are shown in Figure 5 for passenger cars (including taxis). About 93 percent of the movements between the 254 zones have a volume of less than 100. When the number of areas was reduced to 122, about two-thirds of the area-to-area movements were less than 100; with 66 areas about one-fourth of the movements were less than 100; and with 49 areas about 10 percent were less than 100. Also, the number of area-to-area movements which are less than the mean exceeds the number that are greater than the mean showing that the distribution is skewed. This is true for each of the zone groups although slightly less pronounced as the number of areas is successively decreased.

The test program also permitted the determination of the percent of the 1955 trips that were accumulated in each of the 1948 volume classes (Fig. 6). Fifty percent of

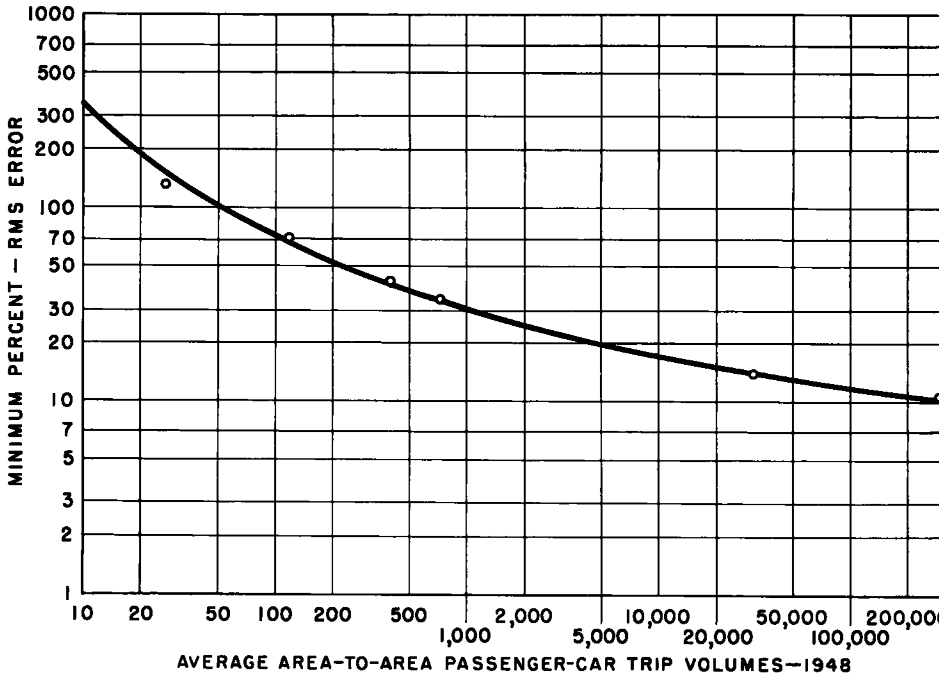

Figure 3. Relationship between average 1948 passenger car trip volume and the minimum percent RMS error.

the 1955 passenger-car trips were made between zone pairs that, in 1948, had a volume of less than 100 passenger-vehicle trips per day. Values for other zone groups and other 1948 volumes can be read from the chart.

In summation then, the preponderance of zone-to-zone movements within a metropolitan area is exceedingly small but because of the large number of such movements, they do, in the aggregate, account for a substantial portion of the present or predicted trips.

Prediction Error as Related to Zone-to-Zone Volume

There is, of course, no a priori reason why small zone-to-zone volumes cannot be forecast with accuracy equal to large zone-to-zone volumes. The converse would likely seem true, that the forecast error should be independent of the volume.

However, there is a priori probability that the error in the expanded number of trips from a "sample" survey is inversely proportional to the number of "sample" trips interviewed as shown below.

Of all trips into and out of zone i there is a certain proportion (p) that will be from or to zone j. Therefore, (p) is the proportion of trip ends in zone i with the other end of the trip in zone j and i-p (equals q) is the proportion of trip ends in zone i that do not have the other end of the trip in zone j.

If (s) trips with an end in zone i are reported by interview, the probable number ($\bar{X}$) with the other end in zone j is (s.p). Mathematically: $\bar{X} = sp$

From any standard statistical text it can also be shown that the standard deviation (σ) of the number of trips reported between zone i and zone j from sample interviews made of trips with one end in zone i is $\sqrt{spq}$. Mathematically: $\sigma = \sqrt{spq}$

The standard deviation (σ) as a proportion of the expected number ($\bar{X}$) is:

$$\frac{\sigma}{X} = \frac{\sqrt{spq}}{sp} = \sqrt{\frac{q}{sp}}$$

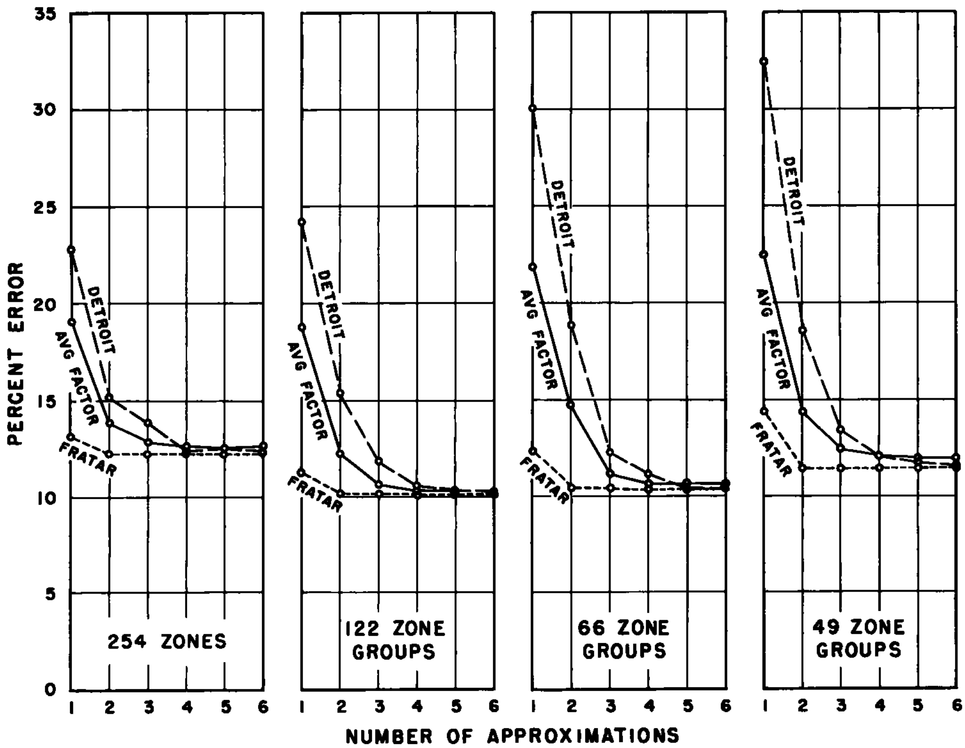

Figure 4. Percent error to be expected for 10,000 trip volumes based on theoretical conditions.

Since p and q are constants for any pair of zones, the percent error varies inversely with the square root of the number of trips between zone i and zone j obtained by interview.

For 254 zones p will have an average value of $\frac{1}{254}$ and q of $\frac{253}{254}$. Thus,

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{\frac{253}{254}}{\frac{s}{254}}} = \sqrt{\frac{253}{s}}$$

Again the average zone had 6,900 trip ends in 1948, of which about 345 were obtained by interview, so on the average s = 345

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{253}{345}} = 0.86$$

Thus, for an average movement in 1948 a standard deviation percent error of 86 percent could be expected.

Since the test of forecasting procedures uses the reported 1948 trips as the base data for calculating the 1955 trips and then compares the result with the reported 1955 trips, it would be expected that the error would be increasingly large for the smaller grip volumes, not because of errors in the forecasting procedure but due to sample variability.

The RMS error in the various 1948 volume classes for passenger vehicles in the seventh approximation by the Fratar method behaves in this manner as is shown in Table 3 for each of the zone groups.

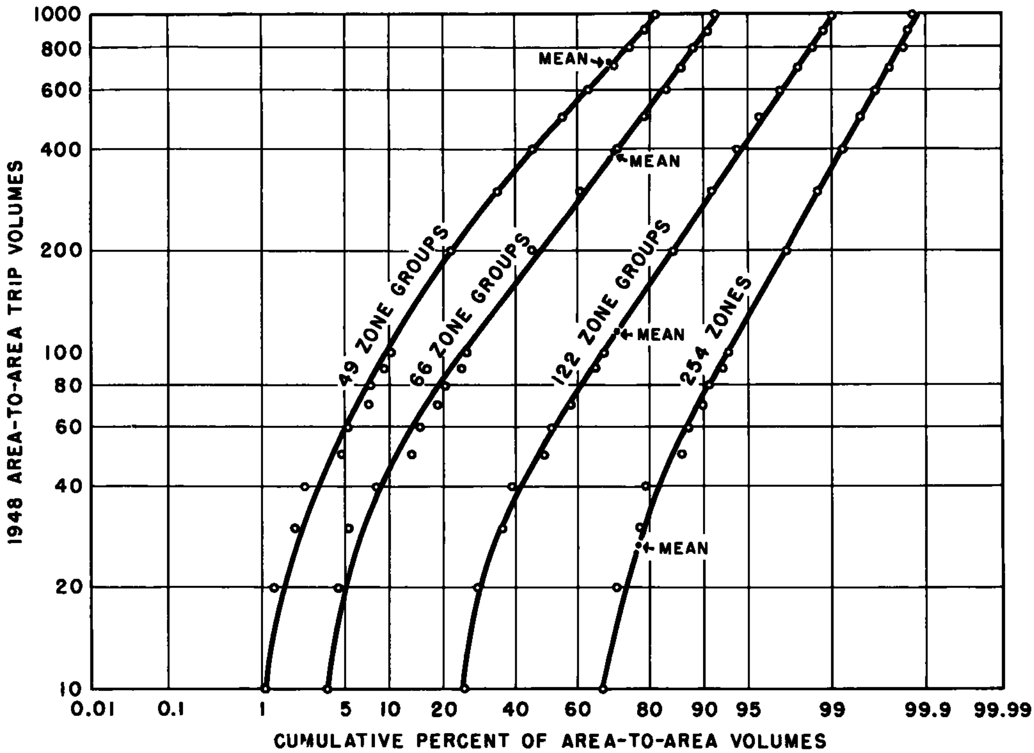

Figure 5. Frequency of 1948 area-to-area trip volumes with various zone groupings. (passenger cars)

RECOMMENDED PROCEDURES

The primary purpose of forecasting zone-to-zone volumes is for the selection and assignment of trips to a transportation network. To do this with reasonable accuracy particularly at each ramp on an expressway network, it is imperative that the zones be of a size consistent with the distance between ramps. Thus, while increasing the size of the zone increases the accuracy of predictions of the zone-to-zone movements, this procedure adversely affects the primary purpose of forecasting. Pending further studies as outlined at the end of this article, it is recommended that zones be established in accordance with present practice and that the zone-to-zone movements be forecast by the Fratar method.

Figure 7 is a flow chart for accomplishing this forecast on an electronic computer. This chart is made up for an input of zone-to-zone volumes as file A and a combination input of present trip ends, future trip ends and growth factors by zones as alternate inputs for file B. The program includes appropriate editing routines for checking the present trip ends and the growth factors if these are available independently from the zone-to-zone volumes in file A. The switches shown on the flow chart are programmed transfer points resulting from decisions made at a remote point in the program. They are not switches on the console of the computer.

A program written from this flow chart includes the computation of the frequency of the new F factors, to be used as a guide for determining the need for continuing additional iterations.

FUTURE RESEARCH

The work to date indicates that the three iterative methods are equally accurate in computing the future trips but the Fratar method arrives at the minimum error in fewer

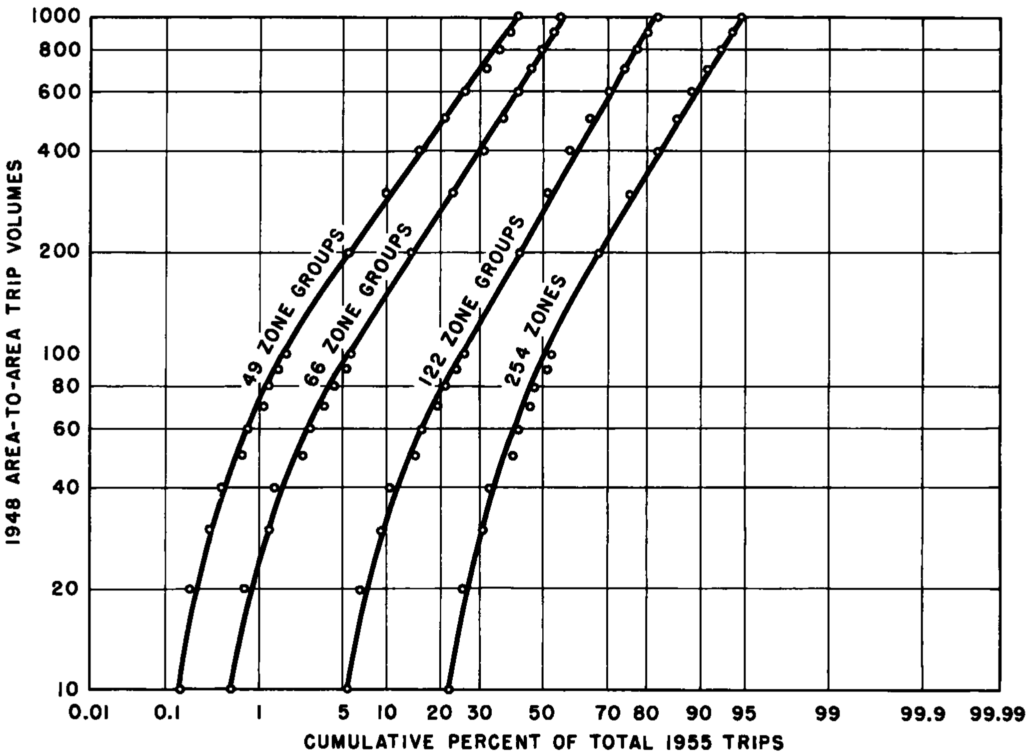

Figure 6. Cumulative percent of 1955 trips by 1948 area-to-area trip volumes with various zone groupings.

approximations. It is also more efficient in its rate of closure.

In addition it has been found that the preponderant small volume movements are individually affected by an inherent sample variability. The summation of these movements accounts for a substantial portion of the total trips. It is also known that the small volume zone-to-zone movements are, on the average, the longer trips within the city that account for proportionately more vehicle-miles of travel and are also the trips most likely assignable to high-type highway facilities.

Accumulating Trips Across A Grid

However, it is not necessary that the individual zone-to-zone movements be accurate if a summation of these volumes crossing the city is reasonably representative of the actual travel. To determine this relationship it is proposed that each zone-to-zone movement be traced from the X and Y coordinates of one zone to the X and Y coordinates of the other. Each time this trace intersects a predetermined section of a grid line the number of 1955 trips for this zone-to-zone movement as projected from the 1948 data and the number as determined from the 1955 survey are "remembered." When all zone-to-zone movements have been similarly traced, the number of "remembered" trips over an appropriate interval of each grid line is totaled. The comparison of the total number of trips projected from the 1948 data with the total number determined from the 1955 survey will give a measure of the accuracy of the projection.

The use of the trace principle automatically "weights" the longer trips properly in that longer trips will cross many grid lines whereas the short trips may cross none or only a few. Further, by choosing an appropriate length along each grid line, the summation of trips to various volumes can be accomplished.

While the trace method appears as a difficult manual task it is comparatively simple to program for an electronic computer and would require about the same computer time as a single iteration of the Fratar method if the number of grid lines is held to a reasonable minimum.

Stabilizing the Small-Volume Movements

Another research project which should be undertaken is the testing of methods for stabilizing the small-volume zone-to-zone movements.

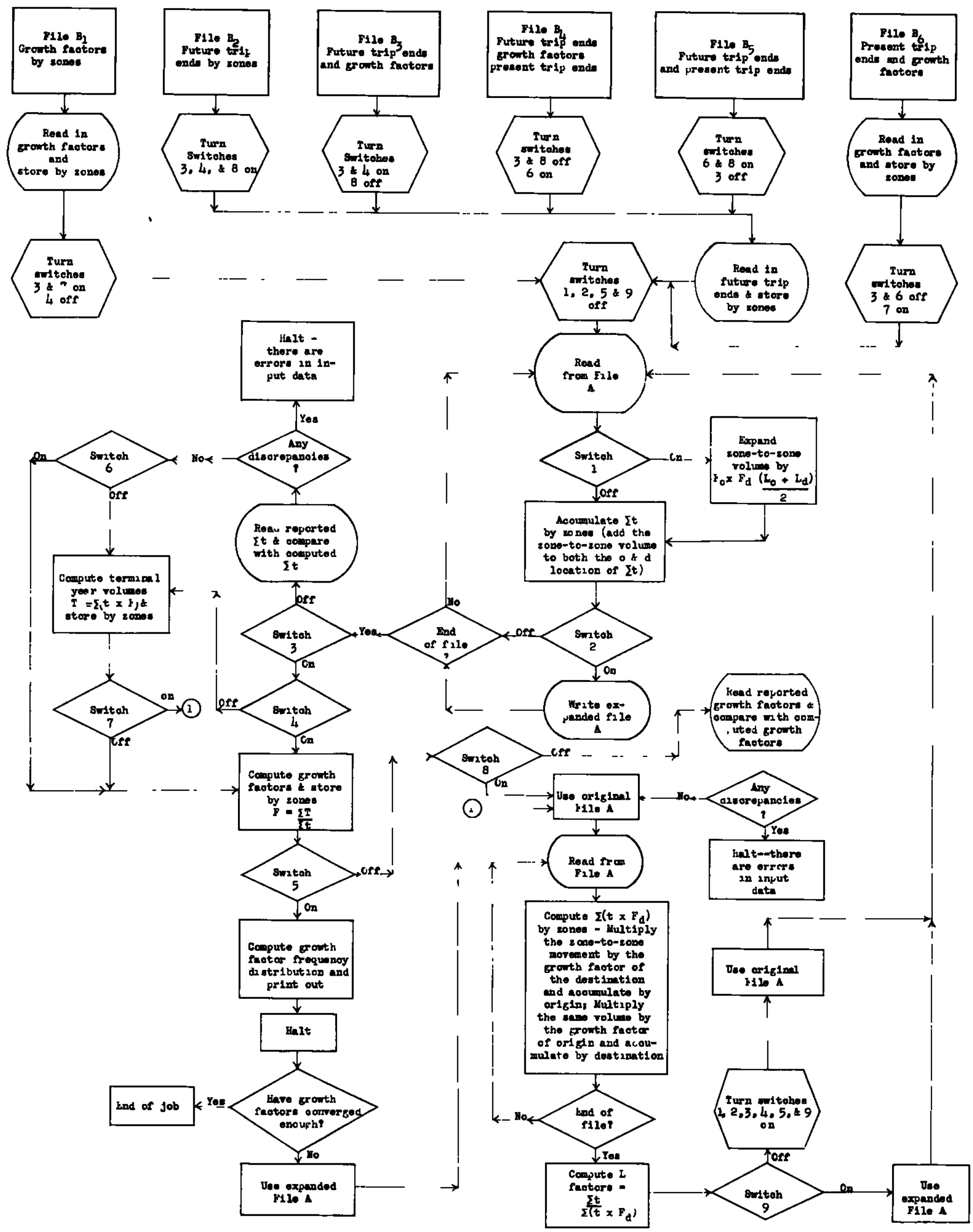

Figure 7. Electronic computer flow chart for forecasting future zone-to-zone trips fratar method.

One of the more difficult problems in forecasting traffic is that of predicting the future number of trips for the zone-to-zone movements that are zero at the present time since all methods tested require the multiplication of existing trips by various factors. The magnitude of this problem can be most easily visualized by remembering that about 67 percent of all possible 1948 zone-to-zone movements in the Washington, D.C., survey were zero and these same zone-to-zone movements account for 22 percent of all 1955 trips.

In addition to the zero volumes, other low volumes are also inherently inaccurate. For an understanding of this problem it is necessary to again resort to statistical formulas. The proportional error that may be expected in random sampling of all of the trips from one zone to a particular other zone is given by the following expression which has been previously defined:

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{q}{sp}}$$

For example, suppose that zone i has a total of 6,000 trip ends. Of these 6,000 suppose that 666 have their other ends distributed as follows: 600 in zone j, 60 in zone k, and 6 in zone 1. With a 1 in 20 sample the 6,000 trip ends in zone i will represent 300 trip ends obtained by interview; therefore $s = 300$. Considering all of the trip ends in zone i, the probability of any trip end having the other end in zone j is 600 out of 6,000 or 0.1. Therefore $p = 0.1$ and $q = 1 - p = 0.9$. Thus for the trips from zone i to zone j the proportional error

$$= \sqrt{\frac{q}{sp}} = \sqrt{\frac{0.9}{300 \times 0.1}} = 0.17 .$$

Thus with a one-twentieth sample, a standard deviation accuracy of 17 percent for the trips between zone i and zone j could be expected. Similar values for zones k and 1 are shown in the following table:

Zone-to-Zone	Volume	s	p	q	Proportional error	Percent error
i to j	600	300	0.1	0.1	0.17	17
i to k	60	300	0.01	0.99	0.57	57
i to 1	6	300	0.001	0.999	1.83	183

If the sample rate is 1 in 20, it is manifestly impossible that the 6 trips between zone i and zone 1 will ever be reported as 6 trips. However, from the expansion of the binomial $(p + q)^s$, the frequency distribution of the reported trips between zone i and zone k and between zone i and zone 1, is estimated as follows:

Reported Number of Trips	Probability of Reported Value— Zone i - zone k	Probability of Reported Value— Zone i - zone 1
0	0.05	0.74
20	0.15	0.22
40	0.22	0.03
60	0.23	0.01
80	0.17	-
100	0.10	-
120	0.05	-
140	0.02	-
160	0.01	-

Thus the 6 trips between zone i and zone 1 are never correctly reported; 74 percent of the time they are reported as zero; and the remaining 26 percent of the time they are reported as 20 or more trips. Similarly the 60 trips between zone i and zone k are reported as 60 only 23 percent of the time, while the remaining 77 percent of the time the reported trips are in error by more than 33 percent.

Adjacent to zone i there will be other zones i_2 and i_3. To illustrate, it can be assumed that zone i_2 has 8,000 trip ends and zone i_3 has 6,000 trip ends; therefore since zone i has 6,000 trip ends, in zones i, i_2, and i_3 there would be a total of 20,000 trip ends which would represent 1,000 interviews.

Since zones i_2 and i_3 are adjacent to zone i, it is probably true that their movements to zone 1 are similar in volume to the movements from zone i to 1. This assumption is justified by the high correlation of distance and trip volume as established by Carroll and others. If this be true it could be assumed that $\frac{1}{1,000}$ of all trip ends in zone i_2, and i_3 are to or from zone 1 as was the case with zone i, i.e., the 20 trips between zone 1 and the three i zones are divided 30 percent to zone i, 40 percent to zone i_2 and 30 percent to zone i_3. If the expansion process $(p + q)^S$ is again used to obtain the probability of the zone-to-zone movements, the results are shown in the following table:

Reported Number of Trips to Zone 1—

Total	From i	From i_2	From i_3	Probability
0	0	0	0	0.37
20	6	8	6	0.37
40	12	16	12	0.18
60	18	24	18	0.06
80	24	32	24	0.02

From a comparison of the above table with the previous one it appears that grouping of zones will improve the accuracy of the low-volume movements. This process can be continued for other groupings. However, instead of using this rather time-consuming computation, the proportional error can be obtained by the simpler equation $\frac{\sigma}{\bar{X}} = \sqrt{\frac{q}{sp}}$ which does not indicate the frequency of the various movements but does, in one operation, compute the resulting error.

The trips between zones i, i_2, and i_3 combined and zone 1 will have a proportional error of

$$\frac{\sigma}{\bar{X}} = \sqrt{\frac{999}{1000 \times .001}} = \sqrt{.999} = 1.00 \text{ or 100 percent.}$$

Thus by grouping three zone-to-zone movements the standard-deviation error has been reduced from 186 percent to 100 percent assuming that the distribution of trips between zone 1 and zones i, i_2, and i_3 is proportional to the distribution of trip ends in the three i zones. It is true, of course, that this assumption will not be exactly correct, but it seems likely that the error of this assumption will be less than the error added by the individual zone sample variability.

The problem of how large a grouping is desirable can be approximated from the equation: $\frac{\sigma}{\bar{X}} = \sqrt{\frac{q}{sp}}$ The limiting value of q is 1.00. It can never be as large as 1.00 and in almost all applications it is not smaller than 0.9. At the same time sp is equal to the number of trips obtained by interview between a pair of zones with perfect sampling. The value of sp can range from zero up to the value of s. The relation between the error of a zone-to-zone movement and the number of interviewed trips making this zone-to-zone movement can be approximated as follows:

Number of Interviewed Trips	Percent Error
0	α
1	100
2	71
5	45
10	32
15	26
20	22
30	18

Considering the undesirability of combining too many zones, it appears that zone-to-zone movements might well be grouped until the accumulated movement represents about 10 interviews.

A method to accomplish this purpose has been worked out but not tested except by hand computation from a small sample. The sample computation indicated that the error is reduced by approximately one-third.

The method requires the use of the binary system in coding a group of zones. For illustrative purposes, a group of 4 zones can be considered although in actual practice probably 16 would be required.

To illustrate, suppose that in region A the area is divided in half with 2 zones in each half. One-half of the zones would be designated AO and the other half A1. These pairs of zones would again be divided in half or into single zones designated A00, A01, and A11. A separate region B would be similarly separated into B00, B01, B10, and B11.

If only trip volumes that represent 10 interviews (or 200 trips with a $\frac{1}{20}$ sample) are considered sufficiently stable so as not to warrant readjustment, a method of combining zones that is amenable to computer operation is required. A suitable method is as follows:

The number of trips from A00 to B00 is examined. If it is less than 200 (10 interviewed trips), combine zone B00 and B01 and find the number of trips between A00 and B00 + B01. If it is still less than 200, combine zone A00 and A01 and find the number of trips between A00 + A01 and B00 + B01. If the number of trips is still less than 200, again double the B area to include 4 zones, and if necessary, double the A area to include 4 zones, and so on until the figure 200 is reached.

The advantage of the binary coding is that it provides the desired grouping through a simple arithmetic operation. The arithmetic operation simply combines the binary portion of the region code by alternate digits. For example if A00 is written as AA_1A_2, and B00 is written as BB_1B_2 the combination is written $A_1B_1A_2B_2$. Starting with 0000, the digit 1 is added successively until the sum 1111 is obtained. The subtotals are then decoded by the $A_1B_1A_2B_2$ pattern and the zone-to-zone movements are then in the proper order for combining as follows:

			Combination—			
Combination	A zone	B zone	1	2	3	4
0000	00	00				
0001	00	01	x			
0010	01	00				
0011	01	01	x	x		
0100	00	10				
0101	00	11	x			
0110	01	10				
0111	01	11	x	x	x	
1000	10	00				
1001	10	01	x			
1010	11	00				
1011	11	01	x	x		
1100	10	10				
1101	10	11	x			
1110	11	10				
1111	11	11	x	x	x	x

From the original zone-to-zone volumes and the combination totals, the preselected volume can be determined.

The combination volume is then reassigned to individual zone-to-zone movements as follows: Suppose that in the previous example all 4 of the A zones were combined and all 4 of the B zones were combined to provide a preselected volume. The total trip ends in the individual zones in the A group are added and the proportion of the total in each A zone is determined (P_{A_1}, P_{A_2}, etc.). Similarly, each zone of the B group is a certain proportion of the B total trip ends (P_{B_1}, P_{B_2}, etc.). Then the total volume (V) between the group is reassigned to individual zone-to-zone volumes ($V_{A_1-B_1}$) by the equation:

$$V_{A_1-B_1} = V \cdot P_{A_1} \cdot P_{B_1}$$

$$V_{A_1-B_2} = \cdot P_{A_1} \cdot P_{B_2}$$

etc.

From sample tests made to date this reassignment procedure appears to improve the accuracy of predicting the future zone-to-zone trip movements. Whether it improves the accuracy of predicting accumulated volumes such as would occur on road sections or ramps should be tested by the process of accumulating the trips across a grid, as described in the preceding section.

Discussion

THOMAS J. FRATAR, Partner, Tippetts-Abbett-McCarthy-Stratton—When the successive approximation, or iterative, method for the distribution of future zonal and intra-zonal traffic was developed it was not assumed that the attractiveness factor selected for the initial application to Cleveland area traffic was the only one that could be used, or necessarily the best. In fact it was recognized that further experimentation would be needed.

Those familiar with the Hardy Cross moment distribution procedure used in structural analyses will recognize that the attractiveness factor used in the successive approximation method for traffic distribution is comparable to the stiffness factor used in moment distribution. Messrs. Brokke and Mertz have referred to different attractiveness factor bases as different methods.

It is gratifying to learn from the research of the authors and their associates with the Bureau of Public Roads that the attractiveness factor basis originally selected when the writer initiated the successive approximation technique for traffic distribution remains the favored one.

Center City Goods Movement: An Aspect of Congestion

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Central congestion in metropolitan areas has been the object of only a little systematized research. Most of the research efforts so far have been oriented toward measuring vehicle delay. Corrective measures to limit the time or locations of goods transfer, or to restrict specific classifications of trucks from entry to the city center, are usually attempts to alleviate the congestion without an understanding of the nature of goods movement in downtown areas. The counting of vehicles is insufficient to gain an understanding of what goods move where, when, and why, in a city's central core.

This paper summarizes research under the sponsorship of the Urban Traffic and Transportation Board of Philadelphia. It is an effort to examine the generative aspects of urban traffic.

The actual goods movement to and from central establishments is presented and related to the efficiency of central transport operations and the economics of goods consolidation.

● **THIS PAPER** summarizes a pilot study undertaken by the Urban Traffic and Transportation Board of the City of Philadelphia, under the direction of the author. The impetus for the study stems partly from local lay interest in alleviating the problems of city center congestion, and partly from the interest of the staff directors in the generative aspects of persons and vehicle movements (1, 2). By pilot study is meant a preliminary analysis of the subject by a professional observer in the transportation field, securing basic data as available, but without the use of a project organization and standard field enumeration procedures. Without any clue of past experience in urban goods movement analysis to serve as a point of departure it seemed appropriate to conduct this type of investigative study.

The subject of the study is center city goods movement, rather than congestion, although the matter of congestion is the backdrop before which goods movement is viewed. An understanding of goods movement itself is an understanding of certain aspects of congestion and therefore is basic to development of either physical plans or public policy towards minimizing transportation conflicts, consistent with the recognized goals of central activities.

One of the primary problems leading to this research project was and is the limitation of current traffic measuring procedures to give a meaningful evaluation of the goods movement aspect of central congestion.[2] Commercial vehicle counts, even seggregated by truck types, do not give an adequate clue as to the requirements for the use of trucks in the city center. Other data called for in origin-destination studies by the standard procedures of the Bureau of Public Roads include the industry and business served by the truck commodity carried. But this data obtained for commercial vehicles is rarely summarized and would not appear to give such a clue either. Any policy concerned with the restriction of commercial vehicle movements in the city center should certainly be based on an understanding of the requirements for vehicle use. This study, therefore, deals specifically with the needs for the movement of goods them-

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[2] Some excellent procedures for analysis of the goods movement aspects of congestion were introduced by Goodwin (3), whose analysis was made from data collected by accompanying the truck driver. The gathering of this type of data, however, has not been done on any large-scale basis, probably because of the high cost of collection.

selves. The study of commodity flows is by no means a new idea, but this is the first attempt known by the author to apply this type of analysis to the city center.

NATURE OF CONGESTION

Because the subject of center city goods movement cannot be broached without involving the term "congestion," it is opportune to put forth a few observations on this word and its semantic interpretations. A standard dictionary definition of congestion is "the action of heaping together in a mass." Early meanings ascribed to the word, dating back 200 years, carry such associated adjectives as "unnatural," "overcrowded," and "morbid." When used by either the press or the transportation analyst, the term invariably has strong negative connotations as related to urban centers, and the spoken word usually involves disparaging tonal qualities as well.

If the current use of the word congestion is associated with an unnatural traffic situation or overcrowded city center, then what is a natural traffic situation and uncrowded city center? Part of the semantic problem would disappear if the word "concentration" were substituted for "congestion." The term "concentration," as used by students of urbanism, connotes something natural and desirable for the furtherance of commerce and culture.[3] Concentration certainly must pay off, otherwise New York City would not have experienced the addition of 40 million square feet of office space on Manhattan Island since World War II (5), superimposed on a piece of real estate already congested to the nth degree. It can be concluded that congestion is a price paid for the advantages of concentration by both private and public segments of the economy.

Certainly, congestion cannot be reduced below some residual level needed to sustain the concentration and centralization that are absolutely essential to the existence of downtown establishments. Central congestion is the friction of space which economists discuss, resulting from the equilibrium between transportation cost and rent, and it is virtually impossible to quantify in an absolute way.

Another word that could be elaborated on under this heading is "conflict." Used in a traffic engineering sense, a conflict is the intersection of two desire lines of travel, such as occurs at a grade intersection. It implies some probabilities that both objects of travel will desire to utilize the same space at the same time. When this probability rises to some significant value, a congested situation may be inferred. Along the line of this reasoning, anything which reduces this mathematical probability of dual occupancy of the same space would inhibit congestion. Thus, the consolidation of goods bound for central stores would be an anti-congestion factor, and the reduction of either pedestrians or passenger cars likewise. However, if pedestrian linkages between establishments are assumed to be a major desired function of the core of the city, it is not logical to think of pedestrian movements as a co-contributor to congestion.

There is growing evidence from the analytical studies of downtown business areas that the foot linkage between establishments is the transportation connection of greatest importance in the highly concentrated central core. At this scale of settlement the motor car, trolley bus, train, and subway are only useful in trips between the core and other functionally differentiated land use areas. They can carry people in and out of the city center, but have only a minor role in central activities themselves.

Under the circumstances, congestion cannot be discussed intelligently without assigning value priorities to the objects of transportation competing for the same space. The value scale may also change at different times of the day. For example, during the morning and evening rush pedestrian movement is usually negatively valued in reference to persons movement by vehicles, but the reverse is true during the business hours. The extent to which center city goods movement is a contributor to congestion, therefore, depends on an assumed frame of reference for the evaluation of congestion. In the Gruen plan for Fort Worth (6), for example, such value is placed on the importance of pedestrian movements in the city center that a single goods movement vehicle would contribute substantially to congestion. In fact, not only is goods movement

[3] In urban sociology, "concentration" is considered one of the five or six ecological processes, others being segregation, invasion, succession, and decentralization (4).

separated by a grade differential, but all vehicular movements are excluded from the walking area core in that plan. Perhaps a more convincing proof of the contribution of goods movement to congestion in a retail center is the costs to which developers have gone to construct grade separated goods movement corridors in the regional shopping centers constructed in the past few years.

AREA OF ANALYSIS

Delineation of the study area was facilitated by three previous major studies, as follows:

1. The Philadelphia-Camden Area Traffic Survey of 1947.
2. "Person-Trips to the Central City," published by the Philadelphia City Planning Commission in 1954.
3. The Philadelphia Central District Study, prepared by Alderson and Sessions for the Philadelphia City Planning Commission in 1950, one of the most detailed functional analyses of a city center yet conducted.

Philadelphia has a fairly well delineated central business district, bounded by rivers on the east and west sides, the link between the Schuylkill Expressway and the Delaware River Bridge on the north at Vine Street, and a quite abrupt functional change of land use in the solid brick row housing on the south. These general boundaries contain about two square miles of land given primarily to commercial activities.

Although it was recognized that there were circulation problems in almost all of the 400 or so blocks comprising the central business district as described above, one salient land use characteristic stood out above all others and served as the basis for delineating the specific study area. This factor was the extreme concentration of activity in 39 central blocks, referred to hereafter as the "core," as compared with remaining 82 percent of the area, henceforth called the "frame." Various terms have been used to describe the functionally different area surrounding the concentrated retail and office core of the city. These terms include "fringe," "transition zone," "perimeter," and "frame." The term "frame" is used in this study as being the most descriptive word. Its use is found in other sources; for example, the Cincinnati Central Business District Space Use Study (7).

The core includes 14 complete censuses of business enumeration districts, as presented in the specially rendered supplement to the 1948 Census of Business for Philadelphia. There was a substantial congruity between the 39 blocks previously referred to and the central traffic enumeration district of the Philadelphia-Camden Area Traffic Survey, No. 000, as well as with major functional areas of the Alderson and Sessions report.

Figure 1 shows scale relationships between the core and the frame, as well as between the central business district and the city as a whole. The extremely limited size of the central core is not typical of Philadelphia alone and is worthy of some further analysis. This phenomenon was probably first expounded on by Hoyt (8) in the early 1930's and lately by Rannells (2), and in the Murphy, Vance and Epstein central business district studies (9). Mumford has repeatedly discussed the city center in terms of a walking distance scale, and what has been true of cities since antiquity in terms of his analysis is proving equally valid for the mid-20th Century American city, in spite of both the decentralization of the past few decades and the development of

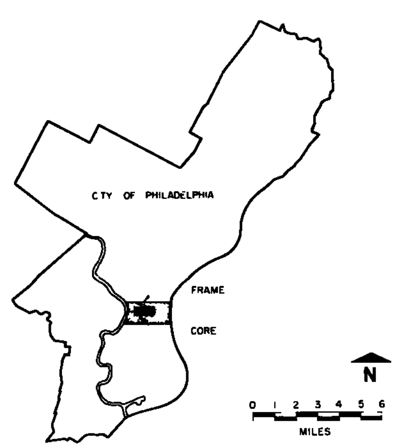

Figure 1. Size of the central business district.

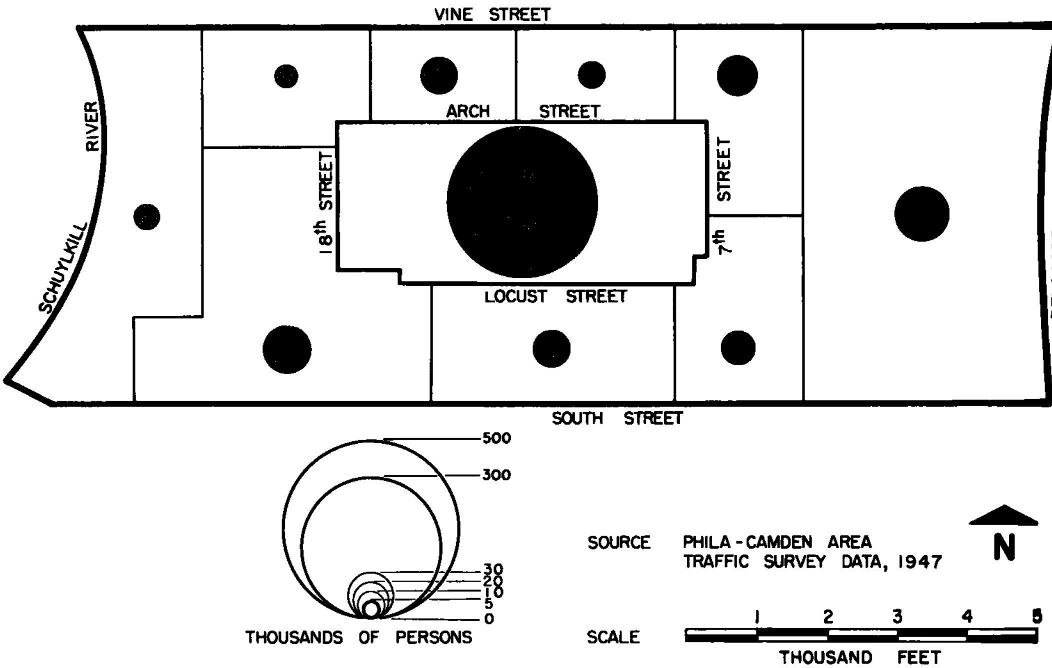

Figure 2. Number of persons entering central Philadelphia, by district of destination.

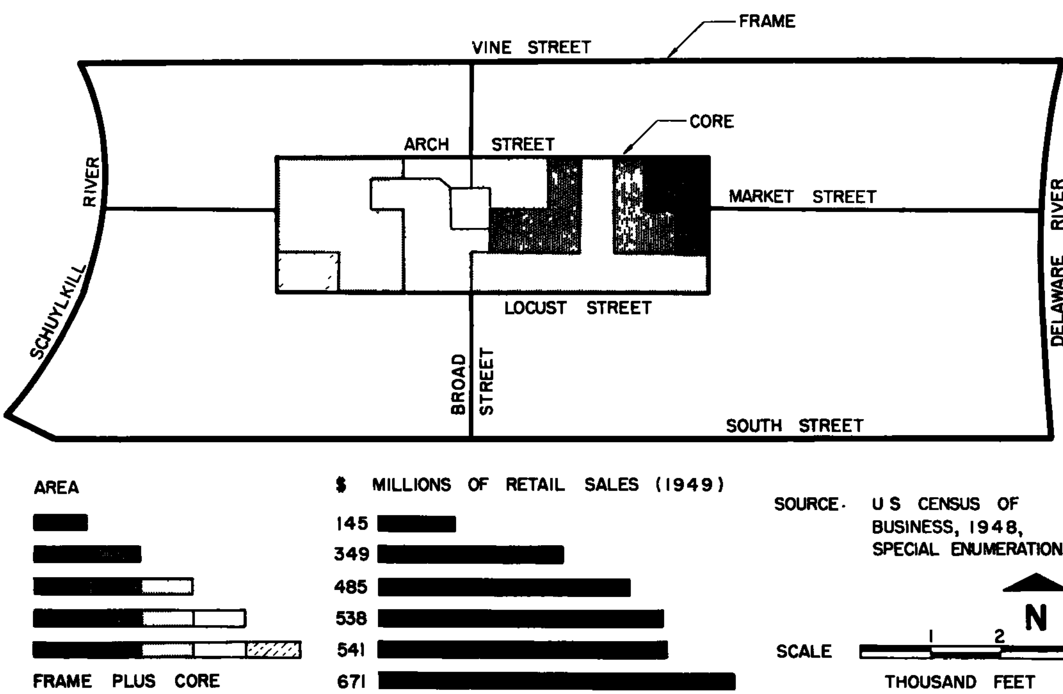

Figure 3. Retail sales productivity of the city center.

mechanized transport. In respect to ground space used for retail sales, consumer services, and general office functions, the core of Philadelphia, the hub of four million people, is only a little larger than the core of Emporia, Kansas, which has a service area of less than 25,000 (10). The major difference in these contrasted cores is that of vertical scale.

Figures 2 and 3 show graphically some of the differential aspects of the core and frame; Figure 4 gives a breakdown of a range of selected indicators which further sharpen the focus on the core-frame concept. As a generalization, the core accounts for about 80 percent of central city activity in Philadelphia. Perhaps the importance of the core is unusually emphasized in this city, which developed an extensive rail and subway system when most western cities were still in the horse-and-buggy stage. Philadelphia entered the automobile age with a well-developed mass transportation system focused on the central business district. Nevertheless, the frame-core differentiation has almost universal validity in the analysis of not only the central business districts of cities, but also community and regional commercial centers as well.

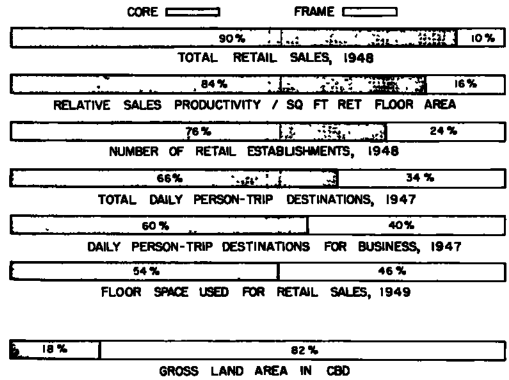

Figure 4. Core-frame contrasts, central Philadelphia.

The central core may be defined as an area in which business and service establishments are in close proximity to each other and linked by a walking distance scale of transportation. Within the confines of this area the main administrative and decision-making activities are carried on for the entire metropolitan complex. Even activities carried on in the outlying areas, such as the buying and selling of land or automobiles, require linkages (2) between core establishments, such as title and insurance companies and the municipal auditor. The core also contains a strong center of retail trade and consumer services and a high level residual market geared to the central business district labor force, in spite of the noticeable decentralization of a large segment of this activity. Although manufacturing, wholesaling with stocks, and some retailing and consumer services, are tending to leave the core, other uses requiring office floor space are increasing sufficiently to compensate for the loss. In effect, the cores of most large American cities are experiencing a change of life, but judging by the increase of floor space being added are emerging with a new strength.

Whereas the core is developed vertically in an intensive way, the frame customarily extends horizontally in an extensive way. The core rarely extends more than 2,000 or 3,000 ft in any lateral direction, but vehicular transportation is the rule in the frame, thus permitting unlimited distances on the basis of transportation, although limited by the market for the type of uses customarily found in the frame.

Establishments located in the frame have broadly varying characteristics, ranging from temporary, tax-paying uses (such as parking and used car lots) to functional groupings of concerns catering to the same need or furnishing the same product. The latter type usually includes automobile services, printing, wholesaling with stocks, and certain types of light manufacturing, just to mention a few typical ones. Structures in the frame, whether converted old dwellings or new functional buildings, are rarely more than two or three stories in height, even in medium to large cities.

Early observers in the field or urban ecology termed the frame a "zone of transition" (11) between the central core and close-in housing. It was recognized as the area of high land values and deteriorated dwellings because of centrality and imminent conversion to core uses. The core, it was thought, would gradually increase in size and expand into the next concentric ring. Actually, the functional difference between the core and frame was not recognized, nor was the limited lateral growth of the core anticipated.

The urban morphology discussed in the last few paragraphs can easily be recognized by viewing a city center from the air or studying oblique aerial photographs. Differences in the building scale between the two elements under discussion are quite

TABLE 1
RELATIVE ASPECTS OF CONGESTION

Item	Core	Frame
Major orientation of concern	Movement conflicts between vehicles and pedestrians	Movement conflicts between vehicles
Periodic flow of goods	Geared to retail trade	Geared to wholesaling, services, and manufacturing
Storage of cars	Disfunctional—uneconomic use of land	Functional—economic use of land
Relationship to a central highway distributor loop	Removed	Proximate or adjacent
Curb loading	Prevalent	Exceptional
Conflicts with surface transit	Major	Minor

apparent. Maps of building bulk, height, and floor-to-ground area ratio also disclose the same observation.

The importance of this immediate discussion to the general question of city center goods movement is that there is such a qualitative difference between the core and frame as to call for totally different approaches in the study of congestion, particularly the goods movement aspects of the problem. Some of these differences may be noted in Table 1; they have not been recognized in congestion and delay studies to date. The typical time and delay study, as a matter of fact, has tended to follow a route directly through the core (see 12, 13, 14), almost on the supposition that movement through the core of the central business district is a desired end. This type of study has only limited application to short-range benefits in the interim period awaiting the operation of freeway systems.

Under the manpower limitations of the current study it was decided to limit the goods movement study to the core, insofar as the most serious aspect of congestion exists there. Therefore, the study was constructed around the congestion problems of the core, which substantially influenced the type and range of data obtained.

GOODS MOVEMENT AND THE DEPARTMENT STORES

Five department stores in central Philadelphia account for well over one-half the retail sales of the core and close to 50 percent of the retail sales floor space. These five stores probably account for at least two-thirds and possibly three-quarters of the goods flow to the core. In addition to retail sales estimated from Bureau of the Census figures and previously mentioned, the central department stores receive and process most of the goods sold in their ten branches in the suburban areas. Furthermore, other retail establishments include mostly street-entrance specialty shops in which goods have a higher average value in terms of size than the average for department stores.

An analysis of goods flow to and from central department stores, therefore, is of paramount importance to an understanding of street congestion in the core of the city. This does not infer, however, that the department stores are responsible for a congested situation in proportion to the percentage of the central retail sales which they command. In fact, the reverse may be true because of the scale on which the department stores handle goods and the lack of any offstreet loading or receiving facilities for most of the street-level specialty shops.

The process of securing data on goods flow from department stores commenced with an interview at the top executive level, followed by conferences with the department head concerned with receiving and shipping, usually with the title of traffic manager. In most cases a certain amount of summary data was available, but because of the varying systems of record keeping an average of one week of contact time was required at each store to examine records, sample data, and develop coefficients for an inter-store comparison.

The primary unit of goods movement is the "piece," which refers to a single package, carton, or bundled assembly of smaller elements. The bulk, size and weight of the piece is geared to both the human scale of handling and mechanical handling equipment. The average piece weighs 33 lb and changes little over the course of the year (see Fig. 10).

The processing and marking areas are invariably on the upper floors of a department store building, which have less productivity as retail sales space. If there is inadequate elevator capacity or magazine space on or near goods-receiving platforms, inefficiencies will result at the loading dock which will soon have repercussions on adjacent streets.

The mere examination of raw goods movement data can present a maze of facts, which, in and of themselves appear difficult to relate directly to the city center congestion problem. Goods arrive at department store docks via over-the-road trucks (termed motor freight), local vendors' equipment, local common and contract carriers, Railway and American Express trucks, mail trucks, and push carts. They may have been consolidated at the city of origin, points en route, or at the city of destination. Motorized equipment includes everything from semi-trailers to motorcycles. Goods leave the

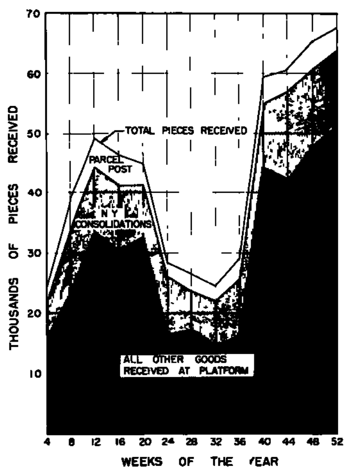

Figure 6. Seasonal variation in imports by mode of conveyance, Store No. 3.

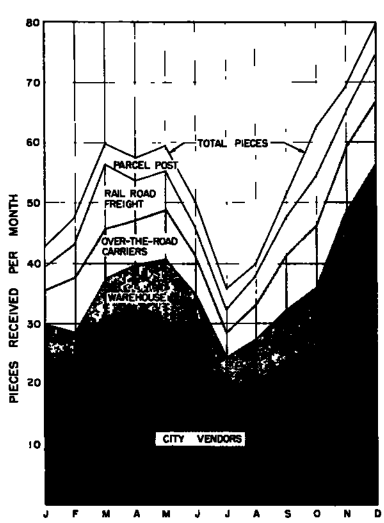

Figure 7. Seasonal variation in imports by mode of conveyance, Store No. 2 (1947).

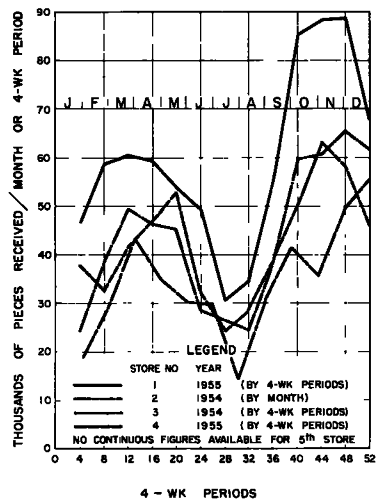

Figure 5. Department store imports, interstore comparison.

stores via United Parcel Service vehicles or some specialty hauling services, but a remarkably high percentage is carried out by patrons.

In terms of the financial responsibility for goods movement to retail outlets and looking toward consolidation implications, it appeared most significant to distinguish between goods originating inside or outside the metropolitan area. The term "metropolitan area" is used here not in the sense of a standard metropolitan area, as defined by the Bureau of the Census, but to connote an urban region within which common and contract carriers can operate without being franchised by the state public utility commission for intercity travel. This distinction further separates motor freight from what are termed "local deliveries," and is of practical importance because local deliveries are the financial responsibility of the vendors, whereas motor freight from outside the metropolitan area becomes intercity transportation and is paid for by the buyers of the goods. Here it is immediately evident that central stores will do everything possible to promote the consolidation of shipments from outside the range of local deliveries, in the interest of reduced freight costs, whereas they are not as much concerned with consolidation of local deliveries, for which they have no financial responsibility.

Figures 5 through 12 summarize goods movement volumes to and from the five central department stores. Each will be

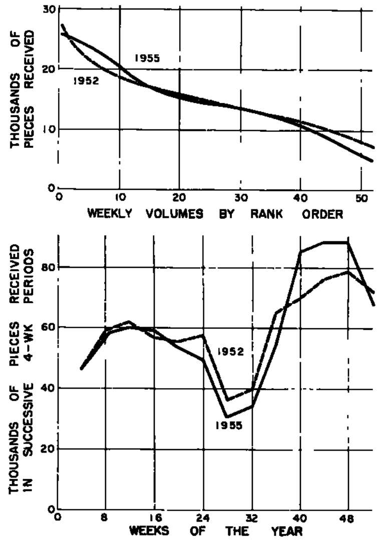

Figure 8. Deliveries to Store No. 1, 1952 and 1955.

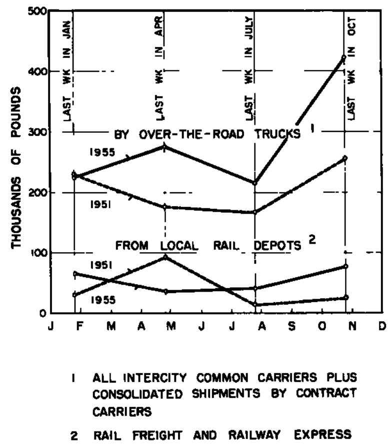

Figure 9. 1951-1955 rail-motor freight comparison, Store No. 1.

discussed in turn.

Figure 5 shows the generally similar characteristics of imports to all of the stores studied. The most significant observation is the extent of seasonal fluctuation. The average daily volume of goods handled in the last twelve weeks of the year is about twice the annual daily average, and the average daily volume in July and August is approximately one-half of the average annual daily figure; Figure 5 shows the extent to which buying habits are Christmas oriented. One important inference is related to the timing of traffic and congestion studies. Traffic counts taken in the midsummer period, for example, will not give a true picture of goods movement conditions for other seasons.

Figures 6 and 7 show seasonal variations in imports to department stores in central Philadelphia by modes of goods movement. With the exception of increased activity from the store's warehouse during the year-end rush, all modes fluctuate in a similar manner.

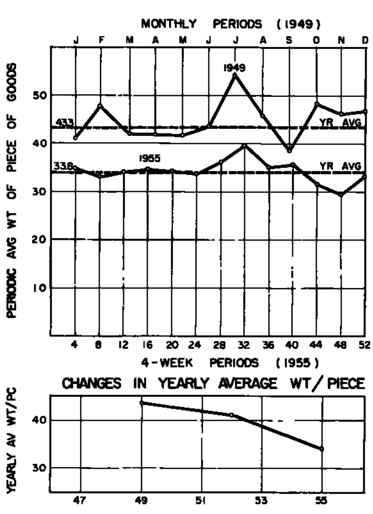

Figure 10. Changes in the average weight of pieces, Store No. 1.

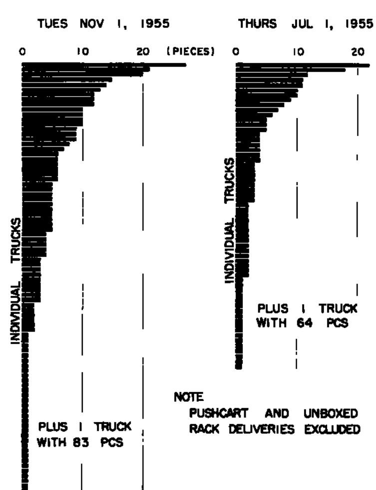

Figure 11. Deliveries from city vendors to Store No. 1.

Figure 8 shows the similarity in goods movement patterns from one year to another. This relationship implies the utility of expanding sample data to construct the goods movement volumes for the entire year. The rank ordering of weekly volumes discloses that about 40 percent of the annual volume is handled in the ten highest weeks, or 20 percent of the time. The ten highest weeks are usually in the fall of the year, although occasionally the Easter rush accounts for one or two weeks in the highest ten.

Figure 9 gives a hint as to changing trends between the use of trucks or rails for the shipment of goods from out-of-town vendors. From these data and the consensus of traffic managers rail movements have been stable over the last ten years, whereas trucks account for the increase in volumes where stores are experiencing a general increase in sales.

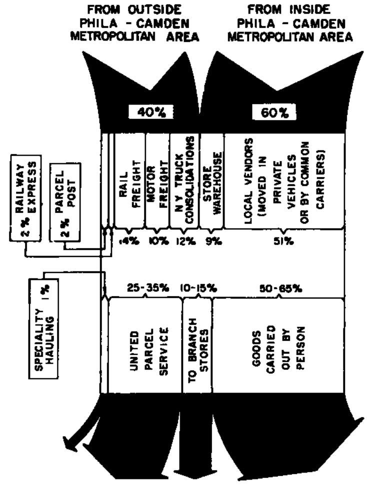

Figure 12. Goods flow diagram, five central Philadelphia department stores.

Figure 10 has already been referred to and is not discussed further.

Figure 11 gives a revealing picture of the spread in volume of goods delivered per truck. Although the movements shown are only for goods originating within the metropolitan area, well over one-half of all imports to the stores come from vendors' establishments within this area. The two days were selected at random as being representative of the summer low and autumn high volume periods. On the November 1 date, for example, the one truck with the greatest volume, 83 pieces, carried as many pieces as 40 vehicles. The meaning of this range is not entirely evident from the figures shown, however. Although a truck may have delivered only a single piece to the particular store, it may have been making series deliveries (see Fig. 13) to a number of establishments, thus representing an efficient operation as far as the use of street space is concerned. On the other hand, it may be that a 12- or 14-ft straight truck moves from a vendor's establishment to a central store and back, occupying 20 or 30 ft of lane space all the way, but carrying only one piece. Traffic managers interviewed indicated that both circumstances take place. To obtain a more accurate idea of the efficiency of truck movements from local vendors, therefore, it would be necessary to know the history of the total truck trip, including how many pieces were left where. The data presented in Figure 11 show the potential of investigating the efficiency of truck loading. The loading platform or curb stall is practically the only location at which the volume of truck contents can be examined, and perhaps a few questions asked of the driver. At best, only crude estimates could be made of the movement efficiency by platform examination; nevertheless, it is believed that such a platform study would materially further knowledge of center city congestion.

Figure 12 shows an estimate of total goods flow in and out of the central department stores. Goods entering from outside the metropolitan area by over-the-road trucks are separated into the two classifications of "motor freight" and "N. Y. consolidations," but the first classification also includes some consolidations from other cities or geographical areas. An estimated 15 or 20 percent of the deliveries from local vendors is consolidated to some extent by local common carriers who have consolidating platforms in the central area. Movements from outside the city represent a higher degree of consolidation, although they are concerned with a much smaller percentage of the goods than is received from local vendors. A surprisingly large percentage of the goods is carried out by customers, partially due to the efforts of the stores to reduce delivery costs by promoting a campaign that "The parcel you carry home gets there fastest." Goods movement to branch stores is handled by the United Parcel Service on a contract basis, and represents a relatively efficient operation in terms of moving a large volume of goods per truck.

To summarize this section of the paper, three features of central city goods movement are emphasized, as follows:

1. The wide seasonal variation in central goods movement to department stores, which must apply to all other retail establishments, has important implications as far as the timing of traffic studies in the central area are concerned.

2. The greatest segment of goods movement to the core areas of large cities no doubt originates within the metropolitan area itself and does not pass through the hands of commercial truckers. This segment is most difficult to consolidate because of the short haul and dispersion of financial responsibility among thousands of vendors rather than a few principal stores.

3. The great number of trucks delivering only a few pieces each, and the space they occupy on the streets as well as at loading docks, gives rise to a serious consideration of the need for some system to reduce deliveries of one or two pieces. Conceivably this could be a consolidation scheme.

GOODS MOVEMENT AND THE SPECIALTY STORES

As a crude definition for the purposes of this study, all retail sales and service outlets situated in the core of Philadelphia other than the five major department stores are termed "specialty stores." In terms of total volume of goods received, some 3,000 of these establishments in the 39-block core account for considerably less goods movement than do the five department stores. However, because of the great number of loading locations the specialty stores no doubt contribute more to central congestion than do the department stores.

The task of studying specialty stores in relation to goods movement posed considerably more problems than the department stores. A few of these stores have their own loading platforms which do not infringe on street or alley space. Others have rear doors facing alleys, but no facilities for getting a vehicle out of the stream of traffic. Most depend on curb service at the front door, with goods received through the front door or via sidewalk elevators. Few of the specialty stores keep records of the number of pieces received each day.

The technique used to gather data on the specialty stores, as well as office buildings, was to select one of the 39 core blocks with a range of establishments and loading conditions which would typify the core itself. Accordingly, the block bounded by Chestnut, Market, Twelfth, and Thirteenth Streets was selected. This block contains more than 600 separate business establishments, 38 of which are street entrance retail sales or service outlets. The block has a working population of close to 10,000.

In the absence of a quantitative analysis of goods movement to the specialty stores a few findings are presented in descriptive form, particularly as they may relate to possible problems attendant upon municipal controls.

One large specialty store selling women's apparel receives more than 90 percent of its goods in daily consolidated shipments out of New York. It is part of a chain operation in which all of the buying is centralized. The goods are transported by handcarts from large over-the-road trucks at the curb to the front door of the store. The tractor-trailer combination arrives at eight each morning and occupies curb space for at least 30 minutes. This occurs coincidentally with the arrival of about 3,200 office workers to the same building in which the store occupies most of the ground floor. After unloading about 40 pieces each day the truck proceeds to other stores of the same chain outside of the central city. The restriction of over-the-road equipment from entering the central core would require transfer of the goods to the platform of a local carrier, with consequent cost and delay to the store. Delivery before rush hours, even with large equipment, might be more favorable to the store in contrast to a prohibition of tractor-trailers in the core, although it still involves extra man-hours and security problems. Here the goods movement aspect of congestion is seen in sharp focus. To what extent should the convenience of pedestrians take precedence over goods move-

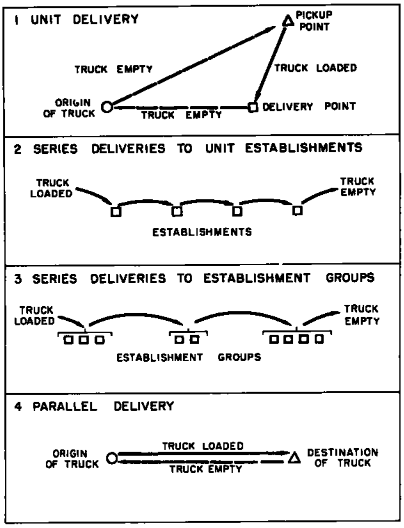

Figure 13. Modes of local goods delivery.

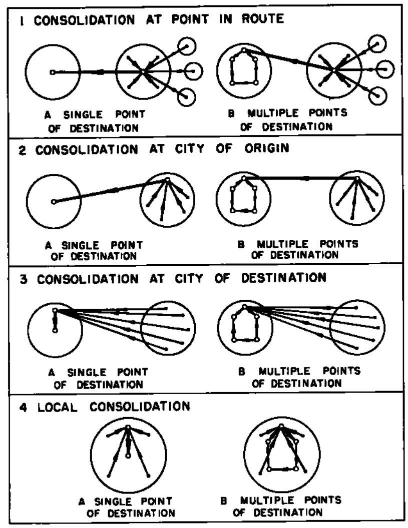

Figure 14. Modes of goods consolidation by truck.

ment, particularly if it adds to the cost of selling merchandise?

In contrast to the foregoing example, a men's apparel store in the same block receives about the same daily volume of goods in eight to twelve deliveries per day of four to six pieces each. Being unaffiliated with a chain, this establishment purchases from a variety of vendors. The goods arrive in a range of vehicles from station wagon to tractor-trailers, although straight trucks with 12- or 14-ft boxes predominate. This store likewise has no means of getting a vehicle off the street or alley for unloading. The prohibition of over-the-road equipment from entering the core would not materially affect deliveries to this store, yet this establishment with its ten or so deliveries daily, at any time, no doubt causes more street congestion than the women's apparel store discussed previously.

Street entrance establishments handling small items (such as jewelry, greeting cards, hosiery, ties) depend primarily on parcel post and railway express for deliveries. This form of delivery represents a form of consolidation (see Figs. 13 and 14). One or two short curb stops are made daily, usually during shopping hours. Unfortunately, this type of service makes almost continuous use of a traffic lane. Almost nothing can be done to advance or retard the hours of delivery to clear the working hours because of the necessity for person-to-person contact between the driver and merchant. Most of these establishments are small shops with only one or two people engaged in the operation. Whereas department stores can detail a crew and supervisor to man the loading platforms at six o'clock in the morning because of the staff flexibility with numbers, it would cause undue hardship for one-man operators to lengthen the working day by several hours.

Concerning the smaller retail establishments, some degree of street congestion arises out of the lack of inventory space. Many have no stock room space whatsoever, and must replenish supplies daily. In some cases the truck stands at the curb while the stock is surveyed and racks are restacked. This condition is also the nature of restaurants and food stores, and again is a type of delivery which is difficult to advance into the early hours of the morning or retard until the evening. This may be part of the cost which society pays for the preservation of the small, independent, decision-making unit of enterprise, which is important in the competitive system.

An important physical characteristic of specialty stores in most cities is the nature of the buildings which have them. They typically inhabit converted houses or older, commercially designed premises which have made no provision for goods handling other than alley doors or sidewalk elevators. More than likely, specialty shops are in small, independently conceived buildings. In some instances the redevelopment of these sites provides integral goods movement planning for a range of establishments with street entrances. The very nature of both public and private redevelopment is that small sites are incorporated into larger ones. Consequently, this phase of the goods movement problem in the core of the city may gradually improve with time if loading space standards are established for new buildings.

GOODS MOVEMENT AND THE OFFICE BUILDINGS

The office buildings studied were those located in the typical block discussed in the previous section. A good range of sizes was included in this block, including buildings of 7, 12, 15, and 38 stories, respectively. The latter building is the tallest in Philadelphia, and typifies the goods movement problem arising out of tall central office buildings.

Goods movement to office buildings suggests classification under the two headings of building services and tenant services. The former includes washroom and cleaning supplies, garbage and rubbish removal, and building materials for redecorating and interior construction. The latter includes mail service, linen service, repairs to office machines, servicing of vending machines, delivery of bottled drinking water, deliveries (usually by United Parcel Service) of personal purchases by employees, deliveries of office supplies and interior furnishings, and moving service at the termination of leases. In addition to building and tenant services there are deliveries of commodities to tenants in accordance with the type of business activity engaged in. These may include samples or materials for sales or manufacturing, although the two items are not characteristic of central core establishments.

An interesting functional difference was noted for the four office buildings studied. The 38-story building, newest of the four, contained no tenants with more than a token requirement for goods deliveries other than for tenant services. No tenant in this building was engaged in either manufacturing or wholesaling with stocks, although this was not necessarily a restriction by the management.

In contrast to this building, constructed in 1932, the 7-story building was built in 1880 and contained mostly establishments requiring a significant amount of goods delivery. More than 80 percent of the floor space in the older building was devoted to furniture, shoe and book sales, with stocks on the premises. As a general rule, in the 39 core blocks the newer the building, the more its occupancy is confined to uses not associated with goods movement.

A strong parallel exists between the older buildings containing specialty stores and the older office buildings. Both represent a filtering down process in the use of space, which engenders goods movement problems. In the former case, the specialty shop may take over the old brownstone house, which was not designed to accommodate goods flow. In the latter, there is a technological obsolescence in space for office use in the older buildings, with some wholesaling or light manufacturing uses taking over the space as loft uses. In the natural redevelopment process new building floor space displaces these loft uses, which are generally forced out of the core or into its perimeter areas. It may be concluded, therefore, that some of the goods movement problems connected with the older downtown buildings gradually are diminishing over the long range, and attention should be focused on truck movements for building and tenant services to the principal office buildings in the central core.

Taking the 38-story Philadelphia Savings Fund Society Building as an example, the problem resolved itself to one of studying curb and loading space demand. As nearly as could be determined, tenant and building services in large office buildings require about one truck stop per day per establishment. With an assumed average curb time up to ten minutes, a structure the size of the PSFS Building would require enough loading space for four vehicles at all times during the day. Although built in 1932, this building has no offstreet loading space, and is dependent on a 70-ft curb loading zone. Building services alone average out to the continuous use of one curb stall.

Large buildings such as the PSFS Building in Philadelphia maintain a loading supervisor at the curb during working hours. These supervisors usually spend all their time expediting turnover at the curb or loading dock, and in no cases determined in the study maintain records of deliveries. Strange to report, they are not authorized to receive goods for tenants, for subsequent internal delivery. No doubt this policy makes sense from the standpoint of the building management, but there are some rather interesting ramifications as far as use of the space at the curb or loading dock is concerned. For example, if a stenographer purchases a dress during the lunch hour and has it delivered by United Parcel Service in lieu of waiting for it to be wrapped, the UPS truck stops at the curb while the driver or messenger carrys the goods to some upper floor of the building for delivery to the specific office. This same process occurs in the case of Railway Express and American Express deliveries, the servicing of vending machines and water coolers, and in fact almost all tenant services. Under the circumstances most truck stops are well in excess of ten minures and a large number require several hours.

It is evident that building management policy can play an important role in reducing both the number of vehicles which arrive at the building and the length of time of each stop. No doubt such a policy has not evolved for very good reasons. For example, a lease requirement that tenants purchase equipment or supplies from specified vendors is probably distasteful to the lessee. However, more important than the duplication of companies supplying the same service, is the matter of internal deliveries. The abrogation of the right of the tenant to receive direct deliveries, other than mail, could be rescinded by lease agreement, or the lease could call for the tenant to designate the building management as the receiving agent for his deliveries. Such a policy, however unpopular with the tenants if generally installed throughout the core area, would reduce the demand for curb space of dock deliveries by at least one-half, according to several building managers interviewed. But, of course, a system of internal deliveries would cost a building management money, to the extent at least of an extra salary. And whereas a man could keep busy full time making internal deliveries to the tenants of a large building, this activity would be an inefficient use of time in a small building. Here, obviously, the social costs of congestion have to be weighed against both costs to the building management and some small inconvenience to the tenants. Nevertheless, it may be just as logical to legislate in the area of building management as it effects use of the loading spaces, as to legislate against the trucking industry concerning delivery hours or restrictions on vehicle movements.

Although the expediting of commercial vehicles at curb loading zones or offstreet loading docks will not reduce the number of truck stops, it will reduce the delay of waiting for a loading space by either double parking or milling around in the streets. A detailed study of truck stops for service or deliveries to large office buildings would be one of the more fruitful areas of congestion analysis, but was beyond the resources of this particular study. Unfortunately, all that can be reported here is from interview notes or limited periods of observation at the curb.

One method of analysis of downtown truck stops was made in the Philadelphia Central City Truck Survey of 1950 (15). In this survey observers circled each of the central blocks every half hour, recording the number of trucks parked, loading, and unloading. The data were rendered on a block basis, and also broken down according to a classification of light, medium, and heavy trucks. The license number of each truck was recorded, so that the same truck would not account for more than one stop, regardless of the number of times it was observed on the half-hour inspections. A correlation was later made by Mitchell and Rapkin (1) between the number of truck stops per block and the area of floor space devoted to the major nonresidential use, such as manufacturing, wholesaling with stocks, business services (general office uses) (1, 2).

Although these correlations point to the beginning of predictable relationships between land use and truck stops, somewhat more refinement is needed in the data collecting process before the Mitchell-Rapkin constructs will be as useful as they could be. For example, using the empirical relationship derived in their study, Store No. 1 would account for about 350 daily truck stops according to its floor area. Actually, on Nov. 1, 1955, one of the highest volume goods movement days of the year, only 125 trucks delivered goods to this store. A reverse situation was found to exist for office buildings. Most of the discrepancy can be accounted for by the long interval between counts. By virtue of the half-hour count interval, at least as many vehicles escaped count as were counted. Most of the vehicles which escaped the screening made very short stops to specialty stores or office buildings, where only one or two pieces were delivered and the truck was away in a few minutes. In some cases, the lack of floor space for storage may account for a greater number of truck stops than if more inventory space were available. This is particularly true of small street level specialty shops.

Because of the growing importance of general office space in the core of cities, greater insight to central congestion may be gained by studying truck movements to office buildings. Such a study must be based on data collected by stationary observers at the curb or loading dock on at least a 12-hr basis. Data needed would include the type of truck by general size classification, length of time clocked at the loading zone, and the nature of the call; that is, pickup delivery or service. Detailed analysis of the nature of congestion will tell the extent of the need for exercising public controls over receiving procedures, and will also point out more specifically than the facts disclosed by this preliminary study the problems of such controls.

THE NATURE OF GOODS CONSOLIDATION

Goods consolidation is one of the most effective ways of reducing central business district congestion. The fewer the vehicles involved in goods movement, the fewer the conflicts between goods movement desire lines and the desire lines of persons movement, either pedestrian or vehicular. Practically all of the existing consolidation-oriented traffic studies deal with truck terminals (16). In addition, the need to group together establishments sharing common goods movement problems and requirements, such as commission houses (17), and the consolidation benefits of union truck terminals have been generally recognized (18). However, in a lengthy search no studies which link goods movement with vehicle movement, or which thoroughly examine the nature of consolidation, have been discovered.

To emphasize the importance of consolidation, a maximum of 40 to 60 trucks could supply Philadelphia's average daily goods requirements for all central district retail sales at currently demonstrated capacities to deliver goods. (These figures are based on a hypothecated consolidation service designed to divide the business between 12 companies operating four straight trucks each with established delivery routes. Actually, the five central department stores account for an average importation of less than 50,000 lb per work day and this could be handled easily by only six trucks.) Actually, the Philadelphia central department stores alone record about 500 truck stops daily during the heavy goods movement peak, and core retail sales in general account for at least 3,000 truck stops on the average day (15).

Goods consolidation is a natural economic development arising from the efforts of buyers of transportation services to save costs by avoiding less-than-truckload rates and minimum-cost charges. For large establishments with a high volume of goods intake, such as department stores, there are additional benefits from consolidation in reducing congestion at the receiving platforms and in minimizing the amount of paperwork connected with the receiving operation. Consolidation is also a natural economic development arising out of the efforts of the suppliers of transportation services to minimize the unit costs of shipments.

Barriers to consolidation include governmental regulations and operating rights, the capital costs of dock facilities for the "breakdown" of consignments, and the requirements of the buyer of transportation service for rapid delivery. In respect to the latter point, the buyers of transportation service usually have conflicting goals. They desire both the economies which consolidation has to offer and the special services which consolidation precludes.

Goods consolidation has both social benefits and social costs. On the benefit side it reduces congestion on the streets by minimizing the number of vehicles engaged in goods movement. On the other hand, under the complicated system of operating rights which has grown up in the separate states under public utility commission regulation, many small commercial trucking concerns owe their existence to their franchises, and the promotion of large-scale consolidation by altering these rights would eliminate many independent trucking companies. Consequently, if the preservation of independent decision-making units of business is a desired social goal, any substantial reduction in the number of these units is an undesirable cost regardless of the congestion they cause.

The matter of regulation of trucking concerns has been preempted by state governments. The concept of the public interest, as far as operating rights are concerned, does not look into the problem of congestion. Municipalities are unaware of the granting of trucking rights. They receive no notice of the hearings, and the state public utility commissioners have no instructions in state legislation regarding their function to look into problems of the city streets. If, for example, only 20 companies were given the right to enter the core area of the city instead of 500, consolidation might increase ten- or twenty-fold.

In the process of this study an examination was made of several hundred of the more than 7,000 operating rights awarded to Philadelphia trucking concerns by the Pennsylvania Public Utilities Commission. These rights are jealously guarded and bitterly contested in tariff and franchise hearings, and account for many relatively empty trucks moving around the city center. Many truckers are franchised to carry only one or two commodities; others are restrictied in the size or weight of packages. In many instances the right relates to specific problems of specialty hauling, but in most cases they appear to represent merely a division of the total trucking business in such a way as to keep relative peace in the industry. In any event, state public utilities commissions are not concerned with the problems of congestion in their licensing policy; but if they were, considerably more consolidation might be effected. Is there any reason, for example, why more than 500 state-licensed commercial trucking companies should have a franchise to deliver goods to the core establishments of Philadelphia when 20 could easily service the area?

Along the lines of this reasoning an example may be taken from the municipal regulation of ambulances, tow trucks, and taxicabs. Although ambulances and two trucks do not contribute significantly to congestion, their freedom to operate in an unregulated way is recognized to be against the public interest by virtue of problems arising out of accidents. With taxis, however, there is a need to license arising out of a limited number of curb zones. The problem here is no different from that of the limited space in which to load or unload trucks either at the curb, in alleys, or in the limited docking areas sometimes provided by establishments.

The question of state or other regulation of operating franchises is a tangential one in this study, but this matter is felt to be one of great importance in working toward the reduction of central congestion. Not enough is known yet of the ramifications of this phase of the problem, and a sampling of a few hundred franchise rights is insufficient evidence on which to base recommendations for changes in public policy at the state legislative level. For this reason, further attempts to understand congestion should certainly involve a full-scale study of the effects of state regulation.

For the purpose of this study local goods delivery has also been institutionalized into four modes, shown diagrammatically in Figure 13. As in the case of the modes of consolidation, these modes of local delivery do not necessarily take place in pure form, but involve combinations of the four.

Unit delivery is the least efficient of all four modes because the truck is empty for more than one-half of its total trip. This mode does not constitute a consolidation. It is only relatively economical of street space when the truck is fully loaded, thus averaging less than a half-loaded condition for the total trip.

The series delivery to unit establishments is the usual type of delivery made by local haulers and carriers with fixed routes. The motion is relatively economical of street space, but has a high unit time of unloading per piece delivered because the unloading is not continuous. This mode of delivery may either consolidate the goods of one vendor to a number of establishments (as in the case of a milk route), or it may consolidate the goods from a number of vendors to a number of establishments (as in the case of a Railway Express Agency route).

In series deliveries to establishment groups the mode is similar to that just described, except that multiple deliveries are made at each vehicle stop. It occurs when the establishments to which goods are destined are clustered, as in the case of a parcel post delivery to various establishments in an office building. The prevalênce of this type of delivery in the core of the city makes it difficult to relate truck stops to establishments of particular types, because one stop may serve many establishments. For this reason there are actually fewer stops to establishments of a given type in the central core than in the outlying areas of the city.

The term "parallel delivery" is given to the last mode because the desire lines of the outbound and return trips parallel each other. This mode occurs when goods move from a city vendor to a retail establishment in the vendor's equipment, with the empty truck returning to the point of origin. It does not represent consolidation because only one establishment is involved at the nodal points. The efficiency of the movements of this mode, in terms of the use of truck and street space, will vary directly with the degree to which the truck is loaded, but the truck will not average more than one-half a load.

As earlier data relating to the flow of goods to department stores indicate, some consolidation already takes place, particularly in intercity motor freight. Four separate modes of consolidation could also be distinguished (Fig. 14). Actually these modes are usually mixed and rarely take place in a pure form. Nevertheless, development of these basic modes aids in the discussion and interpretation of goods movement.

Consolidation at either the city of origin or points en route represents the greatest over-the-road economies. Under these modes of consolidation relatively full truckloads of goods are usually assembled in one city for destination to another, and sometimes even to a single store in the city of destination. In many instances this type of movement involves cartage agreements between intercity motor freight haulers and local trucking companies, although there is a tendency for large intercity truckers to do their own local delivery in smaller equipment than typical over-the-road trucks.

Consolidation at the city of destination represents the least economical mode by virtue of the need to accomodate several vehicles at the consolidating platform in the city of destination in place of one relatively fully loaded truck. In addition, several partially loaded vehicles may be used in the intercity phase of the trip, whereas one consolidated shipment would suffice.

In local consolidation city vendors and truckers carry goods to a common point for assembly and transfer to various central locations. As a city becomes large and consumes much of its own manufactures this type of consolidation becomes more desirable from the standpoint of reducing street congestion. Very little of this type of consolidation now takes place.

The subject of consolidation, like congestion, is difficult to discuss without the development of some constructs of vocabulary. This section has attempted to lay the foundation for analysis of consolidation by developing these ideas and terms. It has also presented certain insights into congestion not readily apparent from the examination of either the vehicle or goods movement in the problems of the fractionalization of goods movement rights under public utility franchises.

ECONOMICS OF MOTOR FREIGHT CONSOLIDATION TO CENTRAL DEPARTMENT STORES

As indicated early in the discussion of goods movement to the central department stores, a distinction must be made throughout the analysis between deliveries from vendors inside and outside the metropolitan complex. This distinction is based on financial responsibility for the cost of goods movement, type of equipment used, operating franchises, and other factors. It is also meaningful to carry this differentiation into the field of the economic analysis of goods consolidation.

First, the economics of local consolidation of inbound motor freight are considered. This represents the third mode of consolidation shown in Figure 14. The basis of this type of consolidation is reduction in costs of local delivery by transferring goods from large over-the-road trucks (usually tractor-trailer combinations) to smaller straight trucks. The terms "motor freight," "motor truck freight," and "motor express" are used interchangeably by traffic managers to connote this mode of movement. The goods are carried in tractor-trailer combinations or large straight trucks, usually referred to as "over-the-road" or "line haul" equipment. Goods moved in this manner are generally purchased f.o.b. vendor's establishment or city of origin, and the cost of the delivery is borne by the buyer.

Because of the proximity to New York and the extent of goods supply from New York factories, the central Philadelphia department stores distinguish between motor freight which is consolidated in New York and that which comes from other cities, termed "New York consolidations" and "motor freight," respectively. Because the shipments from New York under this category are already consolidated for local delivery, the remaining market for local consolidation represents, at the most, about 10 percent of the total goods imports to Philadelphia department stores (see Fig. 12). Actually, some unknown amount of this 10 percent is consolidated in other cities of origin, such as Chicago and St. Louis, but only consolidations of motor freight from New York are segregated in the records.

On the basis of 1954 and 1955 data, the five major Philadelphia department stores receive about 3½ million pieces annually from all sources, or about 116,000,000 lb. At the most, 10 percent of this total weight represents motor freight that conceivably could be consolidated before it enters the central core of Philadelphia. Assuming that this 10 percent (11,600,000 lb) were gathered at one terminal outside the core for consolidated consignment to the five central stores, at a weekly assignment of 85,000 lb to a straight truck with a 12- or 14-ft box it would keep a daytime fleet of three trucks busy on an average annual basis. (These figures are based on estimates of trucking supervisors interviewed.) At a flat rate of $0.30 per 100 lb, this volume of freight would be worth not more than $35,000 annually to a consolidator. This estimate, however, is only a theoretically attainable figure, subject to limitations inherent in both seasonal fluctuations and the costs of goods breakdown for consolidation. (The $0.30 per 100 lb represents the maximum that local cartage managers believe could be established as a tariff for a central consolidation service. Some believe costs might run closer to $0.50 per 100 lb, at which rate the service would not be attractive to potential users.)

The seasonal fluctuation of deliveries to the stores under study has already been discussed (Figs. 5, 6, 7, and 8). Motor freight deliveries fluctuate in the same manner as the other categories of goods, with the summer low about one-half the average annual volume, and the fall high about twice that average figure. This variation indicates that for the foregoing example of consolidation, predicated on a relatively full utilization of truck space, it would require twice the average number of trucks to supply a consolidating operation during the fall goods movement peak. Although it is true that the downtown cartage companies do a larger business in the fall, the fact that they tend not to specialize in goods movement for retail trade alone tends to keep their load factors closer to the annual average than if they were exclusively in the business of central consolidation. Thus, if the central consolidation business must be predicated on a specialty service, as most of the truckers interviewed believe, the seasonal fluctuations noted will assume a greater role as a deterrent to successful operation than they would pose for trucking firms carrying a variety of goods.

As far as central goods consolidation is concerned, however, the important aspect of seasonal fluctuations is not the extra capacity of trucking equipment needed, but the possibility that a local consolidator may inherit primarily the peak season excess from the motor freight haulers. On an average, the central department stores receive 40 percent of their merchandise in the fall quarter of the year. Assuming that motor freight truckers now serving the central stores can economically handle a 20 percent overload based on the average annual rate, excesses above 20 percent overload occur only in 12 or 13 weeks of the year. If a local consolidator could funnel off only the excess volume above 20 percent overload, it would account for less than 50,000 pieces annually, or a dollar volume of about $8,000 worth of local cartage business for all Philadelphia central department stores.

It is readily apparent that the market for the local consolidation of Philadelphia-bound motor freight for reconsignment to the central department stores is quite limited. As long as over-the-road shipments can be brought into downtown stores without excessive delay for 39 weeks of the year there will be no strong desire on the part of intercity carriers to make a breakdown of the consignment at local terminals outside the core for subsequent delivery in smaller equipment, whether or not they use their own trucks for such deliveries.

If the local consolidation market for the reconsignment of inbound motor freight were broadened to include the specialty stores it is conceivable that the goods volume figures just mentioned would be increased by 60 or 70 percent, based on their share of retail sales and other factors. However, there are much higher costs in serving the many specialty stores as compared with the few department stores, so that the over-all outlook for an attractive local consolidation business is no better.

Still another factor inhibiting the entrance of locally-franchised truckers into the business of consolidating inbound motor freight is the fact that they are in competition in this respect with the motor freight carriers themselves. Most of the large intercity trucking organizations are also franchised by the respective states to deliver locally. Under the circumstances they break the consignment down at their own platforms for local delivery in their own straight trucks if it is uneconomical for them to take heavier equipment into the city center.

Thus far no mention has been made of the costs of a breakdown for local delivery in small trucks versus the cost of moving large trucking equipment into the congested core. These costs are best analysed by reference to the estimated cost-volume relationships shown in Figure 15. This figure gives an insight into the analysis which a motor freight carrier would have to undertake in order to arrive at a rational economic justification for the use of a local consolidation service, his own or otherwise.

Figure 15 shows the investment in transportation for any volume up to 100 pieces, and for two alternatives of delivery. The cost of one alternative is given by the line AB, and approximates the cost of delivering goods to a central store via tractor-trailer combination from some point on the regional highway system an hour's time-distance away from the store (including the delays in the core area and the cost of maneuvering at the store). The second alternative is given by the line A'C', and approximates the cost of delivering goods to a central store from the same point on the highway system, but via transfer of the goods at a consolidation platform for local delivery in smaller equipment. In the second alternative it is assumed that the consolidation terminal is half way, timewise, from the point of origin on the highway system to the central store. Thus, if 60 pieces are to be delivered, it will cost about $10.50 to transport them in the tractor-trailer, and $13.00 to transport them via reconsignment.

The other lines in Figure 15 show how these total costs were arrived at. The following assumptions were made:

1. The cost of operating a tractor-trailer combination is $8.00 per hour, including the cost of the driver and helper. (Determined from interviews with motor freight operators.)

2. The cost of unloading goods both at the consolidation platform and at the store is $0.12 per cwt ($0.04 per piece). (Determined from interviews with receiving personnel.)

3. Local cartage costs $0.30 per cwt, including both loading at the consolidation platform and unloading at the store. (Determined from interviews with local haulers.)

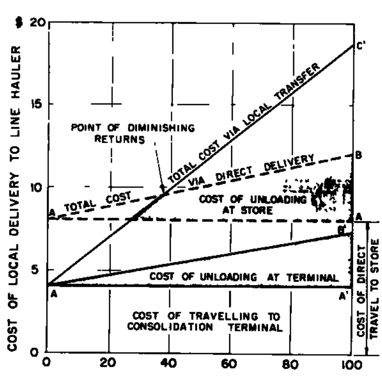

Figure 15. Cost variables in local delivery of motor freight (delivery by local carrier vs intercity carriers).

Returning to the example of a 60-piece delivery, the cost breakdown may be de-

TABLE 2

COST BREAKDOWN IN ALTERNATE MODES OF DELIVERY
(Example based on 60-piece load, see Fig. 15)

Distance Along Line Representing 60-Piece Load Ordinate	Cost Representation	Amount ($)	Total ($)
(a) Alternative 1—Direct Delivery			
Abscissa to line AA	Travel and maneuvering time to central store (1 hr)	8.00	-
Line AA to line AB	Unloading at store ($0.12 per cwt)[a]	2.50	10.50
(b) Alternative 2—Delivery via Local Transfer			
Abscissa to line A'A'	Travel and maneuvering time to consolidation terminal (½ hr)	4.00	-
Line A'A' to line A'B'	Unloading at terminal ($0.12 per cwt)[a]	2.50	
Line A'B' to line A'C'	Loading at terminal, delivery and unloading at store ($0.30 per cwt)[a]	6.50	13.00

[a]One piece is assumed to weigh 33 lb (see Fig. 10).

termined from Figure 15 by observing distances along the ordinate representing a 60-piece delivery (see Table 2).

The intersection between lines AB and A'C' in Figure 15 indicates, for the assumptions made, the point beyond which it does not pay a motor freight carrier to have the shipment transferred for local delivery. This point of diminishing returns occurs at about 40 pieces, or 1,300 lb. Many factors, of course, can alter the relationships shown. For example, a differential in the unloading facilities between the alternate possibilities will change the relative slopes of the lines AB and A'B'. More or less delay would alter the vertical position of the travel time lines AA and A'A'. A higher rate of local consolidation and cartage cost would alter the slope of the line A'C' also. Any or all of these factors may change the position of the point of diminishing returns in a horizontal sense, but it is doubtful if it would lie beyond 60 pieces or at less than 30.

The most significant aspect of the relationships shown in Figure 15 is the fact that, excluding the New York consolidated motor freight, well over one-half of the remaining motor freight bound for downtown department stores in Philadelphia is in shipments comprising more than 40 pieces. Figure 16, for example, shows that 60 percent of the motor freight arrived in shipments of more than 40 pieces each. These relatively large shipments may have represented consolidated shipments out of other cities than New York. The important conclusion, however, is that on the basis of the foregoing analysis it would not have paid for 86½ percent of the trucks bringing motor freight to the particular store to have used a local consolidation service. In other words, if the motor freight haulers have to pay the cost of goods shipment breakdown and subsequent local delivery it simply does not pay them to keep heavy equipment outside the center of the city in a majority of the cases. The foregoing quantitative analysis, although based on rough assumptions, has been corroborated in many interviews with both truck dispatchers and drivers.

As far as the interests of the department stores are concerned, the major advantage to the elimination of over-the-road equipment at their docking platforms is the expediting of the total receiving operation in terms of processing trucks themselves. However, in respect to expediting the flow of goods, a tractor-trailer combination well loaded with packages for the store is more desirable than many trucks delivering the same amount of goods. The offending vehicle to the department store, therefore, is the over-the-road truck which leaves only a few pieces at the establishment. Insofar as the stores pay the cost of motor freight, the question then arises whether they are willing to pay the extra cost of local consolidation, including a time delay in receiving goods. At present they will undertake this extra cost during only a few of the heaviest days of goods movement, when they cannot

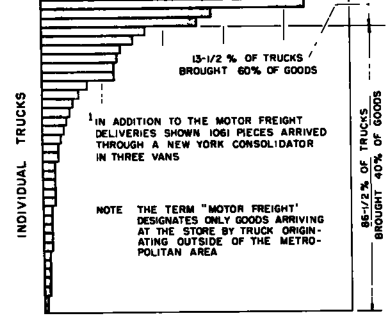

Figure 16. Motor freight deliveries to Store No. 1 on Tuesday, Nov. 1, 1955.

physically accommodate the flow of goods internally. Under these circumstances they call for some shipments to be delivered to the platforms of local carriers, for subsequent delivery to the store at their own cost.

The cost of eliminating a majority of the large motor freight trucks from the city center is actually quite nominal. Based on Figure 16, if the contents of the 32 vehicles delivering less than 40 pieces were handled through a consolidation service it would cost the store about $30, or a little less than $1 per truck. Vehicles delivering less than 20 pieces, however, could be accommodated in one shipment not exceeding the limits of a straight truck at a cost of $12, or $0.46 per truck, and vehicles delivering less than 6 pieces could be eliminated at the dock at a cost of $5.60, or $0.27 per truck. In the last instance, 20 trucks could have been eliminated, or about 16 percent of the daily figure.

CONSOLIDATION OF LOCAL DELIVERIES TO CENTRAL DEPARTMENT STORES

The terms "local deliveries" or "city deliveries" are generally used by store receiving-personnel to include goods which are delivered at the expense of and through means chosen by the vendor. Goods under this category almost always originate within the city or in the surrounding counties, and are brought to the central stores by local haulers or in the vendor's equipment, customarily straight or pickup trucks.

The department stores do not keep records of the delivery equipment or service used by local vendors. Store traffic managers estimate that between 70 and 80 percent of the merchandise from local vendors is carried by local haulers, and that fewer and fewer local vendors are retaining their own equipment for delivery. One local carrier estimates a vendor would have to deliver 85,000 lb per week to warrant owning or operating a straight truck.

As seen from Figure 12, about one-half of all the merchandise sold in the central Philadelphia department stores comes by local delivery from metropolitan area vendors. The gross local delivery volume is close to 1.75 million pieces annually, or about 60 million pounds. The cost of moving this volume at typical local tariff rates, excluding minimum charges, is between $200,000 and $300,000 yearly, and represents about 1½ to 2 percent of the retail sales value of the goods. This cost is borne by the vendor, whereas the cost of motor freight is borne by the stores.

Local vendors could readily deliver to designated points of consolidation, and perhaps save time as compared with direct delivery to the stores. However, it would be entirely unconventional, if not extremely difficult for central stores to assess the cost of the extra transfer against the vendor. If a store were to order its local vendors to deliver to a consolidating platform, it would, without doubt, have to undertake financial responsibility for the remainder of the goods trip. This undertaking would add from 1½ to 2 percent to the cost of the goods, a fairly significant amount in a center city non-expanding retail sales market.

Unilateral action by any one store to consolidate goods from local vendors at a designated platform would put it in a disadvantageous position in a highly competitive market. Obviously, there would be advantages to central stores if the number of lightly-loaded trucks leaving goods at their platforms could be reduced. Nevertheless, the problems of instituting the consolidation of local deliveries on either a modest or a grand scale are at once apparent, as far as action by the stores is concerned.

The cost relationships shown in Figure 15 for motor freight do not apply to the alternative facing local carriers in the consolidation of city deliveries because there are two major differences in local consolidation which favor direct delivery in lieu of consolidation, as follows:

1. Lack of need to change size of truck.
2. Competition among local carriers.

Unlike the motor freight commodities previously discussed, goods from local vendors are not initially carried in very large trucks that are uneconomical to operate on city streets. Cartage agreements between local truckers for the consolidation of local deliveries to downtown stores implies an agreement between two or more companies which are competing for the same commodity. Each local hauler is interested in becoming the consolidating agent, rather than deferring to a competitor. Local haulers and motor freight carriers are, on the other hand, essentially non-competitive with each other, and little enough consolidation has taken place even among the latter groups.

The nature of local deliveries to a central department store is demonstrated by Figure 11, which shows a rank ordering of truck stops to one of the stores on two separate days (chosen to fall within the summer low and fall high periods of goods movement). Although the specific type of delivery equipment is not known, a general concept of efficiency of delivery may be obtained. The term "efficiency," as used here, means the load carried by a vehicle expressed as a percentage of the vehicle's load-carrying capacity, on a volume basis. An efficient delivery, therefore, would be one wherein the vehicle, regardless of type, is fully loaded spacewise.

In some cases goods were brought in by private cars or station wagon, where a few pieces represented 100 percent efficiency, but most of the goods arrived in straight trucks or pickups. In other instances trucks may have been on a regular delivery route, and although only a few pieces were discharged at a given store, the trucks may have been efficiently loaded.

For the two days analysed in Figure 11, the average load per vehicle was about $4\frac{1}{2}$ pieces. The average load increased only 10 percent between the summer low and the fall high periods of goods movement. In contrast, the average load per vehicle arriving by motor freight was almost 18 pieces on Nov. 1, 1955 (excluding New York consolidations), or about four times the average load coming by local delivery.

The magnitude of local deliveries on the observed days for one department store indicates that the operation of one straight truck making deliveries twice daily from a consolidation depot could easily handle the daily volume. A fleet of five straight trucks, therefore, could furnish all central department stores with a consolidated delivery service twice daily, substituting two truck stops for an estimated 300 vehicle stops per day under present circumstances. (This is based on a delivery capacity of 85,000 lb per week for a straight truck.)

CONCLUSIONS

Although this research pertains mainly to goods movement in central Philadelphia, there should be significant implications for any large American city. A few inferences can be drawn relating to the more obvious generalizations, as follows:

1. The larger the city, or the greater its dominance of a region, the greater is the probability that it consumes more of its own manufactures. This no doubt increases the percentage of central core imports which come from local vendors and results in a small average delivery per truck or, conversely, a large number of trucks to supply central establishments.
2. Cities within the sphere of influence of large manufacturing centers, such as New York, Chicago, and Los Angeles, no doubt enjoy a relatively high degree of motor freight consolidation from these centers. In cities within the area of dominant centers the prohibition of large over-the-road vehicles from entering the core may defeat the effort to reduce congestion. In Philadelphia, for example, one van carrying consolidated shipments from New York often accounts for as much volume of goods as 50 or 60 trucks arriving throughout the day.
3. In any form of municipal regulation or public policy a differentiation must be made between the central core and its frame, based on the functional nature of each. In the absence of underground vehicular facilities in the core, vehicles engaged in goods movement or tenant and building services should be given priority over non-commercial vehicles engaged in persons movement, as a higher type of street use in terms of the function of the core. On the other hand, pedestrian movement in the core should be the least compromised. Parking garages, bus depots, post offices, and drive-in establishments should be either restricted from the core or permitted only at peripheral locations in the core.
4. The development of integrated community and regional shopping centers does not necessarily decrease goods movement requirements in the core, because of the

necessity for stores to centralize receiving and marking operations. Although large items of hard goods are not received centrally for branch stores, almost all soft goods sold in the suburban branches are processed at the main store. There is not the slightest indication that this procedure will be changed.

5. Until major redevelopment of city centers takes place, consolidation has most to offer toward alleviating the goods movement aspect of congestion; but because of the wide seasonal variations in goods movement and absence of incentive for stores and local vendors to absorb consolidation costs, further consolidation will probably not take place without governmental regulation.

6. The most fruitful area for reducing central congestion due to goods movement is in some form of municipal regulation controlling the conditions under which goods are received. This could take the following forms:

(a) Establishment of a core cordon and prohibition of entrance by tractor-trailers carrying less than a specified number of pieces (about 40), or weight (around 8,000 lb) of load, with exceptions for "balloon freight." Enforcement could be effected by sporadic inspections at unloading operations in the core area.

(b) Requiring that stores within the inner cordon use the services of a franchised local carrier for individual shipments under, say, 150 lb or 3 pieces. Enforcement could likewise be effected by core inspectors on foot. This would force consolidation by substituting local contract or common carriers for vendors' trucks. Pushcart deliveries could be excepted.

(c) Municipal leasing of certain curb or other locations to licensed carriers engaged in central consolidated deliveries. This would give a limited number of carriers a better opportunity to render an efficient service by having preferred bases of operations. There are ample existing precedents for the limiting of operators in other fields, such as towing, taxi, and ambulance services.

7. The elimination of further truck operating rights in the central core by the state public utility commission is one method of reducing the impact of consolidation on the local cartage industry. It is easier to deny a prospective right than rescind an existing one. These rights run with the individual, and are subject to cancellation when a business is sold. Because a local trucking service does not require a large amount of capital there is a relatively large turnover in businesses. Most public utility commissions have it within their discretionary power to deny applications for franchises subject to finding that the denial will promote the public interest. This procedure would require active participation of agents of the large cities in the public utility commission hearings relative to these franchises.

GLOSSARY OF TERMS

Central Business District (CBD)—That portion of the city center characterized by a wide range of commercial and industrial uses, as distinguished from areas of the city devoted essentially to residential or heavy industrial uses. (In Philadelphia the CBD is generally considered to include an area of about three sq mi and 400 blocks, bounded by the Delaware River on the east, the Schuylkill River on the west, Vine Street on the north, and South Street on the south.

Central Core—That portion of the CBD characterized by the most intense business and commercial activity. The core is based on a walking distance scale of transportation between establishments and is visibly different from the frame surrounding it by virtue of the bulk and height of the buildings. (For this study the core of Philadelphia is considered to include a 39-block area bounded by Arch St. on the north, Walnut St. on the south, 7th St. on the east, and 20th St. on the west.)

CBD Frame—That portion of the CBD characterized by extensive uses of land, such as parking lots and garages, automobile services, wholesaling with stocks, and certain types of light manufacturing. As distinguished from the core, the frame contains low buildings, converted dwellings, and open space in a transitional state.

City Vendors—Manufacturers or wholesalers whose establishments are within the metropolitan complex so that delivery charges are absorbed by the vendor, rather than charged to the central stores. City vendors who do not have their own delivery equipment use the services of transporters who are franchised to operate either within the city or between the city and suburban communities. If goods are transported by a carrier licensed to carry intercity merchandise this connotes a scale characterized as motor freight.

City Deliveries (or Local Deliveries)—These deliveries emanate from local vendors; 80 percent are estimated to be carried by common or contract carriers.

Motor Freight Carriers—This term is used by traffic managers to mean intercity or interstate carriers, who generally do some consolidation at the city of origin or way points along the route. Motor freight equipment generally connotes tractor-trailer combinations or straight trucks above 14 ft in box length.

Motor Freight—Goods transported by motor freight carriers. Any goods arriving by truck whose transportation costs are borne by the retail establishment are classified as motor freight.

Piece—A single box or package or a group of small packages tied together for handling as a unit. The size and weight of "pieces" are geared to ease of handling by platform personnel, and average about 33 lb.

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Travel Patterns in 50 Cities*

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During the past 15 years origin-and-destination traffic surveys of the home-interview type have been conducted in more than one hundred cities. This article presents information regarding the purpose for which trips were made by residents in 50 of these urban areas and the mode of travel they used. Data are also included pertaining to basic household characteristics of the areas such as the numbers of dwelling units, residents, and automobiles owned, and the relations between these characteristics and the volume of trips classified according to purpose and mode of travel. The urban areas have been grouped by population size to disclose whatever travel trends or patterns may exist among cities in the several population groups.

The percentage distribution of major trip purposes is fairly uniform in cities of all sizes. Analysis by mode of travel, however, shows a variable pattern. The proportion of trips by automobiles and taxis increases as city size decreases. On the whole, mass transit is by far the most prevalent mode of travel in the largest cities, but its relative importance varies depending upon the trip purpose. Trips for social and recreational purposes, for instance, generally involve the use of automobiles.

In most cases, the volume of daily trips by residents within an urban area is directly related to the number of persons, dwelling units, and automobiles registered in the area. The relations vary, however, depending upon the trip purpose and mode of travel.

● AMONG the more important factors affecting the planning of streets and highways are the means by which residents travel within the city, the purposes for which the trips are made, and the relations between these trips and residential characteristics such as the number of persons living in the area, the number of dwelling units they occupy, and the number of automobiles they own. At the time this article was prepared, information of this sort was available from origin-and-destination traffic studies[1] of the home-interview type which had been made in 101 urban areas since 1944. The product of these studies includes a great mass of data on the local travel habits of urban residents on an average weekday during the period of the survey.

Data from these studies have already been analyzed and the results have been put to use in each of the individual urban areas surveyed. However, knowledge of the general or average pattern for groups of cities of similar size should be very beneficial to highway planners. Thus it may be possible to establish norms that might be helpful in anticipating the changes which will take place in the traffic patterns of a city as the pattern of living changes.

The primary intent of this article, therefore, is to call attention to the more significant aspects of the many-sided travel patterns for 50 of these cities, considered either singly or in combination. Information from the recent past regarding travel habits of city residents should be valuable to urban planners, highway engineers, and

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*Not presented at the 37th Annual Meeting of the Highway Research Board.

[1] "Traffic Planning Studies in American Cities," by John T. Lynch. Public Roads, Vol. 24, No. 6, Oct.-Nov.-Dec. 1945. The procedures used in these studies are given in greater detail in the "Manual of Procedures for Home Interview Traffic Study," which is available by purchase from the Public Administration Service, 1313 East 60th Street, Chicago, Ill.

economists in attacking the transportation problems of the present and future. It is also hoped that the article will serve to call attention to the quantity and quality of data that have become available as a result of such surveys. A list of the selected cities showing survey dates and population at the time of the study is given in Table 1. It should be noted that almost one-third of the studies were conducted during the latter part of World War II and the year following the end of the war. Some of the variations in trip-purpose and travel-mode patterns which are discussed later may be associated with the year of the basic survey or the geographical location of the study area.

DEFINITIONS

The urban areas referred to in this article are the areas within which the basic sur-

Table 1.—Population and period of survey in 50 urban areas

Urban area	Population	Period of survey
Albuquerque, N. Mex	116,056	June 1949–July 1949.
Altoona, Pa	85,347	July 1950–Sept. 1950.
Appleton, Wis	39,172	June 1953–July 1953.
Baltimore, Md	912,809	Sept. 1945–Oct. 1945.
Bay City, Mich	69,231	July 1948–Oct. 1948.
Charleston, S. C	73,205	Feb. 1947–Mar. 1947.
Chester, Pa	127,408	June 1951–Oct. 1951.
Columbus, Ga	79,192	Oct. 1945–Dec. 1945.
Dallas, Tex	533,606	Nov. 1950–Mar. 1951.
Duluth, Minn.-Superior, Wis	130,847	May 1948–June 1948.
Fargo, N. Dak.-Moorhead, Minn	49,852	June 1949–Aug. 1949.
Grand Rapids, Mich	220,977	July 1947–Oct. 1947.
Harrisburg, Pa	103,303	June 1946–Sept. 1946.
Honolulu, T. H	214,236	Apr. 1947–Sept. 1947.
Houston, Tex	878,629	Mar. 1953–June 1953.
Johnstown, Pa	87,509	July 1949–Sept. 1949.
Kalamazoo, Mich	72,024	Apr. 1946–May 1946.
Lansing, Mich	122,776	Sept. 1946–Nov. 1946.
Macon, Ga	77,665	July 1946–Aug. 1946.
Madison, Wis	104,074	May 1949–June 1949.
Muskegon, Mich	83,724	July 1946–Aug. 1946.
Newark, N. J	1,456,947	Aug. 1945–Jan. 1946.
Norfolk, Va	335,910	June 1950–Aug. 1950.
Norristown, Pa	39,485	June 1949–Aug. 1949.
Philadelphia, Pa	2,233,531	June 1947–Nov. 1947.
Phoenix, Ariz	161,567	Nov. 1946–Feb. 1947.
Pontiac, Mich	79,431	Apr. 1947–May 1947.
Portland, Oreg	453,128	July 1946–Sept. 1946.
Racine, Wis	78,033	Aug. 1949–Oct. 1949.
Reading, Pa	119,851	Nov. 1946–Dec. 1946.
Rockford, Ill	116,000	July 1950–Aug. 1950.
Sacramento, Calif	201,345	Dec. 1947–May 1948.
Saginaw, Mich	112,902	July 1948–Sept. 1948.
St. Louis, Mo	974,545	Apr. 1945–July 1945.
St. Paul-Minneapolis, Minn	915,960	May 1949–Nov. 1949.
Salt Lake City, Utah	196,571	June 1946–Sept. 1946.
San Francisco, Calif	1,468,933	July 1946–Dec. 1946.
San Juan, P. R	312,069	June 1948–July 1948.
Scranton, Pa	137,089	June 1950–Aug. 1950.
Seattle, Wash	518,563	May 1946–Aug. 1946.
Sharon-Farrell, Pa	48,432	June 1949–July 1949.
Spokane, Wash	138,381	July 1946–Dec. 1946.
Tacoma, Wash	138,700	June 1948–Aug. 1948.
Tucson, Ariz	126,900	Mar. 1948–Apr. 1948.
Washington, D. C	1,109,860	May 1948–Sept. 1948.
Wichita, Kans	238,302	Nov. 1951–Apr. 1952.
Williamsport, Pa	55,216	July 1954–Aug. 1954.
Wilmington, Del	181,445	Apr. 1948–July 1948.
Wisconsin Rapids, Wis	16,504	Sept. 1950–Oct. 1950.
York, Pa	77,350	July 1951–Aug. 1951.

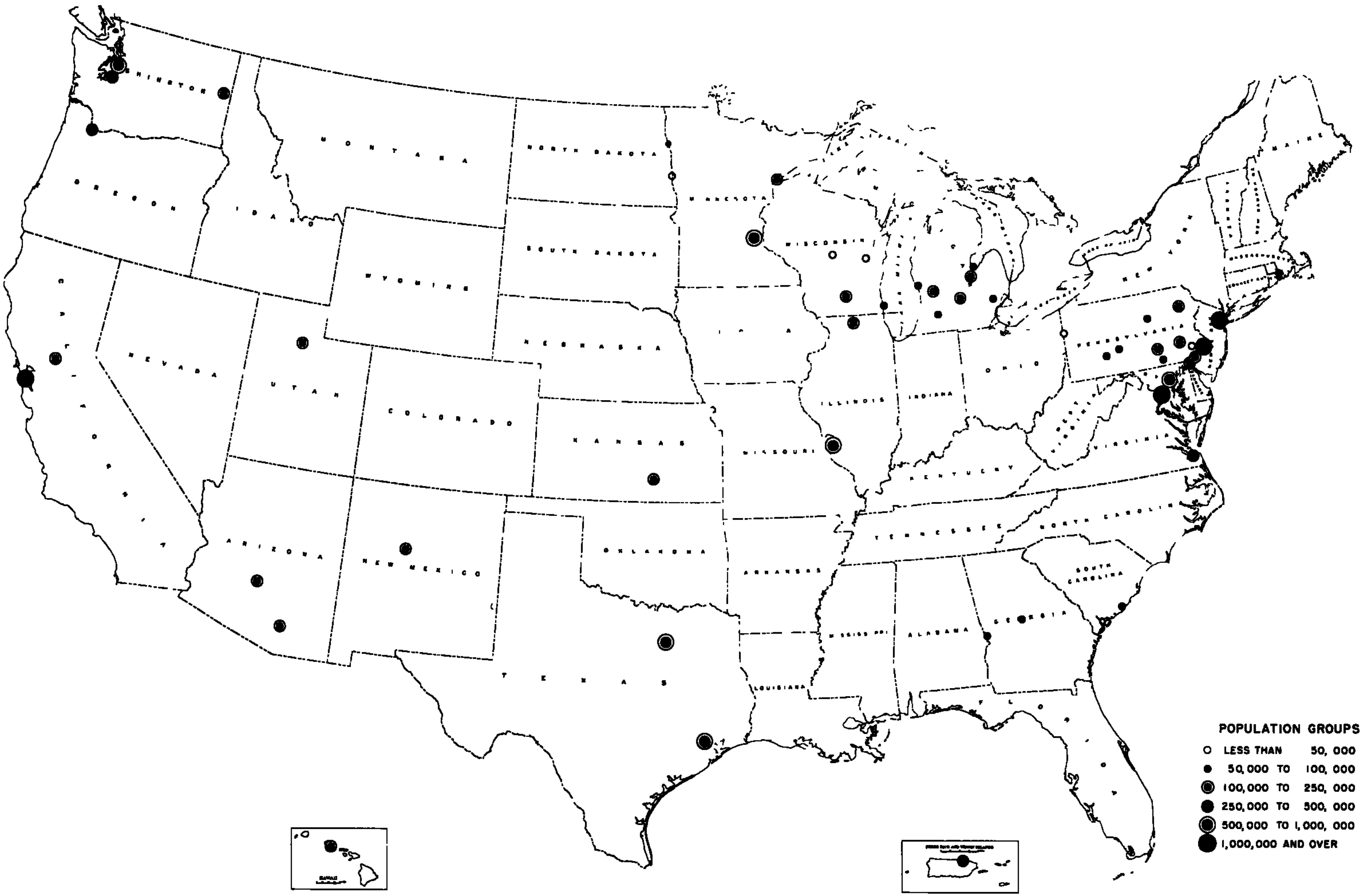

Figure 1. Geographical distribution of the 50 cities included in study.

veys were conducted. They generally include the central city as well as any portion of the contiguous built-up area that may exist beyond the corporate limits. Their boundaries are usually delimited by an imaginary line called the external cordon. These areas resemble but do not coincide with urbanized areas as defined by the Bureau of the Census. In this article the terms urban area and city are used interchangeably.

A trip is defined as a one-way movement in a vehicle by a resident of the urban area. There are no round trips but rather two or more one-way trips. The only trips considered here are internal trips, so-called because both origin and destination are within the boundaries of the survey area. External trips to or from points beyond the external cordon are not included. The external phase of the basic surveys was concerned only with automobile travel beyond the cordon and only automobile-driver trip information was included. These external automobile-driver trips amounted to about 5 percent of the total internal and external automobile-driver trips in the largest urban areas and about 45 percent in the smallest cities included in this study.

As the term is used in these surveys, mode of travel depends upon (1) the type of vehicle used (automobile, taxi, truck, or mass-transit vehicle), and (2) the status of the user (driver or passenger). The modes of travel recorded in most of the individual surveys were as follows: automobile drivers, automobile passengers, taxi passengers, truck passengers, bus or streetcar passengers, railroad passengers, and passengers in other mass-transit vehicles. For purposes of analysis, some of these modes have been combined.

The term purpose of trip is used in its obvious sense to explain why a person made the trip. However, for every internal trip recorded, the survey data show not only why the traveler went to his destination (purpose to), but also why he had been at the point of origin (purpose from). The purposes (both to and from) were originally ten: work, business, medical-dental, school, social-recreational, eat meal, shop, change mode of travel, serve passenger, and home. However, as with modes of travel, some of the trip purposes have been combined.

Household characteristics include the numbers of persons, dwelling units, and automobiles owned, and persons 5 years of age and over. Dwelling unit is used in the sense of the Bureau of the Census—"In general, . . . a group of rooms or a single room occupied or intended for occupancy as separate living quarters by a family or other group of persons living together or by a person living alone."

SCOPE OF ARTICLE

Although at the time of this analysis over one hundred comprehensive urban traffic surveys had been completed, trip purpose-to-purpose tabulations had been prepared in only 50 cities with sufficient uniformity to permit summarizing the results by city groups. These 50 cities seem to provide a sufficiently good distribution among the population groups studied so that the data are representative.

Figure 1 shows the geographical distribution of the selected cities by population groups. The 50 cities accounted for 10.8 percent of the total United States population

Table 2.—Distribution by population groups of all urbanized areas, of urban areas where origin and destination studies have been made, and of urban areas included in the present study

Urban area population groups	All urbanized areas, 1950 census		Urban areas with completed O & D studies		Urban areas included in this study	
	Number	Percent	Number	Percent	Number	Percent
Over 1,000,000	12	7.6	6	5.9	4	8.0
500,000–1,000,000	13	8.3	11	10.9	6	12.0
250,000–500,000	24	15.3	9	8.9	3	6.0
100,000–250,000	70	44.6	43	42.6	20	40.0
50,000–100,000	38	24.2	22	21.8	12	24.0
Less than 50,000	--------	--------	10	9.9	5	10.0
Total	157	100.0	101	100.0	50	100.0

in 1950, and 16.8 percent of the urban population. As Table 2 indicates, the distribution of the 50 cities by population groups among the 157 urbanized areas of the 1950 census is only fair, but it follows very closely the group distribution of the 101 cities from which origin-destination traffic survey data were available.

The present analyses have been limited to two questions: how and why residents make their trips within an urban area. It does not consider two other important questions which relate to the origin and destination of trips within the area. Although these data are available for each city, records of trips from place to place within a city cannot justifiably by combined for more than one city at a time, because it is difficult to relate areas when so little is known about their land-use characteristics.

The process of summarizing data to discover travel patterns, related to purpose of trip and mode of travel, began with the cities where the surveys were made. In each of the 50 cities the procedures recommended in the "Manual of Procedures for Home Interview Traffic Study" were generally followed, and tables were compiled in which trips were classified uniformly by mode of travel and purpose of trip. One tabulation was prepared for each mode of travel, showing the number of trips from each purpose to each purpose. However, the number of travel modes reported in different cities varied; trips by train passengers were reported only in two cities and trips by "other" passengers were reported only in five cities. A typical example of the basic tabulations for an individual city is presented in Table 3.

In the course of assembling and combining the data from different cities it became evident that certain less significant trip purposes and travel modes might advantageously be combined. On the average, the five least important trip purposes accounted for less than 12 percent of the total number of trips, and not one of these purposes accounted for as much as 4 percent. These categories were combined to form a miscellaneous group.

Minor trip purposes and the percentages of trips accounted for by each were as follows: to serve passenger, 3.4 percent; change mode of travel, 3.3 percent; school, 2.3 percent; eat meal, 1.7 percent; and medical-dental, 1.1 percent.

In addition, since business trips amounted to less than 5 percent of all internal trips and were often difficult to dissociate from work trips, the two were combined as work

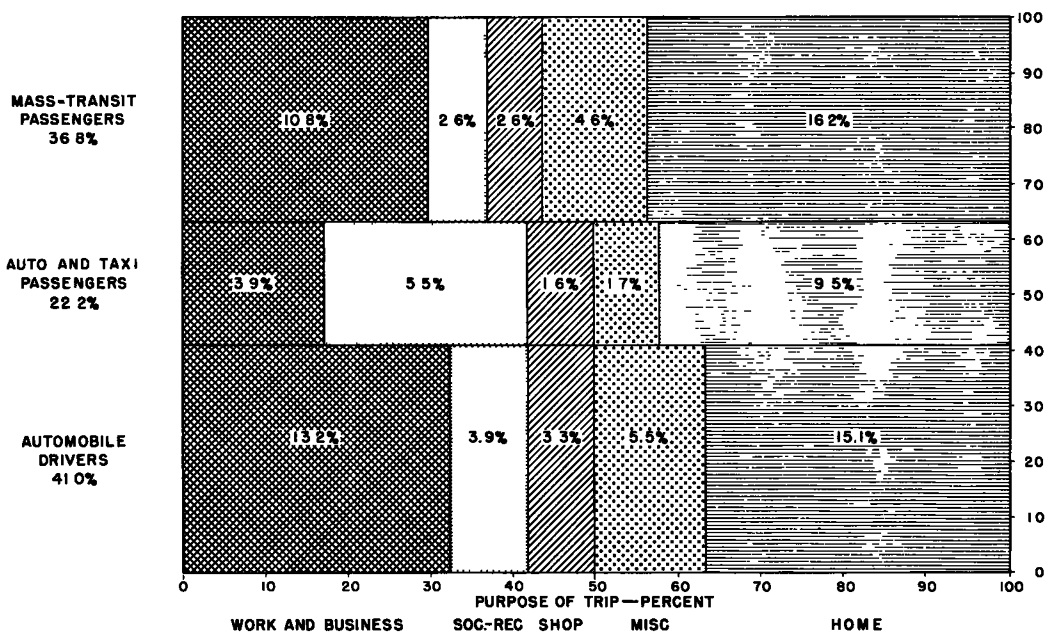

Figure 2. Percentage distribution of trips according to purpose, and further classified by mode of travel.

Table 3.—Number of trips by each mode of travel in Madison, Wis., classified according to trip purpose

Trips from—	Trips to— Work	Business	Medical-dental	School	Social-recreation	Eat meal	Shop	Change mode of travel	Serve passengers	Home	Total
AUTOMOBILE DRIVERS											
Work	8.008	663	89	41	522	3,717	990	---	1,242	11,214	26,486
Business	623	828	10	30	301	190	468	---	210	2,164	4,824
Medical-dental	49	20	10	---	31	9	119	---	50	271	559
School	72	20	10	119	139	290	40	---	150	1,092	1,932
Social-recreation	142	190	40	20	1,377	258	401	10	1,206	6,395	10,039
Eat meal	3,167	171	---	169	290	---	101	---	439	791	5,128
Shop	270	251	29	31	598	139	1,365	11	321	5,333	8,348
Change mode of travel	---	10	10	---	10	20	21	---	20	148	239
Serve passengers	1,924	300	70	209	926	349	620	20	1,776	5,827	12,021
Home	12,648	2,624	341	1,331	5,749	691	4,234	99	6,953	---	34,670
Total	26,903	5,077	609	1,950	9,943	5,663	8,359	140	12,367	33,235	104,246
AUTOMOBILE PASSENGERS											
Work	191	63	30	---	203	503	196	71	---	3,971	5,228
Business	41	217	30	10	184	20	153	---	---	725	1,380
Medical-dental	---	21	---	10	52	---	72	---	---	303	458
School	20	52	53	82	256	188	20	---	---	871	1,542
Social-recreation	92	82	10	89	3,739	297	451	101	---	10,048	14,909
Eat meal	441	10	---	267	251	---	20	---	---	690	1,679
Shop	29	63	10	11	535	62	708	10	---	2,673	4,101
Change mode of travel	30	---	---	---	20	10	22	10	---	271	363
Serve passengers	---	---	---	---	---	---	---	---	---	---	---
Home	4,533	901	313	2,676	9,384	558	2,421	285	---	---	21,071
Total	5,377	1,409	446	3,145	14,624	1,638	4,063	477	---	19,552	50,731
STREETCAR AND BUS PASSENGERS											
Work	130	69	20	10	140	504	220	175	---	7,429	8,697
Business	30	60	---	20	30	---	50	10	---	805	1,005
Medical-dental	---	10	---	10	20	---	---	20	---	300	360
School	161	40	20	90	180	553	201	60	---	5,213	6,518
Social-recreation	20	41	20	20	159	40	70	41	---	3,258	3,669
Eat meal	434	20	---	454	40	---	20	---	---	363	1,331
Shop	40	49	10	50	131	---	150	40	---	2,522	2,992
Change mode of travel	110	10	---	59	70	10	59	40	---	161	519
Serve passengers	---	---	---	---	---	---	---	---	---	---	---
Home	8,153	1,118	382	5,556	3,238	361	1,730	210	---	---	20,748
Total	9,078	1,417	452	6,269	4,008	1,468	2,500	596	---	20,051	45,839
TAXI PASSENGERS											
Work	41	20	50	---	30	10	10	---	---	413	574
Business	10	10	---	10	20	10	---	---	---	149	209
Medical-dental	10	---	---	---	10	---	---	---	---	131	151

School	--------	--------	--------	10	11	20	--------	--------	--------	121	162
Social-recreation	21	11	--------	--------	79	20	--------	--------	--------	481	612
Eat meal	20	--------	--------	--------	10	--------	10	--------	--------	40	80
Shop	30	--------	--------	--------	--------	--------	40	--------	--------	90	160
Change mode of travel	10	--------	--------	--------	20	--------	--------	--------	--------	110	140
Serve passengers	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Home	804	139	110	239	500	60	102	89	--------	--------	2,043
Total	946	180	160	259	680	120	162	89	--------	1,535	4,131
TRUCK PASSENGERS											
Work	92	--------	--------	--------	--------	--------	--------	--------	--------	31	123
Business	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Medical-dental	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
School	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Social-recreation	--------	--------	--------	--------	--------	--------	--------	--------	--------	10	10
Eat meal	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Shop	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Change mode of travel	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Serve passengers	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
Home	11	--------	--------	--------	10	--------	--------	--------	--------	--------	21
Total	103	--------	--------	--------	10	--------	--------	--------	--------	41	154
ALL MODES OF TRAVEL											
Work	8,462	815	189	51	895	4,734	1,416	246	1,242	23,058	41,108
Business	704	1,115	40	70	535	220	671	10	210	3,843	7,418
Medical-dental	59	51	10	20	113	9	191	20	50	1,005	1,528
School	253	112	83	301	586	1,051	261	60	150	7,297	10,154
Social-recreation	275	324	70	129	5,354	615	922	152	1,206	20,192	29,239
Eat meal	4,062	201	--------	890	591	--------	151	--------	439	1,884	8,218
Shop	369	363	49	92	1,264	201	2,263	61	321	10,618	15,601
Change mode of travel	150	26	10	59	120	40	102	50	20	690	1,261
Serve passengers	1,924	300	70	209	926	349	620	20	1,776	5,827	12,021
Home	26,149	4,782	1,146	9,802	18,881	1,670	8,487	683	6,953	--------	78,553
Total	42,407	8,083	1,667	11,623	29,265	8,889	15,084	1,302	12,367	74,414	205,101

Table 4.—Number and percentage of trips by each mode of travel in 50 cities, classified according to trip purpose

Mode of travel	Trip purpose											
	Work and business		Social and recreation		Shop		Miscellaneous		Home		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Automobile drivers	3,679,848	13.2	1,079,942	3.9	910,831	3.3	1,524,373	5.5	4,187,918	15.1	11,382,912	41.0
Automobile and taxi passengers	1,065,361	3.9	1,520,382	5.5	458,798	1.6	486,546	1.7	2,634,629	9.5	6,195,716	22.2
Mass-transit passengers	3,014,103	10.8	736,487	2.6	690,435	2.6	1,270,461	4.6	4,487,541	16.2	10,199,027	36.8
Total	7,759,312	27.9	3,336,811	12.0	2,090,064	7.5	3,281,380	11.8	11,310,088	40.8	27,777,655	100.0

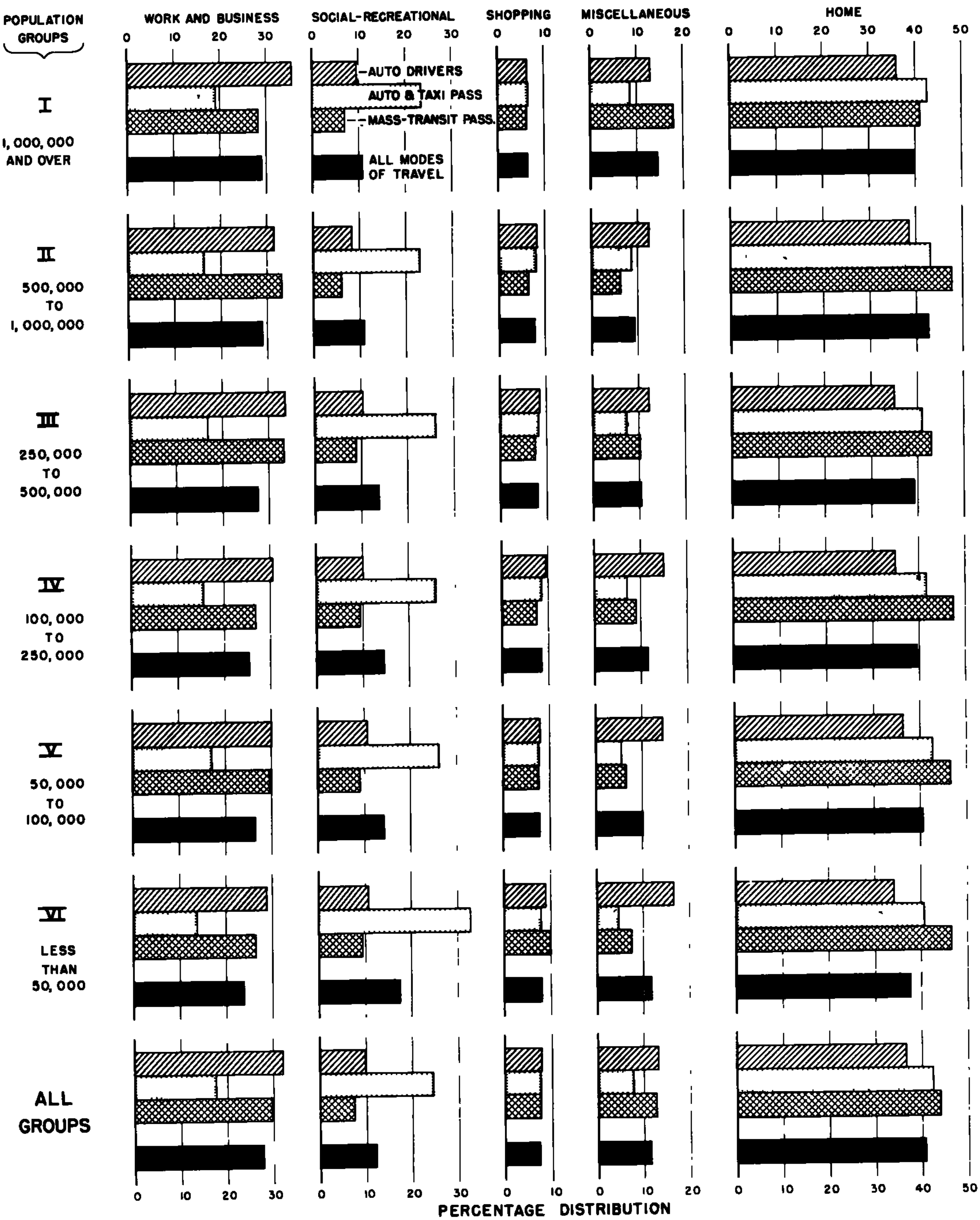

Figure 3. Percentage distribution of trips according to purpose, and further classified by mode of travel and population group.

SUMMARY FOR 50 CITIES

All of the internal trips by residents of the 50 urban areas have been combined in Table 4 and classified according to the five purposes and three modes of travel. Of the total trips numbering almost 28 million, trips by automobile drivers accounted for the largest share and were followed in order by mass-transit passengers and automobile

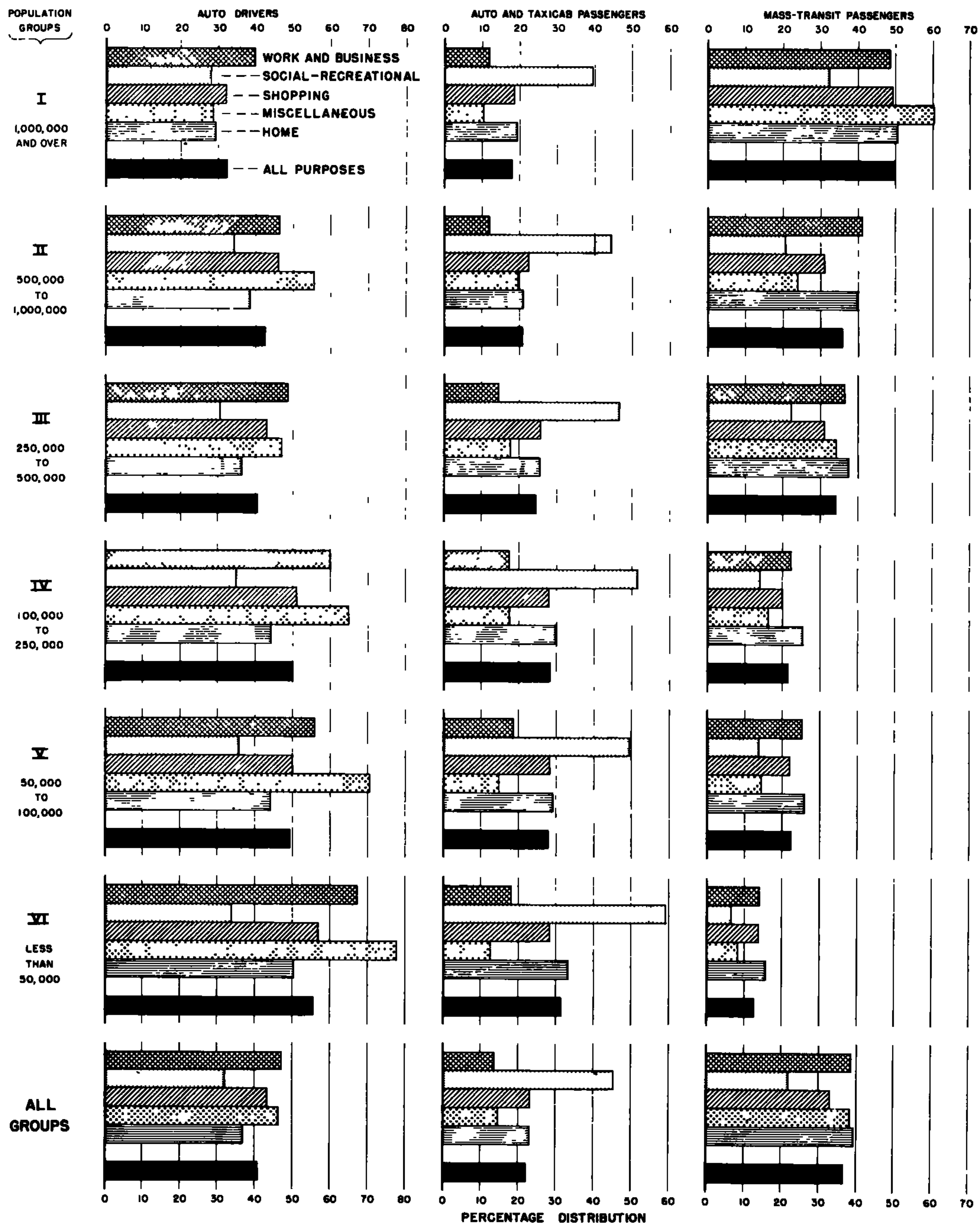

Figure 4. Percentage distribution of trips according to mode of travel, and further classified by purpose and population group.

and taxi passengers. Homeward-bound trips predominated among the five major trip purposes; work and business trips ranked second, and were followed by social-recreational, miscellaneous, and shopping trips in that order.

Although automobile drivers represented the predominant travel mode, mass-transit passengers traveling home constituted the largest mode-purpose category, accounting

Table 9.—Number of trips by automobile drivers and automobile and taxi passengers in each of 50 cities in six population groups, classified according to trip purpose

City	Population group	Number of automobile-driver trips made for purposes of—						Number of automobile- and taxi-passenger trips made for purposes of—					
		Work and business	Social and recreation	Shop	Miscellaneous	Home	Total	Work and business	Social and recreation	Shop	Miscellaneous	Home	Total
Philadelphia, Pa.	1,000,000 and over.	301,490	69,502	32,648	72,655	253,419	729,714	76,711	94,494	23,336	45,475	180,142	420,158
San Francisco, Calif.		423,673	113,942	86,146	208,899	388,421	1,221,081	117,717	163.363	47,283	51,975	260,284	640,622
Newark, N. J.		223,839	56,575	36,654	47,579	278,601	643,248	65,513	66,022	21,021	20,164	154,154	326,874
Washington, D. C.		194,301	60,873	45,886	85,263	145,210	631,533	84,072	96.660	25,047	33,706	174,892	414,377
Total		1,143,303	300,892	201,334	414,396	1,165,651	3,225,576	344.013	420,539	116,687	151,320	769,472	1,802,031
St. Louis, Mo.	500,000–1,000,000.	167,001	31,195	21,747	18,806	216,635	455,384	30,253	12,054	4,526	2,931	45,719	95,483
St. Paul-Minneapolis, Minn.		249,043	85,221	53,954	109,868	285,156	783,242	56,491	128,090	31,694	22,648	178,663	417,586
Baltimore, Md.		138,682	30,395	21.055	22,263	136,185	348,580	44,871	35,016	13,278	18,835	91,386	203.386
Houston, Tex.		283,079	82,573	114,278	161,984	388,703	1,030,617	83,945	112,089	60,187	69,110	242,110	567,441
Dallas, Tex.		148,116	45.630	61,217	89,696	208,231	552,890	40,814	68,188	22,573	33,700	115,969	281,244
Seattle, Wash.		124,257	34,461	24,318	35,910	135,261	354,207	33,336	46,603	12,901	9,224	79,670	181,734
Total		1,110,178	309,475	296,569	438,527	1,370,171	3,524,920	289,710	402,040	145,159	156,448	753,517	1,746,874
Portland, Oreg.	250,000–500,000	143,170	41,536	37,772	55,454	140,772	418,704	34,619	69,522	20.424	9,722	89.206	223,493
Norfolk, Va.		80,240	26,500	19,080	24,220	92,710	242,750	30,960	31,990	12,940	18,180	70,360	164,430
San Juan, P. R.		10,948	4,098	1,389	5,004	9,384	30 823	5,305	8,639	1,411	3,554	12,630	31,539
Total		234,358	72,134	58,241	84,678	242,866	692,277	70,884	110,151	34,775	31,456	172,196	419,462
Wichita, Kans.		109,142	26,936	37,051	67,088	131,879	372.096	41,478	32,520	19,857	21,355	84,004	199,214
Grand Rapids, Mich.		89,493	34,859	34,889	39,578	111,094	309,913	22,531	57.674	18,282	9,177	77.351	185,015
Honolulu, T. H.		40,100	29,282	14,118	27,995	63,209	174,704	15,335	43,022	9,644	11,707	64,443	144,151
Sacramento, Calif.		67,802	16,968	21,702	38,760	69,840	215,072	18,328	21,922	10,078	6,801	41,130	98,259
Salt Lake City, Utah		44,212	15,343	8,499	13,073	51,126	132,253	15,728	23,765	5,590	3,173	37,338	85,594
Wilmington, Del.		37,525	11,243	7,275	15.877	38,551	110,481	15,446	17,014	3,815	6,384	33,029	75,688
Phoenix, Ariz.		62,481	21,784	32,252	42,374	78,069	236,960	17,834	31.533	16,397	12,997	49,599	128,360
Tacoma, Wash.		37,948	11,381	8,118	14,595	40,429	112,471	8,843	13,892	3,986	3,294	21,744	51,759

Spokane, Wash	100,000–250,000	32,262	9,028	5.964	7,748	42.510	97,512	8,706	10,201	3,974	3,070	22,087	48,038
Scranton, Pa		17,326	5,278	2,817	4,422	21,926	51,769	5,795	10,249	3,430	962	18,151	38,587
Duluth, Minn., Superior, Wis.		34,449	10,559	7,424	13,089	31,458	96,979	9,230	23,006	5,183	2,582	26,015	66,016
Chester, Pa		15,279	4,860	4,023	4,843	21,601	50,606	6,694	6,057	3,029	1,243	15,022	32,045
Tucson, Ariz		45,830	14,340	17,110	23,720	53,510	154,510	11,565	20,942	9,387	8,144	31,832	81,870
Lansing, Mich		46,857	12,212	14,461	23,259	46,800	143,589	10,893	19,009	5,421	5,192	25,683	66,198
Reading, Pa		24,896	4,177	2,818	7.993	21,022	60,906	6,579	4,229	1,676	2,002	11,928	26,414
Albuquerque, N. Mex		38,940	14,575	10,769	19,888	45,287	129,459	11,258	27,045	4,753	4,085	33,137	80,278
Rockford, Ill		47,261	17,592	11,932	13,891	65,040	155,716	12,988	22,768	8,353	2,179	37,307	83,595
Saginaw, Mich		40,051	10,614	16,068	25,296	50,860	142,889	11,176	18,900	7,311	4,539	30,063	71,989
Madison, Wis		31,980	9,943	8,359	20,729	33,235	104,246	8,015	15,314	4,225	6,334	21,128	55,016
Harrisburg, Pa		25,130	6,057	5,121	9,474	25,130	70,912	6,222	9,757	2,405	1,527	15,804	35,715
Total		888,964	287,031	270.770	433,692	1,042,586	2,923,043	264,644	428,819	146,796	116.747	696,795	1,653,801
Johnstown, Pa	50,000–100,000	13,488	4,356	4,944	3,984	13,956	40,728	3,061	6,183	2,415	1,166	9,639	22,464
Altoona, Pa		16,224	6,296	5,423	6,186	20,940	55,069	3,936	9.054	3,512	856	13,811	31,169
Muskegon, Mich		24,158	12,721	6,969	11,359	32,209	87,416	8,898	21,526	3,975	2,109	25,787	62,295
Pontiac, Mich		22,089	5,809	5,582	13,195	27,648	74.323	9,690	9,669	3,162	2,603	19,326	44,450
Columbus, Ga		17,602	5,507	5,882	7,212	25,658	61,861	8,377	4,227	1,928	2,929	13,393	30,854
Racine, Wis		25,117	8,384	7,303	16,775	27.210	84.789	5,642	11,721	3,385	3,366	15,862	39,976
Macon, Ga		17,645	1,953	2,549	6,137	21,233	49,517	8,413	3,711	2.214	1,477	14,275	30,090
York, Pa		33,651	7,777	5,381	13,841	26,755	87,405	9,377	9,080	3,477	2,264	16,999	41,197
Charleston, S. C		13.227	5,957	3,718	4,222	18,720	45,844	6,203	8,662	2,435	1.071	15,493	33,864
Kalamazoo, Mich		24,162	10,237	5,329	10,141	29,911	79,780	6,424	11,464	3,223	2,757	17,568	41,436
Bay City, Mich		21,430	13,660	9,085	16,461	32,834	93,470	6,313	18,884	4,132	3,169	22,988	55,486
Williamsport, Pa		13,772	5,304	2,908	8,198	17,890	48.072	3,362	5,902	2.083	1,088	10,140	22,575
Total		242,565	87,961	65,073	117,711	294,964	808,274	79,696	120,083	35,941	24,855	195,281	455,856
Fargo, N. Dak., Moorhead, Minn.	Less than 50,000.	22,435	7,795	3,996	12,797	22,502	69,525	6,286	18,315	2,286	1,747	17,950	46,584
Sharon-Farrell, Pa		12,103	5,267	4,848	7,209	15,508	44,935	3,174	8,364	2,306	698	10,916	25,458
Norristown, Pa		7,097	3,198	1,754	3,310	11,949	27,308	3,046	2,927	886	801	6,464	14,124
Appleton, Wis		13,309	4,277	6,058	7,929	14,945	46,518	2,506	6,895	3,056	1,154	8,631	22,242
Wisconsin Rapids, Wis		5,536	1,912	2,188	4,124	6,776	20,536	1,402	2,249	906	1,320	3,407	9,284
Total		60,480	22,449	18,844	35,369	71,680	208,822	16,414	38,750	9,440	5,720	47,368	117,692
Grand total	All groups	3,679,848	1,079,942	910,831	1,524,373	4,187,918	11,382,912	1,065,361	1,520,382	488,798	486,546	2,634,629	6,195,716

Table 10.—Number of trips by mass-transit passengers and by all modes of travel in each of 50 cities in six population groups, classified according to trip purpose

City	Population group	Number of mass-transit passenger trips made for purposes of—						Number of trips by all modes of travel for purposes of—					
		Work and business	Social and recreation	Shop	Miscellaneous	Home	Total	Work and business	Social and recreation	Shop	Miscellaneous	Home	Total
Philadelphia, Pa	1,000,000 and over.	583,557	135,154	126,102	692,382	861,013	2,398,208	961,758	299,150	182,086	810,512	1,294,574	3,548,080
San Francisco, Calif		296,825	79,652	66,397	86,241	414,667	943,782	838,215	356,957	199,826	347,115	1,063,372	2,805,485
Newark, N. J		284,434	78,023	78,313	54,244	453,361	948,375	573,786	200,620	135,988	121,987	886,116	1,918,497
Washington, D. C		237,164	52,699	38,872	51,167	298,058	677,960	515,537	210,232	109,805	170,136	718,160	1,723,870
Total		1,401,980	345,528	309,684	884,034	2,027,099	4,968,325	2,889,296	1,066,959	627,705	1,449,750	3,962,222	9,995,932
St Louis, Mo	500,000–1,000,000.	428,806	69,134	70,793	30,495	562,209	1,161,437	626,060	112,383	97,066	52,232	824,563	1,712,304
St. Paul-Minneapolis, Minn.		137,017	29,327	33,728	30,394	201,235	431,701	442,551	242,638	119,376	162,910	665,054	1,632,529
Baltimore, Md		201,560	44,773	42,922	46,233	307,263	642,751	385,113	110,184	77,255	87,331	534,834	1,194,717
Houston, Tex		66,022	8,630	14,227	44,125	119,265	252,269	433,046	203,292	188,692	275,219	750,078	1,850,327
Dallas, Tex		68,066	7,421	12,317	22,299	95,968	206,071	256,996	121,239	96,107	145,695	420,168	1,040,205
Seattle, Wash		81,675	25,713	27,015	16,532	132,308	283,243	239,268	106,777	64,234	61,666	347,239	819,184
Total		983,146	184,998	201,002	190,078	1,418,248	2,977,472	2,383,034	896,513	642,730	785,053	3,541,936	8,249,266
Portland, Oreg	250,000–500,000	75,407	27,190	24,837	10,838	110,779	249,051	253,196	138,248	83,033	76,014	340,757	891,248
Norfolk, Va		40,920	8,230	7,180	6,060	55,350	117,740	152,120	66,720	39,200	48,460	218,420	524,920
San Juan, P. R		59,449	16,889	10,040	43,450	85,142	214,970	75,702	29,626	12,840	52,008	107,156	277,332
Total		175,776	52,309	42,057	60,348	251,271	581,761	481,018	234,594	135,073	176,482	666,333	1,693,500
Wichita, Kans		18,508	3,484	5,349	8,927	31,441	67,709	169,128	62,940	62,257	97,370	247,324	639,019
Grand Rapids, Mich		23,407	6,942	5,704	3,331	34,176	73,560	135,431	99,475	58,875	52,086	222,621	568,488
Honolulu, T. H		34,179	18,845	9,064	17,751	82,366	162,205	89,614	91,149	32,826	57,453	210,018	481,060
Sacramento, Calif		14,517	3,708	3,917	8,770	27,344	58,256	100,647	42,598	35,697	54,331	138,314	371,587
Salt Lake City, Utah		21,079	7,642	6,332	3,735	35,060	73,848	81,019	46,750	20,421	19,981	123,524	291,695
Wilmington, Del		28,532	9,317	6,551	7,244	46,242	97,886	81,503	37,574	17,641	29,505	117,832	284,055
Phoenix, Ariz		15,863	5,046	5,484	10,897	34,028	71,318	96,178	58,363	54,133	66,268	161,696	436,638
Tacoma, Wash		14,967	4,724	4,742	5,340	25,400	55,173	61,758	29,997	16,846	23,229	87,573	219,403

Spokane, Wash	100,000-250,000	14,915	4,979	6,177	5,057	32,090	63,218	55,883	24,208	16,115	15,875	96,687	208,768
Scranton, Pa		15,765	9,282	14,017	1,960	40,238	81,262	38,886	24,809	20,264	7,344	80,315	171,618
Duluth, Minn., Superior, Wis		17,648	7,244	4,953	2,468	27,658	59,971	61,327	40,809	17,560	18,139	85,131	222,966
Chester, Pa		8,197	1,922	2,311	3,057	12,680	28,167	30,170	12,839	9,363	9,143	49,303	110,818
Tucson, Ariz		7,310	2,490	2,640	5,590	16,290	34,320	64,705	37,772	29,137	37,454	101,632	270,700
Lansing, Mich		8,543	2,719	2,583	3,797	14,478	32,120	66,293	33,940	22,465	32,248	86,961	241,907
Reading, Pa		23,717	4,907	4,731	3,552	32,885	69,792	55,192	13,313	9,225	13,547	65,835	157,112
Albuquerque, N. Mex		8,668	3,597	3,069	2,266	15,290	32,890	58,866	45,217	18,591	26,239	93,714	242,627
Rockford, Ill		10,911	3,059	6,749	1,354	20,484	42,557	71,160	43,419	27,034	17,424	122,831	281,868
Saginaw, Mich		6,217	2,074	1,427	871	9,471	20,060	57,444	31,588	24,806	30,706	90,394	234,938
Madison, Wis		10,495	4,008	2,500	8,785	20,051	45,839	50,490	29,265	15,084	35,848	74,414	205,101
Harrisburg, Pa		26,782	9,578	5,861	3,299	38,592	84,112	58,134	25,392	13,387	14,300	79,526	190,739
Total		330,220	115,567	104,161	108,051	596,264	1,254,263	1,483,828	831,417	521,727	658,490	2,335,645	5,831,107
Johnstown, Pa	50,000-100,000	11,424	3,924	3,132	1,176	17,940	37,596	27,973	14,463	10,491	6,326	41,535	100,788
Altoona, Pa		6,107	1,823	2,391	946	10,300	21,567	26,267	17,173	11,326	7,988	45,051	107,805
Muskegon, Mich		6,373	4,022	2,307	574	11,360	24,636	39,429	38,269	13,251	14,042	69,356	174,347
Pontiac, Mich		7,122	1,949	1,648	4,813	12,768	28,300	38,901	17,427	10,392	20,611	59,742	147,073
Columbus, Ga		21,645	2,894	3,765	4,024	30,903	63,231	47,624	12,628	11,575	14,165	69,954	155,946
Racine, Wis		7,653	2,916	2,390	2,832	11,257	27,048	38,412	23,021	13,078	22,973	54,329	151,813
Macon, Ga		20,549	4,418	5,006	2,915	33,154	66,042	46,607	10,082	9,769	10,529	68,662	145,649
York, Pa		4,281	1,377	1,496	1,345	6,537	15,036	47,309	18,234	10,354	17,450	50,291	143,638
Charleston, S. C		10,498	5,068	2,261	789	15,885	34,501	29,928	19,687	8,414	6,082	50,098	114,209
Kalamazoo, Mich		7,189	2,546	2,247	3,031	11,144	26,157	37,775	24,247	10,799	15,929	58,623	147,373
Bay City, Mich		4,955	1,978	1,239	1,337	7,017	16,526	32,698	34,522	14,456	20,967	62,839	165,482
Williamsport, Pa		2,401	781	896	498	3,971	8,547	19,535	11,987	5,887	9,784	32,001	79,194
Total		110,197	33,696	28,778	24,280	172,236	369,187	432,458	241,740	129,792	166,846	662,481	1,633,317
Fargo, N. Dak., Moorhead, Minn	Less than 50,000.	3,543	1,690	1,310	885	5,994	13,422	32,264	27,800	7,592	15,429	46,446	129,531
Sharon-Farrell, Pa		4,229	1,489	2,021	585	7,688	16,012	19,506	15,120	9,175	8,492	34,112	86,405
Norristown, Pa		3,908	842	973	1,759	6,527	14,009	14,051	6,967	3,613	5,870	24,940	55,441
Appleton, Wis		1,052	356	445	325	1,994	4,172	16,867	11,528	9,559	9,408	25,570	72,932
Wisconsin Rapids, Wis		52	12	4	116	220	404	6,990	4,173	3,098	5,560	10,403	30,224
Total		12,784	4,389	4,753	3,670	22,423	48,019	89,678	65,588	33,037	44,759	141,471	374,533
Grand total	All groups	3,014,103	736,487	690,435	1,270,461	4,487,541	10,199,027	7,759,312	3,336,811	2,090,064	3,281,380	11,310,088	27,777,655

With some minor exceptions, this trend occurred among trips in each purpose category.

The mode-of-travel pattern by population groups is shown in Figure 4. For all purposes combined, the proportion of trips by mass-transit passengers ranged from 50 percent in the cities with over 1 million population to 13 percent in the less than 50,000 population group. On the other hand, trips by automobile drivers ranged from 32 to 56 percent, and automobile and taxi passengers, from 18 to 31 percent. On the basis of individual trip purposes, the ranges among population groups were much greater in some cases, as seen in Table 7.

It is evident from Figure 4 that the privately owned automobile, considering both drivers and passengers, was the predominant choice for trips to all purposes in cities of less than 1 million population. Automobile travel was also greatly preferred for social and recreational trips by residents of cities in the 1 million or more population group.

Average Trips per City

Table 8 contains the number of internal trips made by residents by each mode of travel and for each trip purpose in the average city within each population group. Although the figures are pure arithmetic means of the total trips made in the cities within each population group, the volumes are indicative of what might be expected in other cities of similar size. Of special note is the regularly increasing volume of trips for each trip purpose from the smallest to the largest population group for each mode of travel.

However, there appears to be a near maximum volume of automobile-driver trips for shopping purposes when cities reach the 500,000-1,000,000 population size. In cities of 1 million population and over, trips made by automobile drivers for shopping purposes exceeded those in the 500,000-1,000,000 population group by less than 2 percent. This is reflected in Table 6 which shows that automobile drivers made only 32 percent of the shopping trips in the largest cities as compared with 46 percent in the next smaller population group. This difference may be explained partly by the inability

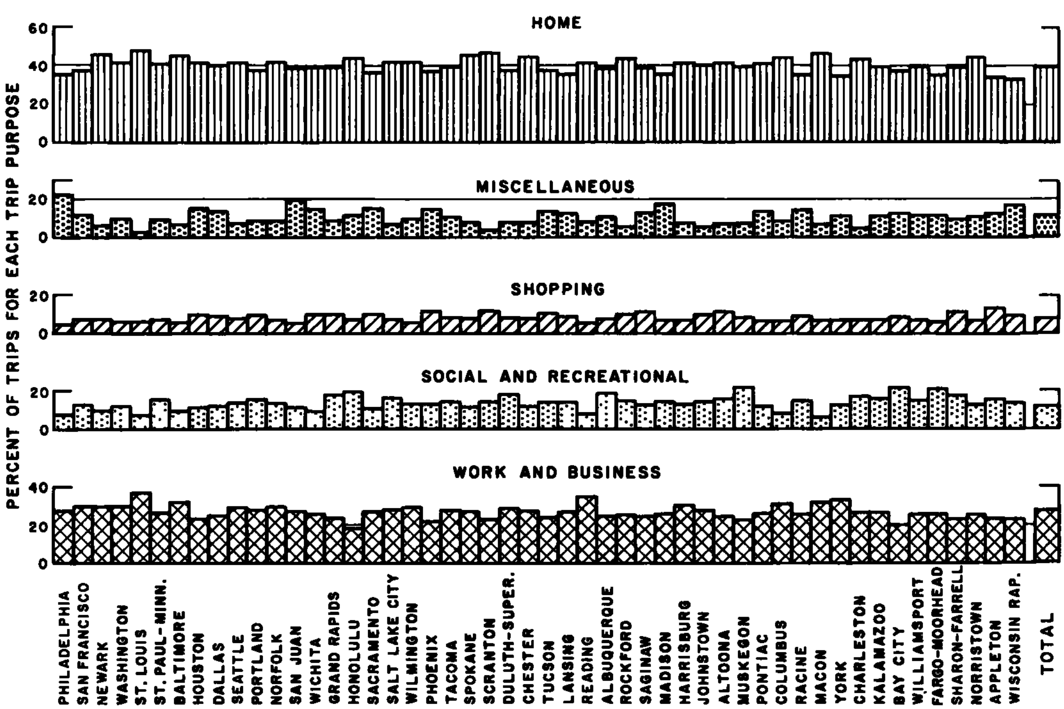

Figure 5. Percentage distribution of trips in each city, according to purpose.

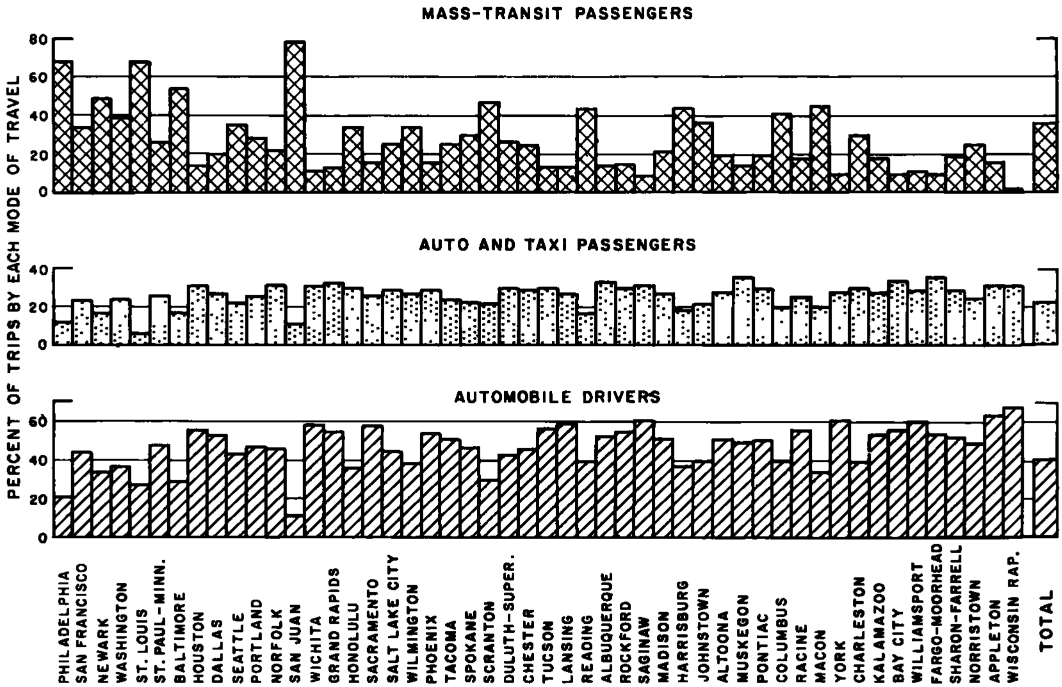

Figure 6. Percentage distribution of trips in each city, according to mode of travel.

of the downtown shopping districts of very large cities to accommodate automobile drivers and partly by the increased availability of transit facilities and taxicabs, particularly around the densely populated areas in the vicinity of the central business district.

DISTRIBUTION OF TRIPS BY INDIVIDUAL CITIES

The number of trips by residents according to purpose in each of the 50 urban areas are presented in Tables 9 and 10 for automobile drivers, automobile and taxi passengers, mass-transit passengers, and for all modes of travel. In these tables the cities are listed in descending order of population size at the time of the basic survey. The general tendency for a greater volume of trips in the more populous urban areas agrees with the same relationship already mentioned in the discussion of population groups, but in the case of individual cities several exceptions are apparent. The more obvious exceptions are readily noticed.

The residents of San Juan made far fewer automobile-driver and automobile- and taxi-passenger trips than persons living in mainland cities of the same size. This relatively small number of trips existed throughout all the major purposes, but applied particularly to shopping trips. The abnormally high number of trips made in Philadelphia for miscellaneous purposes may be related to the large number of mass-transit passenger trips for the intermediate purpose of changing mode of travel. In the St. Paul-Minneapolis area, an unusually large number of trips for social and recreational purposes were made by automobile.

The high volume of mass-transit passenger trips in Philadelphia, St. Louis, and Honolulu is noteworthy, and conversely the relatively small number of automobile-driver and automobile- and taxi-passenger trips in the same cities. In Houston there was an exceptionally large volume of trips by modes other than mass transit, particularly for shopping and miscellaneous purposes. A large number of automobile trips for all purposes is noted in Grand Rapids and Wichita. However, the relative stability of work and business trips and homeward-bound trips is significant throughout all cities.

Table 11.—Range in percentage of trips for each trip purpose by each mode of travel in 50 cities

Mode of travel	Percentage range, by mode of travel, in trips made for purposes of—				
	Work and business	Social and recreation	Shop	Miscellaneous	Home
Automobile drivers:					
Maximum	41.3	16.8	13 6	20.1	47.6
Minimum	22 9	4.0	4.5	4.1	30.4
Automobile and taxi passengers:					
Maximum	31.7	39.3	13.7	12 2	47.9
Minimum	10.6	12.3	4 5	2.5	36.7
Mass-transit passengers:					
Maximum	36.9	16.3	17 3	28.9	54.5
Minimum	12.9	3.0	1 0	2.3	35.9
All modes of travel:					
Maximum	36.6	22.0	13.1	22.8	48.2
Minimum	18.6	6.9	4.6	3.1	34.4

Purpose Distribution

The percentages of trips for each purpose in each of the 50 urban areas are presented in Figure 5. Although generally displaying a pattern of uniformity in the percentage distribution of trip purposes within each city, this chart reveals several proportional trip variations which are not readily apparent in the tables of absolute trip volumes.

The large percentage of trips for miscellaneous purposes in Philadelphia again reflects the volume of trips made by mass-transit passengers for the purpose of changing mode of travel. In Wisconsin Rapids the high percentage of miscellaneous trips may be explained by the fact that over 90 percent of the miscellaneous transit trips in this small Wisconsin city were to school. Madison, Wis., a university city, also had a relatively large proportion of trips to school. The percentage of work and business trips is especially high in St. Louis, particularly among automobile and taxi passengers. This is undoubtedly due in part to the time of the survey which was begun just before the end of World War II. There are other extremes of more or less importance, such as the relatively small proportion of work and business trips in Honolulu, Muskegon, and Bay City, which, in a sense, are somewhat offset by social and recreational trips. However, in spite of these variations among individual cities, the over-all effect is to reemphasize the essentially uniform pattern of trip purposes among the population groups.

Though not shown in this article, similar data also were developed for each separate mode of travel. In most cities the combination of work-business and home trips accounted for about 70 percent of all automobile-driver trips as well as mass-transit passenger trips, with social-recreational and shopping trips each accounting for another 7 to 10 percent. On the other hand, trips by automobile and taxi passengers were more frequently made for a social or recreational purpose rather than work or business. Social and recreational trips generally amounted to one-fourth of the total trips by passengers in automobiles and taxis.

Among automobile drivers, trips to home comprised the major portion of the travel in 41 cities. Work and business trips ranked second in these cities and

Table 12.—Range in percentage of trips by each mode of travel for each trip purpose in 50 cities

Purpose of trip	Percentage range, by purpose of trip, in trips made by—		
	Automobile drivers	Automobile and taxi passengers	Mass-transit passengers
Work and business:			
Maximum	79.2	24.9	78.5
Minimum	14.5	4.8	.7
Social and recreation:			
Maximum	45.9	65.9	61.5
Minimum	13.8	10.7	.3
Shop:			
Maximum	70.6	35.4	78.2
Minimum	10.8	4.7	.1
Miscellaneous:			
Maximum	84.9	37.5	85.4
Minimum	9.0	5.6	2.1
Home:			
Maximum	65.1	38.7	79.5
Minimum	8.8	5.6	2.1
All purposes:			
Maximum	67.9	35.7	77.5
Minimum	11.1	5.6	1.3

Table 13.—Number and percentage of trips by each mode of travel in 50 cities from each purpose to each purpose

Trips from—	Trips to— Work and business: Number	Work and business: Percent	Social and recreation: Number	Social and recreation: Percent	Shop: Number	Shop: Percent	Miscellaneous: Number	Miscellaneous: Percent	Home: Number	Home: Percent	Total: Number	Total: Percent
AUTOMOBILE DRIVERS												
Work and business	1,137,747	4.1	69,070	0.2	103,456	0.4	338,619	1.2	2,042,942	7.4	3,691,834	13.3
Social and recreation	31,001	.1	135,366	.5	43,584	.2	93,036	.3	774,933	2.8	1,077,920	3.9
Shop	43,624	.2	46,590	.2	138,449	.5	43,602	.2	628,494	2.2	900,759	3.3
Miscellaneous	340,199	1.2	93,187	.3	74,324	.2	237,668	.9	741,549	2.7	1,486,927	5.3
Home	2,127,277	7.6	735,729	2.7	551,018	2.0	811,448	2.9	----------	------	4,225,472	15.2
Total	3,679,848	13.2	1,079,942	3.9	910,831	3.3	1,524,373	5.5	4,187,918	15.1	11,382,912	41.0
AUTOMOBILE AND TAXI PASSENGERS												
Work and business	117,942	0.4	42,639	0.2	36,541	0.1	61,531	0.2	837,854	3.0	1,096,507	3.9
Social and recreation	21,597	.1	305,659	1.1	40,438	.1	38,734	.1	1,159,437	4.2	1,565,865	5.6
Shop	12,575	.1	41,213	.1	73,229	.2	9,402	------	351,404	1.3	487,823	1.7
Miscellaneous	48,862	.2	51,781	.2	17,394	.1	26,310	.1	285,934	1.0	430,281	1.6
Home	864,385	3.1	1,079,090	3.9	321,196	1.1	350,569	1.3	----------	------	2,615,240	9.4
Total	1,065,361	3.9	1,520,382	5.5	488,798	1.6	486,546	1.7	2,634,629	9.5	6,195,716	22.2
MASS-TRANSIT PASSENGERS												
Work and business	118,402	0.4	35,234	0.1	38,464	0.2	233,567	0.9	2,533,978	9.1	2,959,645	10.7
Social and recreation	9,086	------	35,688	.1	12,208	------	39,639	.2	598,636	2.2	695,257	2.5
Shop	13,399	------	21,087	.1	23,085	.1	44,347	.2	590,706	2.1	692,624	2.5
Miscellaneous	237,287	.9	52,453	.2	53,753	.2	189,914	.6	764,221	2.8	1,297,628	4.7
Home	2,635,929	9.5	592,025	2.1	562,925	2.1	762,994	2.7	----------	------	4,553,873	16.4
Total	3,014,103	10.8	736,487	2.6	690,435	2.6	1,270,461	4.6	4,487,541	16.2	10,199,027	36.8
ALL MODES OF TRAVEL												
Work and business	1,374,091	4.9	146,943	0.5	178,461	0.7	633,717	2.3	5,414,774	19.5	7,747,986	27.9
Social and recreation	61,684	.2	476,713	1.7	96,230	.3	171,409	.6	2,533,006	9.2	3,339,042	12.0
Shop	69,598	.3	108,890	.4	234,763	.8	97,351	.4	1,570,604	5.6	2,081,206	7.5
Miscellaneous	626,348	2.3	197,421	.7	145,471	.5	453,892	1.6	1,791,704	6.5	3,214,836	11.6
Home	5,627,591	20.2	2,406,844	8.7	1,435,139	5.2	1,925,011	6.9	----------	------	11,394,585	41.0
Total	7,759,312	27.9	3,336,811	12.0	2,090,064	7.5	3,281,380	11.8	11,310,088	40.8	27,777,655	100.0

were foremost in the other nine cities.

Homeward-bound trips also ranked first among automobile and taxi passengers in all cities except one. In the Fargo-Moorhead area, social and recreational trips ranked first for this mode of travel. In all but 10 of the remaining 49 cities, social-recreational trips ranked second and were followed by work and business trips. This order was reversed in the remaining 10 cities.

The pattern of trip purposes for mass-transit passengers resembled the automobile-driver pattern more than that of automobile and taxi passengers, but among transit passengers, home trips predominated in all cities without exception. Work and business trips ranked second in all but two cities, Philadelphia and Wisconsin Rapids, where changing-mode-of-travel and school trips caused the miscellaneous group to exceed work and business trips.

Table 14.—Percentage of trips for each mode of travel in 50 cities, classified according to purpose at both origin and destination

Purpose	Mode of travel [1]			
	Automobile drivers	Automobile and taxi passengers	Mass-transit passengers	All modes of travel
Home	73 9	84 7	88.6	81.8
Work and business	64.8	34.9	58.6	55.8
Social-recreation	19.0	49.8	14 0	24.0
Miscellaneous	26.4	14.8	25.2	23.4
Shopping	15.9	15.8	13.6	15.0
Total	200.0	200.0	200.0	200.0

[1] Percentages add to 200 for each mode of travel because the purpose of each trip is considered twice, at place of origin (purpose from) and at place of destination (purpose to).

The composite of all modes of travel followed the pattern of mass-transit passengers with home trips predominating in all cities, followed by work and business trips in all but Honolulu and Bay City, where social-recreational trips ranked second.

These consistencies in trip patterns suggest the possibility of utilizing the present data in making estimates in cities where surveys have not been completed. Although the ranking of trip purposes is fairly uniform, the limits of the individual percentages show wide variations not directly related to the size of city and indicate that such a basis would provide only a rude forecast at best.

The ranges in percentages of trips for each trip purpose by each mode of travel are shown in Table 11. Despite the wide range between the maximum and minimum percentages, it is seen later that for any particular urban area it is possible to make a fairly reasonable forecast of the absolute volume of trips from which percentages may be computed.

Mode Distribution

The percentage distribution of trips in the 50 individual cities by mode of travel is presented in Figure 6. The most noticeable difference from the previous distribution by trip purpose is the relative lack of uniformity among the several cities when considering travel mode. While not included in this article, similar percentages were developed for each trip purpose and a variable pattern was found in each case. The ranges in the percentage of trips by each mode of travel for each trip purpose and for all purposes are shown in Table 12.

Besides being small in absolute volumes, trips by automobile drivers and automobile and taxi passengers were also few on a relative basis in San Juan, where seven out of nine persons making trips traveled as mass-transit passengers, largely in "publicos" (privately owned public conveyances, usually station wagons, which generally operate over established routes but with no fixed schedule). On the other hand, exceptionally high percentages of automobile trips were observed for each trip purpose in cities of Texas, New Mexico, Arizona, California, Washington, Michigan, and Wisconsin.

It may be that these variations are related to the period during which the basic studies were made or to the geographical area in which the cities are located. Some of the studies where mass-transit facilities played an important role were made during or shortly after World War II when automobile driving was restricted. Also, other evidence indicates that the preference for automobile travel has increased progressively over the decade during which the studies were made in the various cities. Insofar as location is concerned, it is not unusual to find a particularly high proportion of automobile-driver trips in the Southwestern and Pacific States, and certain states in the Great Lakes region where automobile ownership and travel are relatively high.

In spite of the noticeable lack of uniformity as far as mode of travel for each trip purpose is concerned, there was an over-all trend for a larger percentage of automobile trips in smaller cities as would be expected. Conversely, there seemed to be a general trend toward a larger percentage of mass-transit passenger trips in the larger cities. Mass transit was the predominant mode of travel in the largest cities, but automobile drivers comprised over half of the vehicular trips by residents in most of the medium-size and smaller cities. These trends appeared among trips for each purpose.

TRIPS FROM PURPOSE TO PURPOSE

All of the previous discussion has dealt with the purpose of trips in connection with their point of destination. This section considers the purpose from which the trips were made at points of origin, as related to the destination purpose. This type of in-

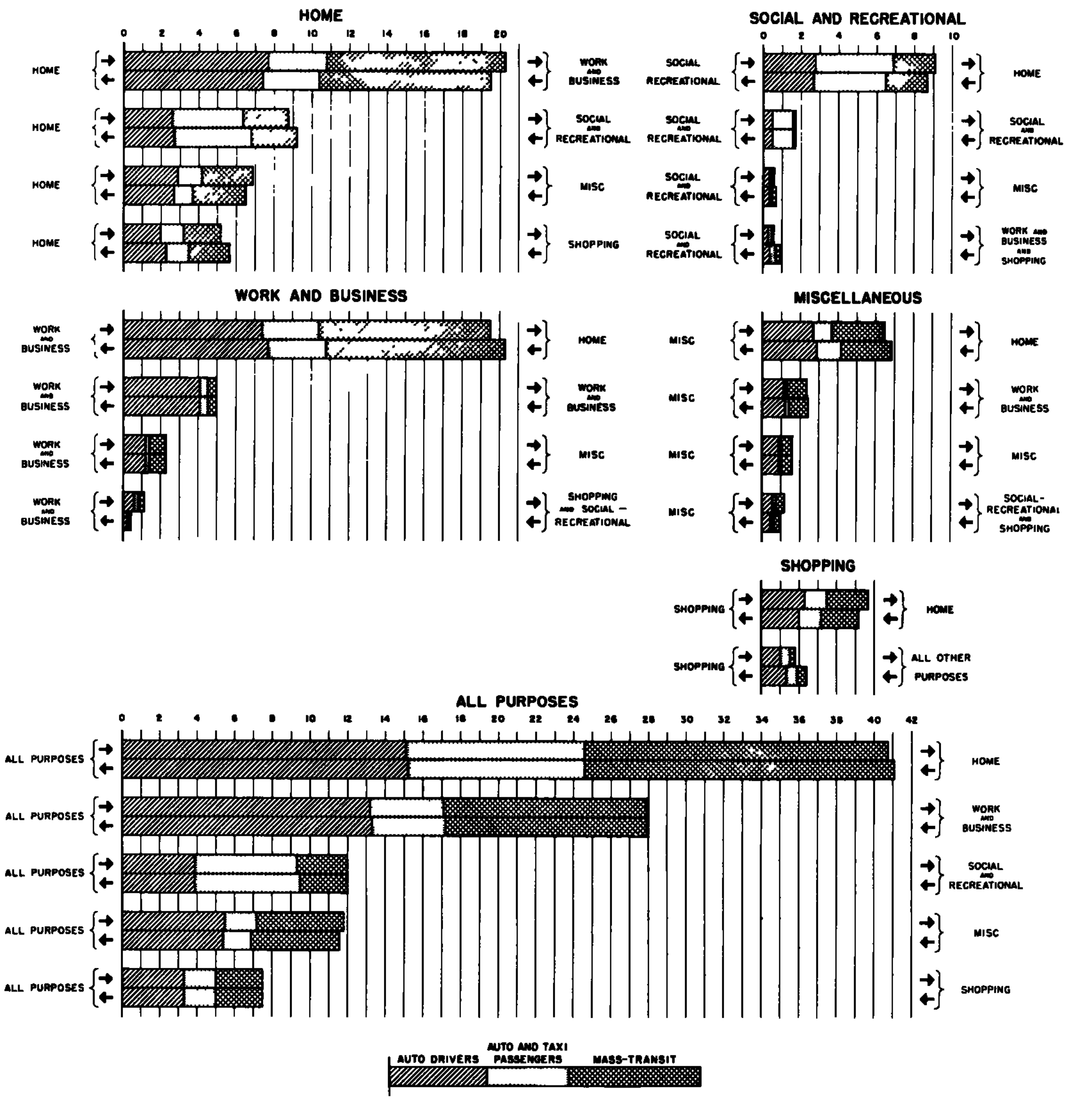

Figure 7. Percentage distribution of trips from each purpose to each purpose, by mode of travel.

formation is presented only in summary form for all 50 urban areas, although detailed data are available from individual city reports. The number of trips made by persons "from" a purpose "to" a purpose are included. This somewhat unusual phraseology is used to express an idea that could not otherwise be expressed precisely in so few words. It describes not only why a person made a trip to his destination, but why he was at the place he left.

Table 13 shows the volume of trips in all 50 urban areas from each purpose to each purpose for each mode of travel. The predominant purposes of trips by all modes of travel were from home to work and business, followed closely by trips from work and business to home. These same trips were dominant among mass-transit passengers and automobile drivers, but ranked second among automobile and taxi passengers. The trips from work or business to home did not quite equal the volume of trips in the reverse direction because of the intermediate trips from work or business for some other purpose prior to returning home. For instance, some of this difference was accounted for by the excess of trips from social-recreational purposes to home, over and above the number of trips from home for social and recreational purposes. Also pedestrian trips, not included in the basic surveys, could have accounted for some of the apparent discrepancies.

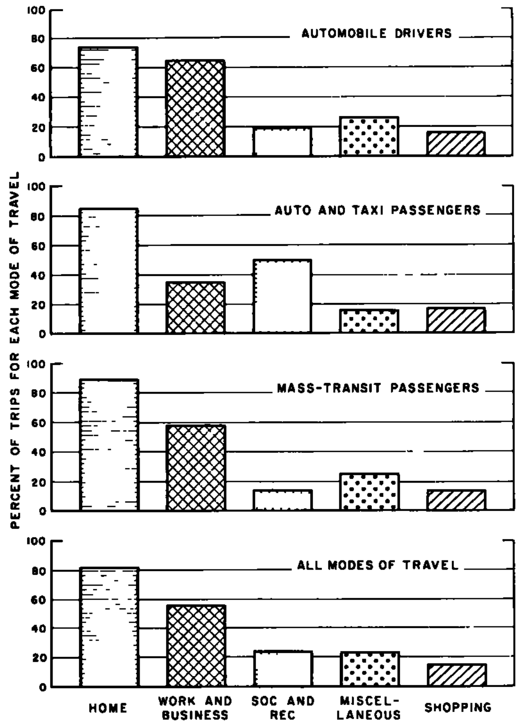

Figure 8. Percentage distribution of trips, both from and to each purpose, by mode of travel.

Trips between home and social-recreational activities were the next most important category (after the home and work-business cycle) among the trips by all modes of travel combined, but they were the most important purpose-to-purpose category among automobile and taxi passengers. Trips between home and miscellaneous purposes ranked second for automobile drivers and mass-transit passengers, third for all modes of travel combined, and fourth for automobile and taxi passengers. The third ranking category among automobile drivers and mass-transit passengers was home trips to and from social-recreational purposes. Trips between home and shopping ranked third with automobile and taxi passengers, and fourth with each of the other modes of travel and with all modes combined. The only other significant purpose-to-purpose categories were the automobile- and taxi-passenger trips from one social or recreational purpose to another, trips from work or business to work or business by automobile drivers, and trips between work or business and miscellaneous purposes by each mode of travel.

Table 13 also shows the percentage distribution of trips from each purpose to each purpose for all travel modes. Trips from home to work and business by mass-transit passengers were the foremost type of internal trips by residents of the 50 urban areas. These trips accounted for nearly 10 percent of the total trips by all modes for all purposes. Trips either to or from home were the most numerous of all. The only other categories of trips accounting for 1 percent or more of the total were trips by automobile drivers for work or business and miscellaneous purposes, and social-recreational trips by automobile and taxi passengers.

Table 13 is the basis for Figure 7 which presents the percentage distribution of trips from each purpose to each purpose, and that proportion attributable to each mode

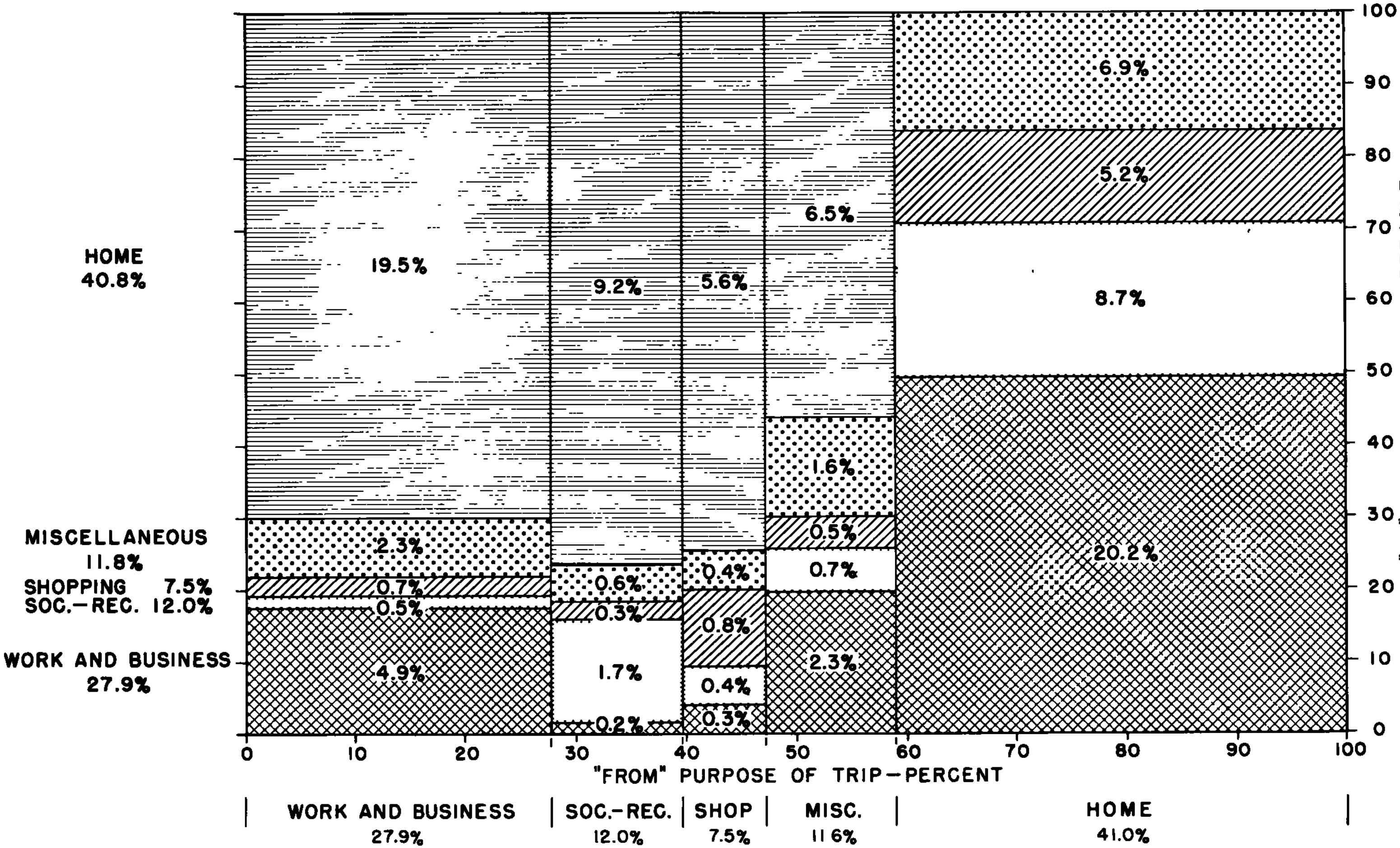

Figure 9. Percentage distribution of trips from each purpose to each purpose.

of travel. Since trips are grouped first by trip purpose and then by all purposes, each trip is represented at least twice in this chart. The arrows indicate the direction of trip purpose. In the upper left-hand corner of the chart, for instance, under the home category, it may be seen that trips in connection with work and business accounted for the largest proportion of home trips. Trips from home to work and business slightly exceeded those in the reverse direction (20.3 percent as compared with 19.5 percent). Mass-transit passengers ranked first in these trips, and automobile and taxi pas-

Table 15.—Selected household characteristics in each of 50 cities in 6 population groups

City	Population group	Number of dwelling units	Number of passenger cars owned	Number of persons, all ages	Number of persons, 5 years of age and older
Philadelphia, Pa.	1,000,000 and over	659,165	257,907	2,233,531	2,048,388
San Francisco, Calif.		554,200	317,400	1,468,933	1,348,835
Newark, N. J.		436,886	245,151	1,456,947	1,345,138
Washington, D. C.		336,181	203,464	1,109,860	992,644
Total		1,986,432	1,023,922	6,269,271	5,735,005
St. Louis, Mo.	500,000–1,000,000	294,757	143,415	974,545	878,377
St. Paul-Minneapolis, Minn.		299,510	226,815	915,960	825,625
Baltimore, Md.		275,778	123,998	912,809	830,909
Houston, Tex.		272,722	256,300	878,629	765,942
Dallas, Tex.		168,066	153,777	533,606	471,064
Seattle, Wash.		188,732	118,622	518,563	471,911
Total		1,499,565	1,022,927	4,734,112	4,243,828
Portland, Oreg.	250,000–500,000	152,586	103,245	453,128	412,358
Norfolk, Va.		108,000	61,480	335,910	293,270
San Juan, P. R.		63,131	8,011	312,069	267,726
Total		323,717	172,736	1,101,107	973,354
Wichita, Kans.	100,000–250,000	79,534	75,888	238,302	206,529
Grand Rapids, Mich.		65,170	52,795	220,977	199,209
Honolulu, T. H.		51,422	32,692	214,236	184,141
Sacramento, Calif.		79,100	53,900	201,345	179,778
Salt Lake City, Utah		57,103	38,851	196,571	172,557
Wilmington, Del.		49,903	30,190	181,445	162,503
Phoenix, Ariz.		48,221	36,372	161,567	145,198
Tacoma, Wash.		48,008	35,175	138,700	125,002
Spokane, Wash.		48,517	29,644	138,381	124,952
Scranton, Pa.		41,362	22,093	137,089	126,541
Duluth, Minn., Superior, Wis.		42,550	25,596	130,847	119,056
Chester, Pa.		35,206	24,449	127,408	114,709
Tucson, Ariz.		38,690	32,910	126,900	113,730
Lansing, Mich.		35,821	30,252	122,776	110,269
Reading, Pa.		37,910	17,184	119,850	112,504
Albuquerque, N. Mex.		34,884	27,469	116,056	100,817
Rockford, Ill.		36,200	33,100	116,000	102,500
Saginaw, Mich.		31,915	27,028	112,902	101,438
Madison, Wis.		33,365	25,328	104,074	94,300
Harrisburg, Pa.		31,599	16,363	103,303	96,100
Total		926,480	667,279	3,008,729	2,691,833
Johnstown, Pa.	50,000–100,000	23,130	13,828	87,509	80,351
Altoona, Pa.		24,060	16,758	85,347	77,477
Muskegon, Mich.		23,507	18,941	83,724	75,099
Pontiac, Mich.		22,251	17,808	79,431	71,851
Columbus, Ga.		20,307	8,808	79,192	70,621
Racine, Wis.		23,280	18,483	78,033	69,508
Macon, Ga.		20,089	9,529	77,665	69,966
York, Pa.		25,310	20,473	77,350	69,387
Charleston, S. C.		20,258	7,179	73,205	65,390
Kalamazoo, Mich.		22,645	17,198	72,024	65,945
Bay City, Mich.		19,561	15,927	69,231	61,454
Williamsport, Pa.		17,016	14,715	55,216	48,675
Total		261,414	179,647	917,927	825,724
Fargo, N. Dak., Moorhead, Minn.	Less than 50,000	15,617	12,688	49,852	44,030
Sharon-Farrell, Pa.		13,657	9,442	48,432	44,310
Norristown, Pa.		10,282	7,466	39,485	36,106
Appleton, Wis.		11,769	11,073	39,172	33,923
Wisconsin Rapids, Wis.		4,700	4,660	16,504	14,428
Total		56,025	45,329	193,445	172,797
Grand total		5,053,633	3,111,840	16,224,591	14,642,541

sengers ranked third behind automobile drivers.

Home trips that were linked with social and recreational purposes were fewer than those involving work and business. Their pattern differed from the latter in that trips from home to social-recreational activities were fewer than the reverse trips. Also, in this case, automobile- and taxi-passenger trips were the most numerous, and were followed by automobile-driver and mass-transit passenger trips. As a matter of fact, home trips linked with work and business were made less often by automobile and taxi passengers than home trips linked with a social-recreational purpose. Figure 7 is adaptable similarly to an analysis of trips associated with other or with all to and from purposes.

Table 14 shows the percentage of trips made both to and from each purpose for each mode of travel. Since for each single trip there are two purposes, one from and one to, the totals add to 200 percent. This table formed the basis for Figure 8, from which it is apparent that first home and then work and business were the top-ranking purposes among all modes except one. Automobile and taxi passengers traveled more frequently from or to a social-recreational purpose (50 percent) than a work or business purpose (35 percent). Work and business trips were relatively more significant among the automobile drivers, since 65 percent of their trips were for that purpose. Mass-transit passengers were the group most likely to be traveling from or to home. The fact that this purpose accounted for almost 89 percent of their trips may be related to the greater possibility that intermediate trips by these persons were made by walking than in the case of automobile drivers and automobile and taxi passengers. Miscellaneous trips accounted for about one-fourth of the trips by both mass-transit passengers and by automobile drivers. Trips to or from shopping amounted to approximately 15 percent of the trips by each mode of travel.

The percentage distribution of trips from each purpose to each purpose is presented in Figure 9 for all modes of travel combined. This chart was constructed in a manner similar to Figure 2. It shows, for instance, that trips from home to work and business predominated, accounting for almost 50 percent of the trips from home and over 20 percent of all trips. The reverse trips from work and business to home also accounted for about one-fifth of all trips, but they comprised 70 percent of the trips from work and business. Trips to home accounted for three-fourths of the trips from social-recreational and from shopping purposes, but in comparison with total trips, they represented only 9 and 6 percent, respectively. The large proportion of trips both to and from home, 82 percent, is particularly apparent in Figure 9.

HOUSEHOLD CHARACTERISTICS

In addition to data concerning the daily trips of residents, the basic origin and destination surveys of the home-interview type provided information concerning the numbers of dwelling units, automobiles owned, residents, and persons 5 years of age and older. Some of these household characteristics for the 50 urban areas are recorded in Table 15. By and large they varied directly with population. This pattern is more

Table 16.—Average number of dwelling units, passenger cars owned, and residents per city for each of six population groups

Population group	Number of cities	Average number (in thousands) of—			
		Dwelling units	Passenger cars owned	Persons, all ages	Persons, 5 years of age and older
1,000,000 and over	4	497	256	1,567	1,434
500,000-1,000,000	6	250	170	789	707
250,000-500,000	2	130	82	395	353
100,000-250,000	20	46	33	150	135
50,000-100,000	12	22	15	76	69
Less than 50,000	5	11	9	39	35
All groups	49	102	64	325	294

Table 17.—Average ratios per city between number of trips by each mode of travel and selected household characteristics in six population groups

Population group	Trips per dwelling unit by mode of travel				Trips per automobile owned by mode of travel				Trips per person by mode of travel			
	Automobile driver	Automobile and taxi passenger	Mass-transit passenger	Total	Automobile driver	Automobile and taxi passenger	Mass-transit passenger	Total	Automobile driver	Automobile and taxi passenger	Mass-transit passenger	Total
1,000,000 and over	1.62	0.91	2.50	5.03	3.15	1.76	4.85	9.76	0.51	0.29	0.79	1.59
500,000–1,000,000	2.35	1.16	1.99	5.50	3.45	1.70	2.91	8.06	.74	.37	.63	1.74
250,000–500,000	2.54	1.49	1.41	5.44	4.02	2.35	2.22	8.59	.84	.49	.46	1.79
100,000–250,000	3.15	1.79	1.35	6.29	4.38	2.48	1.88	8.74	.97	.55	.42	1.94
50,000–100,000	3.09	1.75	1.41	6.25	4.50	2.54	2.05	9.09	.88	.50	.40	1.78
Less than 50,000	3.73	2.10	.85	6.60	4.61	2.60	1.06	8.27	1.08	.61	.25	1.94

apparent in Table 16, which compares the mean averages for each of six population groups. In this table and in all of the following analyses San Juan, Puerto Rico, was omitted because of the significant differences from the pattern of travel in the continental United States.

TRIPS RELATED TO HOUSEHOLD CHARACTERISTICS

The ratios of trips by each travel mode to household characteristics are shown in Table 17 for the average city in each population group. The ratios of total trips and automobile trips tended to vary inversely with population, while mass-transit trip ratios varied directly with population, as seen in Figure 10. The sharp upturn in the pattern for total trips per automobile owned in the highest population group was due to the relatively low automobile ownership ratios in cities of the 1 million or more population group and the greater incidence of mass-transit trips in these cities. The reverse situation caused the low point in this pattern for cities of less than 50,000 population. Some of the other variations of the patterns in the 500,000 to

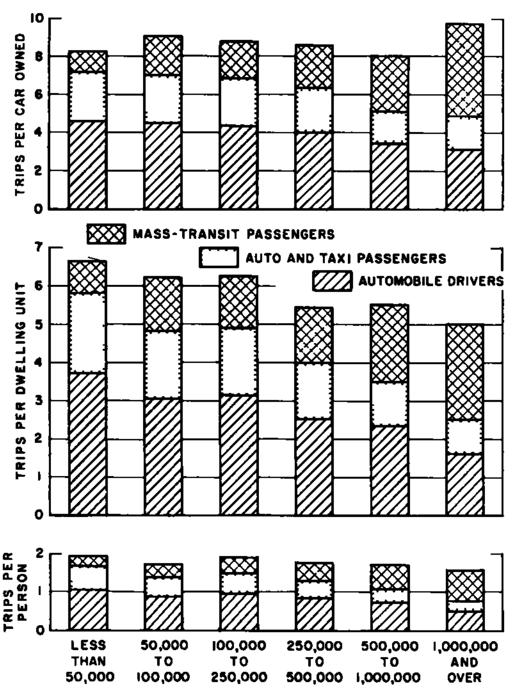

Figure 10. Relation of trips per person, trips per dwelling unit, and trips per automobile to population size of cities.

1,000,000 and 50,000 to 100,000 population groups would be smoothed out by eliminating surveys conducted during World War II.

The basic Tables 9 and 10, giving trip purpose and mode of travel in each of the 50 cities, and the household characteristics shown in Table 15 may be used to develop similar individual city ratios for each mode of travel and each trip purpose. For each trip purpose there appears to be an inverse linear correlation between population and trips per dwelling unit or trips per person for the automobile travel modes; that is, the larger cities have smaller trip ratios. In the case of trips by mass-transit passengers, the correlations generally appear to be direct for each trip purpose.

The relations existing between a few of these trip ratios and the number of automobiles per dwelling unit are shown in Figure 11. It is noted that in areas of high automobile-ownership ratios, the total trips per person and the automobile trips per person

Table 18.—Correlation coefficients computed for certain types of trips and related household characteristics in 49 cities [1]

Mode of travel or purpose of trip	Household characteristic	Correlation coefficient
Mode of travel:		
All modes	Dwelling units	0.987
Automobile driver	Automobiles owned	.975
Mass-transit passenger	Persons 5 years of age and over	.941
Purpose of trip:		
Work and business	Dwelling units	.989
Social and recreation	Automobiles owned	.968
Shop	do	.979
Miscellaneous	Persons 5 years of age and over	.916
Home	Dwelling units	.985

[1] Scatter diagrams, except for social-recreational, miscellaneous, and home trip purposes, are presented in figures 12–16.

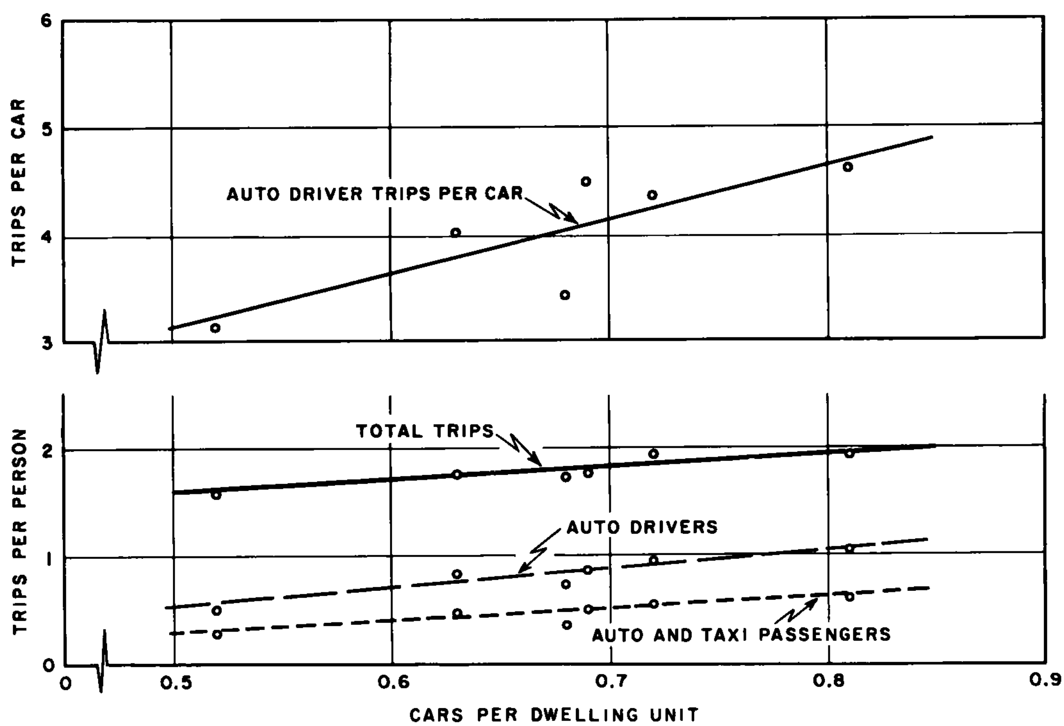

Figure 11. Trips per person and trips per automobile related to automobiles owned per dwelling unit.

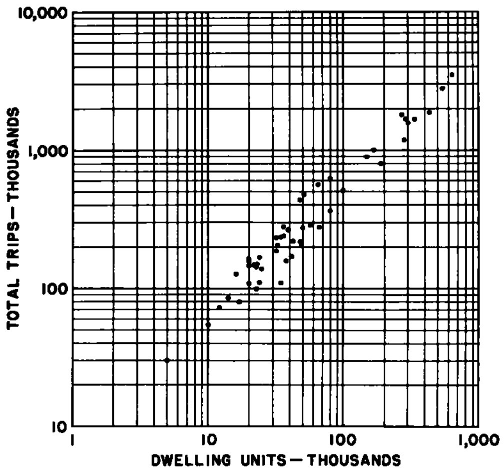

Figure 12. Number of trips related to number of dwelling units.

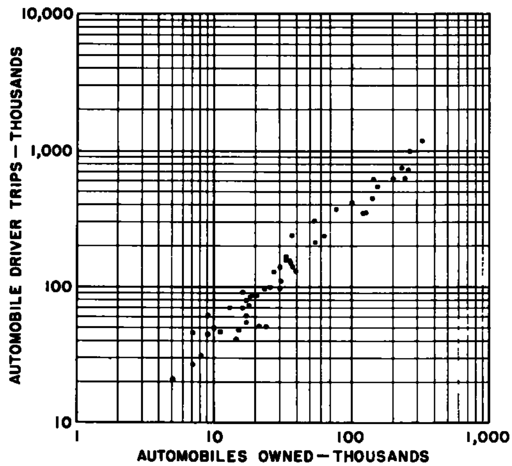

Figure 13. Number of automobile-driver trips related to number of automobiles owned.

were greater. Also, since automobile-driver trips per automobile tended to increase as automobile ownership increased, the number of trips per vehicle may be expected to increase as the ownership ratio of automobiles per family continues to grow. Whether mileage traveled per vehicle follows the same trend depends upon trip lengths. As in the case of Figure 10, these curves are also affected by the data from older studies and by the economic as well as the population characteristics of the cities studied.

Volume of trips and percentage of trips by individual purposes and modes of travel were associated with the ratios of automobiles per dwelling unit and persons per automobile. Although there was fairly good linear correlation between percentage of trips (by purpose and mode) and automobiles per dwelling unit, these correlations were not as high as others relating trips to the absolute household data in each urban area. In the latter case, better correlations were found between volume of trips (by purpose and mode) and the numbers of persons over 5 years of age, automobiles or dwelling units, than between percentage of trips (for a particular purpose or mode of travel) and any one of these variables.

The household characteristic which was most closely related to volume of trips

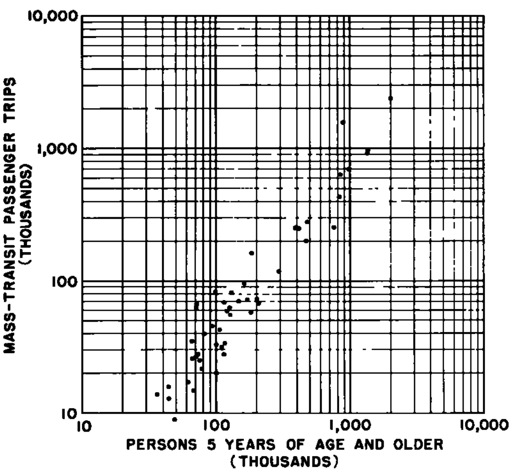

Figure 14. Number of mass-transit passenger trips related to number of persons 5 years of age and over.

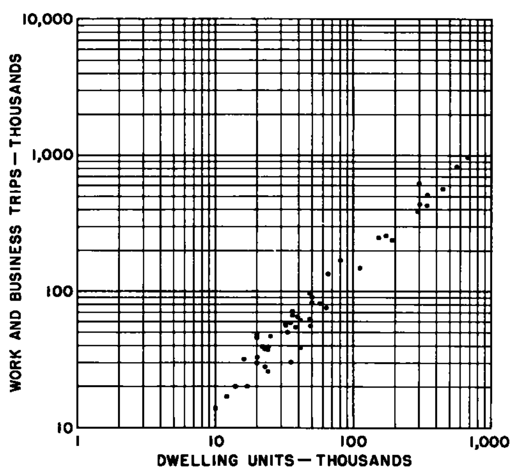

Figure 15. Number of work and business trips related to number of dwelling units.

varied, depending upon the mode of travel or purpose of trip. These relations are shown in Table 18, together with their respective correlation coefficients. These two-variable, linear correlations were deemed to be sufficiently high to forgo the need for testing correlations based upon second-degree equations or logarithms. However, for convenience of presentation the related scatter diagrams shown in Figures 12-16 have been plotted on logarithmic scales.

No attempt was made to associate all household characteristics with the volume of automobile- and taxi-passenger trips, but the scatter diagram in Figure 17 suggests that the number of automobiles owned in the area is a good factor.

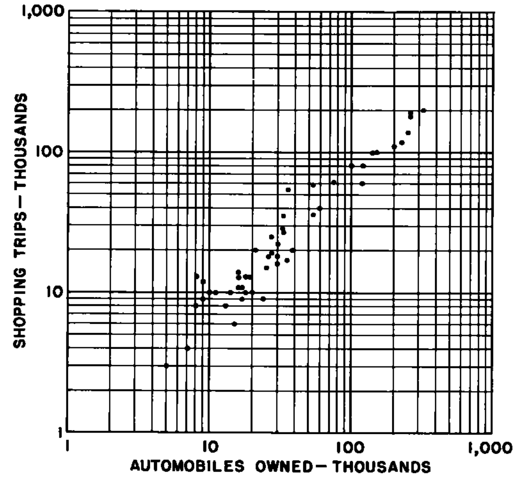

Figure 16. Number of shopping trips related to number of automobiles owned.

The relatively low correlation for trips with miscellaneous purposes is not unusual because of the varying nature of such trips. A better correlation factor is hardly required, however, since there is less cause for estimating these miscellaneous trips due to their relatively small number—less than 12 percent of the total. More favorable multiple correlations might be developed if required. For instance, the addition of the factor automobiles owned to the number of persons over 5 years of age raised the correlation with mass-transit passengers from +0.941 to +0.987.

In view of the large number of automobile-driver trips made for the purpose of going to work and for transacting business, these particular trips were also associated with the several household factors. Although total work and business trips in an area were more closely related to dwelling units (a higher correlation coefficient) than total automobile-driver trips were related to automobiles owned, it was found that work and business trips made by automobile drivers were more closely associated to automobiles owned. In the latter comparison, which is illustrated in Figure 18, the correlation coefficient was +0.984.

In order to more precisely estimate the volume of trips by each mode of travel for each individual purpose, it would be necessary to determine by means of correlation

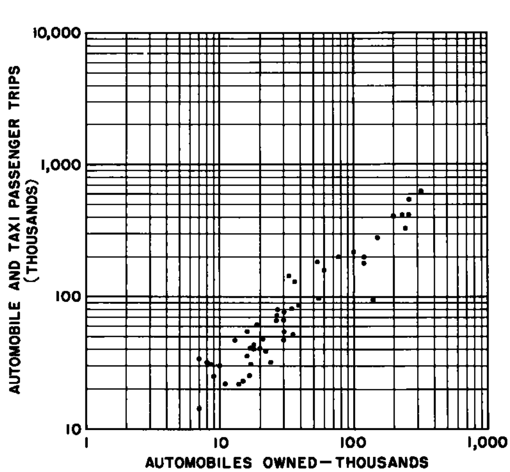

Figure 17. Number of automobile- and taxi-passenger trips related to number of automobiles owned.

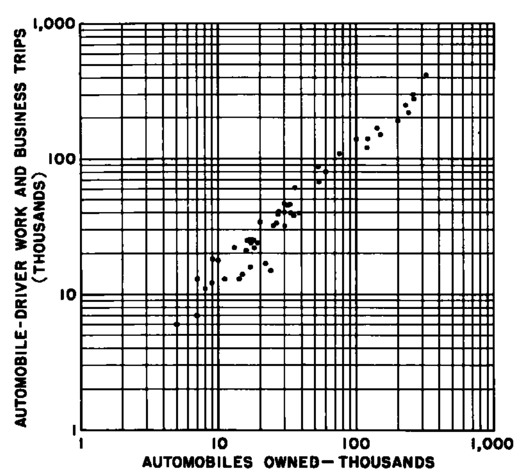

Figure 18. Number of automobile-driver work and business trips related to number of automobiles owned.

techniques similar maximum coefficients for the other modes and purposes. Of course, any application of estimates must be consistent with the resulting standard error. Further development is not attempted here, since this article is primarily concerned with existing conditions within the 50 urban areas. However, this discussion should be sufficiently indicative of the types of analysis which may be continued and expanded in an effort to develop predictive factors representative of local travel in typical urban areas.

Appendix

Up to this point, the discussion has dealt with several aspects of the travel pattern in 50 urban areas with regard to the five major trip purposes and the three most important modes of travel. It was mentioned, however, that the basic origin and destination surveys, which provided the data for these analyses, included information with respect to seven possible travel modes and ten trip purposes; and in certain cases some rather interesting and significant facets of the total urban travel complex were obscured as a result of the combining processes. Several of the more notable individual aspects are included here.

For all cities, medical-dental trips accounted for 5.5 percent of the trips by taxi passengers, and, conversely, taxi-passenger trips accounted for 4.2 percent of the trips for medical or dental purposes. Changing of mode accounted for 10 percent of the train-passenger trips and train passengers accounted for 2.2 percent of the trips to change mode of travel. Also, it is significant that 8.9 percent of the automobile drivers made trips for the purpose of serving passengers. All of the serve-passenger trips were made by drivers of automobiles.

In addition to the cases just cited, there are several interesting facts regarding individual cities, which were concealed when trip purposes and modes of travel were grouped. For example, in Columbus, Ga., Baltimore, Md., Charleston, S.C., Reading, Pa., and Grand Rapids, Mich., over 10 percent of the automobile-driver trips were for the purpose of transacting business. In Pontiac, Mich., and Sacramento, Calif., 14 percent of the automobile-driver trips were to serve passengers. The fact that 11 percent of the automobile-driver trips and 9 percent of the mass-transit trips in San Juan, P.R., were for the purpose of eating is due largely to the prevalent local custom of returning home for lunch at midday.

In the category of trips for the purpose of changing mode of travel, several unusual situations occurred in individual urban areas. These trips accounted for 10 and 25 percent of the total streetcar- and bus-passenger trips in Norristown and Philadelphia, Pa., respectively. Also, in Philadelphia, change-mode trips amounted to 60 percent of the subway- or elevated-railway passenger trips and 24 percent of the train-passenger trips.

Over 12 percent of the streetcar- and bus-passenger trips were to school in Madison, Wis., Pontiac, Mich., Sacramento, Calif., and in Phoenix and Tucson, Ariz. Trips to transact business accounted for 11 percent of all taxi-passenger trips in Charleston, S.C., and in Salt Lake City, Utah, and 13 percent in Seattle, Wash.

With regard to modes of travel, again there are individual city exceptions, which were absorbed in the grouping procedure. Among the more important variations which should be mentioned is the case of Washington, D.C., where taxi passengers accounted for almost 3 percent of all trips. Also truck and taxi passengers combined accounted for over 3 percent of the total trips in Baltimore, Md., and Macon, Ga. Finally, train-passenger trips amounted to 5 percent of the total trips in Newark, N.J., and 2 percent in Philadelphia.

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