NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **24**

URBAN TRAVEL PATTERNS FOR AIRPORTS, SHOPPING CENTERS, AND INDUSTRIAL PLANTS

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by Highway Planning and Research funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Commerce.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

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URBAN TRAVEL PATTERNS FOR AIRPORTS, SHOPPING CENTERS, AND INDUSTRIAL PLANTS

SUMMARY

There is a diversity of findings to report because the nature of the task was to explore relationships between airports, shopping centers, and industrial plants and the traffic patterns they generate. This summary attempts to recount the major findings in concise statements; related findings are given throughout the several separate chapters.

With respect to airport travel:

1. An airport can be among the largest single-site trip generators in a metropolitan area. Although the vehicle-miles of travel created will average less than 1% of the metropolitan total, there can be a tremendous local impact on the highway system, requiring a major part of the capacity of the main access highway at peak hours.

2. Airports serve not only air travelers, but also large numbers of workers and visitors. Total two-way vehicular generation by metropolitan area residents served by the busiest airport considered in this report ranges up to 20,000 trips a day. Work trips can account for up to 50% of resident airport tripmaking and social-recreation trips can account for up to 30%. (Were airport trips by visitors from other metropolitan areas included, these percentages would be lower—visitor tripmaking was largely unreported in the transportation study data upon which this report is based.)

3. Metropolitan area residents rely heavily on the automobile to get to and from the airport, averaging better than 90% at the 12 airports considered. Neither taxis nor public transit carry any appreciable number of resident work or social-recreation trips, and surprisingly few air travel trips.

4. Transit use by residents is principally limited to tripmakers lacking a car or unlicensed to drive.

5. Truck trips average less than 5% of the daily vehicular tripmaking.

6. Air travel is definitely seasonal, typically peaking in mid- or late summer. It is fairly constant throughout the week, with Saturday the low day.

7. Work trips follow an "industrial" pattern, with sharp peaks in the early morning and mid-afternoon. Social-recreation trips are dominantly an evening affair. Air travel trips have both morning and evening peaks, but of relatively low magnitude. Altogether, an airport is an around-the-clock activity, with the composite peak for all trips usually occurring in the late afternoon.

8. Residents' trip origins are scattered throughout the metropolitan areas. About 85% of their trips start at home. Few start from central business districts.

9. Every expectation is that the dramatic growth of air travel will continue, if not accelerate. A reliable estimate is that air travel will triple by 1975.

10. Predictive equations are presented by which metropolitan area characteristics might be used to estimate annual air passenger originations. Multiple coefficients of determination (R^2) are good, but high standard errors indicate wide variation from city to city. Based on 1960 data, the equations will be quickly outdated by increases in air travel participation rates (the number of persons making some air trips each year, and the frequency of their trips).

11. Work trips can be predicted reasonably well from employment.

12. Social-recreation trips average about one per day per thousand population.

13. Resident trip origins can be established according to metropolitan area population distribution by distance or travel time from the airport. Trip rates tend to decrease regularly with increasing distance or time. Work trip rates decrease steeply; social-recreation and air travel trip rates decrease more gradually.

14. Developments in air travel are emerging rapidly. In forecasting future airport activity, a long list of trends affecting ground transportation requirements must be considered.

15. There does not appear to be a "typical" airport. Due to the different functions performed, and the different types of communities served, ground transportation problems tend to vary.

With respect to shopping center travel:

1. The automobile was the only significant form of transport to the 28 major shopping centers studied. Transit accounted for less than 3% of the tripmaking. (Walk-in shopping trips were unreported in the transportation study data.)

2. Trucks and taxis together account for less than 4% of the total vehicular tripmaking. Few truck trips occur during the highway or the shopping center peak hours.

3. The average shopping center peak hour is about 16% of the daily tripmaking, typically occurring about 7 to 8 PM. During the normal highway peak period (4 to 6 PM) shopping center traffic runs about 7% of the daily tripmaking.

4. Evening openings every night of the week are more typical than several years ago, and have, in effect, helped reduce the highway peak-hour problem.

5. Home-based shopping trips make up about one-half of all auto driver trips, with a range from 31% to 68%. Nonhome-based shopping trips make up about one-third of all auto driver trips, and most start from other shopping areas. Most evening peak shopping is home-based.

6. Although acreages, floor space areas, and number of establishments are obviously correlated with shopping trip generation, as single predictive variables, they also yield high standard errors, and are not consistent indicators of tripmaking at any given shopping center.

7. Multiple linear regression equations with up to 12 variables were developed from the data pertaining to 23 shopping centers, but with only minor improvement over the simple linear equations. Consistent relationships may be clouded by the inability to quantify certain center and market area attributes such as the effectiveness of management, advertising, and nearby competition.

8. Work trips average about 12% of all auto driver trips to shopping centers. They do not correlate well with floor space.

9. Work trips (employment) do, however, provide the best simple linear regression for total shopping center trip generation and for auto driver trips to shop.

10. One-half of all shopping trips are shorter than 3 miles, and 75% are shorter than 5 miles. Trips for shopping goods average ½ mile longer than trips for convenience goods. Travel time averages at particular shopping centers range from 9 to 17 min.

11. Shopping center trip production from households decreases regularly with increasing distance or travel time from the center. However, even after reducing trip production to the common standard of home-based shopping trips per thousand autos owned by mile distance, trip rate curves vary considerably for dif-

TABLE 2

TRAVEL MODE DISTRIBUTION OF PERSON TRIPS TO SELECTED AIRPORTS, BY PURPOSE [a]

AIRPORT	WORK TRIPS (%)				SOCIAL-RECREATIONAL TRIPS (%)				AIR TRAVEL TRIPS (%)			
	AUTO DRIVER [b]	AUTO PASS. [c]	TRANSIT PASS. [d]	TAXI PASS.	AUTO DRIVER [b]	AUTO PASS. [c]	TRANSIT PASS. [d]	TAXI PASS.	AUTO DRIVER [b]	AUTO PASS. [c]	TRANSIT PASS. [d]	TAXI PASS.
Atlanta	86.7	10.1	2.6	0.6	37.5	56.3	6.2	—	78.6	21.4	—	—
Buffalo	72.8	12.5	10.0	4.7	15.5	82.6	1.9	—	66.2	30.9	—	2.9
Chicago (Midway)	71.9	12.6	15.5	—	29.9	66.9	3.2	—	53.7	31.1	6.6	8.6
Minneapolis-St. Paul	84.5	12.8	0.8	1.9	17.3	81.8	0.9	—	63.9	32.1	1.6	2.4
Philadelphia	82.5	12.4	3.5	1.6	26.9	72.0	1.1	—	60.2	26.4	2.5	10.9
Pittsburgh	77.7	20.1	2.2	—	22.7	77.3	—	—	61.5	30.7	5.2	2.6
Providence	78.4	21.6	—	—	46.0	54.0	—	—	83.5	16.5	—	—
San Diego	70.6	5.9	23.5	—	37.5	62.5	—	—	75.0	8.3	8.3	8.4
Seattle-Tacoma	90.9	5.4	1.8	1.9	19.7	79.1	—	1.2	74.0	22.2	1.6	2.2
Washington (National)	67.6	19.1	12.9	0.4	15.9	73.4	10.7	—	39.1	49.2	2.2	9.5

[a] From transportation study data (home interviews) for the various cities. [b] Includes drivers of rental and company-owned cars. [c] Includes truck passengers. [d] Includes limousine and interurban bus passengers.

reason, total home interview trips from the subject airports tended to exceed those to the airports.

MODE, WORK TRIPS

In considering the purpose of airport trips, it has proven useful to deal with three groups: (1) work trips; (2) social-recreation trips, including, by transportation study definition, trips to shop, to school, to eat meals, and to ride; and (3) air travel trips, including, also by transportation study definition, trips to change mode, to serve passenger, and to personal business. Unfortunately, the mechanics of trip coding make it impossible to segregate the air traveler from the friend or relative who provides him a ride to or from the airport ("greeters and Godspeeders").

Table 2 shows that a high percentage of all work trips are as auto drivers. The range is from Washington's 68% to Seattle's 91%. As might be expected, a low percentage are as auto passengers. The range is from Seattle's 5% to Providence's 22%.

As also shown by Table 2, airport tripmakers use transit more for work trips than for social-recreation or air travel trips. Excluding Providence, the range is from Minneapolis-St. Paul's 1% to San Diego's 24%.

Although 5% of Buffalo's reported work trips are by taxi, several airports report no taxi trips to work.

MODE, SOCIAL-RECREATION TRIPS

Having shown that work trips arrive predominantly by automobile, it should not be surprising that social-recreation trips do likewise. The major difference is in the number of passengers per auto; for work trips it is low, for social-recreation trips it is high. Thus, the proportion of social-recreation trips by auto drivers ranges from Buffalo's 16% to Atlanta's 38%, whereas the proportion by auto passengers ranges from Providence's 54% to Buffalo's 83% (Table 2).

Relatively few social-recreation trips would be expected to arrive by transit or taxi, and this is borne out. No such transit trips are reported at three airports, and there are less than 2% at four others. Only Seattle-Tacoma reports any taxi trips to social-recreation.

MODE, AIR TRAVEL TRIPS

Finally, there are the air travel trips for which airports exist. Table 3 shows that about 66% are by auto drivers, with a range from Washington's 39% to Providence's 84%. About 27% are by auto passengers, with a range from San Diego's 8% to Washington's 49%.

Transit, including in this broad sense limousines and interurban buses, effectively serves the resident air traveler as well as the nonresident. This is best reflected in the percentages at San Diego and Chicago. On average, however, taxis carry a larger proportion of trips than transit, exceeding 10% at Philadelphia and approaching 10% at Chicago, San Diego, and Washington. Probably this reflects the greater flexibility of taxis in serving residents' homes.

The percentage travel mode distributions for trips *from* the airports are not tabulated here because they are essentially the same as for trips to the airport, with some variation for air travel trips as noted previously.

TABLE 3

PURPOSE DISTRIBUTION OF PERSON TRIPS TO AND FROM SELECTED AIRPORTS, ALL TRAVEL MODES[a]

	TRIPS TO AIRPORT (%)			TRIPS FROM AIRPORT (%)		
AIRPORT	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	TO HOME	TO PERS. BUSINESS	TO OTHER
Atlanta	67.8	5.8	26.4	—	—	—
Buffalo	23.3	33.7	43.0	55.7	14.1	30.2
Chicago (Midway)	34.7	25.7	39.5	82.6	6.0	11.4
Minneapolis-St. Paul	46.8	19.7	33.6	80.3	7.1	12.6
Philadelphia	24.2	32.8	43.1	70.0	9.7	20.3
Pittsburgh	43.0	20.6	36.5	85.9	4.7	9.3
Providence	39.8	37.7	22.5	—	—	—
San Diego	45.9	21.6	32.4	—	—	—
Seattle-Tacoma	35.0	24.2	40.8	81.3	12.4	6.3
Washington (National)	69.8	15.8	14.4	80.1	9.9	10.0

[a] From transportation study data (home interviews) for the various cities.

TABLE 4

OCCUPATIONAL AND CAR OWNERSHIP CLASS DISTRIBUTION OF HOME INTERVIEW TRANSIT TRIPS[a] TO WASHINGTON NATIONAL AIRPORT, ALL PURPOSES[b]

	TRANSIT TRIPS[b] (%)			
OCCUPATION OF TRIPMAKER	0-CAR FAMILIES	1-CAR FAMILIES	MULTI-CAR FAMILIES	ALL FAMILIES
Professional and managerial	1.5	—	—	1.5
Clerical and salesworkers	30.2	14.1	—	44.3
Craftsmen and operatives	5.5	—	—	5.5
Laborers and service workers	33.1	14.0	1.6	48.7
Total	70.3	28.1	1.6	100.0

[a] Taxis excluded. [b] From data of 1955 Washington Metropolitan Area Transportation Study.

TABLE 5

TRAVEL MODE DISTRIBUTION BY SEX OF PERSON TRIPS TO SELECTED AIRPORTS, ALL PURPOSES[a]

	MALE TRIPMAKER (%)			FEMALE TRIPMAKER (%)		
AIRPORT	AUTO DRIVER	AUTO PASS.	TRANSIT PASS.[b]	AUTO DRIVER	AUTO PASS.	TRANSIT PASS.[b]
Atlanta	89	10	1	54	39	7
Buffalo	65	33	2	36	58	6
Chicago (Midway)	72	16	12	24	53	23
Minneapolis-St. Paul	80	18	2	41	58	1
Philadelphia	72	18	10	21	75	4
Pittsburgh	80	20	—	33	56	11
Providence	73	27	—	53	47	—
San Diego	74	15	11	50	38	12
Seattle-Tacoma	82	16	2	42	52	6
Washington (National)	74	20	6	19	59	22

[a] From transportation study data (home interviews) for the various cities. [b] Includes taxis

PURPOSES OF PERSON TRAVEL, ALL MODES

A summary of trips by all travel modes (Table 3) makes it apparent that the major airports tend to be major employment centers. The proportion of trips to work ranges from Buffalo's 23% to Washington's 70%. There is diversified employment at most airports, including not only employees of the airlines, the airport-operations staff, the airport-based state and federal agencies, and the military, but also, importantly, employees of the concessionaires and the air-oriented businesses with offices at the airport. Moreover, large maintenance, training, or crew "home base" facilities at certain airports may have a large effect on home-to-work traffic not common to all airports.

Again it should be emphasized that airport trips by visitors are badly under-reported. This definitely inflates the percentages of work and social-recreation trips reported in Tables 1, 2, and 3 (and subsequently). For example, approximately 10,000 people are employed at Washington National Airport. Assuming that they each make 500 work trips a year (to and from the airport), this would result in some 5 million annual work trips. Last year, Washington National handled more than 6 million arriving and departing passengers. This ratio varies considerably from the data presented in Table 3. It should also be pointed out that Washington National would lean heavily toward trips to the airport for work purposes due to the on-site but non-airport-related government installations which account for some 4,000 of the 10,000 employees.

The proportion of trips to air travel ranges from Washington's 14% to Philadelphia's and Buffalo's 43%. But it should be noted again that trips by visitors are badly under-reported. Were all such trips included, the air travel purpose group might be as much as doubled; recalculating percentages on this assumption would produce an estimated air travel trip proportion of approximately 50%, with corresponding reductions in the proportions of work and social-recreation trips.

Trips from airports, of course, have markedly different purposes. Most are to return home, Table 3 showing a range from Buffalo's 56% to Pittsburgh's 86%. Another distinct group is to work or to personal business, comprising from Pittsburgh's 5% to Buffalo's 14%. The remaining (mixed) purposes account for from Seattle-Tacoma's 6% to Buffalo's 30%. Many trips in the latter group are made by drivers making an intermediate stop at the airports to drop or to pick up passengers.

Factors Associated with Travel Mode

AUTO OWNERSHIP

Table 4 shows that 70% of the Washington airport transit tripmakers are from households without automobiles. Chances are that the percentage would be higher could driver licensing be examined. About 28% of the transit trips are produced by one-car families, and 2% by multi-car families.

Table 4 also shows that professional, technical and managerial occupations are represented by less than 2% of the transit tripmakers; skilled workers, by less than 6%. Thus, more than 92% of the reported transit trips are made by persons in relatively lower-income occupations.

Not shown is the fact that about 65% of these transit trips are made by females, or that 29% are made by non-whites. Most of the female tripmakers are clerical or salesworkers (93%); most of the nonwhite tripmakers are laborers (38%) or service workers (44%).

TRIPMAKER OCCUPATION

At most airports clerical and salesworkers, laborers and service workers, are the most likely to use transit, regardless of trip purpose. Although auto ownership and family income data are lacking in this general analysis, it can be inferred that the higher-income occupations, with higher auto ownership, tend to drive rather than to take transit.

TRIPMAKER SEX

Table 5 shows that male tripmakers tend predominantly to be auto drivers. The 77% average represents a range from Chicago's 72% to Atlanta's 89%. On the average, only 18% of the male tripmakers are auto passengers, and 6% are transit (including taxis) passengers.

Female tripmakers, on the other hand, tend more often to be auto passengers than auto drivers: 51% compared to 35%, on the average. A larger proportion are transit or taxi passengers (10%) than are male tripmakers. The ranges covered by these averages are wider than with male tripmakers.

TRANSIT AVAILABILITY

Transit service to airports is variously provided. Of the ten airports presently considered, only those in Chicago and San Diego are located along important at-grade city streets, served by normal city bus routes. Washington National is served by an express bus route. Only these three airports would be expected to have any significant number of transit trips excluding limousine and taxi service; various data bear this out.

Would the other airports have had more transit trips reported were transit service "better"? Possibly, yes. However, many newer airports are located so far from the densest urban development that conventional transit service is difficult to provide economically, residents' trip origins being too scattered. For the nonresident, of course, adequate airport coach, limousine, and taxi service is both necessary and economical, being a function of more concentrated trip origins, particularly in the central business districts.

Truck Travel

Airports do not seem to be major generators of truck trips, at least not for the travel years considered in this analysis (see Table B-3). For airports where truck trip records were obtained, Table 6 shows that there were from 1 to 11 truck trips per 100 total person trips. Pittsburgh represents the lower rate and Seattle the higher rate (the latter perhaps inflated by runway construction activity during the trip survey period). When person trips are segregated by trip purpose, the truck-to-person trip ratios have an even greater range, particularly as related to social-recreation or air travel trips. As might be expected, truck activity relates

TABLE 6

RATIOS OF TRUCK AND TAXI TRIPS TO PERSON TRIPS, BY PURPOSE, AND TO AUTO DRIVER TRIPS, ALL PURPOSES, TO SELECTED AIRPORTS[a]

AIRPORT	TRUCK TRIPS (NO./100 PERSON TRIPS) TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	TOTAL PERSON TRIPS	(NO./100 AUTO DRIVER TRIPS[b])	TAXI TRIPS (NO./100 PERSON TRIPS) TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	TOTAL PERSON TRIPS	(NO./100 AUTO DRIVER TRIPS[b])
Atlanta	11	129	28	7	9	NA	NA	NA	NA	NA
Buffalo	13	9	7	3	6	22	15	12	5	10
Minneapolis-St. Paul	11	27	16	5	8	19	46	27	9	14
Philadelphia	21	16	12	5	9	36	27	21	9	16
Pittsburgh	8	7	4	2	1	18	38	21	8	13
Seattle-Tacoma	31	45	26	11	16	11	15	9	4	6

[a]From transportation study data for the various cities; NA = not available. [b] All purposes.

more consistently to work trips, with truck trips to pick up or deliver parts and merchandise, and for other purposes, presumably being necessary in some direct proportion to the number of airport workers.

Truck trips per 100 auto driver trips range from Pittsburgh's 1 to Seattle's 16. It should be noted that all types of truck trips are considered here, not just medium and heavy truck trips as normally used for highway design purposes.

Sampling variability makes difficult any exact interpretation of the truck data of Table 6. In designing airport access highways, however, it would appear that the truck percentage may be somewhat lower, based on the airport demand itself, than for highways serving many other types of trip generators. It is noted, for example, that the proportion of truck trips at Los Angeles airport, based on actual counts, is but 2% (*3*); at San Francisco airport, also based on actual counts, but 5% (*4*); and count programs at

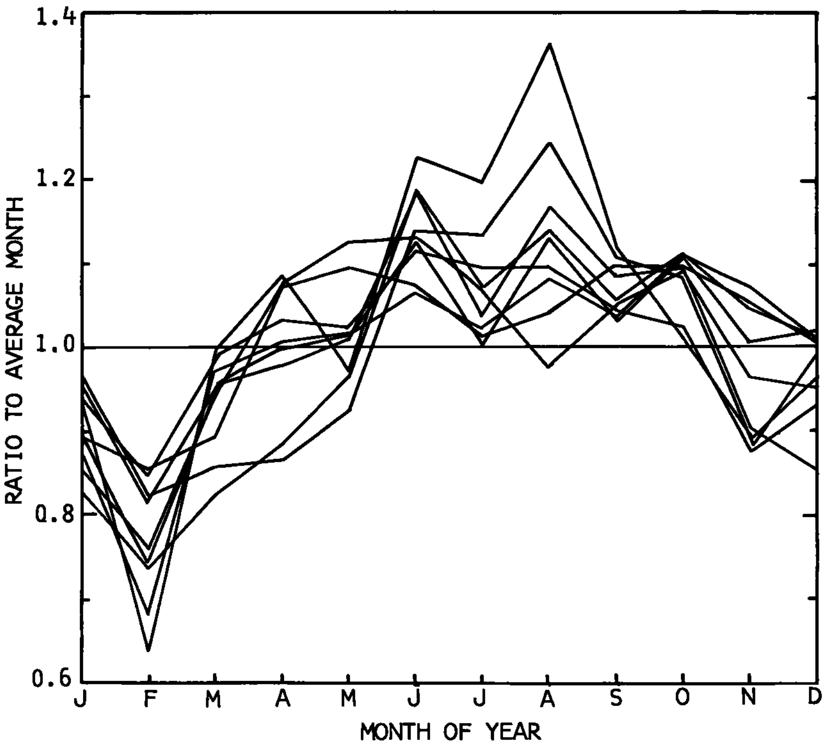

Figure 1. Monthly variation in air passengers at selected airports in selected years.

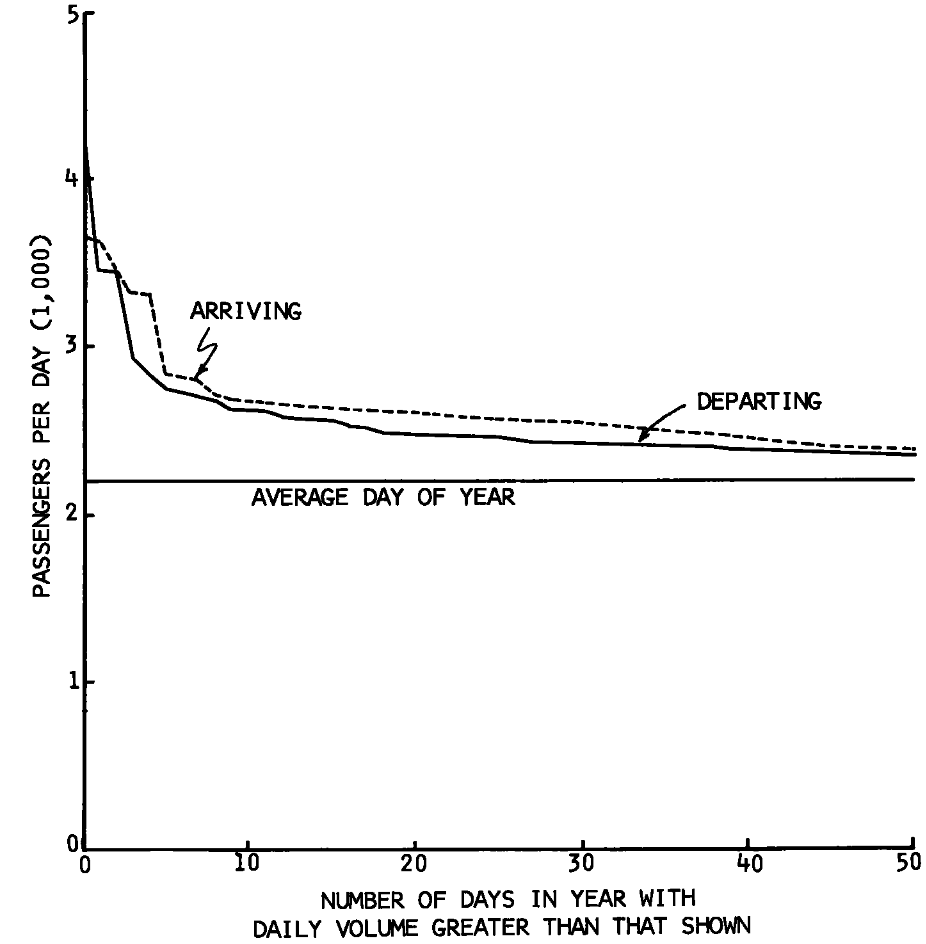

Figure 2. Fifty highest days, air passenger activity at Wold-Chamberlain Field, Minneapolis-St. Paul, 1958.

other airports tend to support the conclusion that truck trips are not numerous.

Taxi Travel

Table 6 also shows that taxi trips relate fairly consistently with person trips to air travel, with total person trips, and with total auto driver trips. For the airports for which taxi trips records were obtained, there were from 9 (Seattle) to 16 (Minneapolis-St. Paul) taxi trips per 100 person trips to air travel; there were from 6 (Seattle) to 16 (Philadelphia) taxi trips per 100 auto driver trips for all purposes. Generally, the rates covered a wider range for person trips to work or to social-recreation purposes.

Time Patterns

MONTHLY

Air travel is definitely seasonal. A national index shows that August is normally the high month for domestic operations, at about 114% of the average month, and February the low month, at about 85% of the average month, with April and October the "typical" months (*5*). International operations are even more definitely seasonal.

Patterns vary by airport. Figure 1 shows the monthly variation for the trip survey year at the airports covered by the present study. The considerable variation can be traced partly to normal intercity travel patterns, all of which show comparable seasonality, and partly to tourist activity. Unfortunately, the statistics of seasonal variation in air travel activity at a given airport, as between residents and nonresidents, are not available. Certainly, vacation and pleasure travel patterns could be much different from ordinary patterns; for example, Miami residents may well go north for a summer vacation, whereas nonresidents from various northern cities go to Miami during the winter.

Parenthetically, it might be noted that the average month of the home interview survey period for most of the urban areas presently considered is also reasonably representative of the average month of the air travel year. For example, the Penn-Jersey Transportation Study home interview survey period was June through November, 1960. Philadelphia airport records show that the monthly average of enplaning and deplaning passengers during this same 6-month period was only 4.7% higher than the monthly average for the whole year. Comparable percentages for other airports were generally in the range of ± 10%.

Seasonal variation in social-recreation and work trips is another matter. The former may be similar to that for air travel trips; the latter may not be. No data have been found on this score.

Extensive passenger data for Wold-Chamberlain Field (Minneapolis-St. Paul) provide further insight into seasonality. Tabulations of daily enplaning and deplaning passengers for 1958 were used to plot Figure 2. Arrayed by decreasing daily volume, curves for both enplaning and deplaning passengers "break" at about the tenth highest day. On the highest day the number of enplaning passengers is 188% and the number of deplaning passengers is 167% of the annual daily averages, respectively. By the tenth highest day, the ratios have dropped sharply to 119 and 123%, respectively. Further decrease takes place at nearly constant rates; that is, the curves are virtually straight lines.

(Similar arrays might be compared with daily counts of ground traffic entering and leaving an airport, to provide various planning factors. Unfortunately, an airport with a permanent counter installation could not be found.)

In preparing Figure 2, it was found that 7 of the highest 20 enplaning days were in August; 5 of the highest deplaning days were also in August. The highest single enplaning day was Wednesday, October 1; the highest single deplaning day was Friday, August 8. The lowest single enplaning day was Thanksgiving; the lowest single deplaning day was Christmas. Averages through the year, of course, would indicate that air travel fluctuates slightly with the day of the week, reaching its peak on Friday and its low point on Saturday.

DAILY

Evidence suggests that hourly trip patterns are similar, Monday through Friday. Separate plots of both home interview total person trips and total auto driver trips, by hour by day, constructed for the Atlanta, Seattle-Tacoma, Wash-

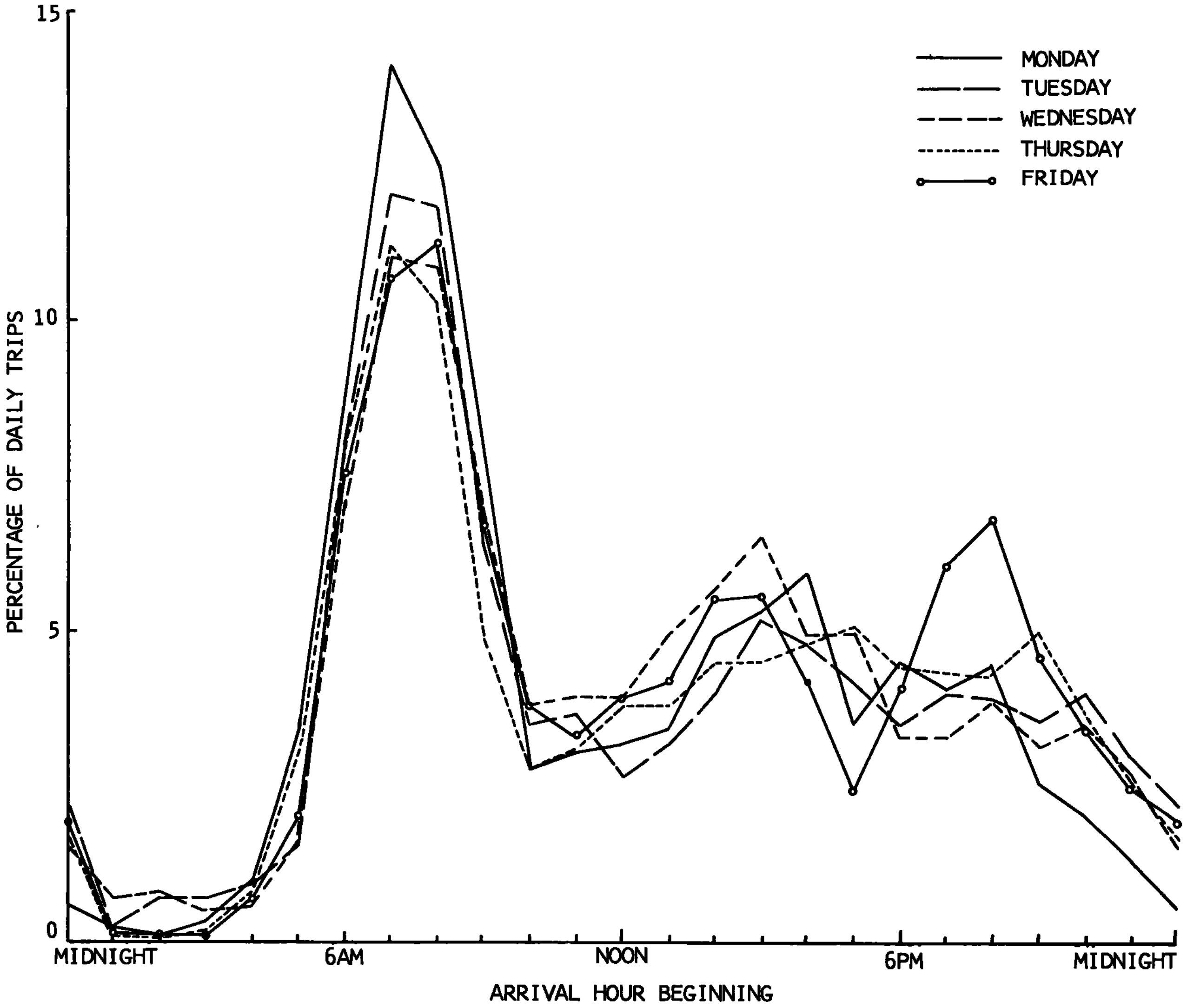

Figure 3. Total person trips to Atlanta, Chicago, Twin Cities, Seattle, and Washington airports, simple average of 3-hour moving averages, by day of week.

ington, Minneapolis-St. Paul, and Chicago airports, showed little variation by day. Figure 3 shows the smoothed composite curves for total person trips.

Although Figure 3 shows consistent hourly patterns by day of the week, daily total tripmaking appears inconsistent. Separate plots of each day's activity as a percentage of the average weekday, Saturdays and Sundays excluded, show that for the five airports considered no day is always high or always low.

Table 7 shows that, combined, all person trips to work at the five airports are relatively constant throughout the week. Social-recreation trips peak toward the end of the week. Air travel trips peak during midweek. These results probably reflect home interviewing problems; direct counts would seem best to establish the day of the week pattern at any particular airport.

HOURLY, PERSON TRIPS

Hourly patterns of person trips by trip purpose show that work, social-recreation, and air travel trips have distinct characteristics worthy of separate examination.

Airport employees create a sharp morning work trip peak around 7 to 8 AM, a lesser peak around 3 to 4 PM, and a still lesser peak around 11 to 12 PM. Figure 4, the composite curve for all airports, reveals a peculiarly "industrial" pattern, reflecting shift changes in mid-afternoon and toward midnight. Like many large industrial plants, an airport is an around-the-clock operation requiring constant manning of key posts.

Figure 4 also shows the hourly pattern of person trips from work. The principal peaks occur around 4 to 5 PM and around midnight. This pattern was typical of most airports in the cross section.

The patterns for individual airports differ mainly in the peak percentages. At important aircraft maintenance centers, such as Minneapolis-St. Paul, the three peak periods tend to attract more nearly equal numbers of trips than at other airports, such as Washington, where office employment seems to create an especially sharp morning peak. The percentage ranges for trips *to* work are, for the morning peak, 14% (Buffalo) to 35% (Washington); for the afternoon peak, 4% (Atlanta) to 15% (Seattle); for the mid-

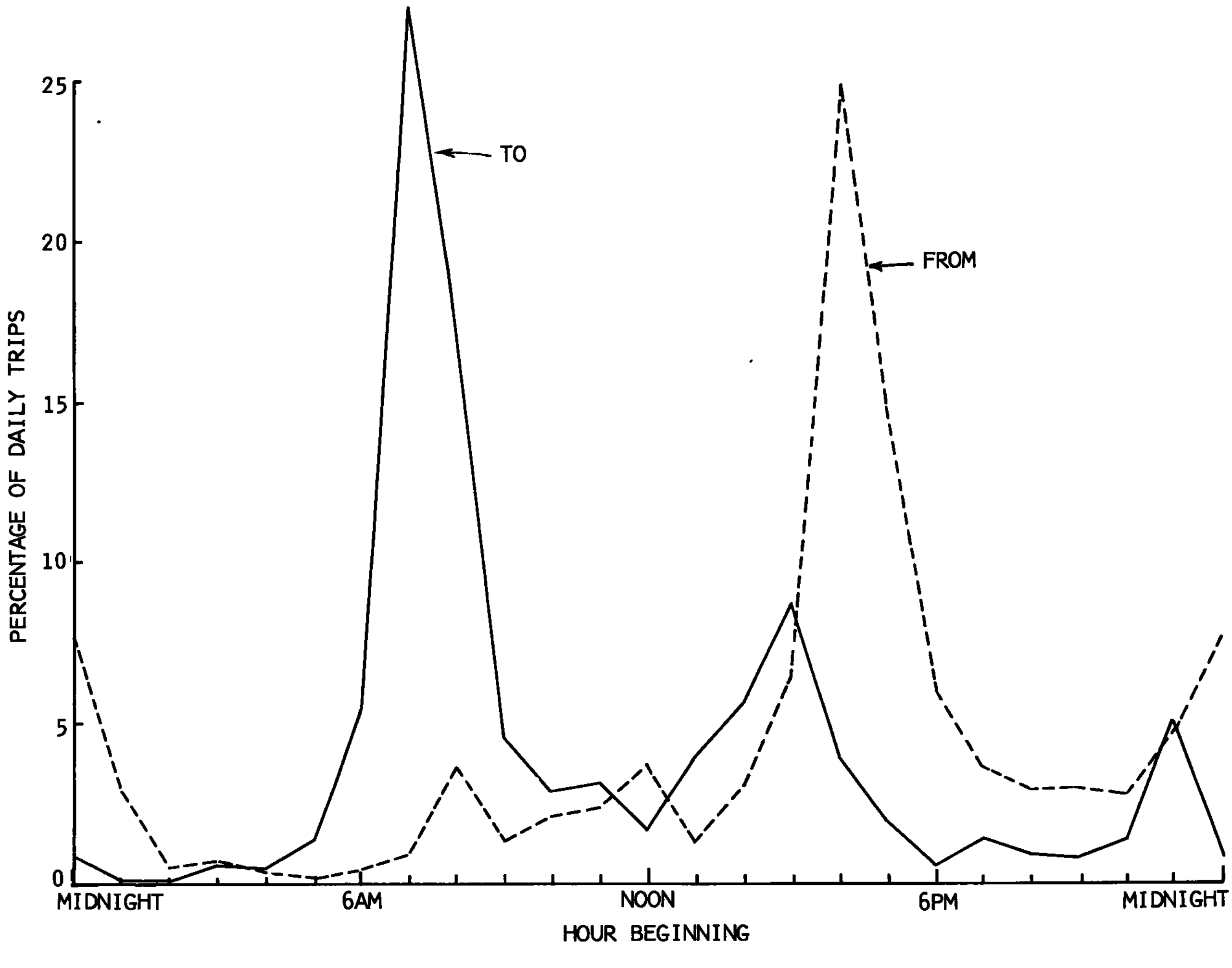

Figure 4. Home interview person trips to and from work, composite curve for selected airports.

TABLE 7

RATIO TO AVERAGE WEEKDAY VOLUME OF PERSON TRIPS, BY PURPOSE, TO SELECTED AIRPORTS [a]

TRIP PURPOSE	RATIO TO AVERAGE WEEKDAY VOLUME (%)				
	MON.	TUES.	WED.	THURS.	FRI.
Work	100.8	101.2	103.9	98.5	95.6
Soc.-rec.	95.5	93.2	93.5	115.6	102.2
Air travel	83.2	110.6	112.3	104.5	89.2

[a] From transportation study data (home interviews) for Atlanta, Chicago, Minneapolis-St Paul, Seattle-Tacoma, and Washington, D C, airports.

night peak, 3% (Buffalo) to 11% (Seattle). Similar differences exist for trips *from* work.

Table 8 shows that employment at airports represents a mixture of many skills. On the average, professional, technical, and managerial constitute the largest single group, followed by craftsmen and operatives, who slightly outnumber clerical and salesworkers, with laborers and service workers the smallest group.

Washington reports by far the largest percentage of clerical and salesworkers: 43% as against the all-airport average of 25%. It is not surprising, then, that it has the sharpest morning work trip peak. Providence reports the lowest percentage of clerical and salesworkers (8%), and by far the highest percentage of craftsmen and operatives (59%). On the whole, however, the major labor force components are relatively consistent.

Social-recreation trips to airports are dominantly an evening affair. Among the seven airports that attracted significant numbers of this trip type, the proportion of daily trips arriving after 7 PM ranged from Seattle-Tacoma's 22% to Pittsburgh's 74% (Buffalo also had 74% and Washington had 73%). The seven-airport average for the hours between 7 PM and midnight was 59%.

The hourly percentage distributions at individual airports were highly erratic, probably due to sampling variability. The single peak hours were consistently 7 to 8 PM or 8 to 9 PM, and ranged from 30 to 50%. No other single hour attracted more than 8% of the daily total at any airport. Figure 5 shows the composite curves for person trips both to and from social-recreation.

By contrast to social-recreation and work trips to airports, air travel trips may occur throughout the day. The hourly percentage distributions of trips to air travel at individual airports showed, for example, that at five airports the peak hour was 7 to 8 AM, but with from 13 to 26%; other airports registered peaks at 8 to 9 AM, 1 to 2 PM, 7 to 8 PM, and 8 to 9 PM, with from 15 to 19%. Similar differences occurred with air travel trips from the various airports.

Figure 6 shows the composite person trip curves for trips to and from air travel at all airports. Somewhat surprisingly, the highest single arrival hour occurs at 8 to 9 PM (8.3% of all air travel trips). Even the 5 to 6 PM peak is higher than the 7 to 8 AM peak, at 7.8 versus 7.7%, respectively. The highest single departure hour occurs at 10 to 11 PM (possibly inflated by "serve passenger" trips *not* associated with air travelers). The second highest departure hour—7 to 8 PM—seems more consistent with recognized patterns. The principal reaction to Figure 6, however, might be recognition of the relatively constant tripmaking throughout the day.

Summarizing, Figure 7 shows the composite person trip curves to and from all airports for all purposes. Due to the extreme peakedness of work trips, the over-all peak hour *to* the airports was 7 to 8 AM, with about 15% of the total daily trip activity. The next highest peak was 8 to 9 AM, with about 12%, and the third highest was 8 to 9 PM, with about 7%. Most other daylight hours ranged between 3 and 7%. Work trips again weight the peaking of trips *from* the airports: the over-all peak was 4 to 5 PM, about the time many employees go home, with about 14% of the daily trips, while the next highest peak was 9 to 10 PM, generally reflecting a combination of social-recreation and air travel trips.

TABLE 8

MAJOR LABOR FORCE COMPONENT PERCENTAGES AT SELECTED AIRPORTS [a]

AIRPORT	PROPORTION OF TOTAL LABOR FORCE (%)			
	PROF.-MNGRL.	CLER.-SALES	CRAFTS.-OPERS.	LABRS.-SERV. WKRS.
Atlanta	31	20	32	17
Buffalo	42	33	11	14
Chicago (Midway)	21	37	22	20
Minneapolis-St. Paul	31	25	32	12
Philadelphia	25	31	30	14
Pittsburgh	42	15	27	16
Providence	22	8	59	11
San Diego	40	20	20	20
Seattle-Tacoma	31	24	21	24
Washington (National)	13	43	22	22

[a] From transportation study data for various cities.

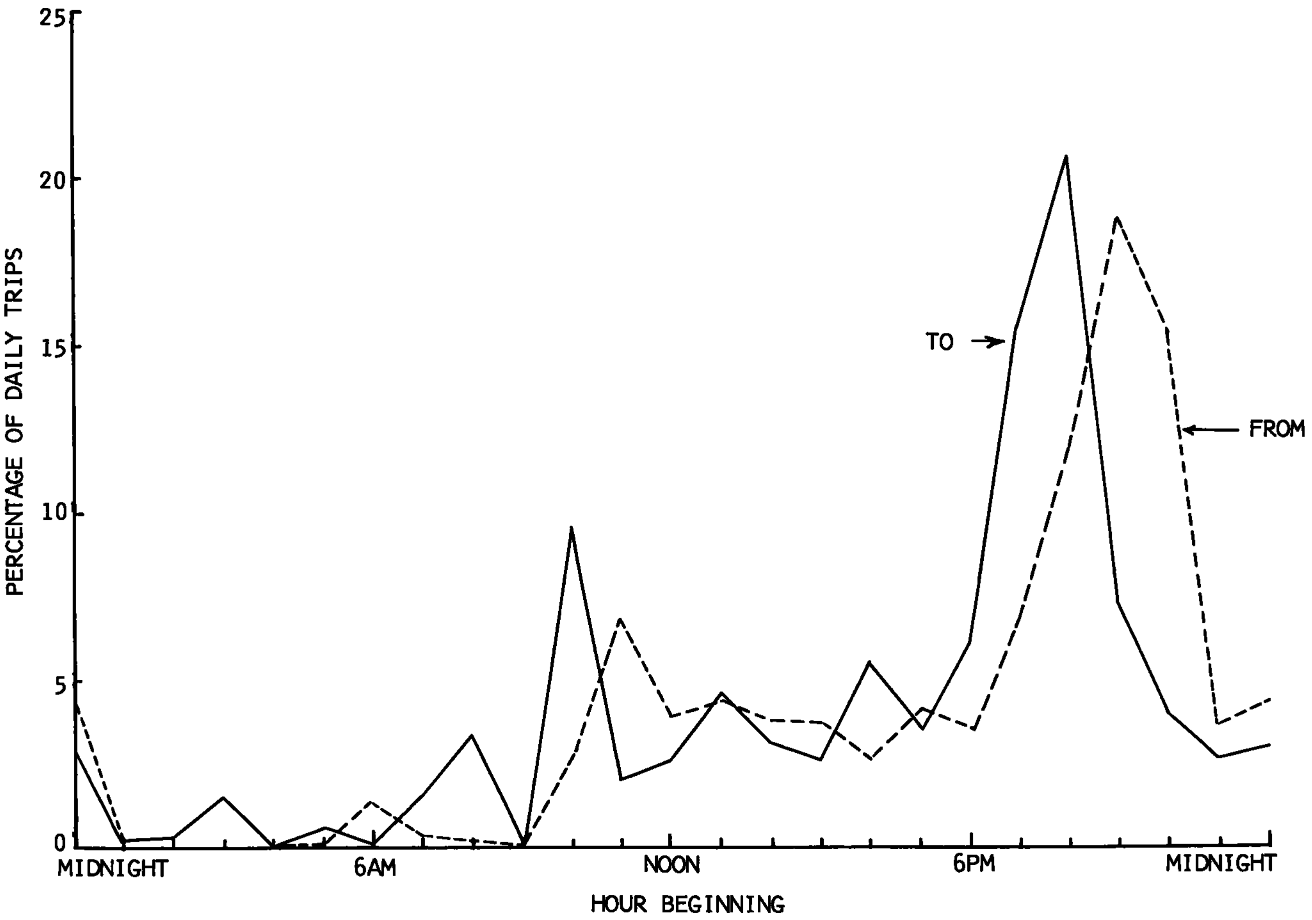

Figure 5. Home interview person trips to and from social-recreation, composite curve for selected airports.

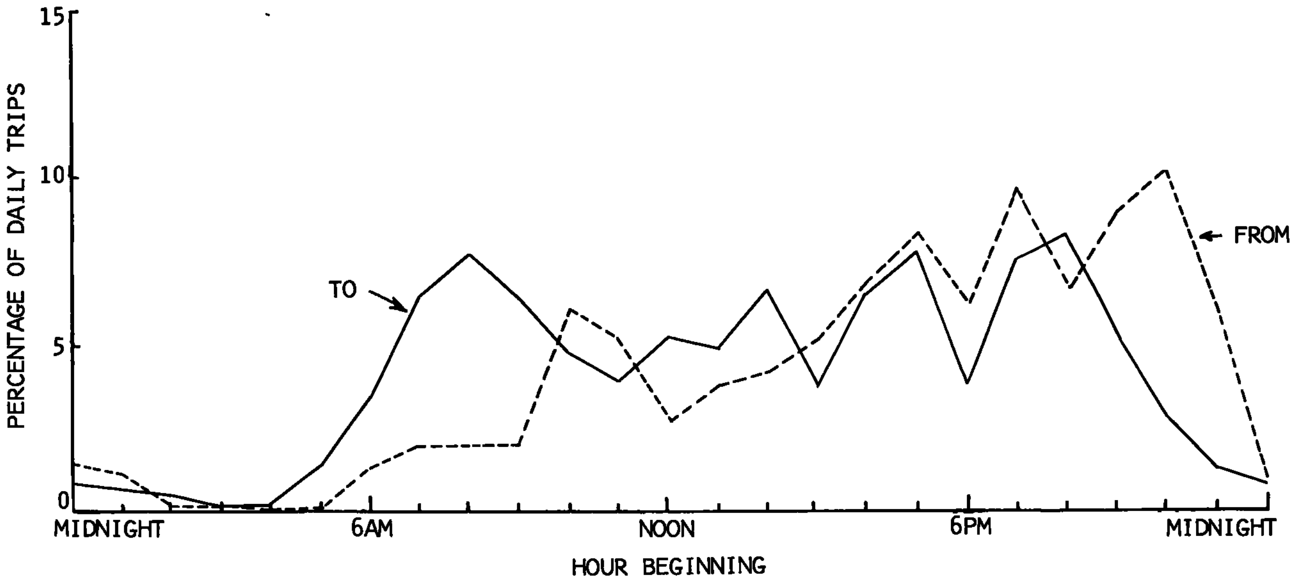

Figure 6. Home interview person trips to and from air travel, composite curve for selected airports.

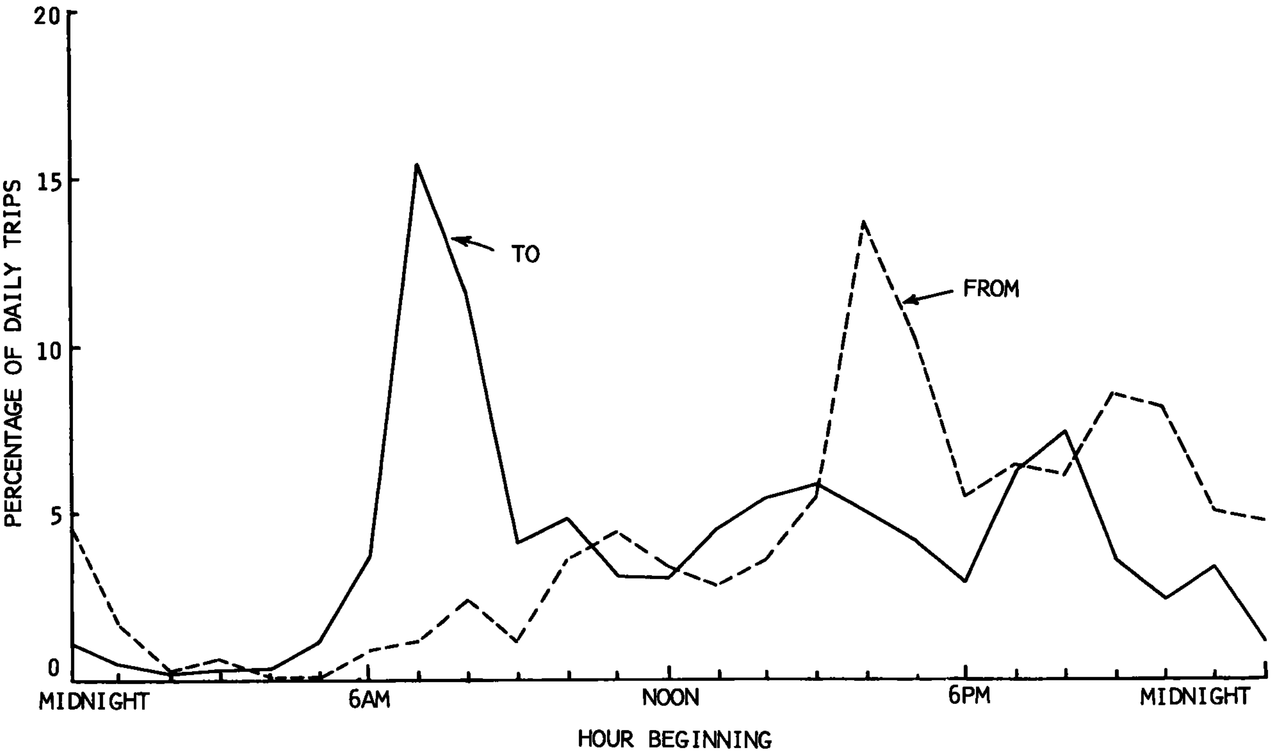

Figure 7. Home interview person trips to and from all purposes, composite curve for selected airports.

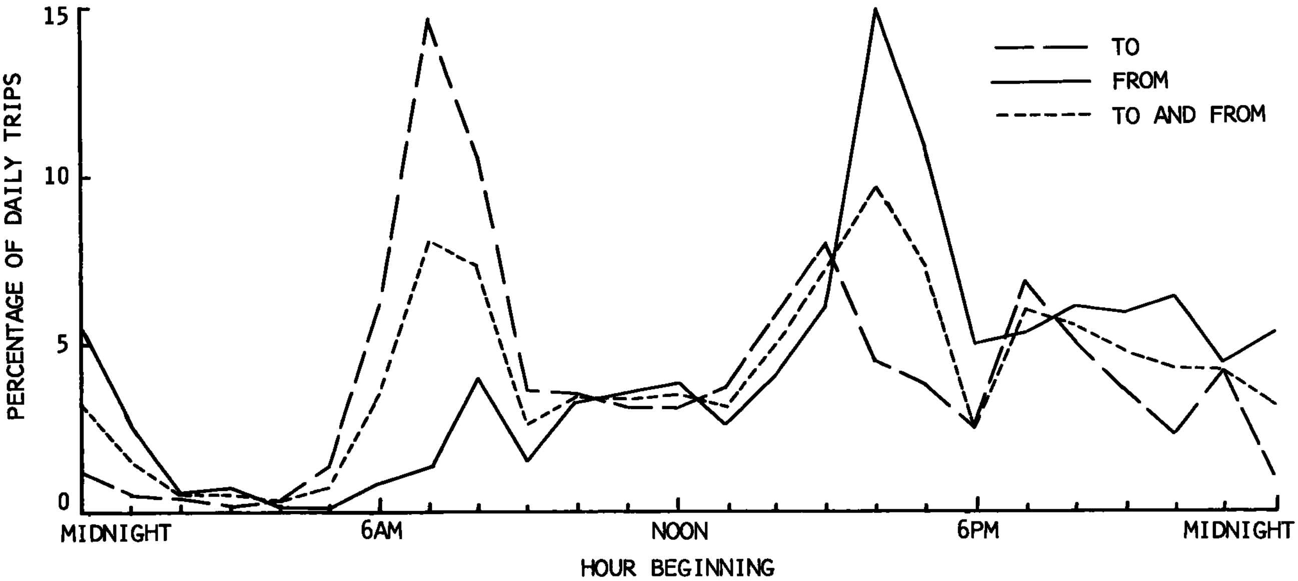

Figure 8. Home interview auto driver trips to and from all purposes, composite curve for selected airports.

HOURLY, VEHICLE TRIPS

With all trip purposes combined, plots of auto driver trips to the individual airports show that there are generally early morning, late afternoon, and early evening peaks to the airports; late afternoon, early evening, and late evening peaks from the airports. In terms of two-way traffic, the late afternoon peak is usually the greatest. At five of the airports the peak was between 4 and 5 PM, ranging from about 8 to 17% of the daily activity. At Chicago, the peak hour was 5 to 6 PM (9%), and at Buffalo, 7 to 8 PM (12%). Figure 8 shows the composite curves to and from all airports. Trips to the airports peak at 7 to 8 AM, with about 15% of the daily traffic. Trips from the airports peak at 4 to 5 PM, but the proportion of the daily traffic is only 10%.

Relatively small numbers of truck trips make it difficult to construct hourly trip distributions for all airports. Plots were reasonably good, however, for Atlanta, Minneapolis-St. Paul, Philadelphia, and Seattle-Tacoma. They showed that most truck activity is during daylight hours and that it is fairly constant throughout the day. Figure 9 shows the composite curve to six airports. As found by many area-wide transportation studies, about 90% of the tripmaking occurs between 6 AM and 6 PM, with some noticeable build-up toward mid-afternoon. The highest peak comes at 3 to 4 PM, when about 10% of the daily trips are made.

Taxi tripmaking suffered the same small-sample problem, with plots reasonably good only for Minneapolis-St. Paul and Philadelphia. They suggested that the late afternoon and early evening hours were the most active for taxis. Figure 10 shows the composite curve to five airports. The peak hour is 7 to 8 AM, at about 8%, although the more consistently high level of activity was around dinnertime (4 to 7 PM), tailing off only slightly to midnight.

ACCUMULATION CURVES

The maximum accumulation of auto driver trips occurs at every airport considered at about 3 PM, but for all practical

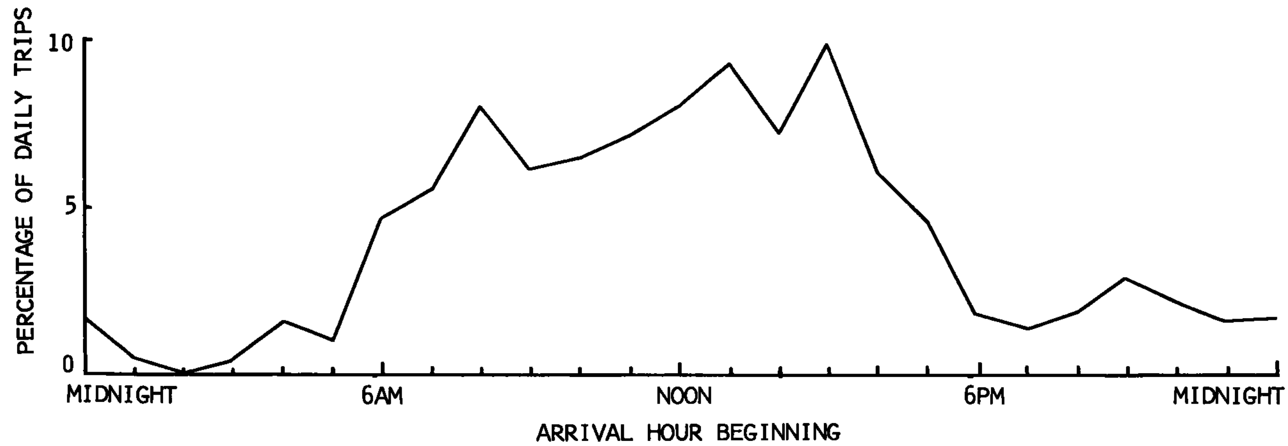

Figure 9. Internal truck trips to selected airports.

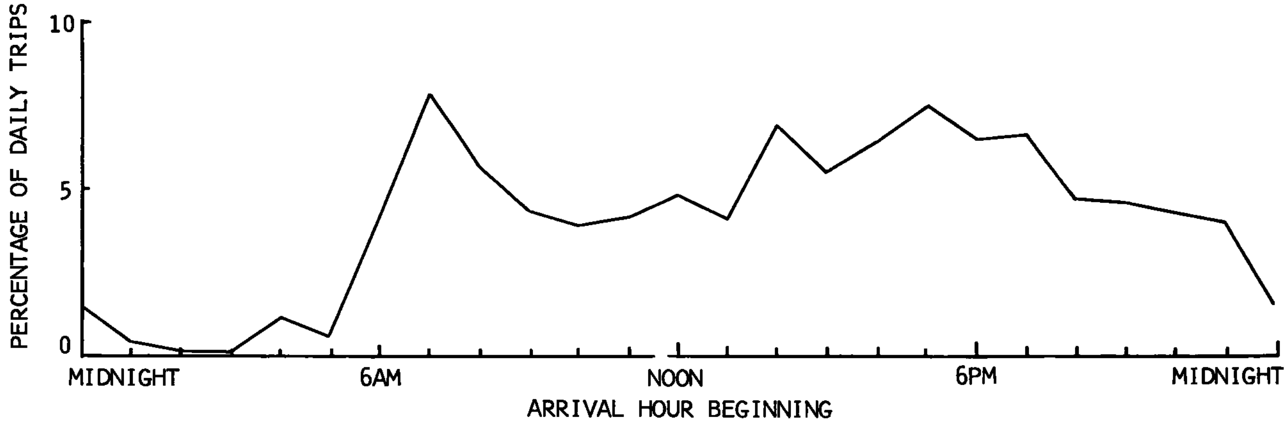

Figure 10. Internal taxi trips to selected airports.

purposes is nearly complete by 9 AM. The patterns are extremely similar until after 3 PM, when they begin to differ considerably: Philadelphia holding the greatest accumulation through midnight; Minneapolis-St. Paul and Washington the least accumulation, quickly dropping by about 6 PM, then holding fairly constant until midnight. The differences appear to reflect the differing proportions of trip purposes at the different airports.

Figure 11 shows the composite accumulation curve for all airports. In constructing the curves, it was assumed that parking lots would be about 10% full at 3 AM. In view of the trend toward long-term overnight parking this may have been somewhat low, but a higher value would not affect the shape of the typical curve, or the hour at which the peak accumulation occurs. Although the present study does not go into parking needs at airports, the individual curves, as well as the composite, may be helpful in determining the demand at various hours for parking spaces.

Travel Times and Distances

Drawn from throughout a metropolitan area, airport trips are on the average quite long. Table 9 shows that air travel trips range from Washington's 5.7 to Pittsburgh's 12.2 beeline miles. The range for social-recreation trips is from Buffalo's 3.0, to Seattle's 13.8 beeline miles. The range for work trips is from Atlanta's 4.2, to Pittsburgh's 9.6 beeline miles.

Measured from "unrestrained travel time trees," and thus excluding terminal delays, the average travel times still reflect the longer-than-average trip lengths. Air travel trips take 26 min, on the average, with a range from Buffalo's 16 min to Atlanta's 43 min. Social-recreation trips take 18 min, on the average, and work trips, 19 min. (Travel times for the Atlanta airport are based on a "restrained" tree, which makes them proportionally higher than the others.)

There is little correlation between the airport-to-CBD distance and the reported average trip lengths or calculated travel times. This is defeated by comparative urban area size and density: at equal distances, traffic conditions at Chicago Midway are urban, whereas at Buffalo Municipal they are practically rural.

Parking and Distances Walked

Table 10 shows that between 4 and 20% of employees park on paid lots, while between 77 and 94% park on

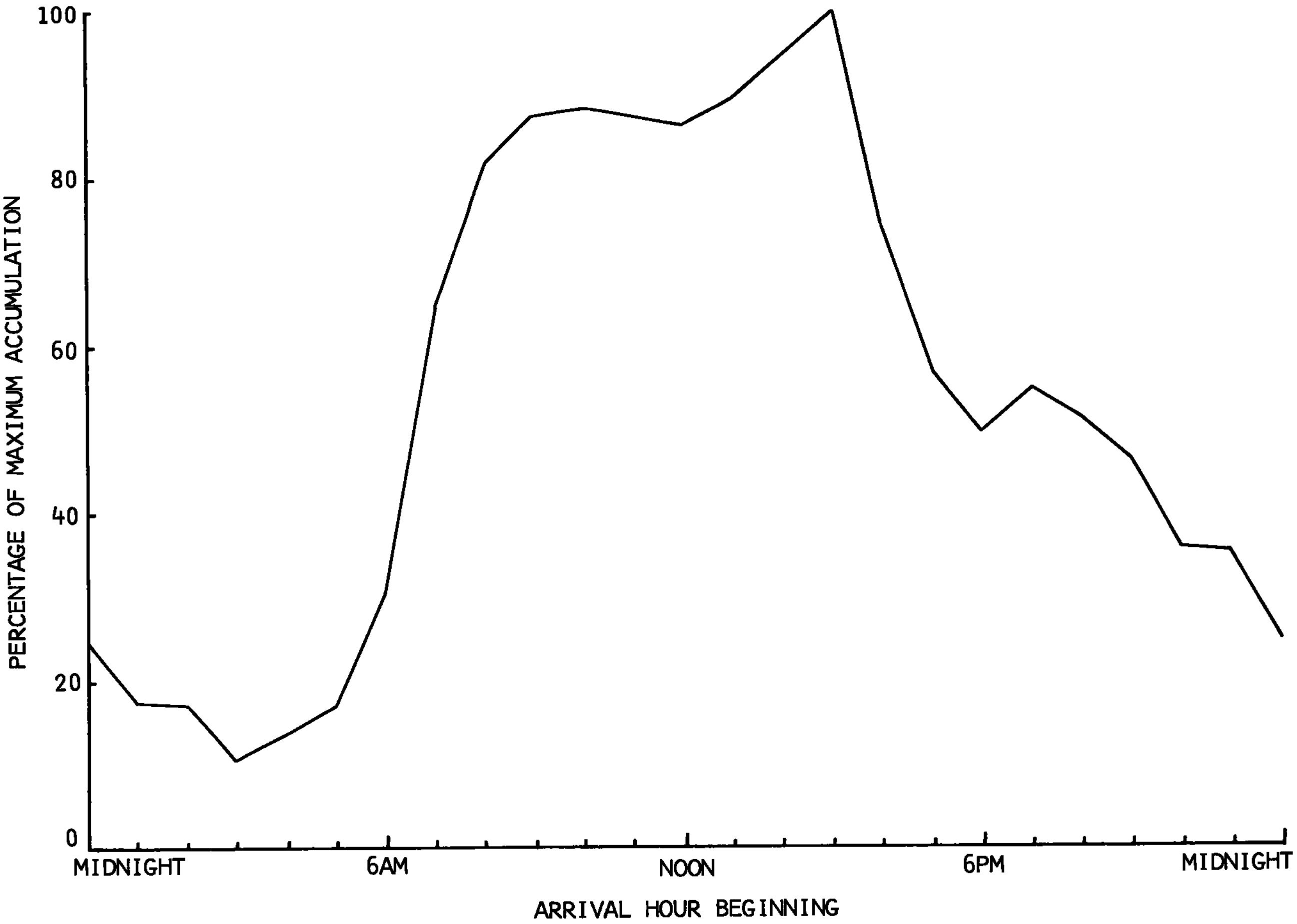

Figure 11. Hourly accumulation of home interview auto driver trips to selected airports, all purposes.

TABLE 9

HOME INTERVIEW AUTO DRIVER TRIP LENGTH AND TRAVEL TIME TO SELECTED AIRPORTS [a, b]

AIRPORT		BEELINE TRIP LENGTH (MI)			ROAD TRAVEL TIME (MIN)		
LOCATION	DIST. TO CBD (MI)	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL
Atlanta	8	4.2	NS	9.2	26	NS	43
Buffalo	9	4.8	3.0	6.7	11	7	16
Chicago (Midway)	9	7.7	6.6	8.8	NA	NA	NA
Minneapolis-St. Paul	8	7.1	6.6	7.8	NA	NA	NA
Philadelphia	6	7.5	6.1	9.9	19	17	25
Pittsburgh	11	9.6	10.2	12.2	21	22	27
Providence	7	4.3	6.9	7.5	17	21	22
San Diego	2	4.3	NS	NS	NA	NA	NA
Seattle-Tacoma	12	7.6	13.8	9.1	NA	NA	NA
Washington (National)	3	4.8	6.7	5.7	18	23	20

[a] From transportation study data for various cities. [b] NA = not available; NS = not significant.

TABLE 10

REPORTED PARKING CHARACTERISTICS OF HOME INTERVIEW AUTO DRIVER TRIPS TO SELECTED AIRPORTS [a, b]

	WORK TRIPS (%)				ALL OTHER TRIPS (%)			
	PARKING LOT				PARKING LOT			
AIRPORT	PAID	FREE	STREET	NOT PARKED [c]	PAID	FREE	STREET	NOT PARKED [c]
Atlanta	4	94	1	2	30	51	6	13
Buffalo	17	66	14	3	39	27	15	20
Chicago (Midway)	6	77	17	1	31	43	11	15
Minneapolis-St. Paul	12	81	3	3	16	45	21	18
Philadelphia	9	80	11	—	35	38	19	9
Pittsburgh	NA	NA	NA	NA	NA	NA	NA	NA
Providence	7	84	7	3	9	81	—	10
San Diego	20	80	—	—	7	29	43	21
Seattle-Tacoma	13	86	1	—	23	35	32	9
Washington (National)	4	91	4	1	23	46	15	15

[a] From transportation study data for various cities. [b] NA = not available
[c] Left for service or repairs, cruised, or otherwise not parked.

free lots. From 1 to 17% park on the streets, and a few do not park at all, presumably leaving cars at airport garages for service or repairs. Nonemployees park on free lots from 35 to 81% of the time. From 7 to 35% park on paid lots; from 0 to 43% park on the streets; and from 9 to 21% do not park. Most of the latter groups would be picking up or dropping off passengers.

"Blocks walked at the destination," as reported in home interview surveys, at least suggests the distance that tripmakers think they walk from parking lots. For several airports examined, the percentage distribution of trips by blocks walked was practically identical; about 90% of the auto drivers report walking less than one block, about 7% less than two blocks, about 2% less than three blocks, and fractional percentages for any greater distances.

Car Loading Factors

The number of persons to a car, or the car loading factor, varies by trip purpose. Table 11 shows that work trips to airports are most frequently by lone drivers, the average loading factor being 1.14 persons per car. The average loading factors for social-recreation and air travel trips are naturally much higher; 2.43 and 1.68 persons per car, respectively. By airport, loadings for social-recreation trips range from Providence's 1.62 to Atlanta's 3.50 persons per car, and loadings for air travel trips range from San Diego's 1.33 to Buffalo's 2.78 persons per car. Work trip car loadings are more consistent. Thus the all-purposes average of 1.45 persons per car, although it approximates a value often used for general planning purposes, will vary according to the facilities provided at various airports and to the pertinent mixture of trip purposes.

TABLE 11

AVERAGE CAR LOADING FACTORS FOR AUTO DRIVER TRIPS, BY PURPOSE[a]

	CAR LOADING FACTOR			
AIRPORT	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	ALL PURPOSES
Atlanta	1.07	3.50	1.47	1.23
Buffalo	1.30	3.49	2.78	2.30
Chicago (Midway)	1.18	2.72	1.59	1.47
Minneapolis-St. Paul	1.11	3.17	2.01	1.51
Philadelphia	1.15	2.65	1.69	1.63
Pittsburgh	1.31	2.60	1.88	1.62
Providence	1.11	1.62	1.92	1.47
San Diego	1.10	1.67	1.33	1.40
Seattle-Tacoma	1.06	1.72	1.80	1.46
Washington (National)	1.13	2.25	1.46	1.22

[a] From transportation study data (home interviews) for various cities.

Annual Growth

With rare exceptions, airport activity increases each year (Fig. 12). Chicago Midway may be considered such an exception, in that it was gradually closed to scheduled operations as the new O'Hare Airport took up the slack. Once the world's most active airport, Chicago Midway must then have been operating nearly at its capacity, and

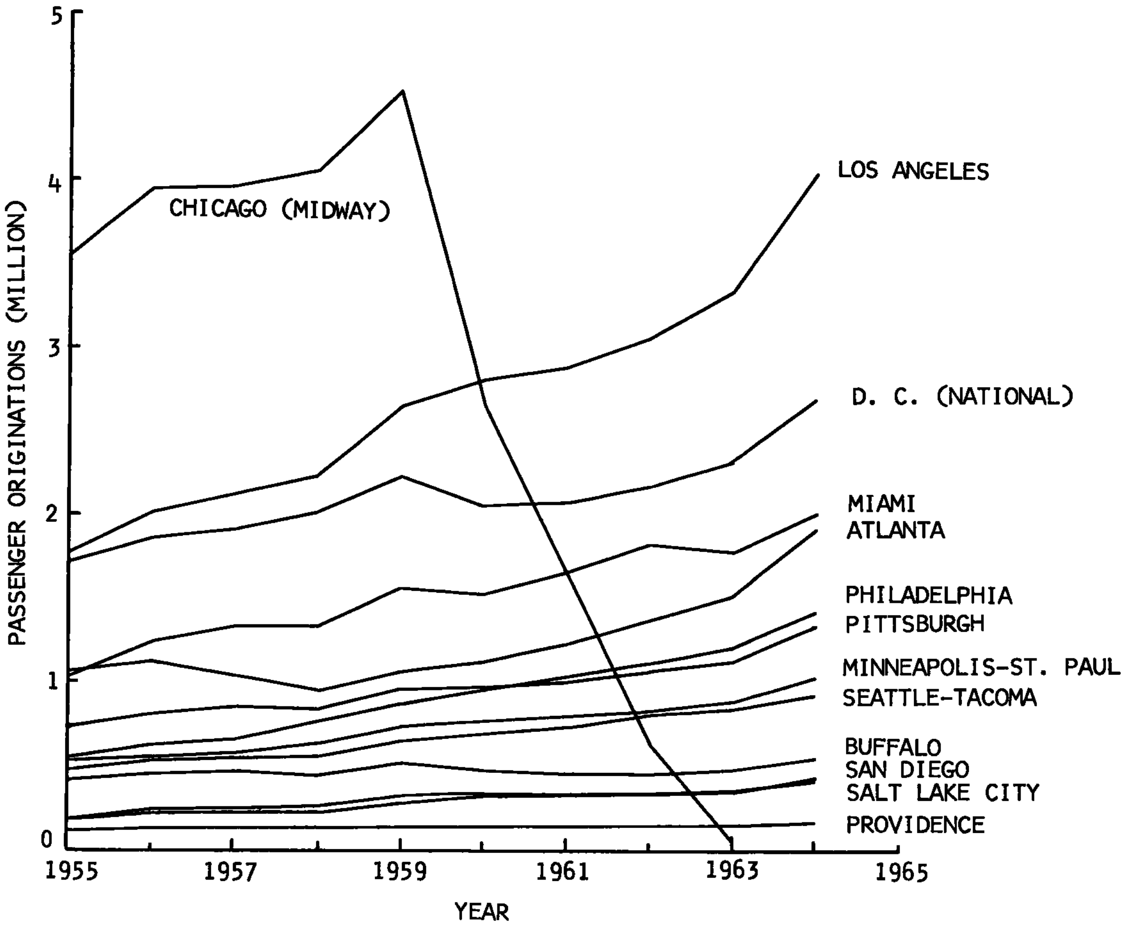

Figure 12. Annual air passenger originations at selected airports, 1955-1964.

TABLE 12

PEAK PERCENTAGES AND DIRECTIONAL TENDENCY OF TRIPS TO AND FROM SELECTED AIRPORTS [a, b]

AIRPORT	PASS. CAR UNITS [c] DAILY TRIPS (NO.)	PEAK TRIPS (NO.)	PEAK RATIO (%)	MEDIUM AND HEAVY TRUCKS DAILY TRIPS (NO.)	DAILY RATIO (%)	PEAK RATIO (%)	VEH. TRIPS IN DOMIN. DIRECTION AT PEAK HOUR (%)
Atlanta [d]	5011	1478	29.5	200	3.8	10.0	NA
Buffalo	5181	386	7.5	171	3.2	17.5	67
Chicago (Midway) [e]	15838	1579	10.0	NA	NA	NA	86
Minneapolis-St. Paul	14751	1555	10.5	736	4.8	4.1	89
Philadelphia	13244	1116	8.4	661	4.8	14.8	67
Pittsburgh	8174	834	10.2	128	1.5	15.6	71
Providence [f]	1278	184	14.4	NA	NA	NA	NA
San Diego [f, g]	480	NA	NA	NA	NA	NA	NA
Seattle-Tacoma	6488	662	10.2	438	6.3	11.4	88
Washington (National) [e]	7621	1856	24.4	NA	NA	NA	97

[a] From transportation study data for various cities. [b] NA = not available. [c] Includes taxis and light trucks [d] Home interview and truck-taxi survey trips only, *to* airport. [e] Home interview survey trips only. [f] Home interview survey trips only, *to* airport. [g] Hourly breakdown not available.

possibly this is what must be planned for in providing ground access to any major airport. Since Chicago Midway has now been reopened to a limited number of commercial flights to relieve pressures at O'Hare, it may be that a major airport will always eventually operate near capacity.

According to Clare (*6*), there are various levels of airport "capacity," encountered at various points along the passenger growth curve. In the order at which they typically are reached, they are automobile parking, terminal access, runways, airspace, and terminal building. In designing highways adequate for traffic needs 15 to 20 years ahead, the implication is that the highway design capacity must be related to these various airport design capacities. With record rates of airport activity growth, highway capacity could be exceeded well before airport capacity.

Design Factors

Although the peak-hour traffic percentages of passenger car units and trucks, and the directional tendency of traffic (Table 12), cannot be applied directly to any specific highway design problem, together they may provide perspective.

Table 12 shows, for example, that the two-way traffic peak percentage ranges around 10%. Minneapolis-St. Paul, Philadelphia, Pittsburgh, and Seattle-Tacoma peak at 4 to 5 PM at 10.5, 8.4, 10.2, and 10.2%, respectively. Buffalo peaks an hour sooner at 7.5%. Chicago peaks at 8 to 9 PM at 10.0%. The highest two-way traffic peak reported was 24.4% at Washington at 7 to 8 AM (Atlanta and Providence percentages are based on trips *to* the airports only; in both cases, the peaks understandably occur at 7 to 8 AM). Directional tendencies during the peak hours cited range from 67 to 97%.

Table 12 also shows, where data were available, that the daily proportion of truck trips ranges from Pittsburgh's 1.5% (trips *to* only) to Seattle-Tacoma's 6.3% (already noted as possibly inflated due to temporary construction activity) of the total daily vehicle tripmaking. The proportion of truck trips during the peak traffic hour ranges from Minneapolis-St. Paul's 4.1% to Buffalo's 17.5%. Sampling variability could seriously affect the latter percentages.

In view of the variations demonstrated for these particular airports, it would appear that more observations are needed. Unfortunately, it seems that systematic traffic counts, including manual classification, are seldom available, even at major airports. Clearly, it would be helpful not only to highway designers but also to airport management to have permanent counter records available on a continuing basis. From these, design factors could be developed with assurance.

TRIP GENERATION

Trip generation for particular land uses is often expressed as the number of trips per unit of area, such as per acre or per 1,000 square feet. This seems too crude an approach to apply to the diverse activities at airports. Careful study of terminal building floor space and general airport plants, graciously furnished by most airport directors, resulted in discounting this approach.

The accepted basis for predicting air travel activity at an airport is by the type and population of the community it serves. A Federal Aviation Agency study (*7*) concludes that air travel trip generation increases with increasing city size and decreases with increasing industrialization (Table 13).

To test the correlation between air travel and city size, the annual rates of originating air passengers per 100,000 population and the resident populations were compared (Fig. 13) for Standard Metropolitan Statistical Areas (SMSA) throughout the United States, using census data and air passenger data reported by the FAA (*8*) for 1960.

The correlation is marred by exceptional cases: the highest rates in the country were, respectively, Las Vegas,

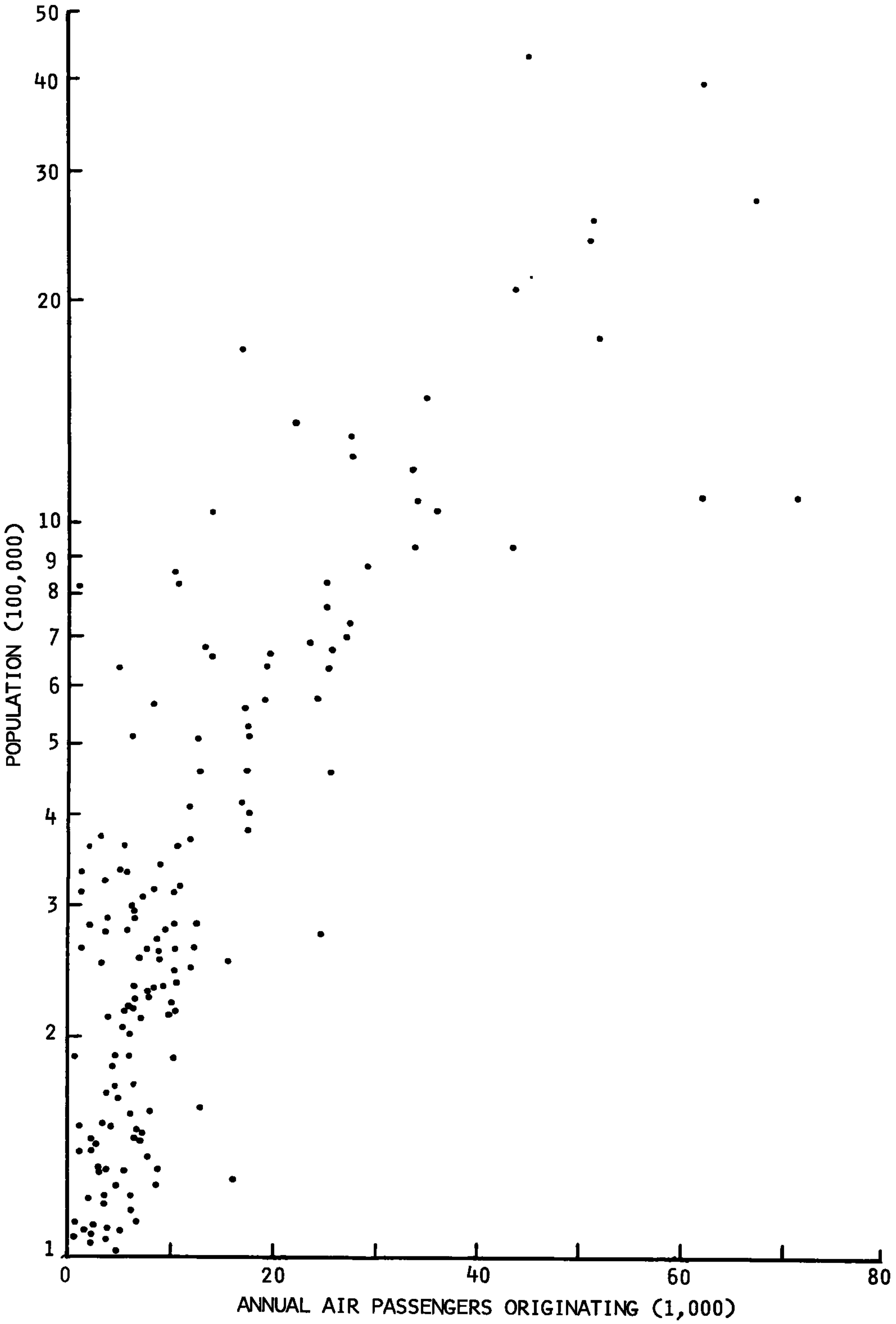

Figure 13. Annual air passenger originations per 100,000 population, 180 Standard Metropolitan Statistical Areas, 1960.

with 2,800 originations per 100,000 population; Miami, with 1,620; and Reno, with 1,530. Some of the lowest rates were: Galveston-Texas City, with 7 originations per 100,000 population; Ogden, with 3; and San Bernardino-Riverside, with 10. The last is a good example of the "shadow effect" where rates are depressed by air travelers choosing to depart from an airport in a larger, nearby metropolitan area (in this case, Los Angeles).

Carrying this work somewhat farther, multiple regression equations were prepared, again using 1960 data, for the prediction of annual originating air passengers on the basis of 15 SMSA socio-economic variables. Results were moderately encouraging; excluding many exceptional cases, an $R^2 = 0.93$ and a standard error of the estimate equal to 67% of the $\overline{Y}$ was obtained. Thus, strong correlations with city size and type were confirmed, but with much variation among cities (see Appendix C for details).

A complication here is that air travel participation rates —reflecting both the percentage of a given urban population making some trips annually, and the number of trips per tripmaker—are steadily increasing. For example, a recent study (*6*) reported that for Southern California airports the number of trips per thousand population increased from 242 in 1951 to 475 in 1962. It must be conjectured that participation rates change differently at different airports.

Clearly, the estimation of air passenger activity is highly complicated, and there are no formulas for quick success. The Port of New York Authority, for example, has outlined several methods that can be used (*9*) and there undoubtedly are others. Recent interest has turned to the still more complicated problem of predicting *intercity* air passenger movements (*10*). (Credit is acknowledged the latter study for suggesting variables to be used in the multiple regression work reported in previous sections.)

Against this background, Table 14 shows the average weekday number of resident air travel trips per 1,000 population at the ten airports considered in this report. Even here there are problems: First, the rates represent different dates—San Diego, 1963; Buffalo, 1962; most others, between 1958 and 1961. Second, they make no allowance for city type and size. Third, different degrees of sampling variability are involved.

Not unexpectedly, then, Table 14 rates are inconsistent. Work trips range from Philadelphia's 0.58 to Atlanta's 5.76 trips per 1,000 population; social-recreation trips range from San Diego's 0.28 to Minneapolis-St. Paul's 1.33; air travel trips range from San Diego's 0.42 to Minneapolis-St. Paul's 2.26. For all trips combined, Atlanta's high rate of

TABLE 13

ANNUAL AIR PASSENGERS PER 1,000 POPULATION, MEDIAN VALUE FOR SELECTED CITIES, 1950 [a]

	AIR PASS. (NO./1,000 POP./YR)				
TYPE OF COMMUNITY	300,000+ POP.	150,000–300,000 POP.	50,000–150,000 POP.	25,000–50,000 POP.	10,000–25,000 POP.
Marketing center and institutional	286	155	144	162	100
Balanced	205	91	79	64	92
Industrial	89	60	22	42	35
All	218	92	96	101	95

[a] From Federal Aviation Agency, *Air Traffic Patterns and Community Characteristics* (1963).

TABLE 14

RESIDENT PERSON TRIP GENERATION RATES TO SELECTED AIRPORTS [a]

		PERSON TRIPS [b] (NO./1,000 POP.)			
AIRPORT	POP. (MIL)	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	TOTAL
Atlanta	0.7	5.76	0.49	2.25	8.50
Buffalo	1.2	0.80	1.15	1.46	3.41
Chicago (Midway)	5.2	1.03	0.76	1.17	2.96
Minneapolis-St. Paul	1.4	3.15	1.33	2.26	6.74
Philadelphia	4.0	0.58	0.79	1.03	2.40
Pittsburgh	1.5	0.86	0.41	0.73	2.00
Providence	0.6	1.11	1.05	0.62	2.78
San Diego	0.6	0.60	0.28	0.42	1.30
Seattle-Tacoma	1.4	1.03	0.71	1.20	2.94
Washington (National)	1.6	3.15	0.71	0.66	4.52

[a] From transportation study data (home interviews) for the various cities. [b] Home interview trips only, compared with home interview area population.

8.50 is nearly seven times that of San Diego's low rate of 1.30 trips per 1,000 population.

In summary, it appears that airport trip generation cannot be completely established from transportation study data representing ten "typical" airports. (Indeed, many reviewers have made the point that there is no typical airport, and that ground transportation requirements must be established uniquely by individual airport.) Air passenger activity and airport employment might best be furnished by the "air experts." From their figures, however, various characteristics of resident air travel trips can be estimated from factors in this report; nonresident air travel trip characteristics will need separate attention. Work trips can be accounted for rather directly from employment, but social-recreation trips must still be accounted for by rule-of-thumb. This report provides some starting points for treating total trip generation at airports, but much remains to be done.

TRIP DISTRIBUTION

Trip rate curves provide a measure of the distribution of trip origins at various distances or travel times from the airport. Curves are given in the following for total person trips and for auto driver trips; for work, social-recreation, and air travel purposes; for distance and travel time. Rates are expressed as trip origins per 1,000 population (trips *to* the airport). Other bases might be used—such as automobiles owned—but population seems adequate for the distributional purpose intended. The curves given are based on home interview trips only, and are calculated to a distance of 20 miles or a travel time of 1 hr, by 1-mile and 5-min intervals, respectively.

Distance Rates

PERSON TRIPS

Person trips for all purposes combined show considerable variation from airport to airport. At the 1-mile interval, rates vary from San Diego's low of about 4 to Pittsburgh's high of about 40 trips per 1,000 population. The range of variation decreases at progressively distant intervals, and the same airports do not have the consistently high or low rates. At the 7-mile interval, for example, rates vary from San Diego's 1 trip to Minneapolis-St. Paul's 7 trips; at the 15-mile interval, from Seattle's 0.5 trip to Atlanta's 4 trips; and so forth.

Figure 14, the composite curve for all airports, is a typical trip length distribution curve, as for any urban activity, except that it has an unusually long "tail." As will be seen, the distributions by major purpose grouping are somewhat different, that for work trips having the steepest slope and that for air travel trips the flattest slope.

VEHICLE TRIPS

Curves for home interview auto driver trips per 1,000 population, all purposes, show fair consistency at all airports,

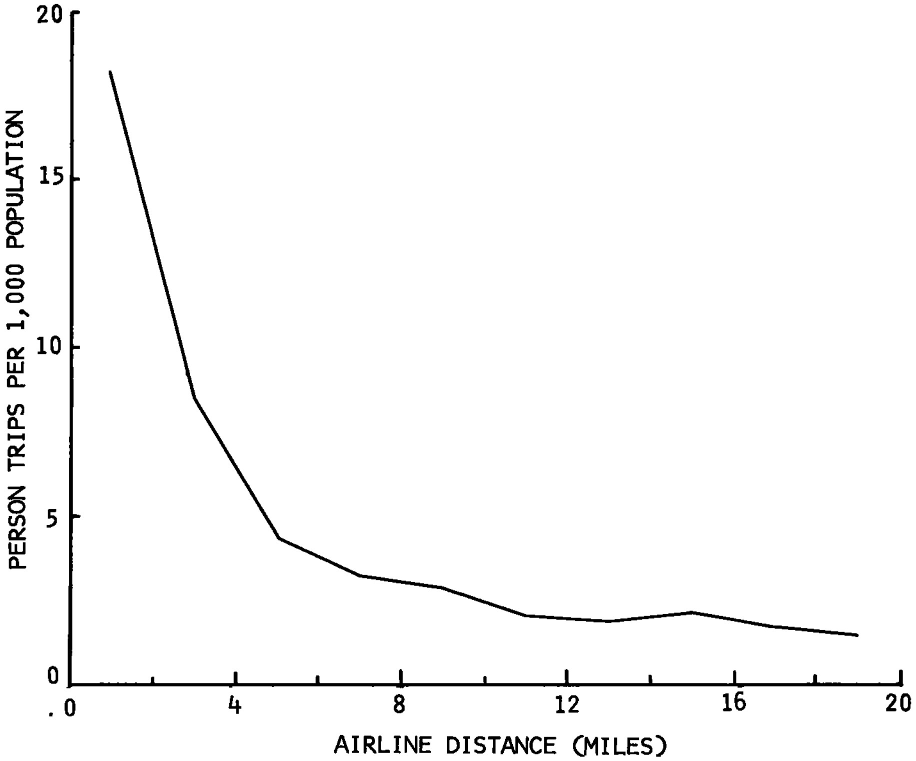

Figure 14. Home interview person trips per 1,000 population, composite curve on distance, all purposes.

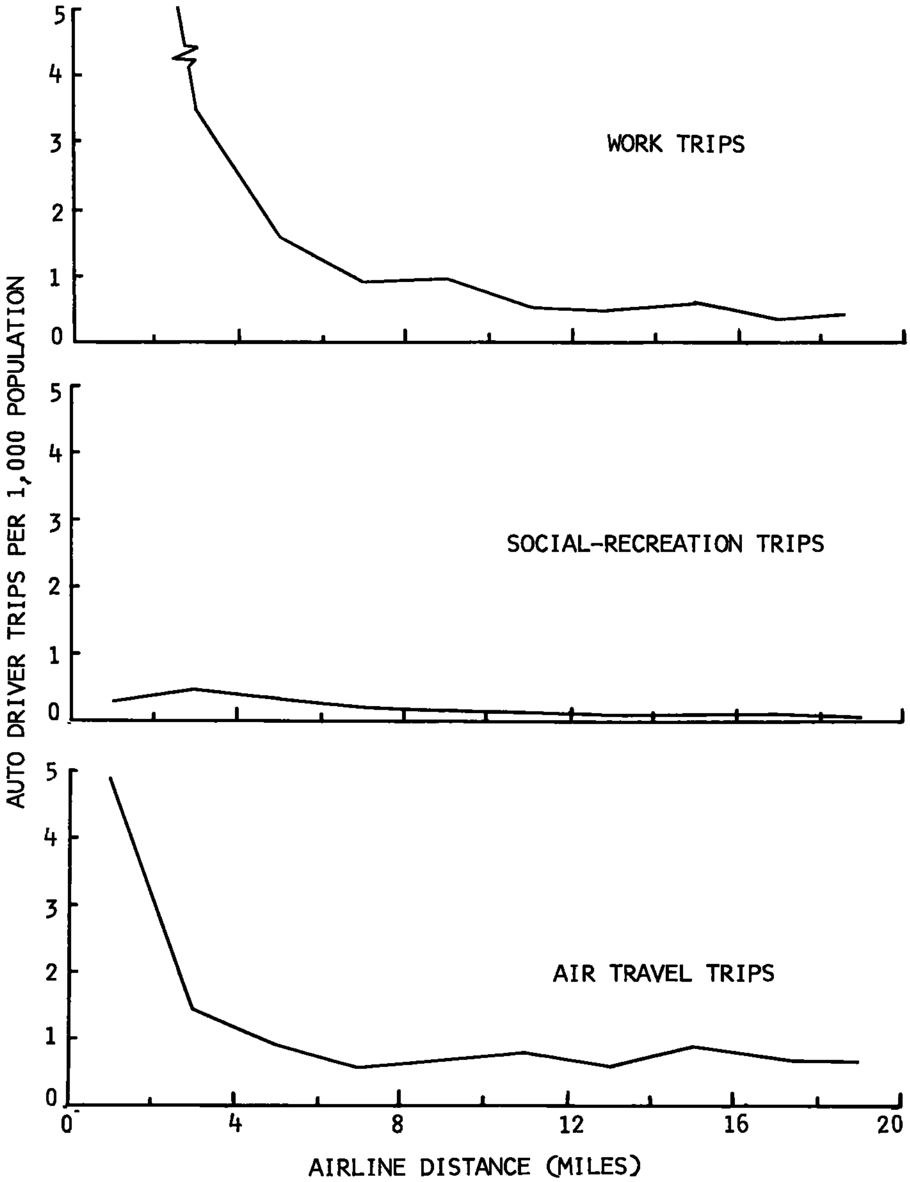

Figure 15. Home interview auto driver trips per 1,000 population, composite curve on distance, by purpose.

particularly at distances over 5 miles. Closer to the airport, however, rates vary through a wide range. Stratification by trip purpose improves the results.

Figure 15 shows the composite curves by purpose for all airports. There are three distinct curves. Work trip rates are very high near the airports: at 0 to 2 miles, for example, the composite trip rate is about 12 per 1,000 population; at 2 to 4 miles the rate drops to just over 3 trips, and continues to drop through remaining distance increments. Social-recreation trips are generated at the greatest rate at about 2 to 4 miles and at nearly a constant rate through remaining distances. Air travel trips are generated at the greatest rate at about 0 to 2 miles (5 trips per 1,000 population), decreasing at 2 to 4 miles (about 1.5 trips), decreasing again at 4 to 6 and 6 to 8 miles, but holding constant, or even increasing, at greater distances. As might be expected, the average rate beyond 6 to 8 miles is higher than for work or social-recreation trips.

Figure 16 shows the composite trip rate curves for both trucks and taxis (but without trip purpose stratification, which would not be meaningful). Truck trip rates decay rapidly, at 0 to 2 miles there being about 7.5 trips per 1,000 population whereas at 2 to 4 miles there are only 0.5 trips, from where the rate steadily decreases. Because they are associated with air travel trips, taxi trip rate curves might be expected to decay less rapidly. However, the longer trips may be discouraged by high fares.

tion curves need not be stratified by population groupings

[a] From transportation study data for various cities. [b] Weighted.

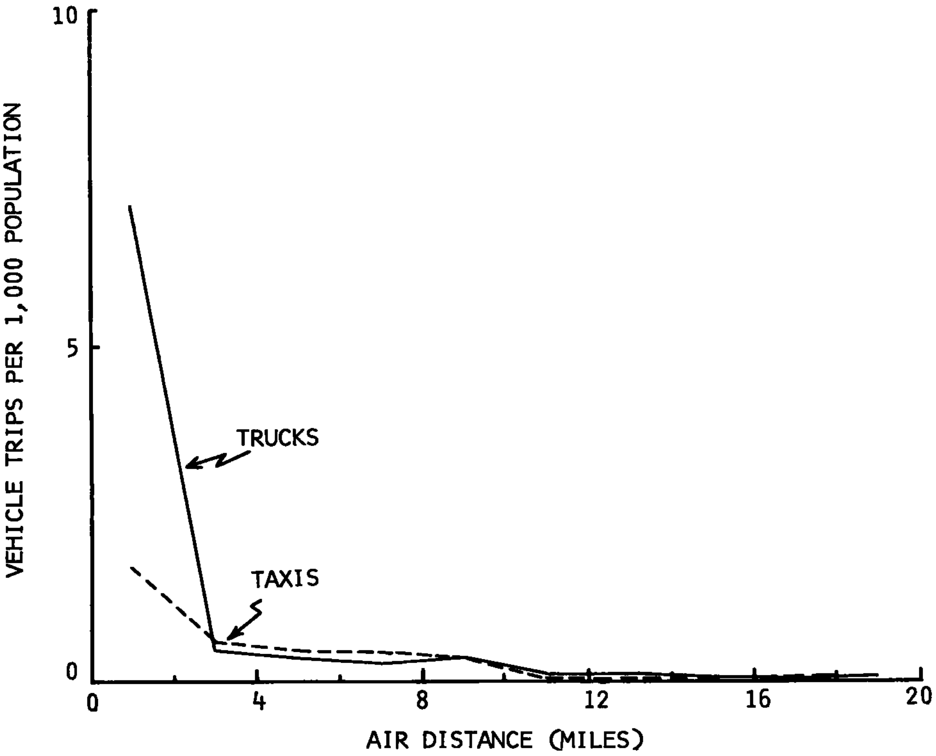

Figure 16. Internal truck and taxi trips per 1,000 population, composite curve on distance, selected airports, all purposes.

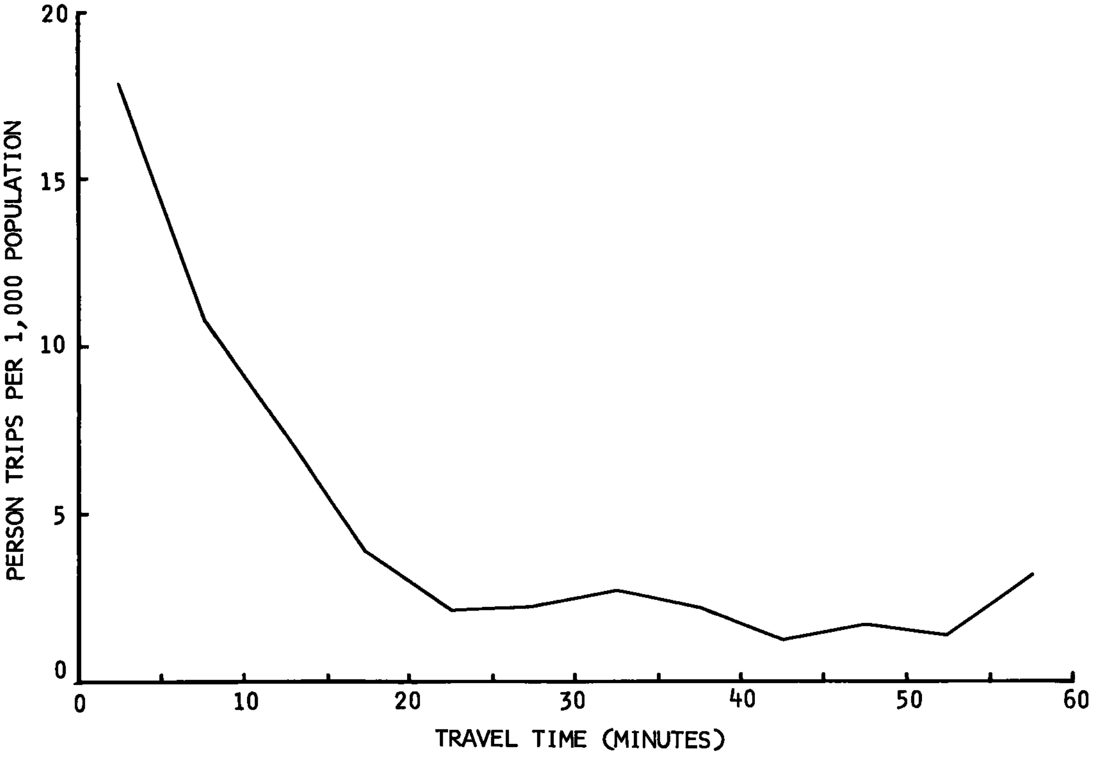

Figure 17. Home interview person trips per 1,000 population, composite curve on travel time, all purposes.

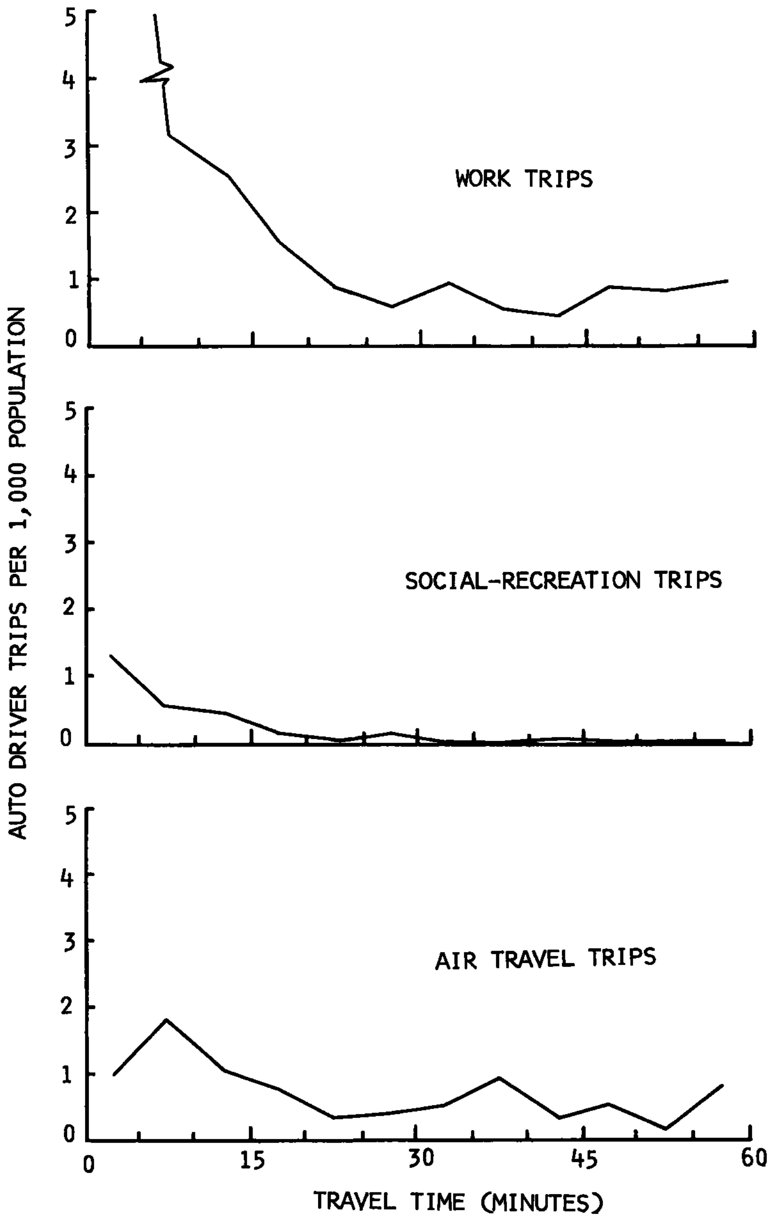

Figure 18. Home interview auto driver trips per 1,000 population, composite curve on travel time, by purpose.

Travel Time Rates

PERSON TRIPS

Trip rate curves based on minimum-path travel trees could be constructed for only the Atlanta, Buffalo, Philadelphia, Pittsburgh, Providence, and Washington airports, such trees being unavailable for the other airports, and travel times as reported in the home interview surveys being inadequate for the purpose. Individual plots of total person trips per 1,000 population, all purposes, for each of these airports showed fair consistency, except in the first 5-min travel band.

Figure 17 shows that the composite trip rate curve is essentially the same type curve as that for distance. Which is more descriptive? Normally the travel time curve would provide the better measure of accessibility. For purposes of predicting the geographic distribution of airport trip origins, however, tests showed both curves to have utility, the one for distance being useful where the one for travel time is unavailable.

VEHICLE TRIPS

Individual airport plots of home interview auto driver trips per 1,000 population, all purposes, again show fair consistency, but with rates varying widely within the 5-min

travel band. Individual airport plots by trip purpose stratification have about the same consistency; that is, neither remarkably good nor bad.

Figure 18 shows the composite trip curves by trip purpose. As with the comparable curves on distance, each purpose curve is unique. Work trips have the steepest slope, social-recreation trips the next steepest, and air travel trips little slope at all.

Origins and Destinations

URBAN AREA

The outstanding characteristic of airport ground travel distribution is geographical dispersion, demonstrated by plotting the home interview person trip origins for the ten subject airports. Figure 19, for the Philadelphia area, is a good example; generally, the cluster of origins nearest the airport consists mostly of work trips, whereas the cluster

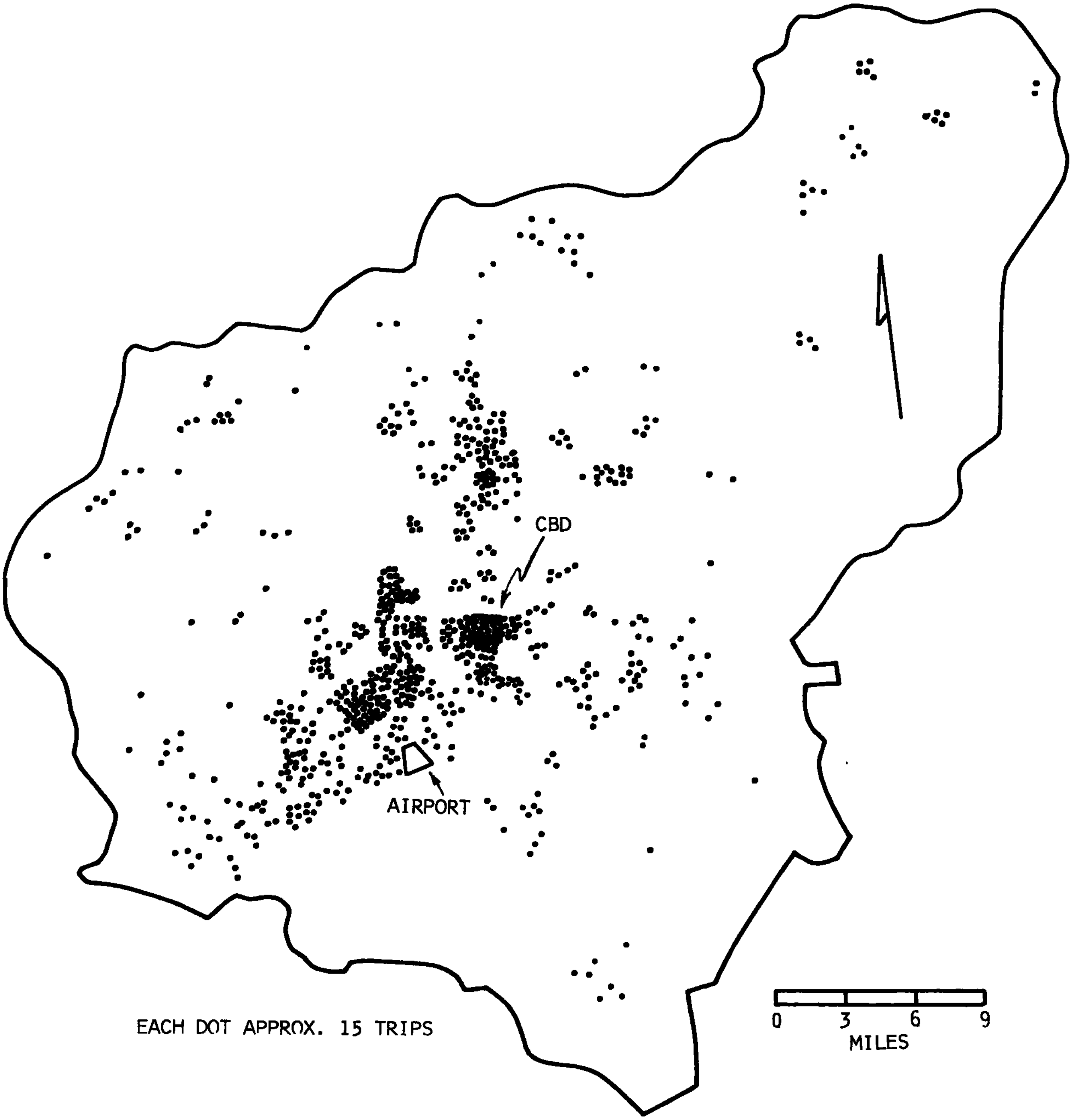

Figure 19. Home interview person trip origins, trips to Philadelphia International Airport, all purposes, all modes.

in and near the central business district consists mostly of air travel trips. The scattered remainder represent a mixture of air travel and social-recreation trips. Plots of both ground origins and destinations show similarly dispersed patterns.

Comparable conclusions have been drawn elsewhere, notably by a 1961 study which plotted air passenger origins for the cities of Chicago, Cleveland, and Washington (*11*). This study drew on an Institute of Traffic Engineers parking study at Chicago Midway (*12*), a postcard handout survey by Fenn College at Cleveland (*13*), and its own special study at Washington. Dispersion is evident in each instance.

Another way to demonstrate dispersion is by calculating air travel trip rates per 1,000 population by distance from the CBD. Table 15 shows that such rates tend to increase with increasing distance (toward the higher numbered study rings). Chicago may be a typical example; in the generally lower income inner rings (rings 1-3) the trip rate is low, with increasing distance toward and through the higher income suburban rings the trip rate rises. Buffalo shows somewhat the same tendency. In Buffalo and Chicago the airports are located in ring 4; in Pittsburgh, in ring 7.

TABLE 15

AIR TRAVEL TRIP RATES PER 1,000 POPULATION, ALL MODES, BY RING [a]

STUDY AREA ANALYSIS RING	AIR TRAVEL TRIPS (NO./1,000 POP.)		
	BUFFALO	CHICAGO	PITTSBURGH
0	2.64	53.89	—
1	0.68	0.82	—
2	0.88	0.22	0.37
3	1.22	0.53	0.93
4	3.41	1.07	0.91
5	2.22	1.01	0.74
6	1.70	2.42	0.47
7	—	2.25	1.63

[a] From transportation study data for indicated cities.

SURROUNDING REGION

For various reasons, roadside interview trips were not obtained from all transportation studies. These represent trips into the study areas, in this case to the airports, from the surrounding region. The airport's location and the relative size and degree of urbanization of the study areas generally determine the number of such trips (Table 16).

In Pittsburgh the airport is located just at the study boundary; that is, at the extreme edge of urban development. Accordingly, 36% of its auto driver work trips, 51% of its air travel trips, and 82% of its social-recreation trips originate outside the study area. Of the total, 51% of all auto driver trips to the airport originate outside the study area. This contrasts strongly with the experience where airports were well inside study area boundaries (roadside interview trips were not obtained for those airports not listed).

CENTRAL BUSINESS DISTRICT

The central business district has special needs for ground transportation to the airport. It remains the most concentrated source of airport trips in major metropolitan areas. Yet its needs may have been overstressed—certainly with respect to resident trip origins.

Bearing in mind that transportation study data do not report, or at best seriously under-report, nonresident trips, CBD airport trip generation is but a small part of total airport trip generation. Table 17 suggests that, even with the addition of unreported nonresident trips, it may be less concentrated a generator than commonly supposed; on the average, CBD's account for only 3.3% of all airport trip origins. The range is from Atlanta's 1.1% to San Diego's 8.1%. Except in Buffalo, Chicago, and Pittsburgh, there are more auto than transit trips.

When both the CBD and its surrounding high-density activity—together comprising the central area—are considered, concentration increases; on the average, central areas account for 7.7% of all airport trip origins. The range is from Atlanta's 1.9% to Chicago's and San Diego's 13.5%. As with CBD's, central areas generate more auto than transit trips.

Much has been said about whether CBD's provide economic justification for special travel facilities linking them with airports. Some groups espouse direct freeway connections (*14*), other groups favor rapid transit (*15*). With the present dispersion of resident trip origins and destinations, and the probability of increasingly dispersed nonresident trips, the trends are working against rapid transit as a favored solution.

RESIDENTS VS NONRESIDENTS

About eight of ten resident trips to the airport start at home (clearly, the nonresident percentage would be much lower). About 85% of all auto driver trips to work start at home, as against 76% of such trips to air travel, and 71% to social-recreation. About 86% of all auto passenger work trips start at home, as against 80% of such trips to social-recreation, and 70% to air travel. Transit trips display the most marked disparity by trip purpose: 95% of all transit

TABLE 16

PROPORTION OF TOTAL AUTO DRIVER TRIPS ORIGINATING OUTSIDE STUDY AREAS [a]

AIRPORT	TRIPS ORIG. OUTSIDE STUDY AREA (%)			
	TO WORK	TO SOC.-RECR.	TO AIR TRAVEL	ALL PURPOSES [b]
Buffalo	7	11	15	12
Minneapolis-St. Paul	3	4	7	5
Philadelphia	8	7	16	12
Pittsburgh	36	82	51	51
Seattle-Tacoma	3	4	16	9

[a] From transportation study data for various cities. [b] Weighted average.

TABLE 17

PROPORTION OF TOTAL HOME INTERVIEW PERSON TRIPS TO AIRPORTS WITH ORIGIN IN CENTRAL BUSINESS DISTRICT, OR CENTRAL BUSINESS AREA, BY MODE [a]

	TRIPS FROM CBD (%)			TRIPS FROM CENTRAL AREA (%) [c]		
AIRPORT	BY AUTO	BY TRANSIT [b]	TOTAL	BY AUTO	BY TRANSIT [b]	TOTAL
Atlanta	1.1	—	1.1	1.9	—	1.9
Buffalo	0.6	2.4	3.0	6.9	3.1	10.0
Chicago (Midway)	2.3	4.2	6.5	5.5	8.0	13.5
Minneapolis-St. Paul	2.0	—	2.0	2.1	0.4	2.5
Philadelphia	1.9	0.4	2.3	7.4	0.9	8.3
Pittsburgh	0.5	1.0	1.5	5.6	1.0	6.6
Providence	—	—	—	2.0	1.0	3.0
San Diego	5.4	2.7	8.1	8.1	5.4	13.5
Seattle-Tacoma	4.6	0.9	5.5	7.4	0.9	8.3
Washington (National)	2.2	0.5	2.7	10.3	2.4	12.7
Average	2.1	1.2	3.3	5.5	2.2	7.7

[a] From transportation study data for various cities. [b] Includes bus, airport limousine, and taxi trips.
[c] Includes CBD.

passenger trips to work start at home, 83% to social-recreation, and but 65% to air travel (Table 18).

How do nonhome-based trips affect trip rate curves based on population? Adversely, to be sure. Yet because the curves are intended to determine the directional orientation of trips, not the gross number, the effect may be insignificant. Many nonhome-based trips will still originate in the sector where the driver lives. A more difficult problem is determining nonresident trip origins.

In most large cities resident and nonresident air travel trips may approximately balance; that is, the city is neither predominantly an "importer" nor an "exporter" of air travelers. In 1956, for example, almost one-half (48%) of the air passengers departing New York City's airports resided in the New York-New Jersey-Connecticut Metropolitan Area. The percentage in 1963 was virtually the same (49%) (*16*). Almost the same proportion was found in a study at Cleveland's Hopkins Airport; slightly more than one-half (53%) of the outbound air passengers surveyed in 1957 were nonresident (*13*). However, smaller cities are apt to be "exporters." It seems logical, for example, to suppose that more people from Milford, Conn., would need to fly to Chicago, than the reverse.

For any given day, however, the mix may vary widely. A 1962 study (*17*) at Boston's Logan International Airport showed the resident-nonresident percentages for departing air passengers to be: Monday, 63-37; Wednesday, 33-67; Thursday, 41-59; Friday, 31-69; Sunday, 54-46. The average weekly percentages were not given, but a near balance is suggested.

Attractive vacation areas naturally will attract many nonresident air travelers. A recent study (*18*) reported that 65% of the Seattle-Tacoma International Airport passengers were nonresidents in the State of Washington. An older (1951) study (*19*) reported that 68% of San Diego's Municipal Airport departing passengers were nonresidents.

Residents and nonresidents tend to employ different travel modes. Combining 1963 figures for the three major New York airports, 60% of all resident trips were by auto, 20% by taxi, 17% by airport coach, public bus or limousine, and 3% by other means. Comparable percentages for nonresident trips were 32, 34, 32, and 2, respectively. Moreover, there was significant variation by airport. For example, resident trips to LaGuardia were 52% by auto; to John F. Kennedy, 59% by auto; to Newark, 68% by auto. Comparable percentages for nonresident trips were 24, 32, and 42, respectively.

TRAVEL IMPACT ON HIGHWAY NETWORK

Although airports may be among the largest trip generators in metropolitan areas, they may account for only a fraction of the total travel. Of the airports sampled, Chicago Midway generates the most travel—approximately 220,000 vehicle-miles. Yet this is only 0.72% of the 31 million vehicle-miles of travel (VMT) in that study area on a typical weekday. Every airport considered accounted for less than 2% of the total travel in its study area, ranging from 0.26% (San Diego) to 1.68% (Atlanta).

Traffic impact becomes significant only when considering the airport traffic zone itself. In Pittsburgh, for example, it was found that the daily airport VMT accounted for about 32% of the daily total traffic zone VMT. During the afternoon peak hour, the percentage increased somewhat, because the two-way airport traffic peak was sharper than that of other traffic.

To take the comparison further, airport travel accounted for about 40% of the total travel on the main airport access road (Airport Parkway) on a daily basis. Again, the percentage was somewhat higher during the afternoon peak hour. Fortunately, in 1958 there was not a difficult capacity problem on this main access road. Its four 12-ft lanes carried about 20,000 vehicles a day near the airport entrance. But consider the capacity used up at this point by

airport tripmakers alone: on a 24-hr basis, about 25%; on an afternoon peak-hour basis, about 47%.

Because the Pittsburgh airport is far from downtown, its main access road is not called upon to serve as much non-airport traffic as such roads in areas where the airports are more centrally located. At Chicago's Midway and San Diego's Lindbergh Airports, for example, where terminal buildings directly abut major arterial streets carrying mixed traffic through dense urban development, the impact of airport trip generation on the highway network is much greater.

PREDICTING AND TESTING RELATIONSHIPS

Predicting Trip Generation

Future trips to and from the airport should be considered by trip purpose. Work trips can be estimated from expected employment. Social-recreation trips can be estimated from expected population. Air travel trips (both resident and nonresident) might be estimated on the basis of city type and socio-economic characteristics. In each case, estimation might best start with total person trips, from which the proportion using transit can be estimated and subtracted. The remainder can be reduced to automobile trips by assuming car loading factors by trip purpose group. Truck and taxi trips, airport bus, interurban bus, and limousine trips can be estimated by ratio to automobile trips.

Predicting Trip Distribution

Resident auto driver trip origins by small subareas of the metropolitan area can be estimated on the basis of population-based trip rate curves, by trip purpose, by travel time, or by distance. Nonresident auto driver trip origins might be assumed to take the same pattern (although this cannot be demonstrated with transportation study data).

Assignment to the highway network, based on network speeds, can produce estimates of traffic on the main access roads approaching the airport from all directions. Truck and taxi trips may be assumed to approach the airport directionally in proportion to automobile trips. Airport bus and limousine trips may be assumed to approach from the downtown direction. Trip totals must be normalized to the trip generation control totals.

Testing Predictive Procedures

The predictive procedures just described were "tested" by estimating current trip generation at the major Salt Lake City and Miami Airports. For comparison purposes, transportation study data were taken to represent actual tripmaking. (Thus, both sets of figures compared are afflicted by sampling variability problems, so that the test is approximate at best.) The results were only moderately encouraging. Total daily vehicle trips to the airports were underestimated by 23% for Salt Lake City, by 19% for Miami. The estimation of air travel and social-recreation trips was less accurate than the estimation of work trips (see Appendix C, Backcheck Results, Airports, for detailed results). There is one bright spot, however—apparently trip distribution curves need not be stratified by population groupings on family income, occupation, auto ownership, and so forth. The population distribution alone was adequate for predicting the directional orientation of tripmaking.

TRENDS

Air travel is growing rapidly. A Federal Aviation Agency official has commented (*20*): "Broadly speaking, it is now speculated that air traffic (revenue passenger-miles) may triple by the end of 1975." Air travel is encouraged by its increasing economy, improved safety and convenience, better airport access, better airport design, and by many other improvements that make air travel more attractive and within the means of a growing number of people.

What are the implications for ground traffic? While air travel trips alone will create a critical need for effective ground transportation to airports, work and social-recreation trips will also increase with increasing airport activity. A larger labor force will be required to serve more travelers and more airplanes. Although automation may somewhat offset the labor force growth, particularly in baggage handling and ticketing management, maintenance activity will enlarge and peripheral activities on the airport site seem certain to expand. And, although increasing familiarity with airport activity may reduce the number of curiosity seekers, social activities separate from air travel will swell the number of social-recreation trips.

Total person tripmaking will probably continue to emphasize autos. An increase in two-car families will let more residents drive to the airport instead of taking taxis or transit. An increasing proportion of nonresident trips will come from the surburbs—as nonresidential activities become increasingly dispersed—and they, too, will make increasing use of autos for airport travel. (A 1963 study (*30*) by the National Car Rental System indicated that more than 60% of all car rental business is generated at airports.) The average number of passengers per automobile will probably continue to decrease. Such trends suggest that vehicle traffic at airports will increase even faster than person traffic.

Air cargo shipments have been increasing rapidly and industry leaders talk of an annual growth rate of at least 10% over the next five years. Juan Trippe, president of Pan American World Airways, has been quoted (*22*) as

TABLE 18

PROPORTION OF RESIDENT NONHOME-BASED TRIPS TO AIRPORTS[a]

TRIP PURPOSE	TRIPS (%) AUTO DRIVER	AUTO PASS.	TRANSIT PASS.	ALL MODES
Work	15	14	5	14
Soc.-Recr.	29	20	17	22
Air Travel	24	30	35	27
Average[b]	20	22	18	21

[a] From transportation study data for various cities. [b] Weighted.

saying: "The day comes still closer when air freight will become as important as passenger traffic in producing revenue." In time there may be complete separation of air cargo and air passenger airports. At present, however, expansion of existing cargo facilities is more typical, recently announced expansions including that at Philadelphia (costing $3.6 million) (*23*) and at New York's JFK (costing $1.5 million) (*24*). Certainly such developments will create much more truck traffic at airports.

Time patterns of resulting total ground traffic at airports may shift somewhat. With larger aircraft, air travel trips for business purposes (about 85% of all air travel) may become more peaked. All the travelers who want to may be able to get away at the start or end of the working day. However, more off-season vacation travel may somewhat smooth the present summer peaking of total air passenger activity.

More shifting, still, may be spatial patterns of ground traffic. Trips may become more dispersed as cities grow outward from their centers. Not only will homes be increasingly scattered, but so also will be the businesses, industries, and institutions that generate business air travel. This means, for airports now near the edge of urban development, that traffic will approach more evenly from all directions.

Continued urban growth may also require more airports and increasing functional specialization. For example, one concept (*25*) is that rather than plan a number of large, general-purpose airports in outlying areas, planning should be for one large transcontinental jet airport, if essential to the region, in an outlying location and a number of smaller fields around the central city in the direction of the future centers of suburban growth. In effect, this has happened in Washington, D. C., and Chicago, the longer flights arriving at Dulles and O'Hare, and the shorter flights at National and at re-opened Midway. It will certainly rearrange ground transportation requirements.

All these trends—growth in total aiport tripmaking and changes in travel mode, time, and spatial patterns—make it increasingly difficult for highway designers to be certain they are providing adequate ground access. Indeed, various other developments might decrease ground travel by highway. First, there is still talk of rapid transit linking airports and central cities; second, there is the growing "air-taxi" service between outlying areas and major metropolitan airports (*26*); third, there is the broadening horizon for helicopter applications (*27*).

One thing stands out from even a superficial review of the "air literature"—air transportation is evolving tremendously fast. New developments are the rule. Provision of ground transportation to fit changing and growing needs will become increasingly critical.

CONCLUSIONS

This chapter has demonstrated what was known all along—airports create a considerable amount of ground traffic. However, some new dimensions may have been provided with respect to the varying purposes of this ground traffic. Airports are seen not only to serve air travelers, but also to employ many workers and to entertain many visitors. There is suggestion, too, that further diversification of airport activities may be expected to add still new inducements to swell ground traffic.

Metropolitan area residents rely heavily on the automobile to get to the airport. Neither taxis nor public transit carry any appreciable number of trips to work or to social-recreation—and surprisingly few trips to air travel. Visitors from other areas depend more on these travel modes. Even visitors, however, are tending more often to rent automobiles conveniently available at airport terminals.

Residents' trips are scattered throughout the metropolitan areas, as most of their trips start at home. Few start from central business districts. Many visitors' trips, however, are concentrated in the central cities, and this creates special transportation requirements. Various forms of rapid transit are sometimes suggested to meet these requirements.

Every expectation is that the dramatic growth of air travel will continue—if not accelerate. So many factors are involved that only the "air experts" have a good chance of making accurate growth forecasts. Highway engineers, however, should keep aware of trends, such as shifts in travel mode use and changes in average car occupancy, that may cause ground traffic to increase faster than air traffic.

Some relationships reported here may prove useful in rounding out the picture of total trip generation at airports. Note should be made, however, that many of them are already historical; they have changed since the tripmaking records were taken. Nevertheless, a number of "rough and ready" trip estimation techniques will be apparent among the relationships expressed, and may provide helpful perspective in the task of planning for efficient airport access by highway.

CHAPTER THREE

SHOPPING CENTERS

Shopping centers have rapidly become part of the American way of life. In the 1957 edition of the *Directory of Shopping Centers* (*28*) some 2,000 centers were listed; in the 1965 edition, nearly 10,000 were listed; and the preface to the 1964 edition predicted that "by 1975 the number will surely grow to 15,000 unless there is an unforeseen disaster of major proportions in the national or world economy."

Importantly, the preface to that same edition also predicted continued developments in shopping center design, including "many new advances in the new shopping centers—year-round climate controlled malls will be in greater evidence, recreational facilities for the entire family will become more integrated features of the new shopping centers, and in almost every way conceivable shopping centers will transplant all of the services and activities of the central city core to the new centers of population in the surburbs."

Such developments, already clearly evident in the newest centers, will impose heavy traffic demands on the major streets and highways that serve the centers. Deep concern will be felt by highway officials: they must provide not only for traffic to and from shopping centers, but also for through traffic on the abutting streets.

The present research is directed toward developing factors and relationships that may be helpful in determining the probable traffic impact created by a new shopping center. They are based on a study of tripmaking to 28 major shopping centers in Atlanta, Buffalo, Chicago, Denver, Miami, Minneapolis-St. Paul, Philadelphia, Pittsburgh, Providence, Seattle, and Wilmington, Del. Many were regional shopping centers. Others were simply the largest centers in their metropolitan areas during the year for which tripmaking was reported (see Table B-3).

The following sections of this chapter include, generally, a review of the Pittsburgh pilot study (*29*), a report on the shopping center and travel characteristics at more than a score of shopping centers in various cities, a study of the interaction between shopping centers and highways, and a discussion of techniques for predicting trip ends and trip distribution.

DATA CHARACTERISTICS AND ANALYSIS

The Pittsburgh Pilot Study

Before assembling data from other sources, a pilot study (*29*) was made with data from the Pittsburgh Area Transportation Study. Its purpose was to determine the elements of primary interest, and to set up practical procedures for both processing and analysis. It explored the characteristics of all shopping trips as produced at households and as attracted at shopping places, then, considering individual shopping centers, developed a tentative method for predicting shopping center trips and their impact on the highway system. Some key findings were as follows:

1. Average auto driver travel times to shop were virtually the same at all households regardless of distance from the CBD. Although shopping trips were longer (airline distance) at households farther from the CBD, increased travel speeds held any difference in travel times to 3 min. For transit shopping trips, however, both trip lengths and travel times increased with increasing distance (Table 19).
2. Auto driver trips increased from 3% to 71% of all shopping trips, while transit trips decreased from 76% to 6% in going from households without a car to those with two or more (Table 20).
3. Hourly shopping patterns were strikingly different as between the CBD, shopping centers, and all other shop destinations (Fig. 20).

The trip generation and trip distribution technique developed was deemed applicable only to home-based shopping trips, the remainder to be treated as a proportion of home-based shopping. Moreover, the technique would apply only to trips within a 10-min free travel time, or approximately 15 to 20 min using the Bureau of Public Roads approach to network travel time (*30*). As a result of these restrictions, the technique distributed about 75% of the trips to the centers.

As part of this work, curves were developed showing the decay of trip rates (auto driver trips per 1,000 population) for both shopping goods and convenience goods by time from the center. It was noted that for an equal radial distance from the center the trip rates from a zone on the suburban side of a center markedly exceeded those on the CBD side of the center, as was also observed in Washington by Silver and Hansen (*31*). It appeared due to the varying effect of the CBD as competition, and to the varying downtown transit service available.

Backchecking proved a reasonable simulation of trip distribution by comparison of estimated versus actual trips assigned to minimum time paths on the highway network. The technique was intended to apportion trips directionally; assigned trips were then prorated to match study-reported trips, previously established as the trip generation control. For illustration, Figure 21 shows predicted versus reported trips to Center C by travel time increment for zones on the CBD side and zones on the suburban side.

Further work evaluated the traffic impact on the highway network with respect to peak-hour capacity. The vehicle-miles of travel produced and the percentages of capacity required by the shopping center for various conditions, including the shopping center peak at 7 to 8 PM,

TABLE 19

CHARACTERISTICS OF HOME INTERVIEW SHOPPING TRIPS IN PITTSBURGH BY RESIDENCE RING AND MODE [a]

	TRIP CHARACTERISTICS								
	AUTO DRIVERS			AUTO PASS.			TRANSIT PASS.		
RESIDENCE RING	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)
1	36	1.6	12	30	2.1	13	34	1.3	20
2	40	1.7	13	31	1.8	13	29	1.6	24
3	49	1.7	12	31	2.2	14	20	2.6	26
4	56	1.8	11	29	1.9	11	15	3.4	29
5	60	1.8	11	27	2.3	13	13	4.5	31
6	60	2.1	12	29	2.5	13	11	4.4	28
7	65	2.4	11	31	3.0	13	4	6.1	35
All	56	1.9	11	29	2.2	13	15	3.4	28

[a] From Pittsburgh Area Transportation Study.

TABLE 20

CHARACTERISTICS OF HOME INTERVIEW SHOPPING TRIPS IN PITTSBURGH BY CAR OWNERSHIP CLASS AND MODE [a]

	TRIP CHARACTERISTICS								
	AUTO DRIVERS			AUTO PASS.			TRANSIT PASS.		
NO. CARS OWNED	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)	TRIPS (%)	AVG. DIST. (MI)	AVG. TIME (MIN)
0	3	2.4	15	21	2.1	13	76	2.6	24
1	58	1.8	11	32	2.2	12	10	3.8	29
2	71	2.1	12	23	2.6	14	6	3.8	31
3 or more	71	2.2	11	23	2.9	13	6	2.7	31
All	56	1.9	11	29	2.2	13	15	3.4	28

[a] From Pittsburgh Area Transportation Study.

were compared (Table 21). The impact can be severe on the major access road, but dissipates quickly over a number of arterials within 1 mile of the center.

The Shopping Centers

Twenty-three shopping centers in nine metropolitan areas were studied. Resulting predictive techniques were then tested on additional shopping centers in Wilmington. Table D-1 gives selected physical characteristics of all the centers studied. Throughout, the shopping centers are designated alphabetically to preserve their anonymity.

The site areas vary from 12 acres (D, which has by far the lowest parking/floor area ratio) to 90 acres (P, which is one of the nation's largest shopping centers and the second largest trip attractor in the group). Total floor area, for all purposes, ranges from 155,000 to 800,000 sq ft and is equivalent to "gross leasable area" as defined by the Urban Land Institute (*32*).

The number of establishments ranges from 18 to 80. This also helps to indicate the size and attractive power of the center (a study by Berry (*33*) showed, for unplanned centers, that some correlation existed between trips and number of establishments).

Parking spaces range from 1,000 to 6,000, averaging 3,600. Only three centers provided less than 2,000 spaces, and two of those have the two smallest area figures.

Two centers were opened in the late 1940's, 18 in the 1950's, and 3 in the 1960's (to obtain processed transportation survey data, few new centers could be represented).

Market Area Characteristics

DEFINITION

Definitions for "market area" are numerous, and possibly none is adequate for the purpose of this study. It has been

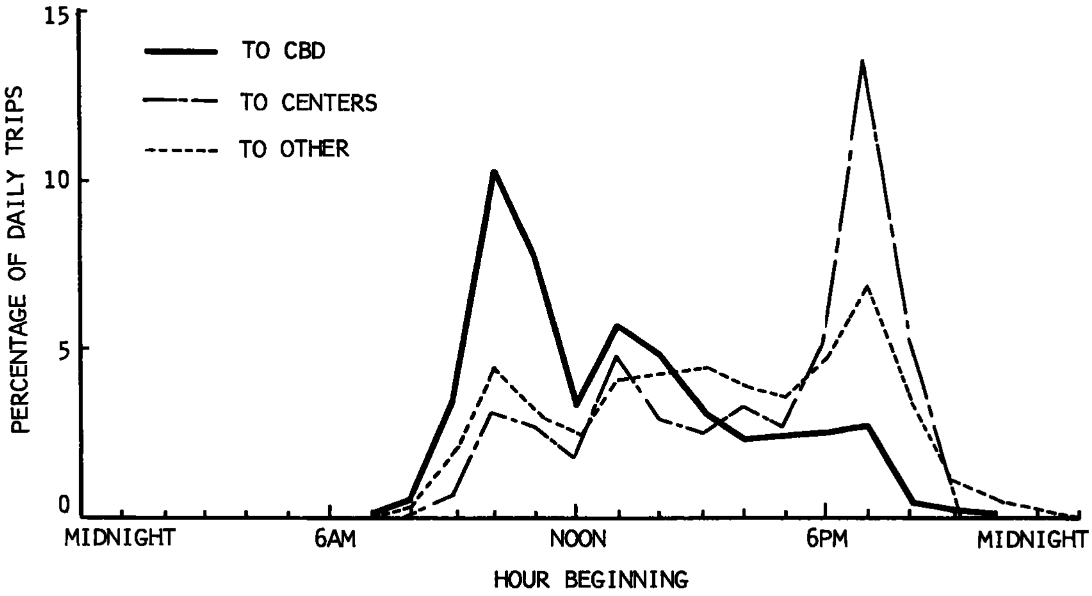

Figure 20. Home interview person trips to shop at the central business district, at all shopping centers, and at all other destinations, Pittsburgh, 1958.

common practice to draw a line at a given time or distance from the center and thus define it. But trips to shopping centers extend to great distances, and it would be possible to exclude a sizeable proportion of trips by such a definition. A designation of primary, secondary, and fringe "trading areas" is sometimes used to circumvent this problem.

In another technique, Berry (*33*) divided the region surrounding Chicago centers into eight sectors, drawing the boundary at the distance where the trip accumulation leveled off in each sector. The trading areas so designated accounted for at least 80% of the trips to each retail area. The trading areas overlapped considerably where there were no topographical or major nonresidential land use barriers separating adjacent major retail districts.

The overlap was also demonstrated in a consumer survey made for the Chicago Tribune (*34*), which covered 2,000 shoppers going to 37 major retail areas in metropolitan Chicago. Residents of an area did not restrict their shopping to just one or two centers, but visited seven to eight centers for shopping over the course of a year.

The point to be drawn from these and similar studies is that market areas are not mutually exclusive; even within its primary trading area, competition from downtown or another shopping area acts to reduce the number of trips to a given center. This was shown by Voorhees, Sharpe and Stegmaier (*35*) in measuring the difference in corridor shopping trips to Silver Springs Shopping Center on the CBD side and on the suburban side. Thus, market areas are very difficult to define exactly.

Therefore, despite the fact that market areas vary from shopping center to shopping center—obviously they are

TABLE 21

PROPORTIONS OF TRAVEL AND CAPACITY USED BY VEHICULAR TRIPS TO SELECTED SHOPPING CENTERS IN THE PITTSBURGH AREA[a]

	SHOPPING TRAVEL				DESIGN CAPACITY USED (%)			
	IN STUDY AREA		IN ZONE		ZONAL ART. STREET		MAIN ACCESS STREET	
SHOPPING CENTER	TRAVEL (VEH-MI)	(%)	TRAVEL (VEH-MI)	(%)	24 HR	PEAK HOUR	24 HR	PEAK HOUR
A	5871	0.08	3990	5	8	22	29	78
B	16199	0.23	6220	9	19	45	16	38
C	10262	0.14	7844	8	15	40	39	106
D	9381	0.13	10340	9	15	25	20	33

[a] From Pittsburgh Area Transportation Study.

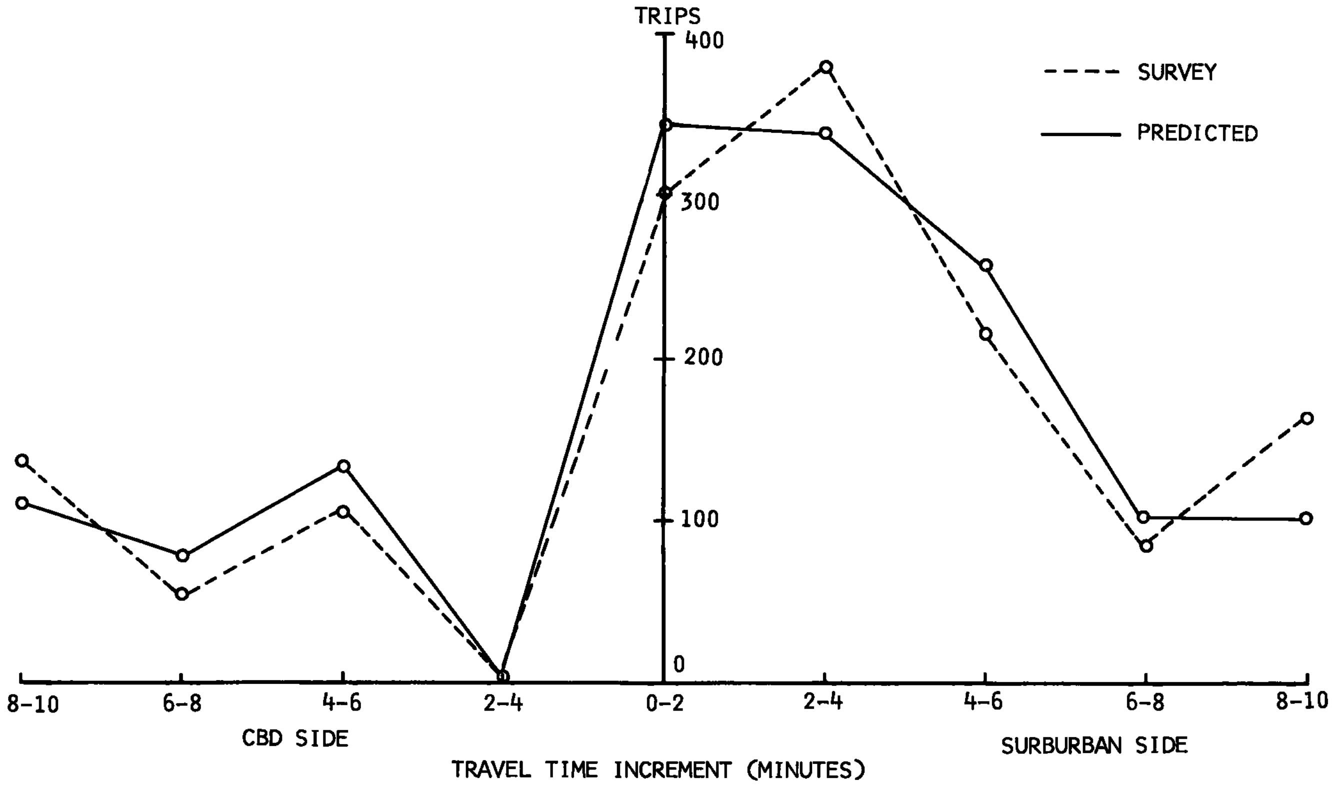

Figure 21. Auto driver shopping trips to Center C, predicted and actual survey volumes, by travel time.

affected by the location and attractiveness of other competition, the arrangement of land uses and topography, and probably by highway network geometry—a common frame of analytical reference will be established for the purpose of this report: unless otherwise noted, "market area" covers the area within a 5-mile radius of each shopping center, or within a 20-min travel time.

In almost every case the 20-min time band encompasses a larger part of the urban area than does the 5-mile radius. Thus it includes more extreme conditions, with densities representing the highest levels of the urban area mixed with those representing virtually undeveloped land. About 95% of most centers' shopping trips are accounted for within this travel time, as against about 75% within a 5-mile radius.

SOCIO-ECONOMIC CHARACTERISTICS

In each center's market area the population, the level of car ownership, and the percentage of auto driver trips to shop at the center vary. Gross population density differs considerably both on a time and on a distance basis. (It should be noted that for some centers the market area extends outside the study area boundary, whereas statistics are limited to the area inside the study area boundary.) Car ownership levels vary, also. Income data were available from only two of the eleven studies contributing data to this investigation. Consequently, analyses of market areas, and their component trip data, have not explored the influence of income on shopping patterns, except as it is reflected in car ownership and gross population density.

Shopping centers are most frequently located in low-density and high car ownership areas. Figure 22 shows how car ownership per 1,000 population at one center (Q) decreases both toward the CBD (inside) and toward the study area boundary (outside). More typically, the outside rate, representing newer suburban development, would hold constant, while the inside rate would decrease as shown, due to the generally older, higher-density and lower-income residential areas encountered toward the CBD.

A preview of the effect of shopping center location on trip generation is presented in Figure 23. Auto driver trip rates per 1,000 sq ft of shopping center floor space tend to increase in direct proportion to the number of cars owned within 20-min travel time. Later, the results of multiple regression analysis will show that market area characteristics and trip rates are not necessarily correlated. Perhaps this is because, where shopping center locations are well chosen, there are few significant differences among market areas.

Trip Characteristics

TOTAL TRIP VOLUMES

Table D-2 gives the number of trips to each shopping center by mode, by survey source. In some instances,

the roadside interview or truck-taxi trips to the centers could not be isolated from other destinations in the zone. Where known, the percentage of all vehicle trips accounted for by the home interview survey has been listed to show its dominant role in total tripmaking. Centers A, B, and Q, which show the lowest percentages, are located close to the cordon lines.

The automobile is the only significant mode of travel to shopping centers. Transit plays little role in suburban shopping. In only two cases does it carry more than 5% of the trips; one of these is in Chicago and the other in a dense suburb of Pittsburgh (incidentally, the center with the lowest parking/floor space ratio).

TRUCK AND TAXI TRIPS

Truck and taxi trips are a small part of total tripmaking to shopping centers, ranging from 0.8 to 9.2%, and aver-

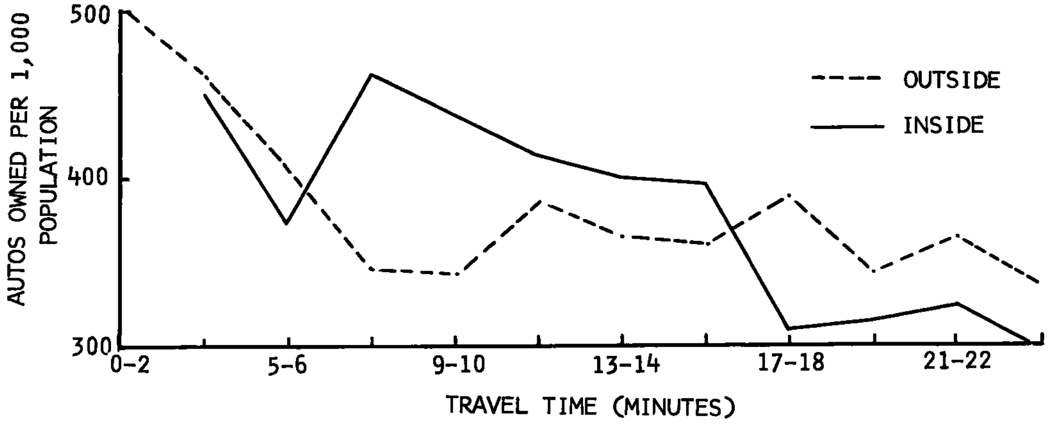

Figure 22. Auto ownership by travel time increment from Center Q.

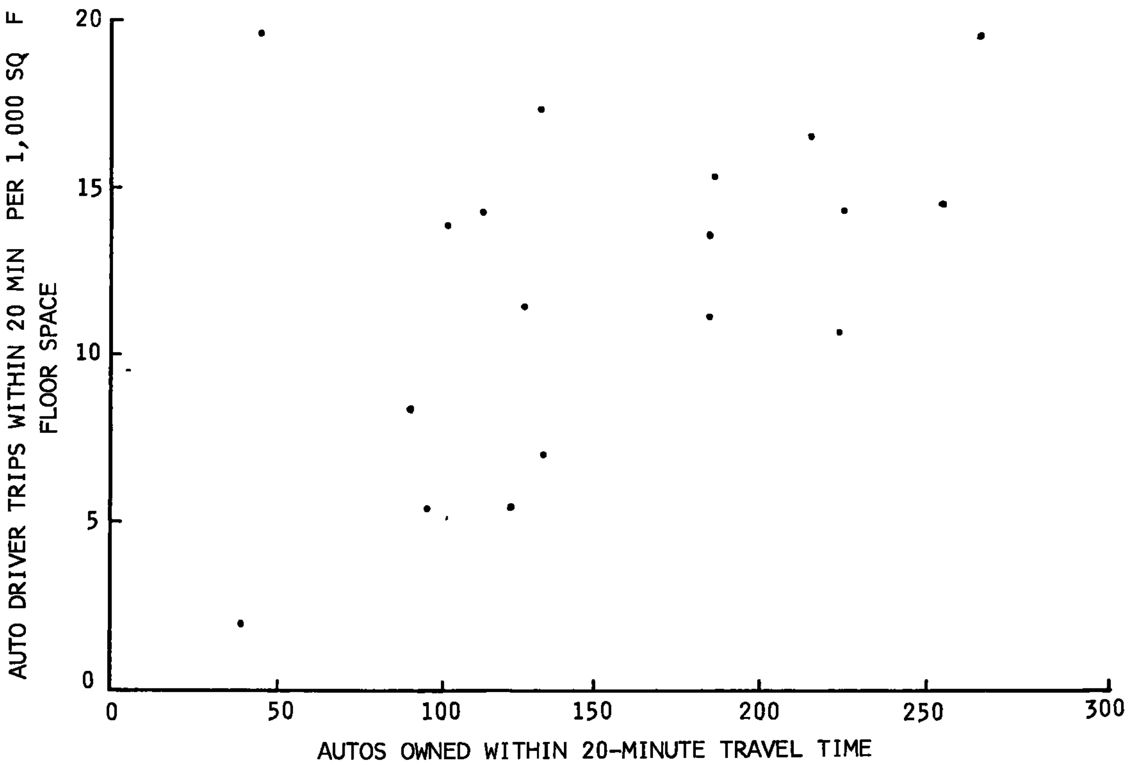

Figure 23. Auto driver trips per 1,000 sq ft of floor space, by market area auto ownership.

aging 3.8% of internal vehicle trips. The highest percentage occurred at Center L (with the lowest total trip volumes, certainly an exceptional case). Only one center attracted more than 400 truck trips per day, and only eight attracted more than 200 trips. Taxi trip samples were so few (frequently nonexistent) that they have not been separated from the truck data. Estimating truck trip volumes and distributions is clearly a minor part of estimating total tripmaking to a shopping center.

Generation rates based on gross floor area or the number of establishments are erratic. The scatter in Figure 24 showing gross floor area rates has at least two explanations: first, is the sampling and reporting of truck trips (some centers show less than ten sample trip records); second, gross floor area is probably not as good a generation base as sales or storage area might be (the latter being unavailable).

Arrival hours for truck trips are dissimilar to those for passenger cars. Anywhere from 21 to 38% of daily truck trips will be made before 10 AM, 28 to 51% between 10 and 2 PM, and 21 to 41% between 2 and 6 PM. Not surprisingly, volumes between 6 PM and midnight are least (0 to 9%).

Truck trips are directed primarily to convenience goods outlets, secondarily to shopping goods outlets, and insignificantly to nonshopping activities at centers. The detailed destination land uses for truck trips, obtainable in five study areas, showed ranges of from 36 to 84% of trips to "convenience goods" destinations (largely food and drug), 12 to 38% to "other retail," and 10 to 52% to "other" land uses.

WORK TRIPS

Work trip characteristics deserve investigation because they represent employment, which is sometimes used to predict shopping trip attractions to a center. Although the work trip data include visits by sales and service personnel, as well as return trips to work by employees who may have left the center temporarily, they are the best available measure of daily employment at the time of study.

Person work trips to each center were examined by occupation group. Table 22 summarizes the results. Coding vagaries were evident, but some variation was probably due to varying nonretail activities in the centers. Generally, the smaller centers showed the highest percentages of pro-

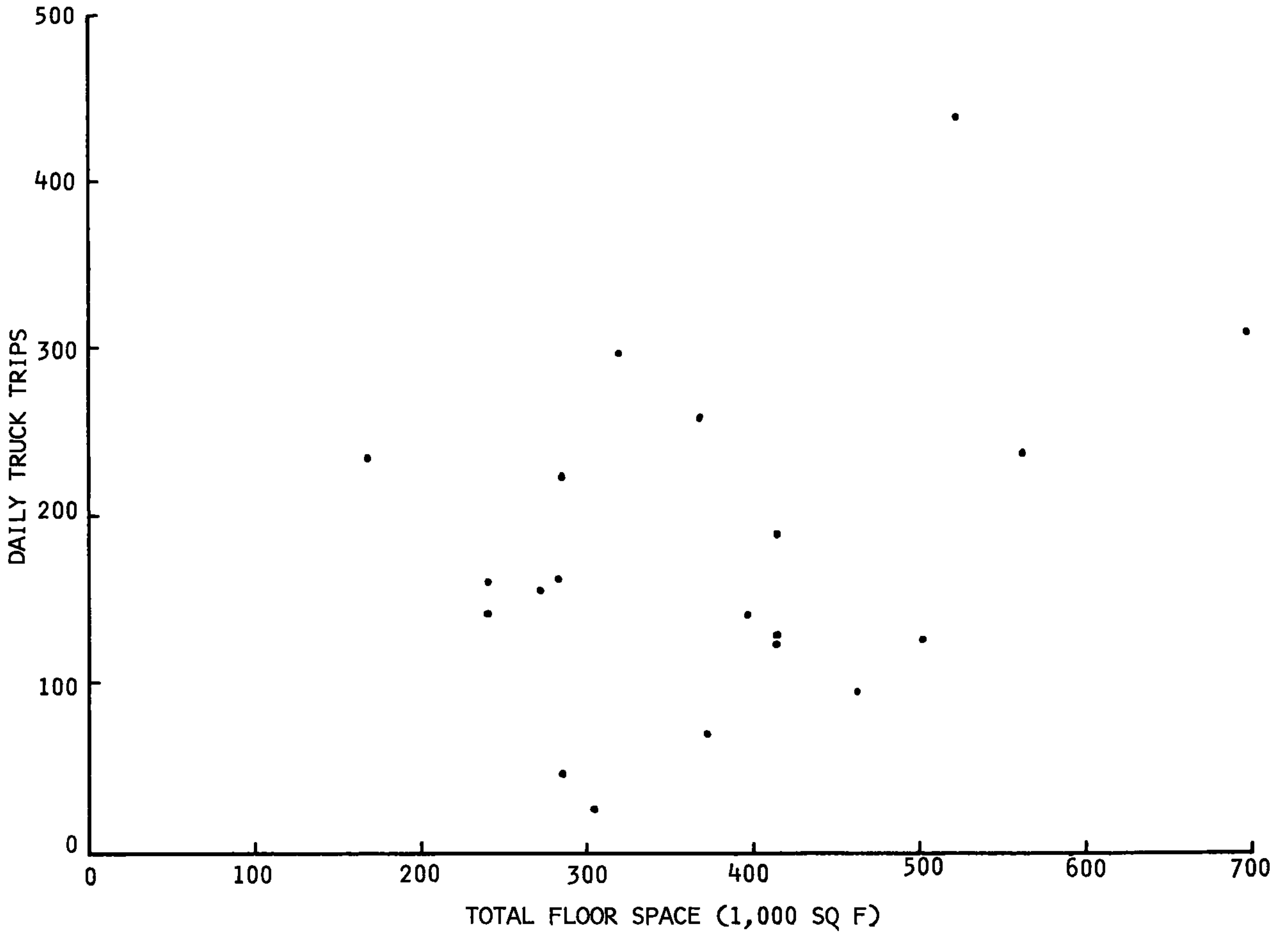

Figure 24. Daily truck trips per 1,000 sq ft of floor space.

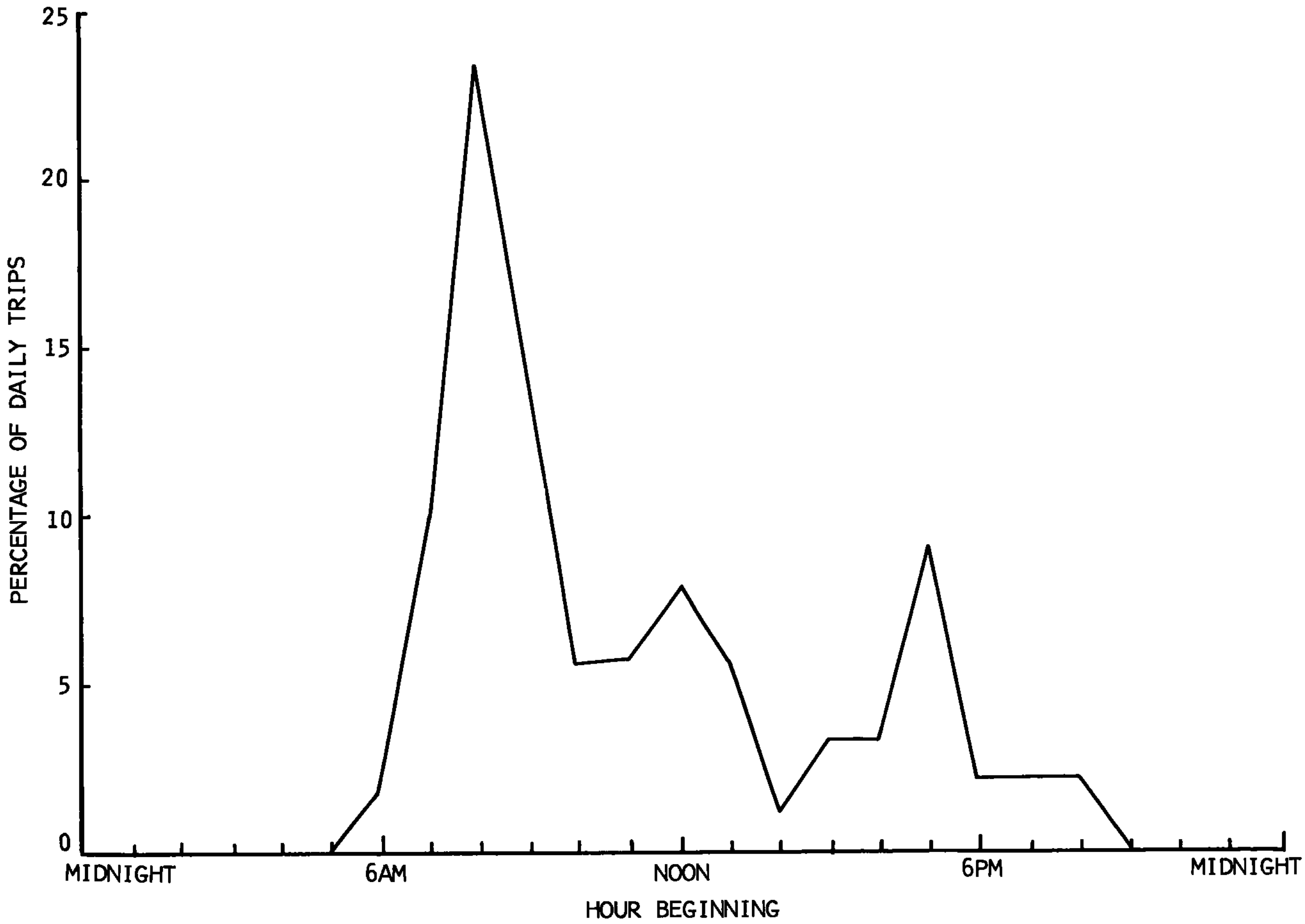

Figure 25. Auto driver trips to work by arrival time, three Miami shopping centers.

fessional, technical, and managerial employees, and the lowest proportions of craftsmen and laborers. The percentage of clerical and salesworkers for all centers generally ranged between 40 and 60%.

The number of person work trips ranged from 231 to 2,031. Related to floor space, there were from 0.97 to 4.05 trips per 1,000 sq ft, with a mean of 2.5 trips per 1,000 sq ft. Here again, the major variation is probably due to different amounts of nonretail activity at the centers.

Twelve percent of all auto driver trips to shopping centers are to work, with the proportion varying from 7% to 19%. Work trips to seven centers equal or exceed 15% of all auto drivers trips, but at eight other centers they are less than 10%.

Plots of auto driver trips to work by arrival hour were made for each center. A typical pattern is shown in Figure 25. More than one-third of the daily work trips arrive between 8 and 10 AM. Others arrive throughout the day—salesmen and employees at late-opening shops—and there is another pronounced peak in the late afternoon, perhaps the influx of sales personnel for the evening hours.

SHOPPING TRIP CHARACTERISTICS

Although women make from 64 to 77% of all shopping trips, regardless of mode, males will account occasionally for up to one-half the auto driver trips (Table 23). Women make from two-thirds to all transit trips, and at least four-fifths of all auto passenger trips.

TABLE 22

DISTRIBUTION OF LABOR FORCE COMPONENTS AT MAJOR SHOPPING CENTERS [a]

OCCUPATIONAL GROUP	RANGE (%)	AVG., ALL CENTERS (%)
Prof., tech., mgr.	8–60	31
Cler. and sales	12–68	50
Crafts and opers.	0–29	8
Lab. and service	0–23	11

[a] From transportation study data for various cities.

TABLE 23

DISTRIBUTION OF TRAVEL MODE TO SHOP BY SEX OF TRIPMAKER[a]

SEX OF TRIPMAKER	USE OF MODE (%) AUTO DRIVER	AUTO PASS.	TRANSIT PASS.	AVG.
Male	24–50	10–21	0–38	23–36
Female	50–76	79–90	62–100	64–77

[a] From transportation study data for various cities.

Where car ownership could be identified as a household characteristic (for the 8 centers in Pittsburgh and Buffalo), it was found that the highest proportion of male shopping trips came from one-car households. The ratio between the sexes for all shopping trips was 38:62 for one-car households; 29:71 for two-car households; and 15:85 for households without cars. Considering drivers only, males from one-car households outnumbered female drivers to shop by 59:41, no doubt acting more as chauffeurs than shoppers. The lowest male trip percentages occurred in Atlanta and Minneapolis, where the peak shopping hours occurred in the afternoon rather than in the evening.

Average car occupancy rates for all shopping centers varied from 1.42 (at the biggest center in Atlanta) to 2.18 (at the only regional center in Denver). The average for 8 shopping centers with 1958 or earlier data was 2.00 persons per car, with a range of from 1.79 to 2.10; for 14 centers with 1961 or later data the average was 1.89, with a range of from 1.42 to 2.7 persons per car.

Combining the evidence on tripmaking by sex and household car ownership, it may be reasonable to expect that as the number of multi-car households increases, the proportion of female driving trips will increase, and the car occupancy figures will decrease. Thus, with a given level of total person trips, auto driver trips will increase as time passes. Static trip generation rates for auto driver trips would, therefore, underestimate future tripmaking.

Home-based shopping trips may make up only one-third of all auto driver trips to a center. What is more, they never amount to more than two-thirds of the total auto tripmaking to centers—a significant consideration in developing predictive devices. However, all home-based shopping trips by automobile (that is, drivers and passengers) range from 61 to 86%, and average 72%.

Significant fluctuations occur in the proportions and numbers of nonhome-based shopping trips: 9% of all auto driver trips to as high as 30%. Those centers with the most nonhome-based shopping trips share the characteristic either of proximity to the CBD or of belonging to the lower hierarchy of major centers within their areas.

When summarized by trip purpose "from" (trips from work, from shop, etc.), as in Table 24, the primary source of nonhome-based shopping trips is seen to be other shopping—never less than 6% of all trips to shop and as high as 16% (in Seattle). Except for personal business, other trip purposes "from" show a scattering that accounts in total for perhaps 5 to 10% of shopping trips.

The separation of shopping trips into those for convenience goods and those for shopping goods was occasionally difficult, even though most studies used a two-digit land use coding system. One study permitted "shopping center" as a specialized land use code, making it impossible to separate some trips into convenience goods and shopping goods categories. Some studies appeared to have simplified coding by showing excessive numbers of trips to department stores. In contrast, the one study that additionally used different trip purpose codes for shopping goods and convenience goods trips showed less than 10% of the trips to three major centers coded to the shopping goods trip purpose—seemingly low. In spite of the problems, stratifications were eventually made at all centers for several analytic purposes. Possible inconsistencies should be kept in mind, nevertheless, throughout later discussions.

OTHER TRIPS

Other trips to the centers are mostly to work, already shown to range from 7 to 19%, with the miscellaneous purposes "social-recreation," "personal business," "serve passenger," "school," and "eat meal," accounting for between 5 and 30%. Personal business is perhaps the most stable of these elements, all centers sharing to a

TABLE 24

DISTRIBUTION OF HOME INTERVIEW AUTO DRIVER SHOPPING TRIPS, BY ORIGIN[a]

ORIGIN OF TRIP	SHOPPING TRIPS (%) RANGE	AVG.
Home	55–85	69
Work	0–8	4
Shop	6–17	11
School	0–0.5	0.3
Soc.-recr.	3–5	4
Eat meal	0–4	2
Pers. business	1–9	6
Med.-dental	0–6	1
Serve pass.	0–7	3

[a] From transportation study data for various cities.

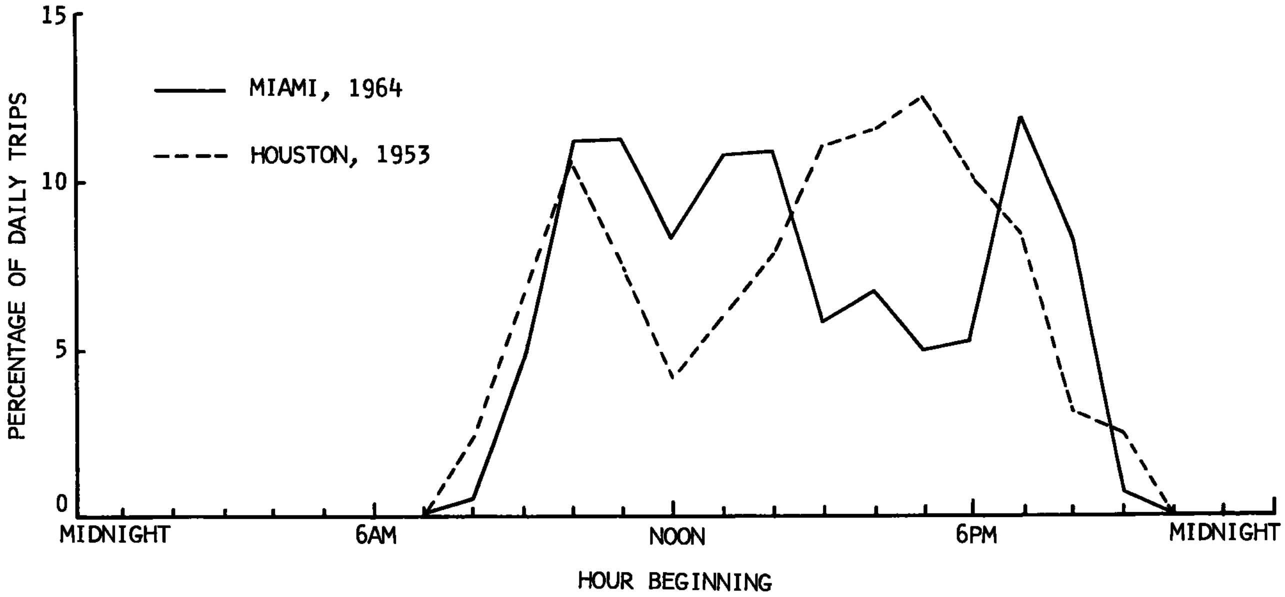

Figure 26. Auto driver trips to shop, by hour.

degree in banking, insurance, and other services such as barbershops and beauty parlors. Much of the difference between centers is accounted for by social-recreation travel. Considering "serve passenger" trips as shopping trips reduces the range; the total nonshopping travel to shopping centers, including work trips but excluding "serve passenger," ranges from 14% (R) to 33% (C and T).

TRAVEL PATTERNS BY HOUR

Patterns of shopping travel by time of day are changing. Figure 26 compares part of an illustration in "Shopping Habits and Travel Patterns" (*35*) showing the 1953 hourly patterns to selected centers in Houston with the 1964 hourly patterns to selected centers in Miami. Other things being equal, and assuming comparability of time reporting, the significant change appears to be an intensification of evening shopping.

The evening pattern in Miami is reasonably representative of the patterns in Seattle, Buffalo, Minneapolis, and Denver. Atlanta and Pittsburgh, however, are different. Atlanta data show steady shopping during seven midday hours (10% of the day per hour), with a decline after 4 PM. Pittsburgh data show, aside from a small peak at noon, that no hour accounts for more than 5% of the daily volume until after 4 PM, when between 7 and 8 PM shopping peaks at 25% of the daily volume.

Preceding comparisons have been based on average weekday traffic. The upper half of Figure 27 shows shopping trip arrival patterns for Center U on days with and without evening shopping. With evening shopping, besides the expected evening differences, there are differences in the morning peaks, probably resulting from later store openings. But, significantly, the combined 2-hr volume between 4 and 6 PM is 15.5% of daily shopping trips with daytime openings, and 15.8% with evening openings—virtually the same.

Patterns of arrival for home-based and nonhome-based trips show that the nonhome-based trips peak during the early afternoon with few trips in the evening (Fig. 27), whereas the home-based trips peak in the evening with fewer trips in the afternoon. There are fewer nonhome-based trips than home-based trips for each hour throughout the day.

Typical time patterns of total auto driver trips, illustrated by Miami data, reveal that they are fundamentally the same as for shopping trips alone; from 10 AM to 3 PM there is a fairly consistent level of activity, tapering off until after 6 PM, when another, and most frequently the highest, peak hour occurs (Fig. 28). Typically, the hours of peak highway travel are hours of subdued activity at shopping centers.

Peak-hour percentages for total auto driver trips vary among centers (Table 25). The composite average peak hour is 15.8%, but individual centers range from 11.0 to 26.4%. In all cases, the data shown are for average weekday travel; neither Saturdays nor the peak shopping season of the year (Thanksgiving to Christmas) are included.

It is difficult to choose one specific peak-hour percentage for shopping center design purposes. Trips to Centers P and W, with evening shopping, show 14.5% and 13.5% for shopping trips (considering all traffic, percentages would be lower). The centers with highest daily volumes averaged 13.9%; those with lowest daily volumes averaged 17.9%. One thing is clear—an evening peak hour is almost always a higher percentage than a daytime peak hour.

Whether or not there is evening shopping, the percentage of all shopping center trips occurring during the

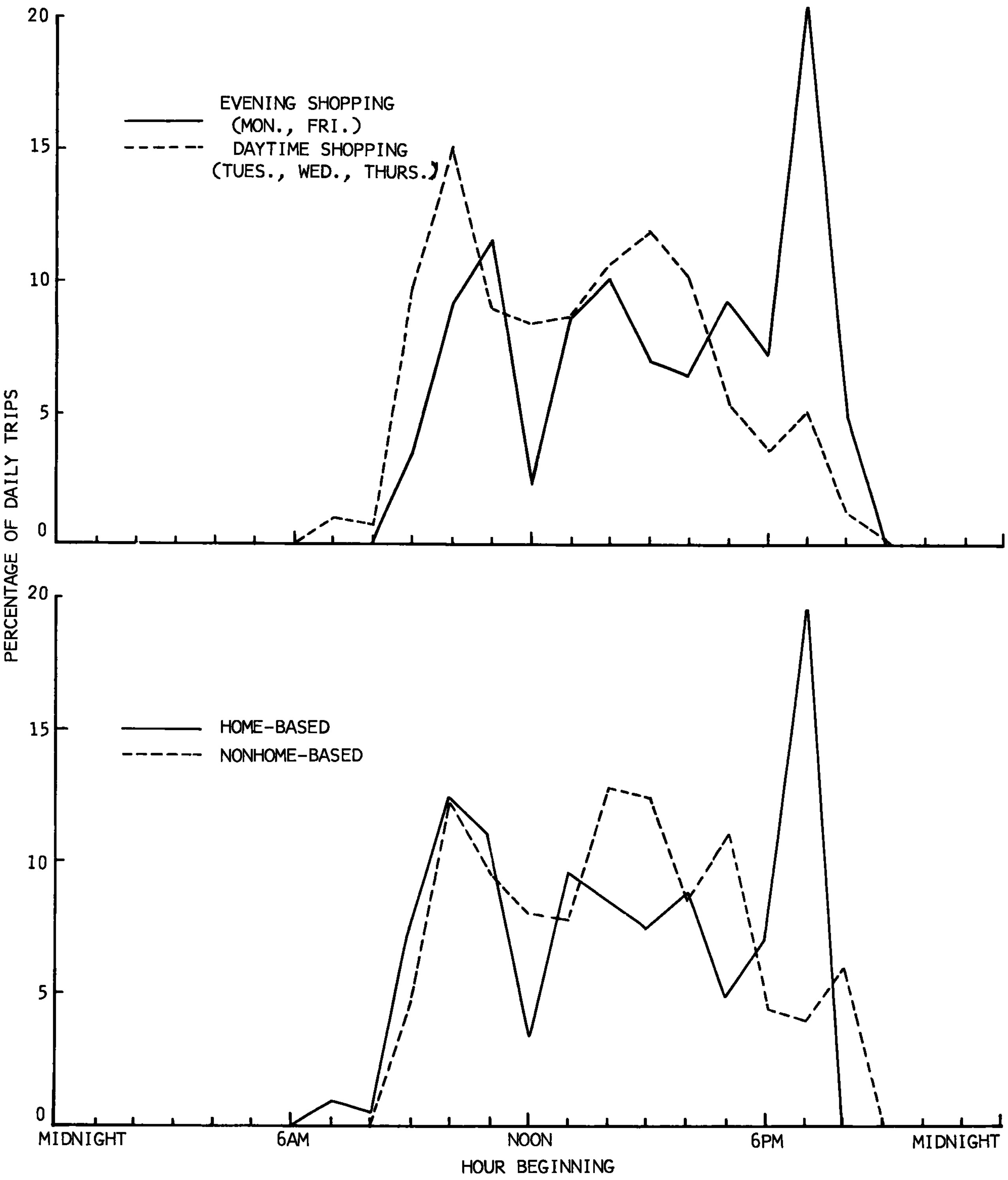

Figure 27. Auto driver trips to Denver center to shop, home-based and nonhome-based, daytime and evening shopping, by arrival hour.

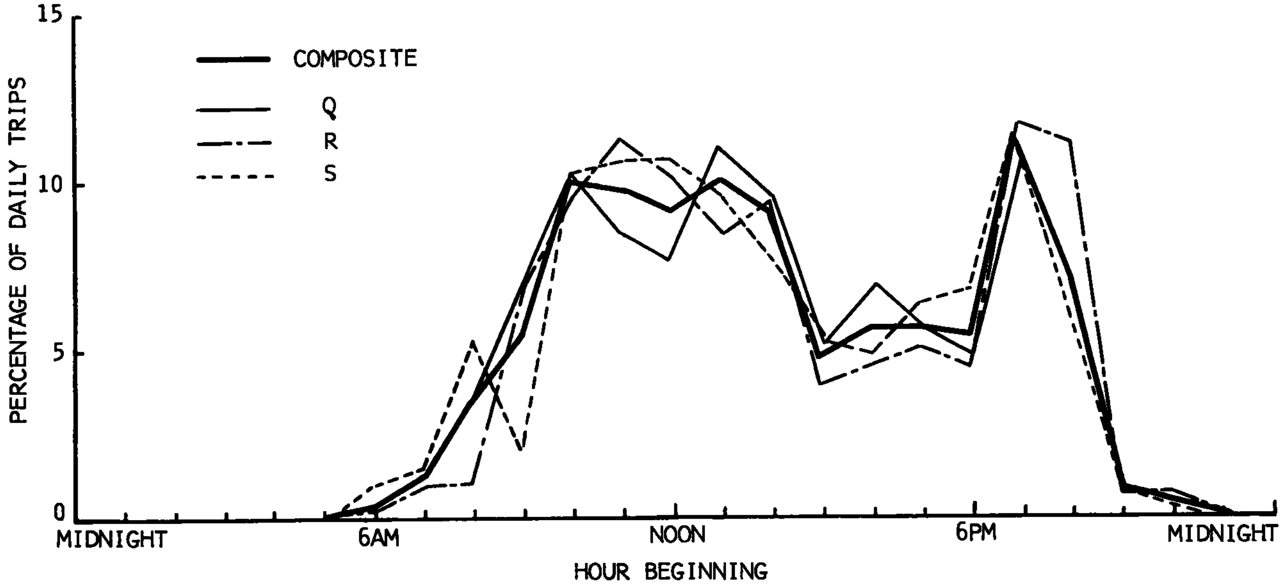

Figure 28. All auto driver trips to three Miami centers, by arrival hour.

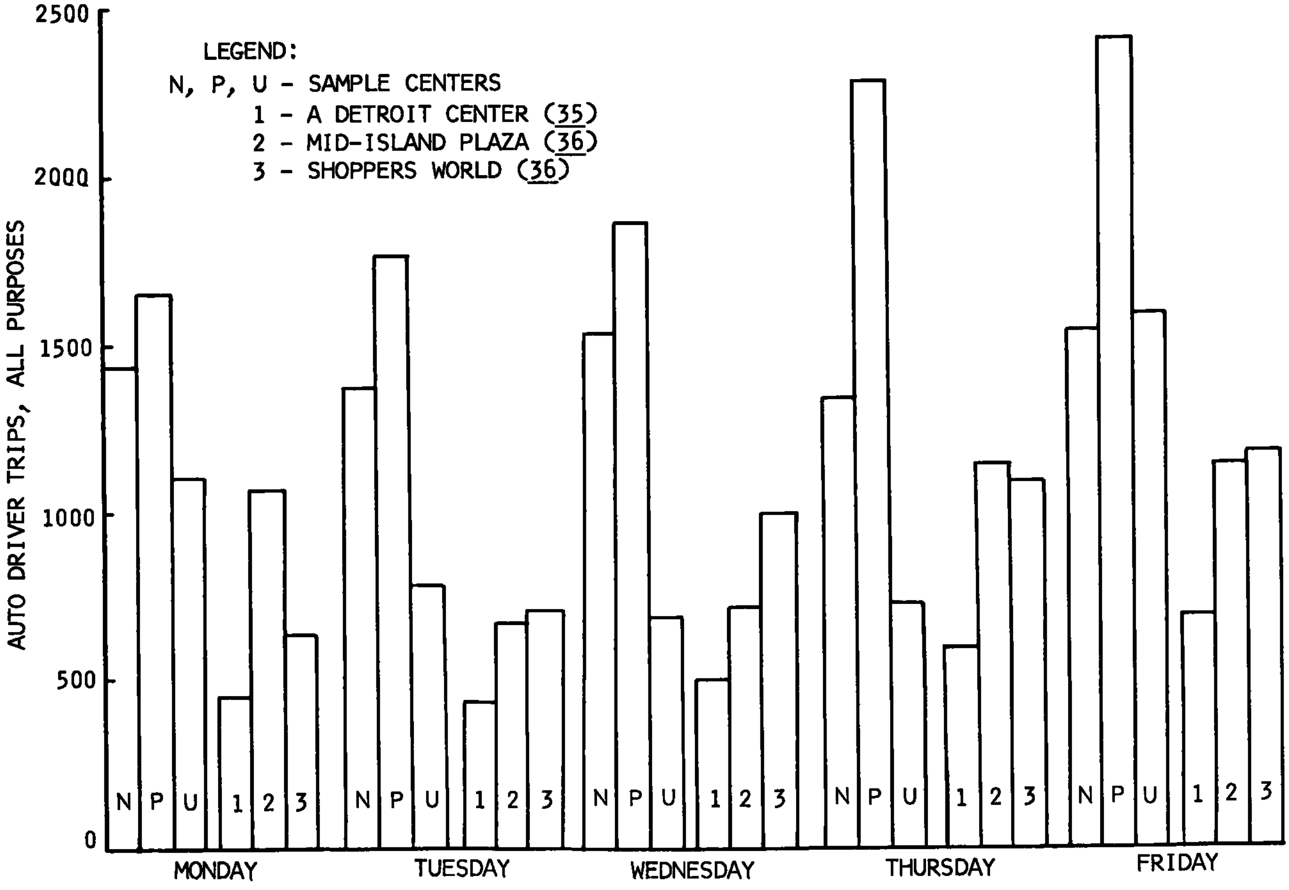

Figure 29. Auto driver trips to selected shopping centers, by day of week.

TABLE 25

SHOPPING CENTER ENTERING PEAK HOURS AND PROPORTIONS OF DAILY VOLUMES[a]

PEAK HOUR	NO. OF CENTERS	% OF DAILY VOLUME	
		RANGE	MEAN
10–11 AM	1	—	11.3
12–1 PM	2	11.0–12.0	11.5
1–2 PM	4	11.2–12.7	12.2
2–3 PM	2	12.0–15.0	13.5
3–4 PM	1	—	16.9
6–7 PM	1	—	12.2
7–8 PM	12	11.3–26.4	17.3

[a] From transportation study data for various cities.

normal peak highway hours from 4 to 6 PM is remarkably constant. For all centers, the average hourly volume during this period was 6.6% of the daily total. The low (Center G) was 4.6%, the high (Center L) was 11.5%. Fourteen centers were within 1% of the average (see Table B-1).

Travel patterns by day of week vary between shopping centers because of variability in evening openings. Figure 29 shows the distribution of daily volumes to three centers based on home interview survey data. Centers N and U, open on Monday and Friday nights, show highest volumes then, and lowest volumes on Tuesday and Thursday. Center P shows daily volume increasing through the week, although the center was apparently not open on Tuesday and Wednesday nights.

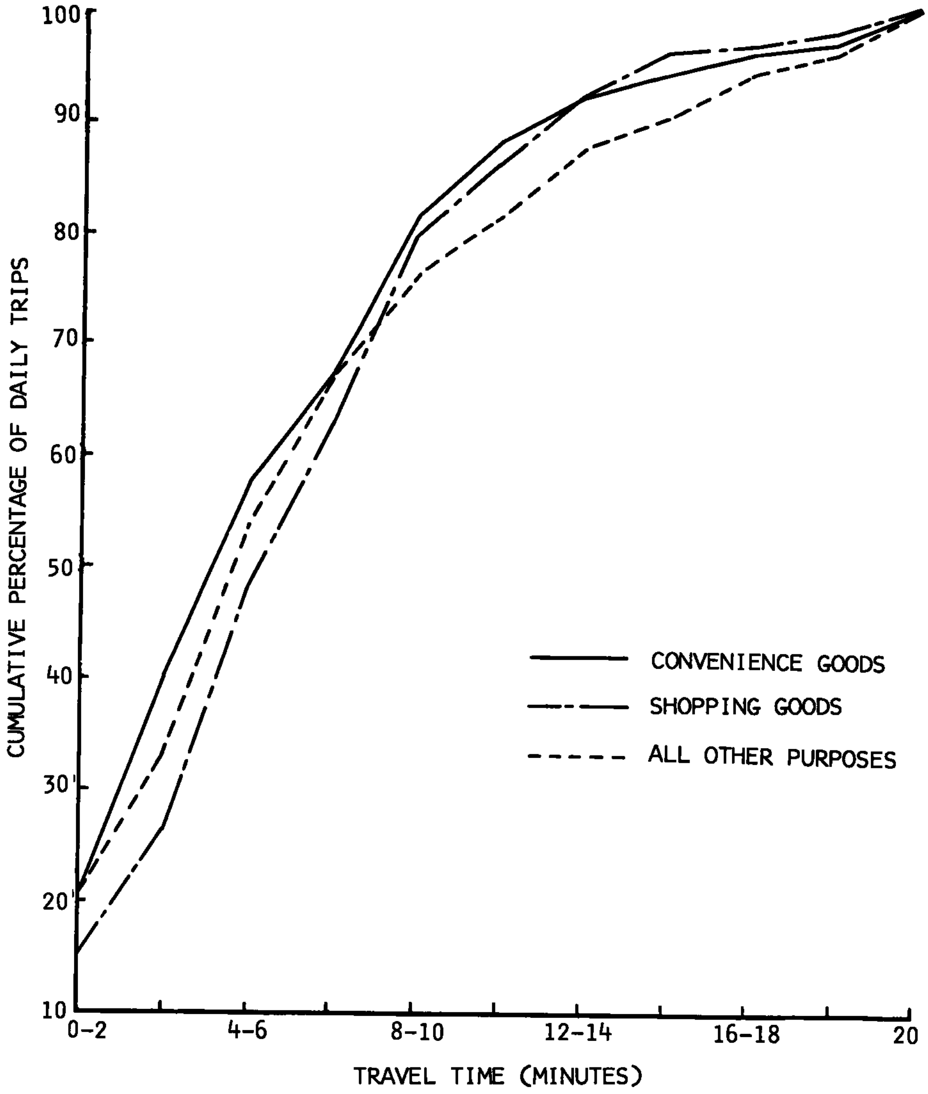

Figure 30. Auto driver trips to Buffalo centers for shopping goods, convenience goods, and all other purposes, cumulative distribution by travel time.

Shown for comparison, but at different scale, are 1953 data for a Detroit center (total cars parked during the day) presented in "Shopping Habits and Travel Patterns" (*35*) and data for Mid-Island Plaza (1959) and Shoppers World (1953) centers, presented by Cleveland and Mueller (*36*). The Detroit center shows a pattern similar to P. Mid-Island Plaza shows clearly the effect of Monday, Thursday, and Friday night openings on daily volume. In every case, Friday volumes are the highest of the week. This was also demonstrated by the results of a survey for the *Denver Post* (*37*), which reported that 45% of Denver shoppers preferred Friday evening for shopping.

AUTO DRIVER TRAVEL TIMES AND TRIP LENGTHS

Table D-3 gives travel time, distance, and speed characteristics of auto driver trips to shop at all centers. Reported elapsed time is averaged for all shopping trips from actual trip reports. Calculated average road travel time is obtained from travel time tree data. Calculated average terminal time is the difference between the two. Reported average airline speeds (obtained by dividing the average airline distance by the reported average elapsed time) vary from 10.0 mph to 17.4 mph, with typical averages of 12 to 13 mph.

Trips for shopping goods are longer, on the average, than trips for convenience goods as given by Table 26, in which shopping goods trips include only those to department and apparel stores, and all other shopping trips are grouped under convenience goods. With the exception of Minneapolis, the shopping goods trip lengths vary only slightly between seven metropolitan areas. Convenience goods trips show more variation, partly because of more varied destination land uses, but are always shorter than shopping goods trips, the average difference being one-half mile.

The cumulative distribution by travel time of shopping goods, convenience goods, and "other" auto driver trips to four Buffalo centers is shown in Figure 30. As expected, convenience goods trips accumulate most rapidly. Beyond the 6-to-8-min time band, the parallel shopping goods and convenience goods curves show the difficulty of stratifying by destination land uses. "Other" trips, which include those to work, have the highest proportion of long trips.

Although for all shopping centers, generally, arrival patterns were dissimilar, the trip length distributions of home-based and nonhome-based trips were not. A comparison for two Minneapolis centers (Fig. 31) by mile increment and as cumulative curves illustrates that trip lengths are similar. However, Table 27 shows that there was greater variation in other metropolitan areas.

OTHER TRIPMAKING CONSIDERATIONS

Many trips to shopping centers are multi-purpose. Shopping centers facilitate such trips, because trips may combine shopping (both for shopping goods and convenience goods) and personal business. The analyst using home interview survey data must assume, where such trips occur, that the reported trip purpose was the primary one. Nevertheless, inconsistencies of trip reporting undoubtedly exist.

TABLE 26

AVERAGE LENGTHS OF AUTO DRIVER TRIPS FOR SHOPPING GOODS AND CONVENIENCE GOODS[a]

	AVG. TRIP LENGTH (MI)	
AREA	SHOPPING GOODS	CONVENIENCE GOODS
Atlanta	2.87	2.38
Buffalo	3.14	2.66
Denver	2.88	2.66
Miami	3.20	3.04
Minneapolis	4.29	3.39
Pittsburgh	2.77	2.62
Providence	2.61	1.88
Seattle	3.10	2.16
All	3.11	2.60

[a] From transportation study data for various cities.

TABLE 27

DISTRIBUTION CHARACTERISTICS OF AUTO DRIVER SHOPPING TRIP LENGTH FOR SELECTED CITIES[a]

	TRIP LENGTH DISTRIBUTION (%)			
	HOME-BASED		NONHOME-BASED	
AREA	UNDER 3 MI	UNDER 5 MI	UNDER 3 MI	UNDER 5 MI
Atlanta	70	95	57	75
Buffalo	63	87	55	77
Denver	53	81	65	91
Miami	58	83	64	77
Minneapolis	53	74	54	71

[a] From transportation study data for various cities.

Another problem is a possible need for seasonal adjustment; presumably, home interview survey data represent average annual weekday travel. Shopping may be more seasonal than other travel, and shopping trip comparisons among cities may be obscured because different studies collected data at different seasons. However, checks indicated that no seasonal adjustments were necessary for subsequent trip generation analyses.

SOME INTERRELATIONSHIPS

Trip Rates Related to the Center

TOTAL VEHICLE TRIPS

Examination of trip generation rates is based principally on vehicle trips rather than person trips. Because transit tripmaking is negligible, there is no major question about "modal split." In these first few paragraphs, truck trips are included with automobile trips rather than treated separately. Subsequent discussion concentrates on auto trips alone.

Trips per acre, for 23 centers, ranged between 30 and 392, with a mean of 160. Harding's (*38*) finding for five California centers drawing from 9,000 to 19,000 vehicles per day showed from 280 to 480 trips per acre, with a mean of 339. Only six centers (in the present study) exceed the minimum California trip rate. Thus, acreage alone can be a deceptive basis for trip generation at specific centers.

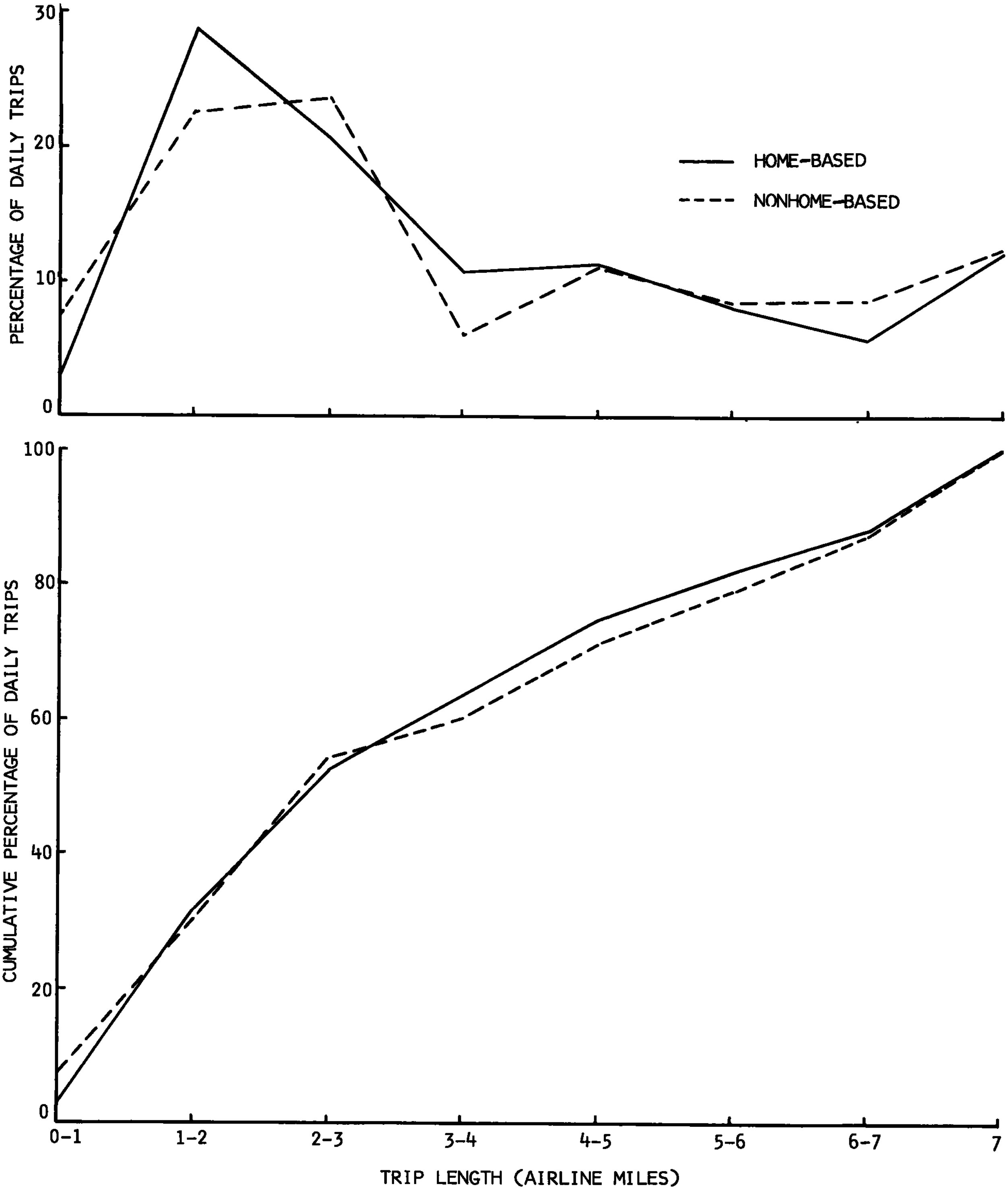

Figure 31. Home-based and nonhome-based auto driver shopping trips, frequency and cumulative distributions by distance, Centers O and P.

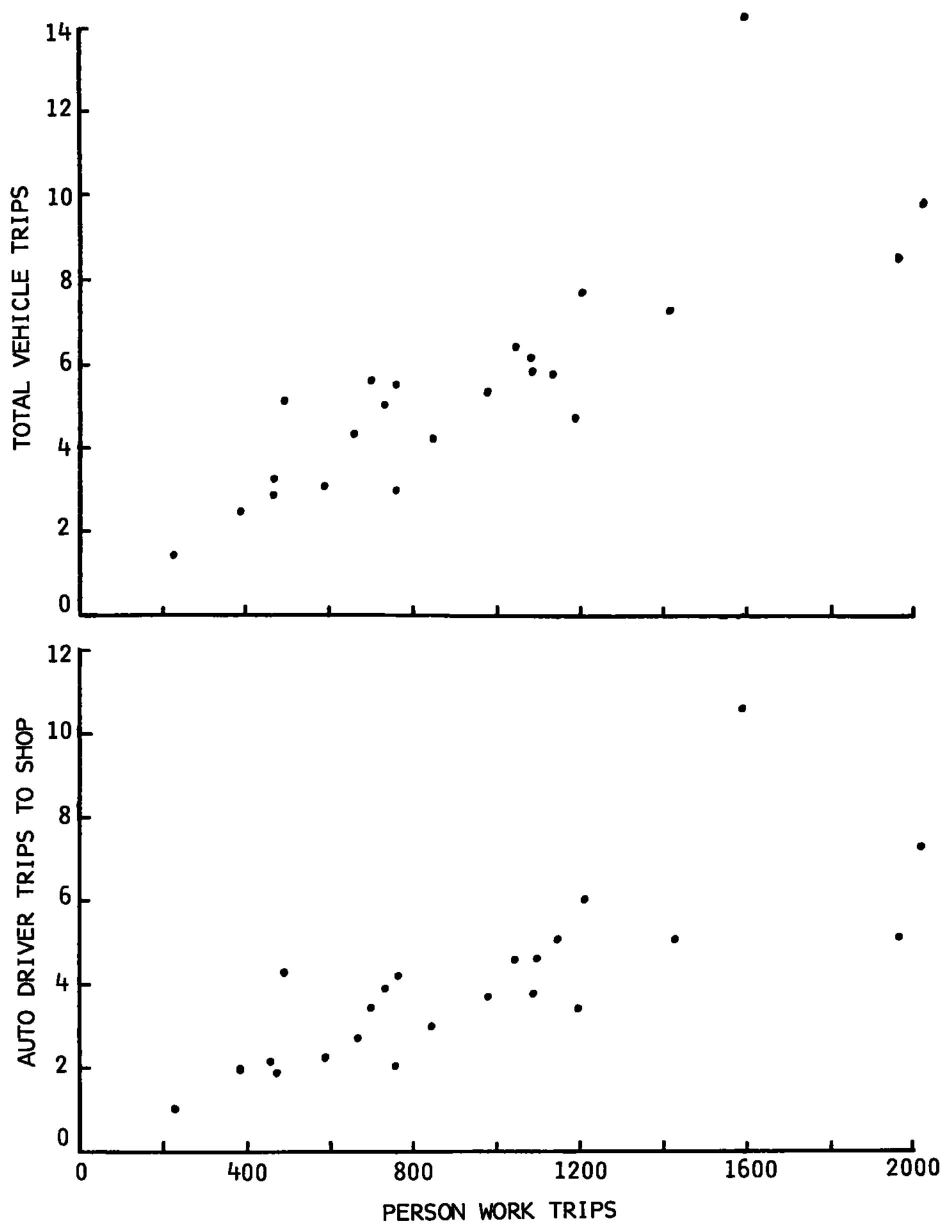

Figure 32. Total vehicle trips, and auto driver trips to shop, per person work trips.

Relating trips to number of establishments resulted in a mean of 122 trips per establishment, with a range from 41 (at A) to 216 (at U, one of the highest in average floor area per establishment). Used alone, this variable also seems a shaky basis for trip generation at specific centers.

There was an average of 16.08 trips per 1,000 sq ft of floor space, and a range from 6.26 to 27.42 (at L and Q, respectively). A study by LARTS (*39*) showed comparable data ranging from 9 to 46 trips. Plotting the various trip rates against floor space showed considerable scatter and no evident change in the rates with center size.

The final test with total vehicle trips related them to person work trips at each center. Figure 32 shows the results, a better correlation being evident here than in preceding tests with physical characteristics of the center. However, predicting total vehicle trips to specific shopping centers from only one independent variable could lead to conclusions of doubtful accuracy (see Appendix C for linear regression equations for Figs. 32 and 33.)

AUTO DRIVER TRIPS TO SHOP

Trip rates per 1,000 sq ft of total floor area varied from 4.4 to 20.7, with a mean of 10.7 trips per 1,000 sq ft, the lowest being Center L, the highest Center Q. Thirteen centers averaged between 9.0 and 13.9, and 18 ranged between 7.0 and 15.9 trips per 1,000 sq ft.

Trip rates per establishment were slightly more con-

sistent. The mean rate was 82.7 trips per establishment, with a spread from 45.7 (at L) to 142.2 (at U), and only 9 centers showed rates from 70 to 100 trips. Shopping trips were also related to person work trips, and averaged 4.4, with a spread from 2.6 to 8.8 trips per work trip. Also plotted in Figure 32, the relationship is similar to that found for total vehicle trips.

TRIPS BY FLOOR SPACE USES

Separation of floor space into three categories of "convenience goods," "shopping goods," and "other" uses was possible at most centers. To make land use classes comparable with trip data, "convenience goods" includes foodstores, drugstores, and gas stations only. All other shopping trips are classified as "shopping goods." This is a different classification from that used earlier in determining trip lengths. Auto driver trips were related to both floor space and number of establishments for each category. Figure 33 shows the wide scatters resulting with floor space, although a reasonably good relationship is seen for shopping goods trips. The scatters were more pronounced when trips were plotted against the three types of establishments.

Explanations for some of the variations can be found. For instance, Center P is low on convenience goods trips and high on shopping goods trips because of trip coding problems. Centers A and L, lowest in shopping goods trips, have two other common characteristics—they are lowest in total trips, and each lacks a major department store. Shown last in Figure 33 are "other" trips, excluding work trips. "Other" trip destinations include bowling alleys, banks, insurance and finance offices, other offices, restaurants, theaters, vacant stores, and so on. One center even contains a hospital and medical center. The group also includes "serve passenger" trips for several centers in the illustration, although these trips were excluded in the regression analysis. "Other" trips show the greatest scatter and the least relationship to floor space. Because they account for an average of 17% of daily volume, "other" trips are a major source of scatter in relating total vehicle trips to floor area figures.

AUTO DRIVER WORK TRIPS

Auto driver trips to work are highly significant because both truck trips and total vehicle trips have been related to person work trips more successfully than to any other single variable.

However, auto driver work trips relate poorly to floor space (upper half of Fig. 34). Varying trip generation rates within the array of different land uses are the probable cause. Obviously, banks and other offices generate work trips at higher rates than bowling alleys and theaters. The variability between centers in evening openings is possibly also an influence. Where possible, prediction of work trips from the number of employees is obviously better than the use of floor space indices.

Trip Rates Related to Market Area

OVER-ALL AREA RATES

Trip prediction based on market area characteristics is an alternative to trip prediction based on shopping center characteristics. An exploratory look was taken by plotting auto driver trips per 1,000 population against shopping center size (lower part of Figure 34). The range of values suggests some interrelationship, but small success in accurate trip prediction by such a broad approach.

TRIP RATES BY DISTANCE FROM CENTERS

Trip rates decrease with increasing distance from the center. The trip length distributions in Figure 30 showed that about one-half of all shopping trips were under 3 miles and about three-fourths were under 5 miles long. Analysis of trip rates based on population demonstrates this decline within the market area. In addition, the pilot study had shown that trip rates vary by market area segments. Consequently, "inside" and "outside" zones were designated. This designation of a zone is based on whether its travel time from the CBD is less than or more than the travel time from the CBD to the shopping center.

Figure 35 shows the trip rate decline with increasing distance, and the difference between inside and outside trip rates for selected cities. Table 28 gives comparable data for other metropolitan areas. Trip rates are based, except for Denver, on a composite of two or more centers to reduce the effect of sampling variability.

Because there was shown to be a ½-mile difference in average trip length for shopping goods and convenience goods trips, their trip rates must vary by mile increment. Figure 36 shows the difference in the patterns for trips to two centers in Minneapolis. Convenience goods trips exhibit very high trip rates within 3 miles of the center, and then drop steeply. Shopping goods trips, with lower rates throughout, show much less sensitivity to distance.

TRIP RATES BY TIME

Trip rates decrease with increasing travel time from the centers just as they did with increasing distance. Figure 37 shows the similar patterns of trip rate change for all shopping trips in Pittsburgh, Buffalo, and Chicago.

Trip rates again differ between inside and outside zones, and for shopping goods versus convenience goods. Figure 38 illustrates, with combined data from four Pittsburgh centers, that the inside-outside stratification affects shopping goods trips more than convenience goods trips. In Pittsburgh, where the major centers are so spaced that the central business district is the only major competition, both convenience goods curves exhibit the same pattern, but shopping goods trips are generated at a higher rate from the outside than from the inside zones. The similarity with the Miami convenience and shopping goods curves by distance (Fig. 36) is notable.

HOME-BASED SHOPPING TRIPS

The last examination of trip generation rates in the market area employed home-based shopping trips against a base

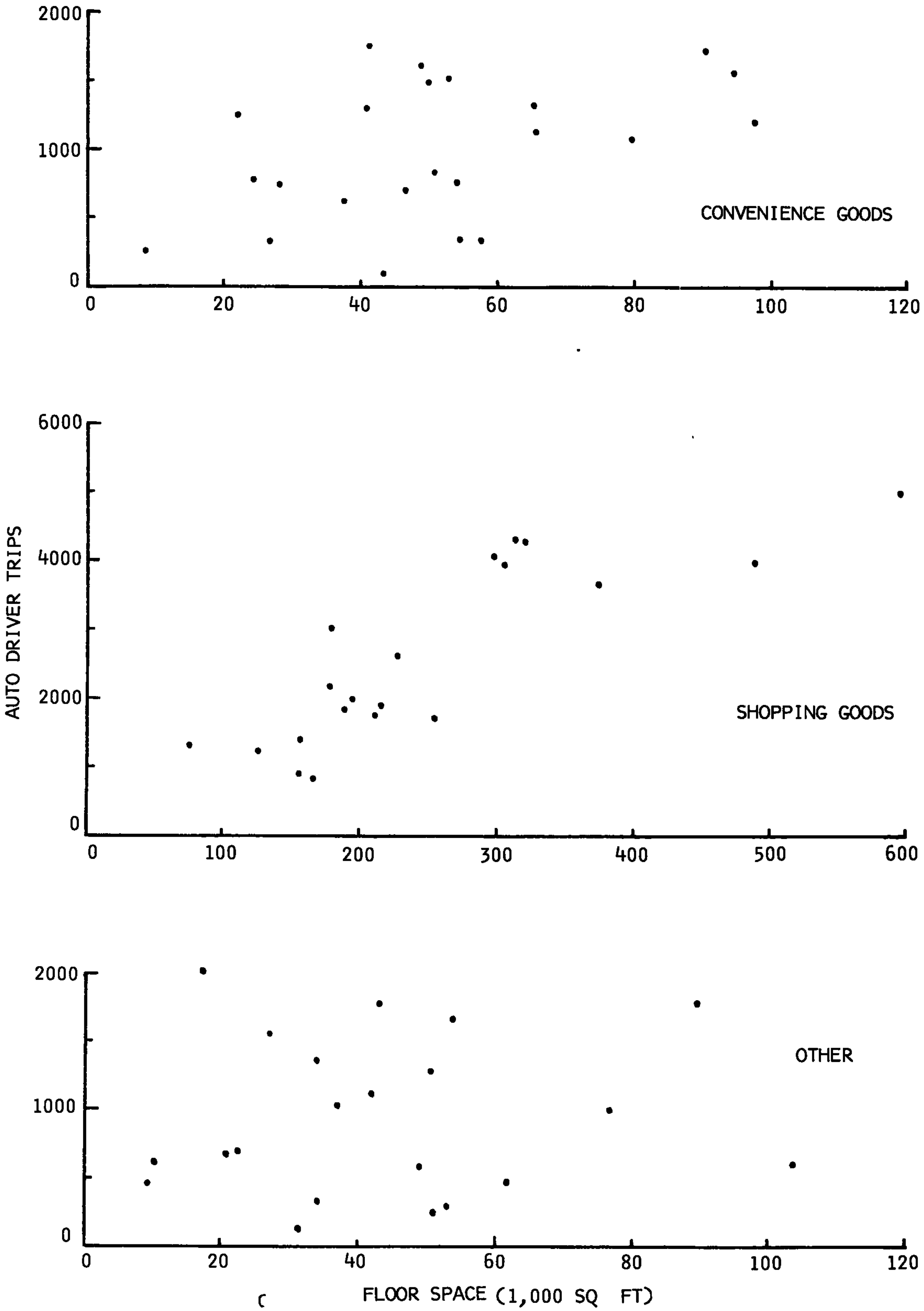

Figure 33. Auto driver trips for convenience goods, shopping goods, and all other trips per 1,000 sq ft of floor space.

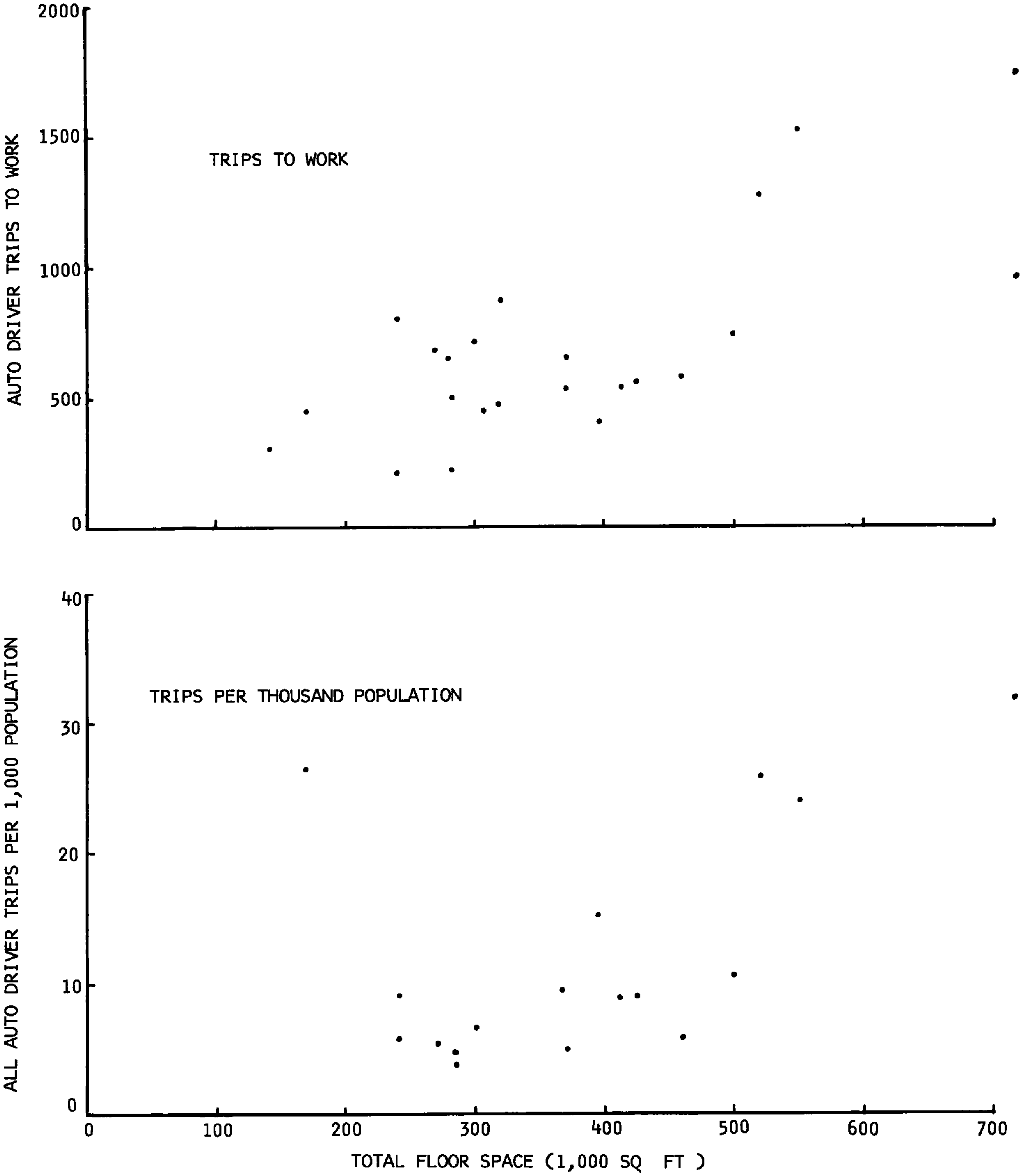

Figure 34. Auto driver trips to work, and all auto driver trips per 1,000 population, by total floor space.

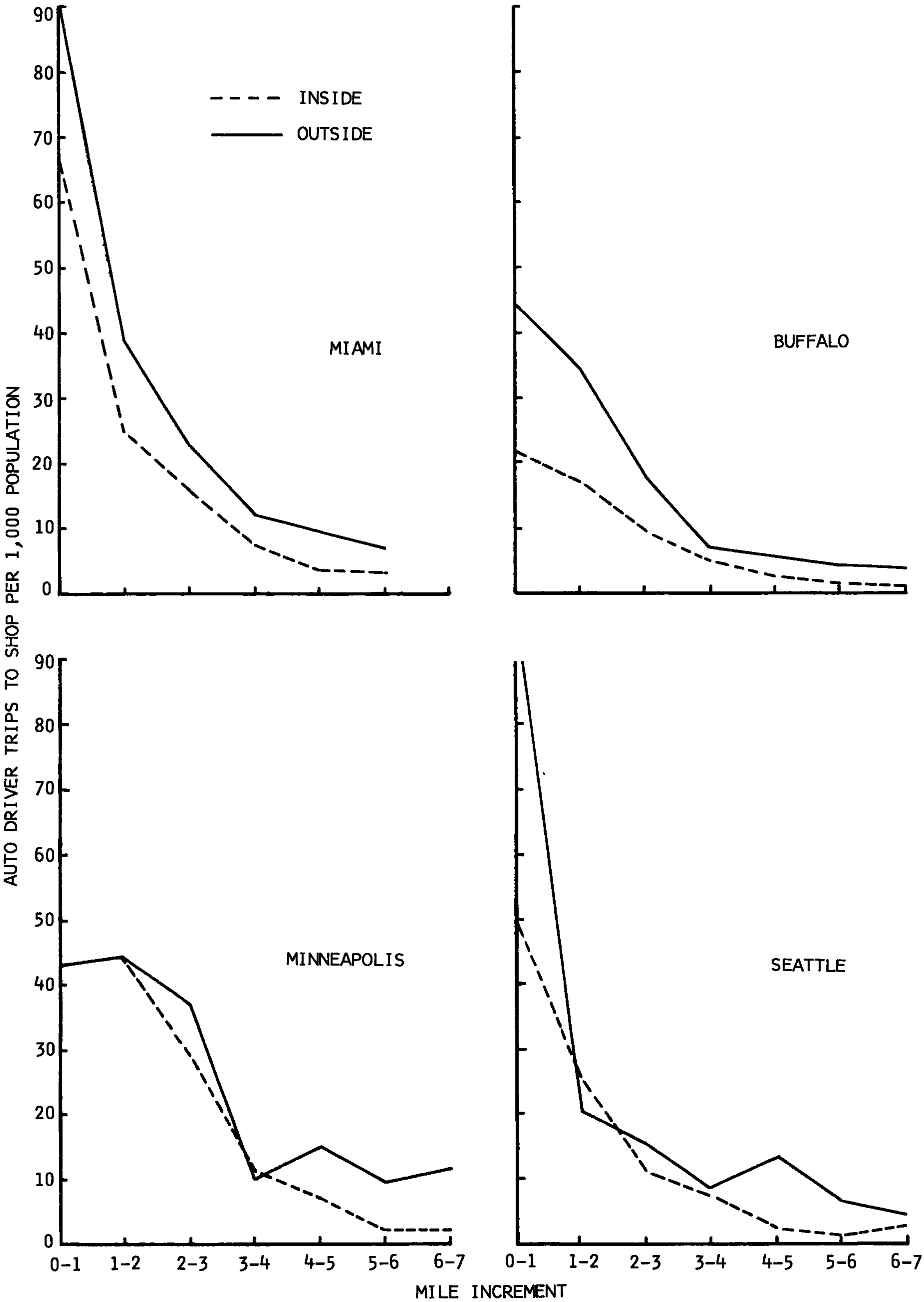

Figure 35. Auto driver shopping trip rates, inside and outside zones, by distance, selected cities.

TABLE 28

AUTO DRIVER SHOPPING TRIP RATE BY MILE INCREMENT[a]

MILE INCREMENT	SHOPPING TRIP RATE (NO./1,000 POP.)					
	ATLANTA		CHICAGO		DENVER	
	IN	OUT	IN	OUT	IN	OUT
0–1	107.5	25.7	80.5	—	—	45.7
1–2	28.8	37.3	16.0	27.5	9.8	10.6
2–3	18.1	13.8	7.0	6.2	12.8	10.5
3–4	7.9	9.6	3.6	3.3	2.6	6.8
4–5	3.1	10.1	1.2	4.2	0.9	2.7
5–6	1.6	5.1	1.2	1.9	0.6	3.4
6–7	1.9	1.7	0.5	2.5	1.2	3.4

[a] From transportation study data for Atlanta, Chicago, and Denver.

of autos owned by zone. Figure 39 shows that trip rates for four centers vary markedly (P being superimposed by travel time in approximation of distance). Even with market area differences in car ownership extracted, the effect of other variables weights against a simple model for trip generation and distribution using market area data.

Effect of Competing Retail Centers

EFFECT ON TRIP RATES

One of the variables affecting market area trip rates is the competition from other retail centers. For example, differentials in "inside" and "outside" trip rates can be

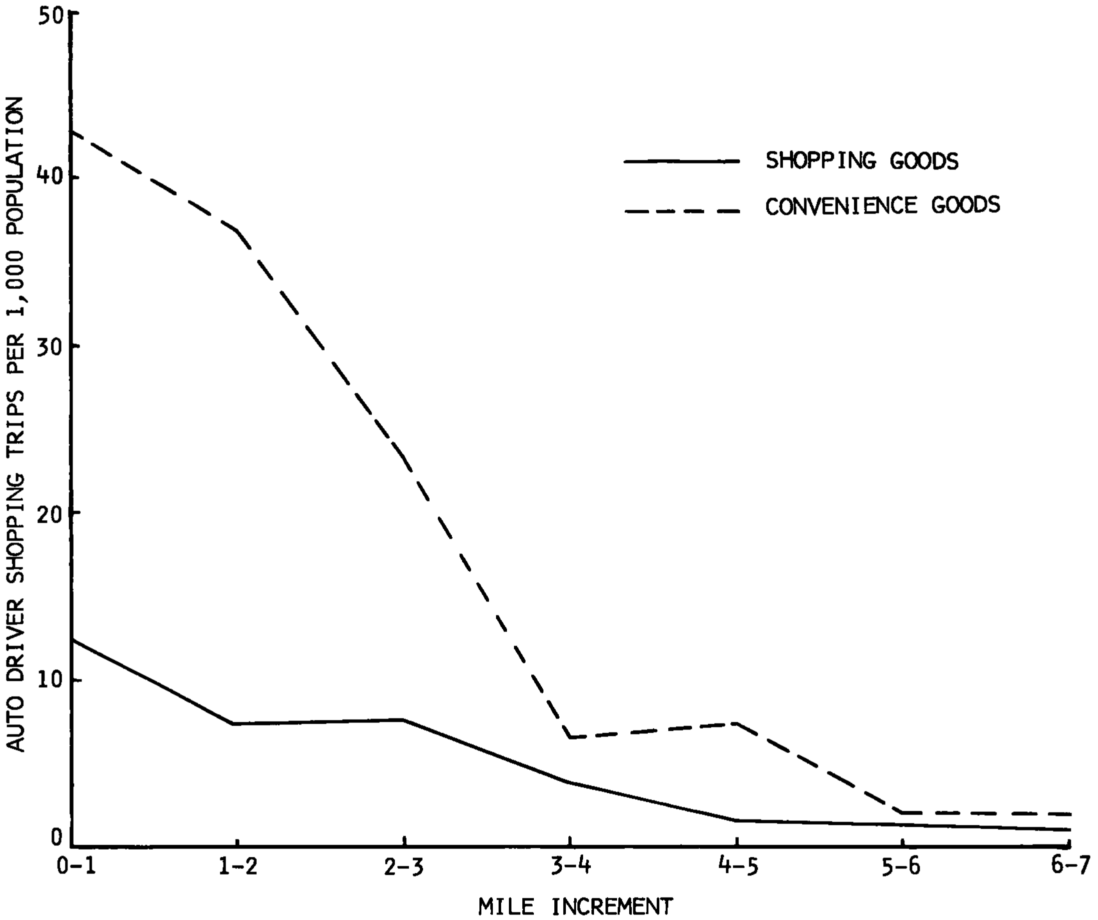

Figure 36. Auto driver shopping trip rates by goods type, by distance, Centers O and P.

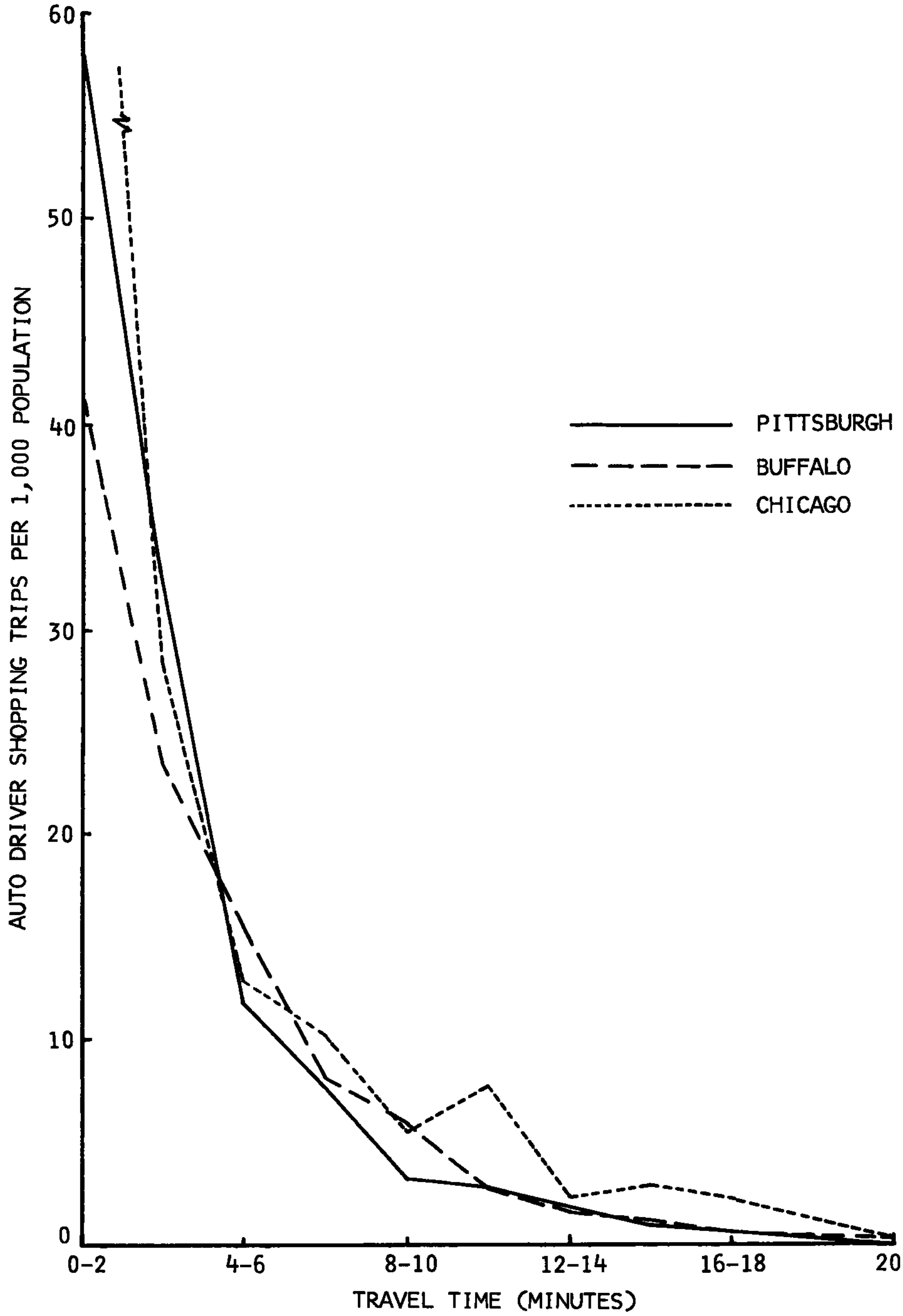

Figure 37. Auto driver shopping trip rates by travel time, selected cities.

related to the central business district. Figure 40 shows trip rates for all trips to shop from inside zones at four Buffalo area centers; within the first 3 miles of each center their ranking by trip rates is also the order of ranking by CBD distance. Center H rates are also reduced by the influence of Center E. Although less influenced by downtown, Center G rates fall off rapidly and exhibit a low point in the 4- to 5-mile increment, which includes or is close to both Centers E and H. The effect of competition clearly warrants consideration in trip generation analyses.

EFFECT ON TRAVEL PATTERNS

Earlier studies, such as "Shopping Habits and Travel Patterns" (*35*), demonstrated that suburban centers draw traffic from beyond an adjacent center only when a greater selection of goods is offered. Thus, the large center generally reaches beyond the smaller one in attracting trips. Figure 41 shows that the larger of two centers in Minneapolis attracts trips from the north and west areas beyond the smaller center, but the smaller center does not attract

from beyond the larger. On the other hand, Figure 42 shows two-way overlapping between Center E and other centers in Buffalo. Center F, for example, draws trips north of Center E, but Center E attracts some trips beyond each of the three outlying centers. Competition for trips in the intervening areas between adjacent centers is evident in both Figures 41 and 42. The area between Centers E, G, and H sends trips to all three, and undoubtedly to downtown too. In Figure 41 both centers attract trips from the area between them and the central business district.

Lack of customer attachment to only one retail center is also demonstrated in a *Chicago Tribune* customer survey

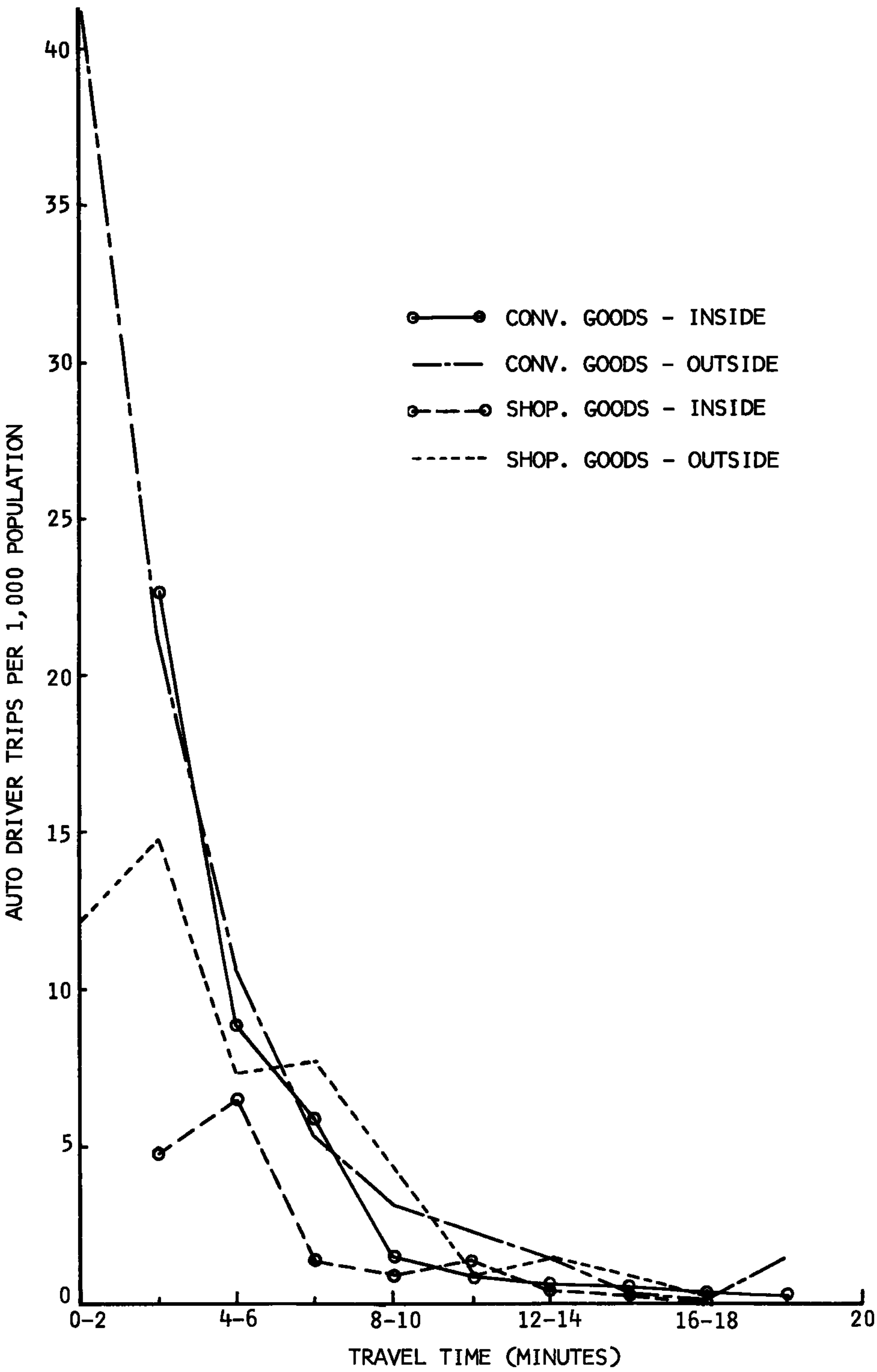

Figure 38. Auto driver shopping trip rates by goods type, inside and outside zones, Pittsburgh, by travel time.

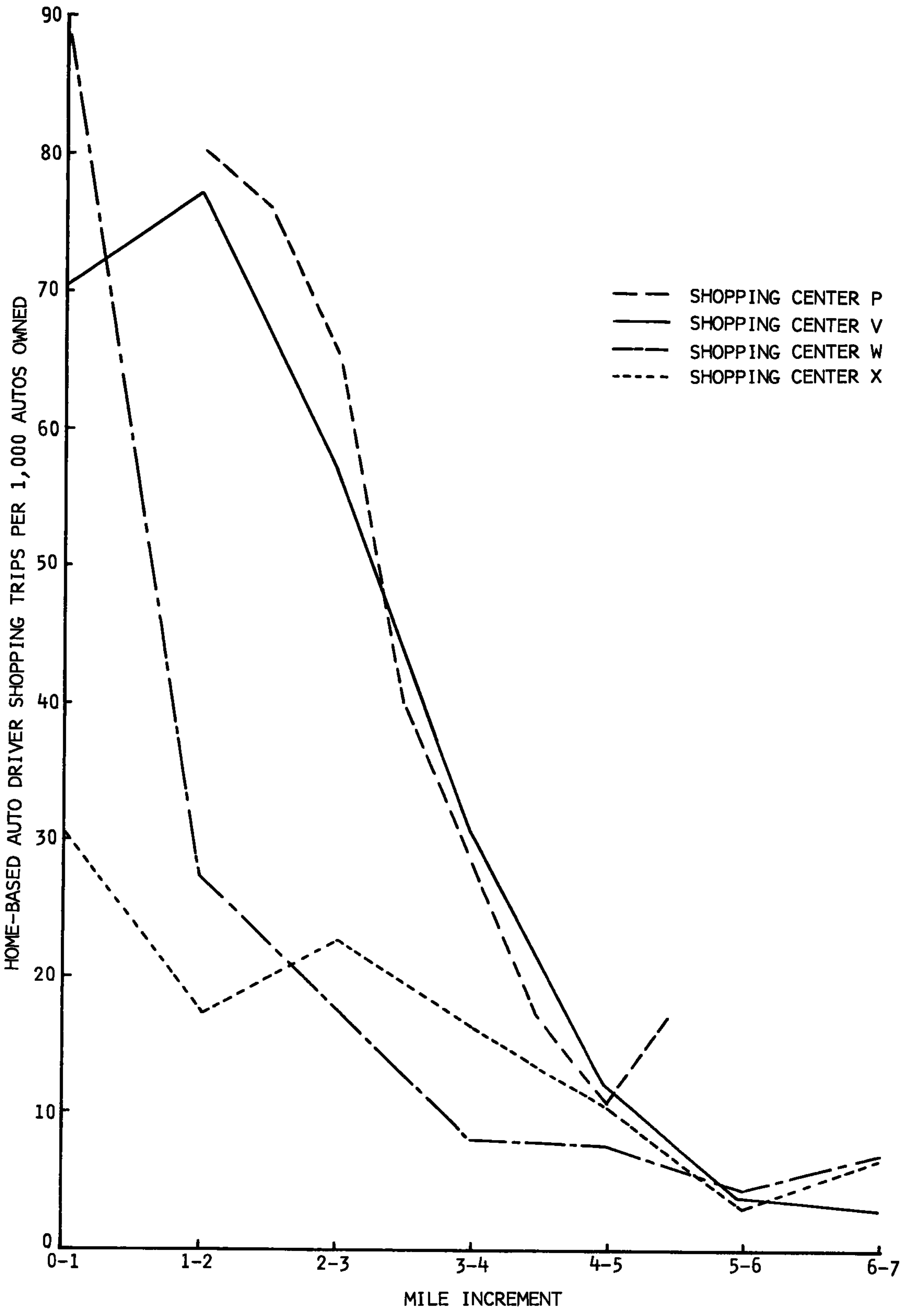

Figure 39. Home-based auto driver trips per 1,000 autos owned, by distance, selected cities.

(*34*), selected results of which are given in Table 29. Reading across, for example, shows that 72% of the families living within the primary trading zone of the Old Orchard Shopping Center make *some* shopping trips during the year to the Loop (probably in addition to shopping at Old Orchard). Only 76% make some trips to Old Orchard, none make trips to Evergreen Plaza, 61% make some trips to Golf Mill, etc. In several instances a higher percentage of families shop at centers outside, rather than inside, the primary trading zone in which they live; for example, 83% of the families living in the Edens Plaza primary trading zone shop at Old Orchard, and only 56% at Edens Plaza. Because the number of trips per year to each center is unknown, this does not necessarily mean

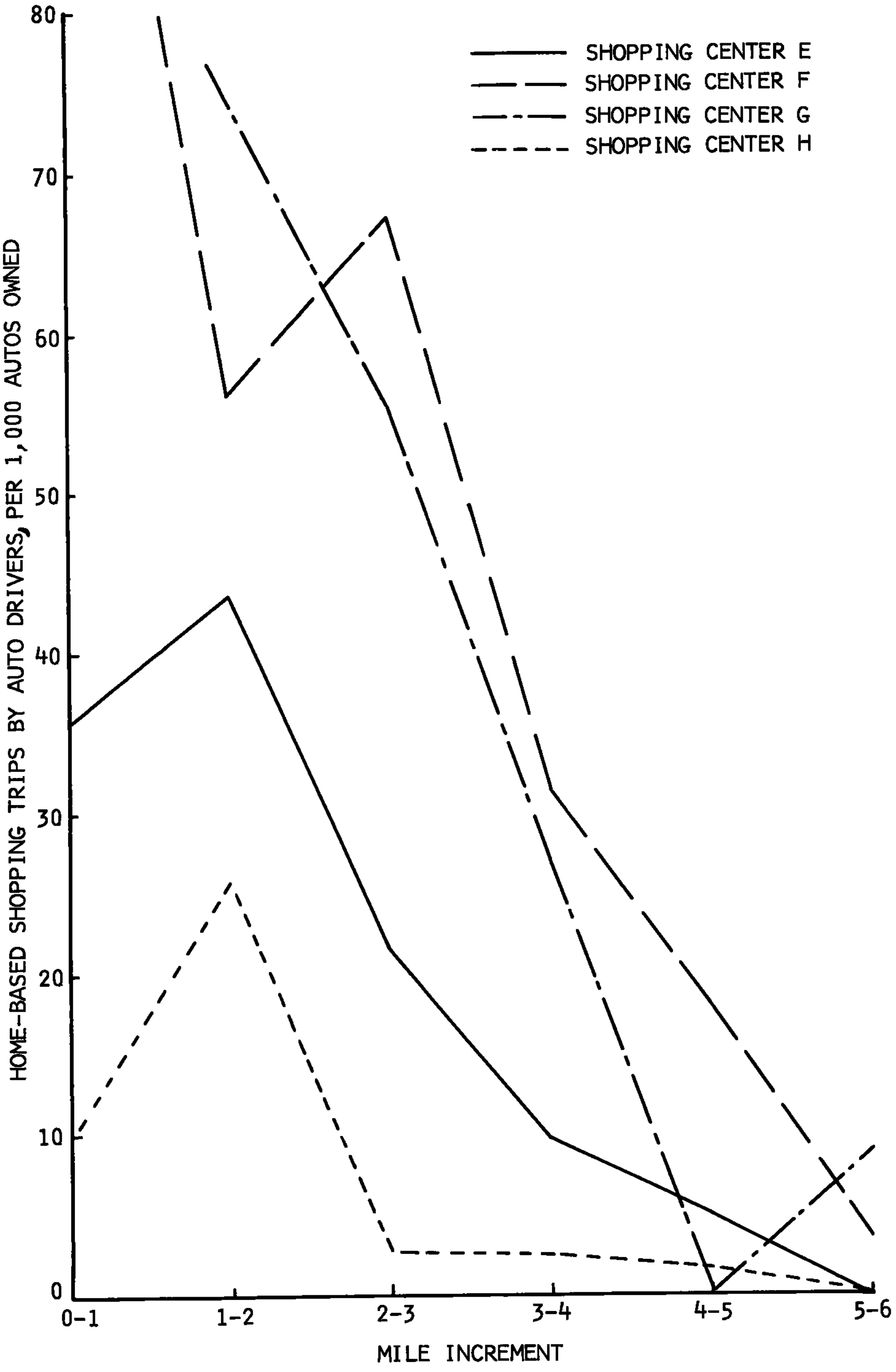

Figure 40. Auto driver shopping trip rates, inside zones, Buffalo, by distance.

TABLE 29

"CROSSPULL" BETWEEN MAJOR CHICAGO SHOPPING CENTERS[a]

"RESIDENT" PRIMARY TRADING AREA	% OF FAMILIES LIVING IN "RESIDENT" PRIMARY TRADING AREA MAKING SHOPPING TRIPS DURING THE YEAR TO						
	THE LOOP	OLD ORCHARD	EVERGREEN PLAZA	GOLF MILL	HARLEM-IRVING	OAK BROOK	EDENS PLAZA
Old Orchard	72	76	—	61	23	5	49
Evergreen Plaza	74	5	71	—	—	6	—
Golf Mill	71	82	—	68	33	—	50
Harlem-Irving	64	53	—	47	61	11	22
Oak Brook	52	13	—	—	13	67	—
Edens Plaza	68	83	—	65	—	6	56

[a] From "How Chicago Shops" (*35*).

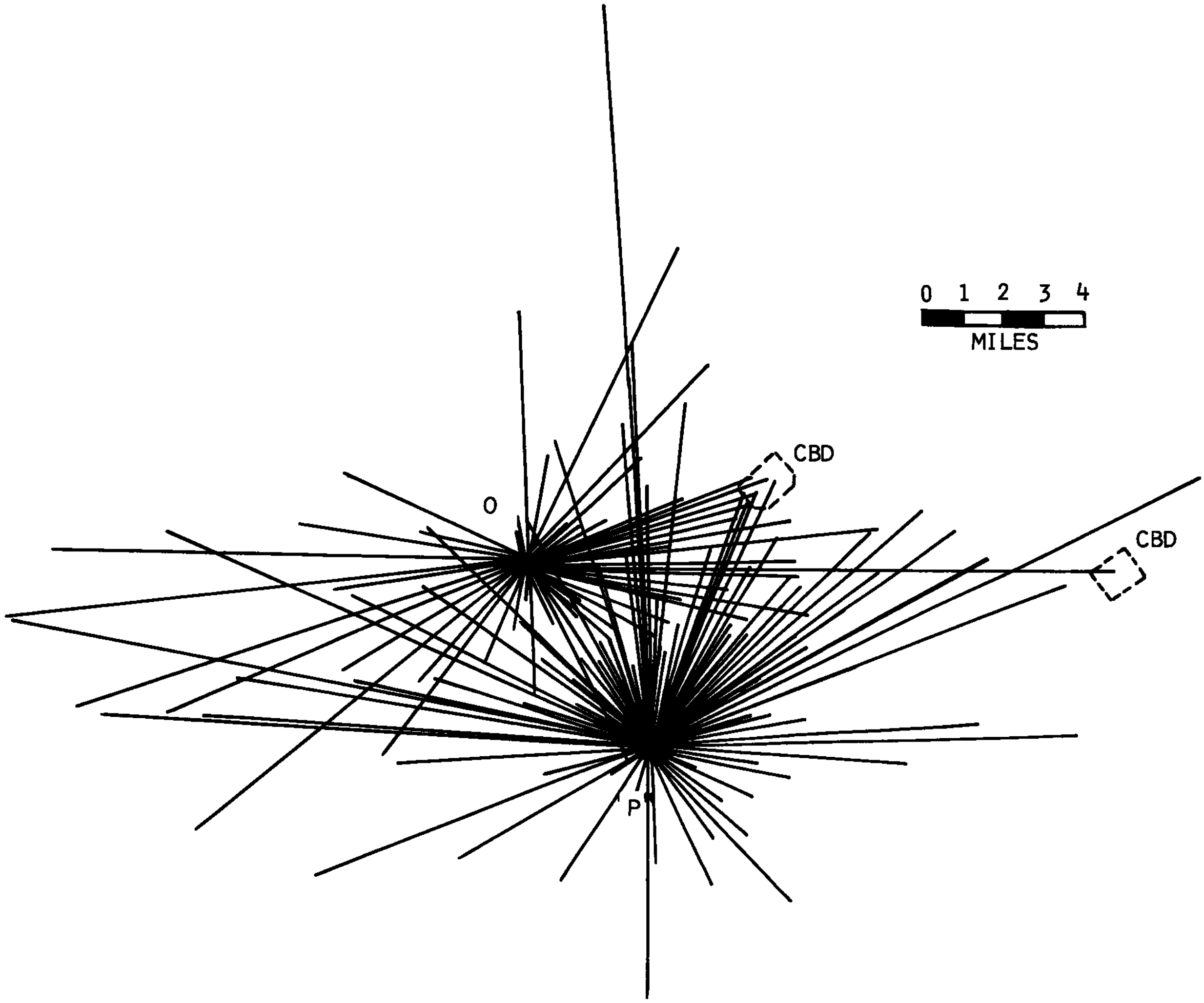

Figure 41. Desire line map (unweighted by volume) of home interview auto driver trips to shop, Centers O and P.

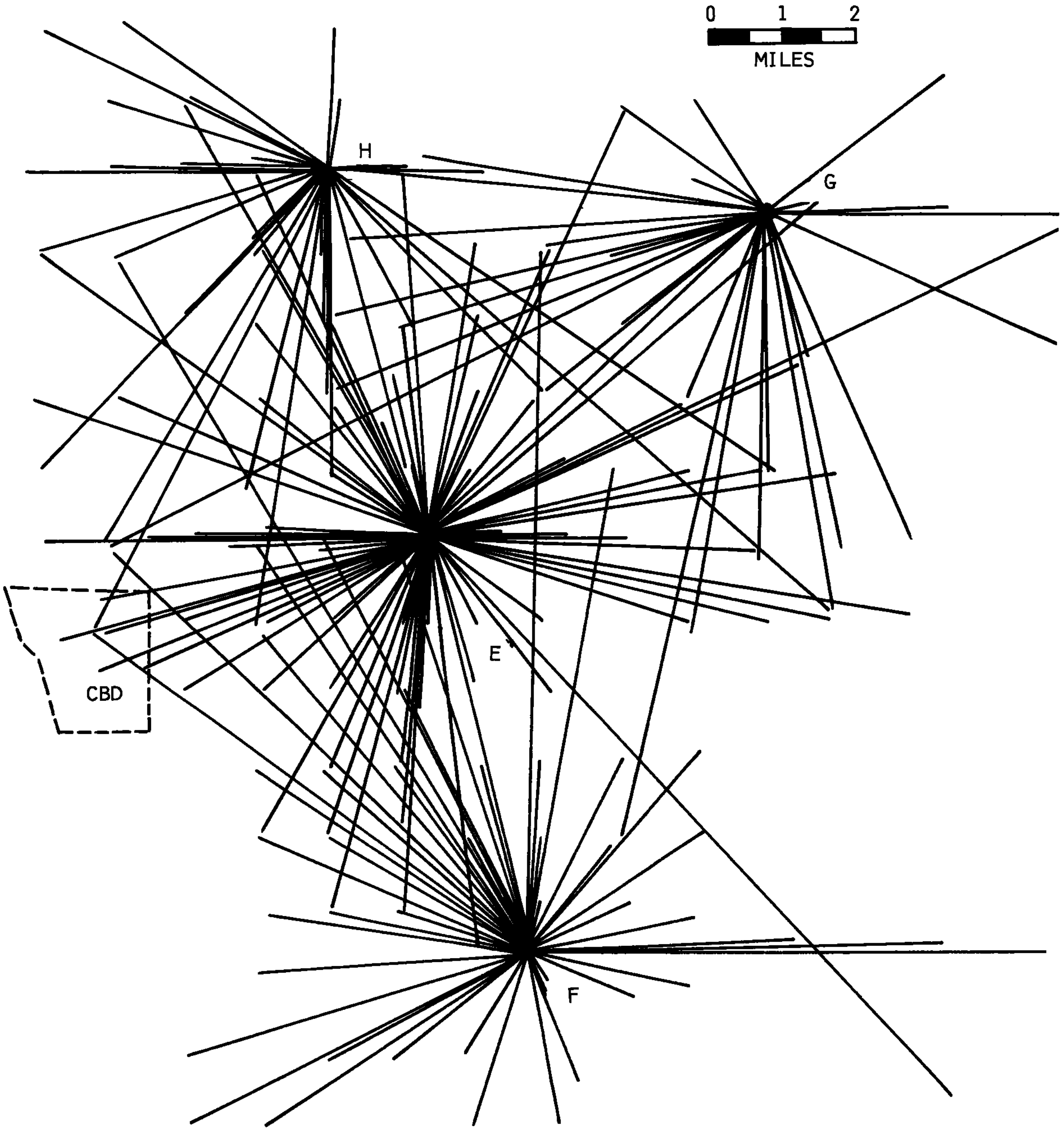

Figure 42. Desire line map (unweighted by volume) of home interview auto driver trips to shop, Centers E, F, G, and H.

more total trips to Old Orchard than to Edens Plaza from the Edens Plaza trading zone. However, the overlapping of trading areas, and the ability of one center to attract trips from the primary trading zone of another, are characteristics of present suburban shopping trends.

Effect of Time

It would seem that trend effects on trip generation might be evaluated by comparing data gathered between 1956 and 1964 in the different metropolitan areas. But none provide two points in time for the same center.

Chicago Tribune consumer surveys (*34*) show that with the passage of time shoppers tend to visit more locations. How much of the resulting increase in travel is due to increased mobility and how much to an increase in the number of shopping centers? The number of regional centers in the Chicago area rose from 2 to 12 in less than a decade.

Total trip generation at shopping centers probably increases through time, even discounting the time span required for centers to become established in the community. Commonly, new stores and services are added years after centers open. This can be seen by comparing the statistics for given centers in successive editions of the *Directory of Shopping Centers* (*28*). Moreover, merchandising and management techniques improve through experience with the actual market demands in particular market areas. Of course, retailing is a dynamic activity—to quote Berry (*33*):

> Retailing is always trying to adjust to new states of balance, but as it moves towards them conditions change and the goal moves further on. There is the incessant chase of a moving equilibrium.

SHOPPING CENTERS AND THE HIGHWAY NETWORK

The Interaction

The interaction of the shopping center and the highway system is of two-way interest. The traffic operations analyst, concerned with peak-hour volumes, exit configurations, and capacity analyses on abutting highways, is interested in the influence of the center on highways. The planning analyst, concerned with trip generation or distribution of trips within the market area, may be more interested in the influence of the highway system on the center.

Here, using transportation study data, the emphasis is different from that where traffic counts or interviews were taken at centers, such as the Cleveland-Mueller (*36*) or LARTS (*39*) studies. Different resources provide different outlooks on some aspects of both the planning and operations problems.

Effect of Centers on the Network

TRAFFIC FLOW PATTERNS

Shopping center traffic dissipates quickly in the highway network. This can be illustrated by the 24-hr traffic flow map constructed for all auto driver trips to Center U (Fig. 43). Using a traffic assignment highway network, showing arterial streets only, trips were manually assigned to minimum travel time routes from each origin zone to the shopping center zone, and aggregated by route. Trips were summarized, also, as they crossed imaginary radii at 1-mile and 2-mile distances from the shopping center. At 1 mile, 92% of the shopping center traffic remains on the arterial system, but is distributed among 9 major routes. At 2 miles, only 61% remains, distributed among 13 major routes. (Fig. 43 is atypical in that a freeway diverts trips around the CBD and develops higher trip rates in the northwest sector than might otherwise occur.)

Table 30 shows the directional orientation of shopping center traffic assigned to the highway networks serving Center U and four other shopping centers. Traffic is summarized by quadrant as it crosses circles drawn at ½-mile, 1-mile, and 2-mile intervals. Quadrants are designated by centering the first on a radial highway between the shopping center and the CBD. As seen, the highest proportions of traffic at the ½-mile mark come from the direction of the CBD (the CBD quadrant); the lowest proportions, from the opposite (outer) quadrant. These proportions tend to persist through the 1-mile and 2-mile marks. Table 30 also shows that at the ½-mile mark one route may carry up to 46% of the traffic to the center. However, the traffic quickly fans out over many routes with increasing distance from the centers.

SHOPPING CENTER TRAFFIC AS A PROPORTION OF ALL ARTERIAL TRAFFIC

Shopping centers account for an insignificant amount of total travel in a metropolitan area. In the Pittsburgh pilot study, all trips to four centers represented only 1% of all vehicle trips. Because shopping center trips were shorter than average, they represented an even smaller proportion of the total vehicle-miles of travel. At the traffic zone level no center drew more than 9% of the vehicle-miles of travel in the zone.

However, the centers required from 8 to 19% of the available street capacity in their respective zones. In one extreme case, the proportion of the main access street capacity required by shopping center travel in the peak shopping hour was more than 100%.

More precise measures are obtained by detailed counts at shopping center sites. A survey by the New Jersey State Highway Department (*40*) provided data on volume demands at a major shopping center and "free standing" department store opposite it. On the four major approaches to the center, shopping center trips ranged from 14 to 25% of all traffic, the highest occurring on the highest volume route.

Peak-hour characteristics were similar to those of the home interview data described earlier. The peak inbound flow occurred between 7 and 8 PM, and the peak outbound flow between 9 and 10 PM. Percentagewise, the peak two-way volume was 10% of the 13-hour total traffic. The inbound peak hour was 14% of the 13-hour inbound total, and the outbound was 15% of the outbound total. Trips to the centers ranged between 9 and 17% of total traffic on the approach roads between 5 and 6 PM, a smaller proportion than during offpeak hours.

CAPACITY ANALYSES

Because of the unusual characteristics of shopping center travel patterns, typical procedures for analyzing capacity problems differ from the usual highway capacity analysis. First is the determination of daily shopping center volume and its distribution on the approach roadways. Second is the selection of design hours. Typically, they will be the highway peak hour (5 to 6 PM), the entering peak hour (7 to 8 PM), and the departing peak hour (8 to 9 or 9 to 10 PM). A peak Saturday afternoon condition should also be studied. Knowledge of approach highway volumes during these periods is essential.

Design hour volumes, obtained from the application of peak-hour percentages to daily travel estimates, must be assigned to exits and entrances, whose configuration and number affect the capacity problems on abutting highways. Inasmuch as site, highway, and directional traffic distribution characteristics are likely to be unique for each center,

TABLE 30

DIRECTIONAL CHARACTERISTICS OF TRAFFIC TO SHOPPING CENTERS, ALL INTERNAL AUTO DRIVER TRIPS [a]

MILE INCRE-MENT	QUAD-RANT	CENTER E		CENTER N		CENTER P		CENTER Q		CENTER U	
		% OF DAILY TRIPS	NO. OF ROUTES USED	% OF DAILY TRIPS	NO. OF ROUTES USED	% OF DAILY TRIPS	NO. OF ROUTES USED	% OF DAILY TRIPS	NO. OF ROUTES USED	% OF DAILY TRIPS	NO. OF ROUTES USED
½	CBD	39	1	43	2	66	3	18	1	35	2
	Outer	22	1	23	1	9	2	10	1	8	1
	Left	21	1	31	2	0	0	46	1	22	1
	Right	15	1	3	1	21	2	24	2	27	1
	All	97	4	100	6	96	7	98	5	92	5
1	CBD	39	1	40	2	21	3	18	2	31	4
	Outer	18	3	22	3	9	1	10	2	8	2
	Left	21	1	23	4	34	2	30	3	26	3
	Right	12	1	1	1	21	3	13	1	27	5
	All	90	6	86	10	85	9	71	8	92	14
2	CBD	22	3	35	4	16	5	17	4	17	6
	Outer	14	5	16	4	8	6	8	4	6	2
	Left	13	4	10	7	28	6	24	4	15	3
	Right	15	5	9	3	16	2	7	1	23	4
	All	64	17	70	18	68	19	56	13	61	15

[a] From transportation study data for various cities.

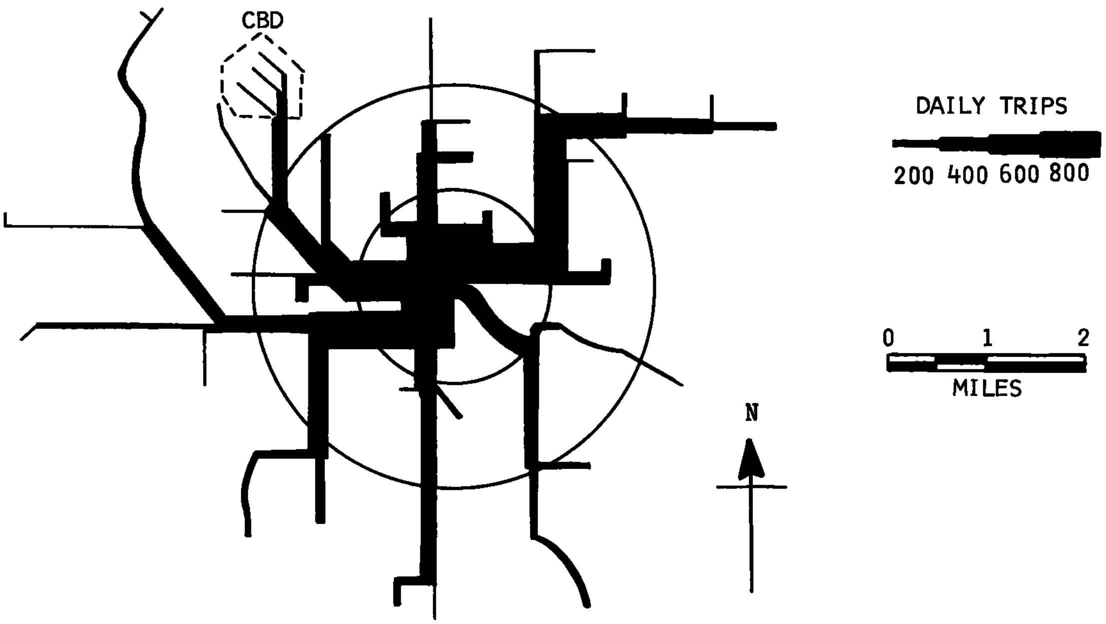

Figure 43. Traffic flow map of all auto driver trips to Center U.

exit and entrance configurations must be individually analyzed. Counts made at seven Chicago area shopping centers showed the most heavily used entrances attracting from 20 to 50% of the peak-hour volume. Even with eight entrances, one may carry one-third of all traffic. Maximum single entrance volumes ranged between 550 and 650 vph (*41*).

Obviously, the principal problem is in making provision for high volume left turns against opposing straight through flow (much of which will also be entering or leaving traffic) at access points and affected intersections. For more detailed discussions on capacity analyses and design hour volume percentages, the reader should consult the references in the bibliography.

COMPETING CENTERS AND CONNECTING ROUTES

The minimum time route connecting two adjacent shopping centers not only carries all trips traveling between the centers, but also carries trips between each center and the intervening residential areas. But congestion and serious conflict on the connecting highway do not necessarily develop as a consequence.

Traffic volumes attracted to both Center O and Center P on the connecting minimum time path nowhere exceeded 15% of total traffic. Average daily traffic traveling from center to center was only 265 vehicles. Buffalo provided a similar example; trips between Center E and Center G amounted to less than 200 vpd. Total shopping center travel on the minimum path connecting them was never more than 11% of total traffic.

Effect of Network on Shopping Centers

If trip rates of two zones at equal distance from a shopping center are higher in the zone with the lower travel time to the center, it follows, other things being equal, that the highway network has a positive effect on shopping center trip generation in that zone. Markedly better service levels in one part of a market area do seem to result in more tripmaking from that area; this was suggested by the traffic flow map for Center U (Fig. 43). Subject to various technical limitations, this can be demonstrated yet another way.

Reading across Table 31 from right to left shows that at any given distance trip rates *do* increase as travel time decreases. Aggregating data for five centers in five different cities, all zones at 4 to 5 miles distance, for example, average 15 trips per 1,000 autos owned at 16 to 17 min travel time, increasing to 88 trips per 1,000 autos owned at 8 to 9 min travel time. (Automobile ownership was used as a base to reduce socio-economic differences.) Reading down, on the other hand, the trip rates show an erratic but general tendency to remain uniform. Thus better service levels, as measured by higher travel speeds, do appear to affect shopping center trip generation at the origin.

Effect of Highway Improvements

When general highway improvements are provided in a metropolitan area the suburban shopping center will generally derive more benefit than downtown.

Demonstration requires a hypothetical case in which residential densities decline regularly in all directions from the CBD, and highway speeds correspondingly increase. Figure 44 shows areas encompassed by lines of equal travel time from both the CBD and a shopping center. For convenience, the selected time is one-half that between the center and downtown. In the larger area surrounding the shopping center, although population density is lower, the fact that the population typically possesses more mobility and income per capita may mean that the purchasing power equals or exceeds that of the area surrounding the CBD.

Figure 44 next shows the increase in area resulting from a uniform increase of speed with no change in travel time. The area gain for the shopping center considerably exceeds that for the CBD, and the effect is accentuated by the

TABLE 31

TRIP RATES BY TIME WITHIN MILE INCREMENTS, ALL AUTO DRIVER TRIPS PER 1,000 AUTOS OWNED [a]

	TRIP RATE (NO./1,000 AUTOS)				
TRAVEL TIME GROUP (MIN)	2–3 MILE INCREMENT	3–4 MILE INCREMENT	4–5 MILE INCREMENT	5–6 MILE INCREMENT	AVG.
4–5	119.7				119.7
6–7	90.8	49.4			80.3
8–9	70.1	34.2	88.1		63.0
10–11	80.0	33.1	27.7		38.8
12–13		33.6	23.5	37.4	30.3
14–15		19.9	18.4	20.4	19.3
16–17			15.1	16.2	15.6
18–19				7.7	7.7
Avg.	78.5	33.0	24.5	19.2	

[a] From transportation study data for various cities.

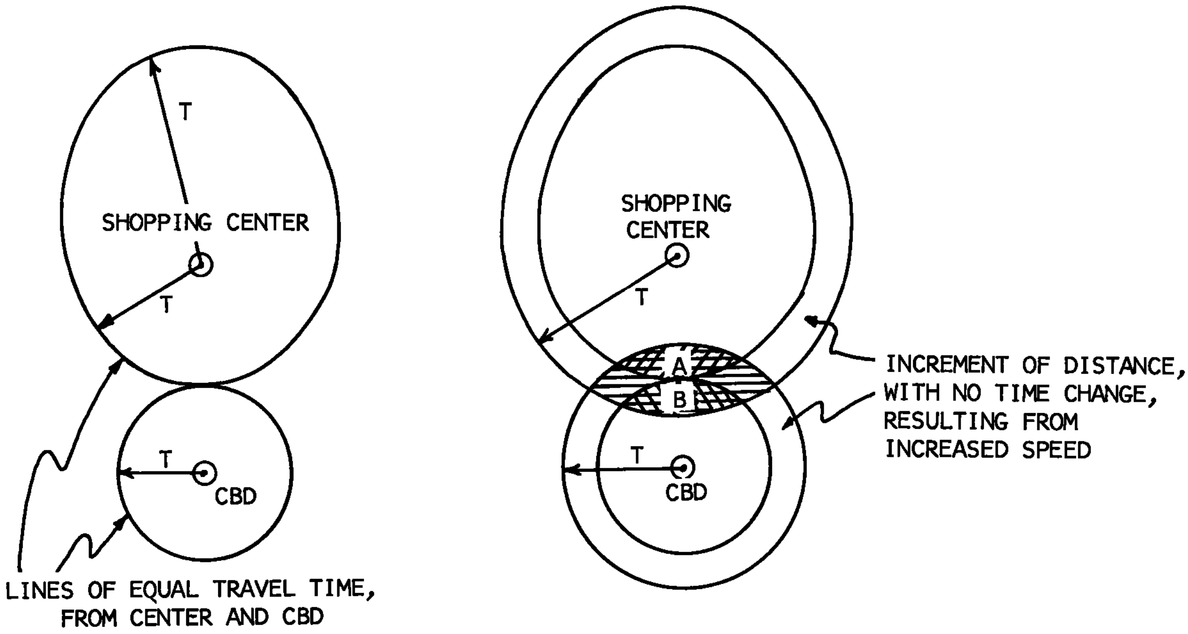

Figure 44. Influence of highway improvements on central business district and shopping center market areas. Shaded area (right) is market area overlap resulting from a uniform speed increase. Area A denotes penetration of original shopping center market area, within time T, *by central business district. Area B is that portion of original CBD market area now reached from shopping center in time* T.

resulting overlap in market areas. The proportion of the shopping center's original market area now penetrated by the CBD is much smaller than the reverse penetration by the shopping center (Areas A and B, respectively). Thus, a uniform improvement in highway service not only improves upon the initial area advantage of the shopping center but also provides greater gains in shared market areas. The general case holds, at least until downtown and suburban travel speeds approach equalization.

ESTIMATING AND DISTRIBUTING SHOPPING CENTER TRIPS

Past Experience

Methods used in the past to estimate the number and distribution of shopping center trips have taken either of two approaches: (1) predicting center trip attractions exclusively from center characteristics; and (2) predicting trips by aggregating those produced at residence zones. Linear regression with one independent variable generally has been associated with the former, but findings in this research have indicated the low accuracy that may be expected (see table of simple linear equations in Appendix C). The second approach generally employs model techniques requiring knowledge of all shopping travel and all retail land use in an urban area, and thus has not had application here to the problem of trip estimation. Trip distribution within the market area has been accomplished similarly with the two types of approach. The objective here has been to find a middle ground, for both estimation and distribution, that will lead to accurate results using techniques and data that are likely to be available for the typical study situation.

Estimating Trips By Multiple Regression

THE VARIABLES

A listing of the dependent and independent variables used in the analysis is given in Appendix C. Briefly, the dependent variables included, in addition to total auto driver trips, four other categories of auto driver tripmaking. No person trip categories were employed as dependent variables.

The independent variables were of two kinds: center-related, and market-area-related. The first included data on floor space, parking spaces, number of establishments, etc.; the second included population, auto ownership, and other area-wide characteristics. The maximum number of independent variables used in any one test was 14, of which 8 represented center characteristics.

Several evident influences on shopping center travel still could not be accounted for. Three variables defying quantification are management skill and experience, the contrasting advertising or drawing power of national and local department stores, and the effectiveness of competition from satellite or nearby retail activities. The importance of these and possibly other influences on trip volumes was made clear by the analysis.

THE TESTS

Multiple linear regression analysis has been made practical by the use of computers, and two computer programs were employed in this investigation. One was a multivariate analysis technique (referred to hereafter as MANOVA) described by Seal (*42*). The other was the stepwise regression analysis of the University of California Medical

School (*43*). The latter technique was used primarily to choose hypotheses to be tested in the MANOVA program, although both techniques can be used to determine best fitting linear equations for predictive purposes.

The procedure was basically an analysis of variance, the MANOVA program being used to calculate the variance of the best fitting model incorporating all variables, those of less inclusive models, and then testing to determine whether the variance differences were significant. If not, the simpler models were accepted. Because of the numerous combinations of variables possible as hypotheses for the simpler models, the stepwise regression was used to identify those with the most significance. Thus the choices for analysis of variance tests were reduced to the workable and probably meaningful few.

The first tests indicated that market area variables were not significant in the prediction of shopping center trips. To test the finding further, and also to determine whether seasonal trip adjustments might lead to better correlations, another test series was developed with modified variables. The results confirmed the first conclusions about the insignificance of market area data and showed that seasonal adjustments were not warranted. Descriptions of these and other regression tests are found in Appendix C.

THE EVALUATIONS

The practical significance of the multiple regression models is indicated in several ways. The model using the 14 variables slightly better than halved the standard error of estimate for all auto driver trips to the center. Put another way, the "explanation" provided by the model for all auto drivers trips leaves unexplained one-fifth of the original variance about the general mean. The unexplained variance with many of the simpler models was not much greater.

Appendix C shows the results of applying the whole model, and simplified models derived from the last test series, to data from three Wilmington shopping centers. These equations can be employed to predict shopping trips only with limited reliability. The larger residual variance that persisted seems attributable more to the influence of other unspecified variables than to nonlinearity of the variables treated.

The principal value of the regression tests was, consequently, in establishing the significance and influence of different variables. Total person work trips (employment) was the most significant single variable. Other important variables were the floor space categories, age of data, and age of center. Among the non-significant variables were market area characteristics such as income, population, and autos owned.

In general, the signs of coefficients followed expected patterns. Regression coefficients for work trips, distance to competition, and shopping goods floor space were positive in predicting shopping trips, indicating an increase in trip volume for increase in these variables. Coefficients for data age, speed, and the other two floor space categories were negative, signifying reductions in trip volumes as these variable values increase. The behavior with respect to data age confirmed the earlier conclusion concerning changes in trip generation rates with time. And, although the speed relationship seems contrary at first glance, Table 30 indicates that the maximum trip volumes are indeed drawn from the CBD quadrant where population densities are greater and speeds generally lower.

Distributing Trips from the Center

PRACTICAL CONSIDERATIONS

If shopping center trips are estimated and aggregated by residence or origin zones, no problem of trip distribution exists. But when this is impossible because of data or cost considerations, and when trips are estimated from shopping center characteristics, the distribution of traffic on approach highways must be determined in most traffic analyses. Trips may be distributed crudely by quadrant, as shown earlier, but more refinement is desirable. Yet techniques should not require the assembly or processing of data not usually available to the analyst. At best, the applicable data are likely to come from Bureau of Census or transportation survey sources.

The trip distribution procedure described in the following has been developed from these considerations. Its objective is therefore to make possible the distribution of center generated trips to the highway network at the center. If, at the same time, generation at each residence zone is reasonably simulated, this is a collateral benefit.

THE PROCEDURE

The proposed technique, described in detail in Appendix C, is based on the premise that shopping center trip distribution can be accomplished with a knowledge of population distribution, travel times on the highway network, the location of the principal competition, and a description of trip rate relationships by time.

Dealing first with the last item, it has been shown that shopping trips per 1,000 population attracted to a center decrease in a regular fashion as travel time increases. Time, rather than distance, is essential. The regularity is shown in composite shopping trip rate curves in Figure 45, where the lowest curve is that for cities using "free flow" travel times, and the middle curve represents the average condition for seven metropolitan areas including 19 shopping centers. The latter curve is the basis for computing trip productions for origin zone or district.

The other ingredients of population, travel times, and competition will generally be available for major metropolitan areas. At least two "trees," or travel time listings, from the center and its prinicipal competition to each origin zone must be known. Time from the shopping center is necessary to determine the basic trip rate. Time from the competition is necessary to determine adjustments to the basic trip rate. (Adjustment factor derivation and application is described in Appendix C.)

Trip productions by zone are computed and modified using the population, time, and adjustment factors. Trip volumes are then totaled and compared to the independently prepared estimate of total trip generation. Agreement is merely coincidental, because the trip rate curve is an average, and zonal trip productions must be factored to bring the totals into agreement. This last step incor-

porates an assumption that non-shopping trips have the same distribution characteristics as shopping trips, because the normalization merely insures that all trips to the center are distributed (and modified by competition) in the same way. Although it is a recognized drawback, the fact that non-shopping trips include many trip purposes with both home-based and nonhome-based origins weighs against explicit distribution procedures.

EVALUATION

The technique was applied to one of the shopping centers in Wilmington, with the results shown in Figure 46. In this case, the central business district was treated as the only competition. The division of travel time increments into inside and outside zones illustrates the effectiveness of the procedure in simulating competitive influences.

Other tests were made at other centers allowing for the competitive effects of both central business districts and shopping centers. Adjustment factors for basic trip rates were averaged, in these cases, for both the downtown and the competing center. Résults were equally reasonable.

In summary, the trip distribution technique is clearly of sufficient accuracy to justify its use in determining approach highway volumes. The simulation of zonal trip production was not specifically evaluated, although Figure 46 indicates that estimated trips are reasonably close to survey reported trips when zones are grouped by increments of travel time from the center.

Application of Estimating and Distribution Techniques

Trip generation at major shopping centers can be estimated with multiple linear regression equations more precisely than by any form of simple linear regression. However, the equations given in Appendix C should only be applied where data fall within the ranges of the present samples. Even with the best of circumstances, considerable tolerance

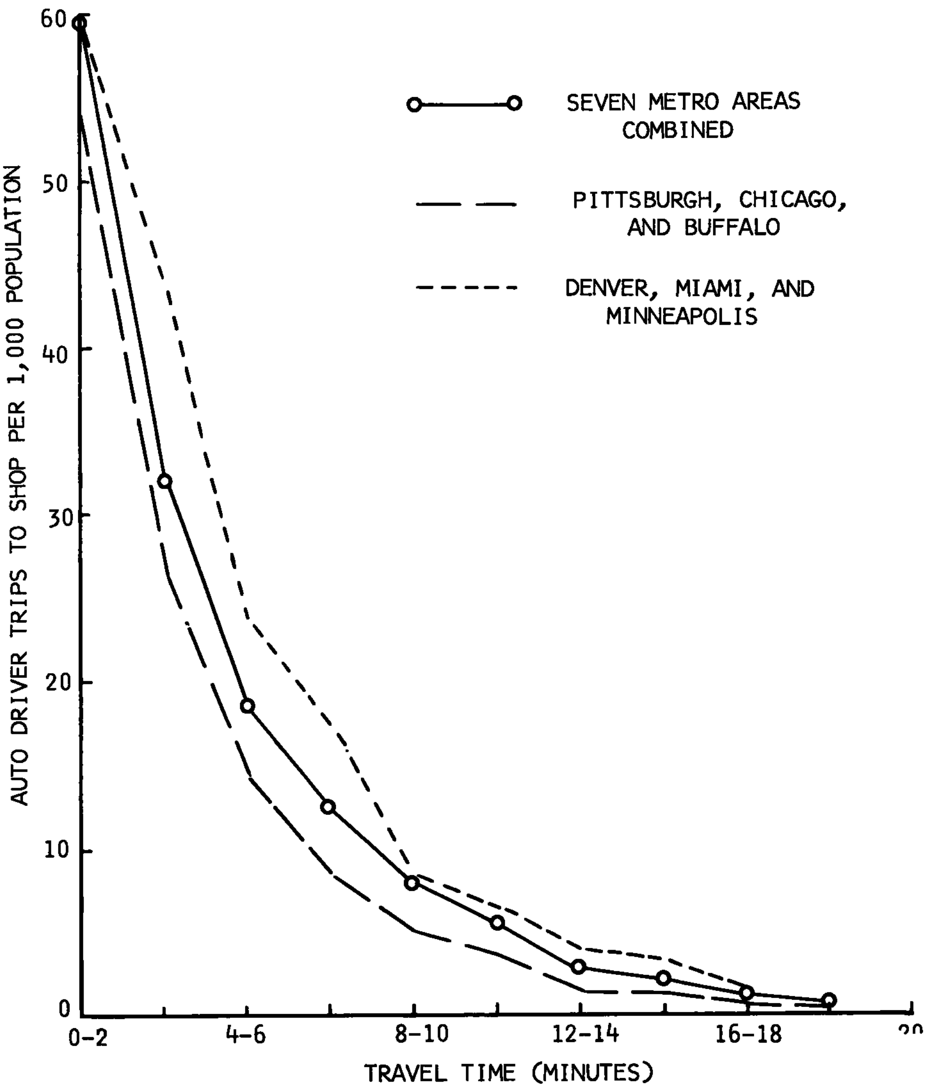

Figure 45. Home interview auto driver shopping trip rates, composite curves on travel time.

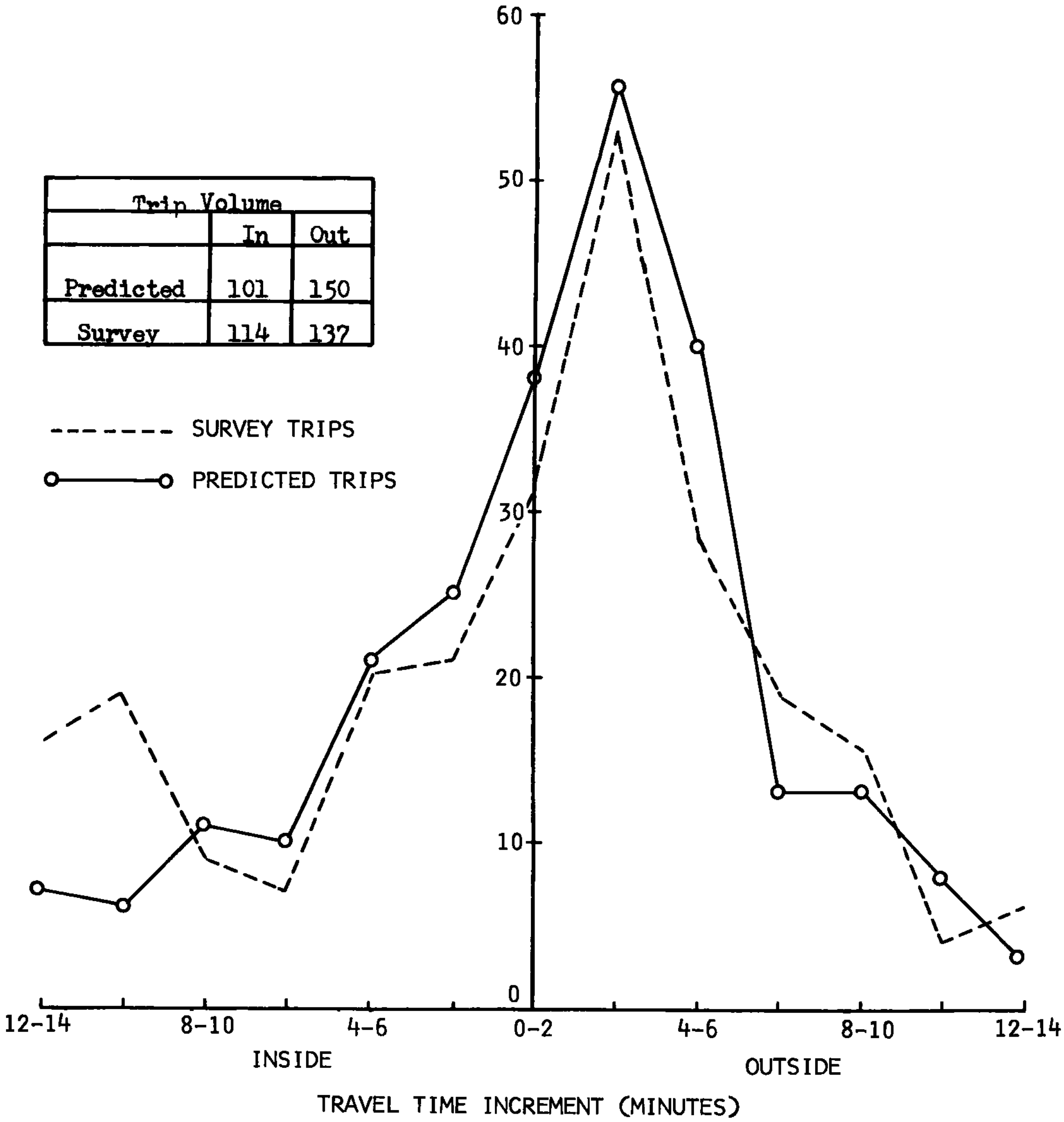

Figure 46. Auto driver shopping trips to Center B-B, predicted and survey volumes, by travel time.

must be placed on results, presumably because varying management and competitive conditions cannot be quantified.

The procedure for distributing trips permits accurate assignment of shopping center generated volumes to the highway network. Population data by area, and travel time data, should be available wherever proposals for major shopping centers are likely to occur. Even though the technique does not separately describe the patterns of non-shopping travel to and from centers, application to several situations has demonstrated its effectiveness in simulating survey travel characteristics.

CONCLUSIONS

The investigation of shopping center travel characteristics, as represented by urban travel surveys, has developed several major findings. First, and obviously, the automobile was the only significant form of transport to and from the 28 shopping centers studied. Transit accounted for less than 3% of tripmaking, and truck volume (including light trucks) was less than 4%.

Because car ownership is increasing, and average car occupancy is decreasing, trip generation rates are not static. Analysis of shopping center travel from households owning two or more cars showed lower car occupancy and higher proportions of female drivers than for one-car households. Multiple regression anlysis showed trip rates in the more recent travel surveys to be higher than in the older studies. Accurate assessment of changing trip rates may not be possible, however, because changes in retail marketing practices and retail-to-residential land proportions may be more significant than changes in driver characteristics.

Changes in retail practices have affected the daily time patterns of shopping travel over the past decade. Now, store openings every weekday night rather than on just one or two nights are common practice. Shopping center travel now peaks in the evening, and activity is subdued during the normal highway peak hours. Nevertheless, design and capacity analyses should review anticipated volumes for each separate peak.

The mutual impacts of shopping centers and the highway system are considerable. But although the shopping center causes high volumes in its immediate vicinity, its generated traffic is quickly dissipated within 1 mile of the center. Even on routes connecting two competing centers, the combined volumes are small, typically less than 15% of the total volume.

The highway impact on shopping centers is shown by the need to use time rather than distance in market area and trip distribution analyses. The importance of highway speeds is also evident in the differential benefits of general urban highway improvements on shopping center and downtown market areas.

Estimates of shopping center tripmaking can be made by simple linear regression with only limited reliability. Person work trips (representing employment estimates) proved a better base for trip generation than did total floor space. Multiple linear regression produced better results, and demonstrated that shopping center attributes rather than those of the market area were necessary. Even so, much tripmaking was unexplained, because variables reflecting the effectiveness of center management and nearby competition could not be quantified.

Distribution of trips on approach highways near the center can be determined from travel time and population data, allowing for the influence of principal competition. Tests on several shopping centers showed that the survey reported trip distribution could be simulated using data normally available for every design and capacity analysis problem.

CHAPTER FOUR

INDUSTRIAL PLANTS

Industry is the economic mainstay of most metropolitan areas. Although in recent years manufacturing employment has been gaining less rapidly than employment in government and the service industries, it is still true that most metropolitan areas cannot maintain competitive economic growth without a strong industrial base.

Transportation costs are a major factor in industrial efficiency. If these costs become great enough, industrial concerns may curtail expansion or even relocate. In effect, the broad purpose of the present research project is to develop factors and relationships by which transportation planners, traffic engineers, and highway designers can be guided in providing efficient highway linkage and keeping transportation costs low. Such relationships are needed not only for new industrial sites, but also for older, well-established sites.

To achieve this purpose, both automobile and truck travel to more than 50 major plants has been analyzed from the results of areawide transporation studies of various years. They are located in Atlanta, Buffalo, Chicago, Denver, Detroit, Minneapolis-St. Paul, Pittsburgh, Providence, and San Diego. Several additional plants in the Wilmington, Del., area have been analyzed by way of testing certain predictive relationships. Brief descriptions of most plants, as they existed in the travel survey years, are included in Table B-4. As promised to plant managers providing information, anonymity is preserved by using only reference numbers for plant identification.

For presentation purposes, plant travel data have generally been combined by city and by plant employment groupings. Necessarily, travel data were first separately analyzed for each plant. Space limitations preclude publication of these separate analyses; they are, however, preserved in the project records, as are similar analyses of airports and shopping centers.

The major parts of this chapter consider general trip characteristics, trip generation, trip distribution, trends affecting trip generation and distribution, trip prediction and testing, and conclusions and implications that can be drawn.

GENERAL TRIP CHARACTERISTICS

Mode and Purpose of Person Travel

MODE, ALL TRIP PURPOSES

Table 32 suggests that as plants grow larger there is a tendency toward mass transit as an important mode of employee travel. For plants under 5,000 employees the proportion of trips by transit averages about 11%. For plants with between 5,000 and 10,000 employees the transit proportion rises to about 22%, while for the two plants with over 10,000 employees the proportion reaches 31%.

Part of the apparent effect of Table 32, however, stems from the fact that many of the larger plants in the cross section are located in the older, more highly built-up portions of the metropolitan areas represented. The different socio-economic characteristics of residents within a 3- to 5-

TABLE 32

TRAVEL MODE DISTRIBUTION, HOME INTERVIEW PERSON TRIPS TO SELECTED PLANTS, ALL PURPOSES [a]

PLANT EMPLOY-MENT GROUP	PERSON TRIPS (%)				
	NO. OF PLANTS	AUTO DRIVER [b]	AUTO PASS.	TRANSIT PASS.	WALK TO WORK [c]
0–999	9	61.1	21.7	13.0	4.2
1,000–1,999	12	69.9	16.3	10.6	3.2
2,000–2,999	8	61.2	17.7	11.5	9.6
3,000–3,999	4	63.9	26.0	7.9	2.2
4,000–4,999	7	58.6	22.9	12.0	6.5
5,000–9,999	4	51.4	19.5	22.6	6.5
10,000–19,999	2	39.5	23.9	32.5	4.1
Average [d]	46	56.0	21.2	17.3	5.5

[a] From transportation study data for various cities. [b] Excludes trips to serve passenger.
[c] Walking trips not available for plants in Atlanta, Minneapolis-St. Paul, and San Diego. [d] Weighted.

mile radius, and the different level of transit service available, would be the better explanation for greater transit usage than would be total plant employment.

Concomitantly, the proportion of auto drivers decreases with increasing plant size: under 5,000 employees the average is 62%, between 5,000 and 10,000 employees it is 52%, and over 10,000 employees it is 42%.

There is relatively little variation in the proportion of automobile passengers: under 5,000 employees the average is 21%, between 5,000 and 10,000 employees it is 19%, and over 10,000 employees it is 23%. In effect, car loading factors increase with increasing plant size: from 1.33, to 1.38, to 1.61 for the three employment groups, respectively (as derived by dividing the sum of auto drivers plus auto passengers, by auto drivers; more exact numbers will be provided later).

Walk-to-work trips were not reported for all cities. Nevertheless, this mode of travel accounts over-all for about 6% of all person trips to all plants in the cross section. Many newer plants, distant from nearby residential development, report no walk trips; other, older plants report as high as 40% (plant 25, Pittsburgh).

Table 32 excludes auto driver trips to drop off passengers at or near the plant ("serve passenger" trips). Table 33 shows that, if included, they would be a significant proportion of the total auto driver trips to the plants. Based only on those 19 plants where serve passenger trips were not already eliminated by "linking" (*44*), the average proportion was about 9%. There appears to be no systematic relationship to plant size. The highest proportion (24%, plant 49, Providence) fell into the smallest plant size, while the next highest proportion (16%, plant 17, San Diego) fell into the largest plant size.

MODE, WORK-NONWORK TRIPS

By the usual definition, work trips include not only trips to the location of a person's place of employment, but also trips to locations that must be visited in performing a normal day's work. For example, trips by a salesman calling on prospective customers, or trips by electricians, carpenters, plumbers, etc., would all be classed as trips to work. There were slight variations as between studies; in some instances the distinction between "personal business" and "work" trips was not clean-cut. Such problems of definition are considered minor, however.

Few plants attract any significant numbers of nonwork trips. Table 34 shows that for all plants together the proportion of nonwork trips, by all modes, totals just under 5%. There is little variation by plant size, but noticeable variation by travel mode; most such trips are by automobile rather than by transit. (Walking trips other than to work are not reported by any of the studies.)

Throughout the various analyses that follow, therefore, the emphasis falls naturally on work trips, which constitute 95% of all trips to the subject plants. Fortunately, these work trips are closely related to plant employment. It may be timely here to establish this relationship.

Approximately one-half of the plants here considered had already been selected by the various transportation

TABLE 33

PROPORTION OF HOME INTERVIEW AUTO DRIVER TRIPS TO SERVE PASSENGER TRIPS TO SELECTED PLANTS [a]

PLANT EMPLOY-MENT GROUP	AUTO DRIVER TRIPS TO SERVE PASS. (%)
0–999	13.1
1,000–1,999	7.2
2,000–2,999	8.6
3,000–3,999	—
4,000–4,999	13.0
5,000–9,999	6.1
10,000–19,999	11.3
Average [b]	9.4

[a] From transportation study data for various cities. [b] Weighted.

TABLE 34

DISTRIBUTION OF HOME INTERVIEW NON-WORK PERSON TRIPS TO SELECTED PLANTS, BY TRAVEL MODE [a]

PLANT EMPLOYMENT GROUP	TRIPS (%) AUTO DRIVER [b]	AUTO PASS.	TRANSIT PASS.	ALL MODES [c]
0-999	6.2	3.1	—	4.4
1,000-1,999	2.8	5.4	—	2.8
2,000-2,999	6.7	7.7	1.3	5.6
3,000-3,999	5.5	5.2	—	4.9
4,000-4,999	7.4	11.6	2.0	7.3
5,000-9,999	5.4	5.5	1.8	4.2
10,000-19,999	3.9	4.3	2.3	3.3
Average[d]	5.5	6.8	1.7	4.8

[a] From transportation study data for various cities.
[b] Excluding trips to serve passenger.
[c] Excluding walk-to-work trips.
[d] Weighted.

studies for their "work place" accuracy check. This check compares the number of survey reported first work trips to the plant reported employment, minus absentees. In some cases studies ask for average daily attendance; in most cases, however, studies must establish the absentee rate. Generally, this rate seems to run about 10%; that is, one in ten employees is absent on any given day for vacation, illness, or other cause. The New Castle County Land Use-Transportation Study has established a slight variation by plant employment size: up to 500 employees the rate is 3.2%, between 500 and 1,000 employees 9.9%, above 1,000 employees 10.1% (*45*). Considering the average size of plant represented in this report, and for easy reference, 10% is assumed as a standard rate.

Factors Associated with Travel Mode

AUTO OWNERSHIP

Based on the 25 plants in the Pittsburgh and Buffalo areas, Table 35 shows that at least 60% of all transit trips to work are captive; that is, they are made by persons who do not own a car, or cannot drive. The percentage might be higher if drivers who temporarily lacked access to a car were included as captive (they could not be identified on the basis of trip records alone).

In fact, two-thirds of the modal split variation can be "explained" by knowing the number of workers who do not drive or who come from a carless family. Statistically, these variables work best when used to predict the percentage of workers who drive to work ($r^2 = 0.64$). The relationship appears to be linear and negative; that is, the higher the proportion of carless-nondriving workers, the lower the proportion of workers who drive to work. Transit trips cannot be predicted as well from the same variables, because carless-nondriving workers have the option of riding as auto passengers.

It is instructive that the captive proportions vary by tripmaker occupation group. Not shown in Table 35 is the fact that only 35% of the transit trips by the professional-managerial group are captive, 58% by the clerical-sales-worker group, 56% by the craftsmen-operatives group, and 77% by the laborers-service workers group.

That so many tripmakers from carless households can drive, and that so many from car-owning households cannot, is perhaps surprising. The percentages, by tripmaker occupation group, are, respectively, 13-14%, 14-29%, 13-18%, and 33-54%.

TRIPMAKER INCOME

Income data related to tripmakers is available only for plants in the Buffalo area. These data show that auto passengers have the highest family income ($9,127), auto drivers the next highest ($8,544), and transit passengers the lowest ($7,186), according to the weighted averages for nine plants.

Table 36 presents the same data in terms of the modal distribution by family income range. The lower family income ranges, particularly the three ranges from $2,000 to $5,000, produce the highest percentages of transit tripmakers. The higher family income ranges rely more on the automobile.

TABLE 35

DISTRIBUTION OF HOME INTERVIEW TRANSIT TRIPS TO WORK AT SELECTED PLANTS, BY CAR OWNERSHIP CLASS, BY DRIVER-NONDRIVER, AND BY TRIPMAKER OCCUPATION [a]

TRIPMAKER OCCUPATION GROUP	TRANSIT TRIPS (%) 0-CAR FAMILY		1-CAR FAMILY		MULTI-CAR FAMILY		ALL FAMILIES	
	DRIVER	NONDRIVER	DRIVER	NONDRIVER	DRIVER	NONDRIVER	DRIVER	NONDRIVER
Prof. and mgr.	0.3	2.0	5.1	0.8	0.4	—	5.8	2.8
Cler. and sales	0.8	5.6	5.1	1.8	1.1	0.7	7.0	8.1
Crafts. and opers.	3.3	21.3	20.5	5.1	2.7	2.7	26.5	26.4
Lab. and service	4.1	8.4	4.8	5.3	0.3	0.5	9.2	14.2
Average	8.5	37.3	35.5	13.0	4.5	1.2	48.5	51.5

[a] From transportation study data for 25 plants in Pittsburgh and Buffalo.

TRIPMAKER SEX

To start with, Table 37 shows that more than 90% of all trips to work at the 25 Pittsburgh and Buffalo plants considered are by males. Well over one-half of all trips are by male auto drivers, as compared to the very small proportion by female auto drivers. The remaining percentages in Table 37 suggest that females are far more likely to be auto or transit passengers than the males, but equally likely to walk to work. In fact, the data show that 61% of all males drive, 16% are auto passengers, 15% are transit passengers, and 9% walk. The figures for females are 26, 39, 26, and 9%, respectively.

TRANSIT AVAILABILITY

With few exceptions, every plant examined had transit service of some kind during the survey year. Predominantly, this was bus service, although many of the Pittsburgh plants had both bus and streetcar service. Additionally, Pittsburgh's plant 7 had commuter railroad service. Perhaps not surprisingly, about 36% of its nearly 10,000 employees reported riding "transit" to work—the highest proportion for any plant studied. Employees of four Chicago plants (plants 20 through 23) reported trips by rapid transit, and at each plant the total proportion of transit trips exceeded 24%. It should be noted, however, that the proportions of Chicago plant employees actually using rapid transit ranged only from 1 to 10%, and that less than 5% of Pittsburgh's plant 7 employees rode the commuter train.

Truck Travel

Altogether, the 38 plants for which truck trip records were obtained from the transportation studies developed about 4,000 internal truck trips and about 1,200 external truck trips, or about 135 trips per plant. Although three-fourths of the trips are by medium and heavy trucks, this magnitude of tripmaking would not appear to represent the major impact of a manufacturing plant on its servicing highway system.

TABLE 36

RELATIONSHIP OF MODE OF TRAVEL TO INCOME RANGE OF TRIPMAKER'S FAMILY, FOR NINE PLANTS IN THE BUFFALO AREA [a]

FAMILY INCOME RANGE	TRIPS (%) AUTO DRIVER	AUTO PASS.	TRANSIT PASS.	ALL TRIPS
0-1,999	79	17	4	8
2,000-2,999	50	36	14	2
3,000-3,999	50	25	25	4
4,000-4,999	61	29	10	9
5,000-5,999	72	21	7	22
6,000-7,999	72	25	3	17
8,000-9.999	65	27	8	14
10,000-14,999	75	20	5	9
15,000-25,000	65	28	7	7
Over 25,000	67	31	2	8
Average	69	25	6	100

[a] From Niagara Frontier Transportation Study data.

Table 38 shows that the 38 plants average 3.52 truck trips (0.92 light truck trips and 2.60 medium and heavy truck trips) per 100 person trips. There seems a slight tendency for smaller plants to develop higher truck trip rates. Although this may be entirely a function of the particular sample, it does seem reasonable that the larger plants would tend to rely more on rail and water shipments. Certainly this is true of the large steel mills and automotive assembly plants included.

Generally, total truck activity should reflect total person activity. This was the rationale of the Chicago and the Pittsburgh Area Transportation Studies, and the basic method used in these studies to predict future truck tripmaking (*46*). Truck trip rates per 100 auto driver trips provide a less stable predictive base than do rates based on person trips, because of the variation in modal split at each plant.

TABLE 37

TRAVEL MODE DISTRIBUTION OF HOME INTERVIEW PERSON TRIPS TO WORK AT SELECTED PLANTS, BY CAR OWNERSHIP CLASS AND TRIPMAKER SEX [a]

MODE OF TRAVEL	TRIPS (%) 0-CAR FAMILY MALE	0-CAR FAMILY FEMALE	1-CAR FAMILY MALE	1-CAR FAMILY FEMALE	MULTICAR FAMILY MALE	MULTICAR FAMILY FEMALE	ALL FAMILIES MALE	ALL FAMILIES FEMALE
Auto driver	0.1	—	43.5	1.2	11.9	1.2	55.5	2.4
Auto pass.	3.5	1.1	9.5	1.9	1.7	0.7	14.7	3.7
Transit pass.	6.3	1.1	6.7	1.2	0.8	0.2	13.8	2.5
Walk-to-work	2.4	0.5	3.5	0.4	0.5	0.1	6.4	1.0
Average	12.3	2.7	63.2	4.7	14.9	2.2	90.4	9.6

[a] From transportation study data for 25 plants in Pittsburgh and Buffalo.

TABLE 38

RATIO OF INTERNAL TRUCK TRIPS TO INTERNAL PERSON TRIPS AT SELECTED PLANTS[a]

PLANT EMPLOYMENT GROUP	TRIPS (NO./100 PERSON TRIPS) LIGHT TRUCKS	MED. AND HVY. TRUCKS	ALL TRUCKS
0-999	0.71	4.83	5.54
1,000-1,999	1.61	4.22	5.83
2,000-2,999	0.70	2.55	3.25
3,000-3,999	0.80	1.10	1.90
4,000-4,999	1.72	3.46	5.18
5,000-9,999	0.65	1.84	2.49
10,000-19,999	—	1.79	1.79
Average[b]	0.92	2.60	3.52

[a] From transportation study data for various cities.
[b] Weighted.

TABLE 39

SEASONAL VARIATION IN REPORTED ATTENDANCE AT NINE PLANTS IN THE BUFFALO AREA[a]

WEEK	ATTENDANCE (% OF AVG. WEEKLY ATTENDANCE FOR PERIOD) PLANTS 8 AND 10-16	PLANT 9
May 7-10	100.4	115.4
May 14-18	100.9	113.3
May 21-25	100.8	107.9
May 28-June 1	101.4	114.0
June 4-8	101.6	112.5
June 11-15	101.4	96.0
June 18-22	101.8	45.8
June 25-29	101.3	84.6
July 2-6	100.9	111.1
July 9-13	100.1	110.5
July 16-20	98.9	110.7
July 23-27	97.1	91.8
July 30-August 3	96.0	91.8
August 6-10	97.4	94.3

[a] From Niagara Frontier Transportation Study data

TABLE 40

RATIOS OF WORK TRIPS BY DAY OF WEEK TO AVERAGE WEEKDAY TRIPS, BY MODE, FOR NINE PLANTS IN THE BUFFALO AREA[a]

DAY OF WEEK	WORK TRIPS (%) AUTO DRIVER	AUTO PASS.	TRANSIT PASS.	ALL MODES
Monday	119	97	136	115
Tuesday	86	116	73	92
Wednesday	98	89	118	97
Thursday	115	103	73	109
Friday	82	95	100	86

[a] From Niagara Frontier Transportation Study data.

Taxi Travel

For all practical purposes, industrial plants generate no taxi trips. Less than 200 trips were attracted by the 38 plants just considered—an average of about 5 trips per plant. Except possibly for research and development plants located near airports, and for other special cases, highway design problems can probably ignore taxi travel.

Time Patterns

MONTHLY

Excepting seasonal industries, defense industries, and others subject to drastic changes in product demand, most will attempt to maintain consistent employment throughout the year. Although annual statistics were not obtained from the subject plants, Table 39 does report the seasonal variation at the subject Buffalo plants over the period of the home interview survey. Eight of the nine plants display a remarkable consistency of worker attendance over the three-month period. Each plant showed virtually the same pattern. The below-average attendance after mid-July may indicate that spread-out, or staggered, vacationing was permitted. By contrast, plant 9 appeared to favor plantwide vacationing in mid-June. During the week of June 18-22 plant attendance was about one-half what it was during most other weeks. It is not known whether the dip after mid-June was for remaining vacations or for a production cutback.

DAILY

Sampling variability makes it difficult to establish daily variations in work trips at any single plant. Stratification reduces the reporting sample seriously. However, considering all the plants for a particular study area together may be suggestive of any significant variation that occurs.

Table 40 presents ratios of daily work trips to average weekday work trips, by mode, for nine plants in the Buffalo area. Both total trips and travel mode distribution vary by day of the week. Monday is the peak day for all modes combined; Friday, the low day. Monday is the peak day for auto drivers and transit passengers; Tuesday is the peak day for auto passengers. Friday is the low day for auto drivers; Wednesday, for auto passengers; and Thursday, for transit passengers.

HOURLY

Most subject plants operate three shifts: the prime shift starts between 6 AM and 8 AM; the smaller afternoon shift starts between 2 PM and 4 PM; and the still smaller night shift starts between 10 PM and 12 PM.

Considering each plant separately, the prime morning shifts range from 44% to 93% of the total daily tripmaking. At some plants different occupational groups tend to arrive at different hours (generally in the order: plant personnel, office personnel, executives), and the prime shift peak may actually be spread over two or more hours. Afternoon peaks seldom exceed 20%, night peaks 10%.

It bears emphasizing, however, that the peak traffic period occurs when shifts change between 2 PM and 4 PM, when

the two-way traffic becomes the sum of the morning and afternoon shifts. Even assuming that some morning shift workers remain through the shift change, there must still be considerable competition for street space at the critical 15-min traffic peak.

Figure 47, showing auto driver trips by plant employment group, reflects no significant or systematic variation of peaking according to plant size. There may be a slight tendency for the morning peak percentage to increase with increasing plant size; but again this may be an accidental result of the particular plant groupings. The least typical curve, with more trips arriving between 6 AM and 7 AM than between 7 AM and 8 AM, is for plants with less than 1,000 employees. These plants, and those with more than 10,000 employees, are also the only ones with more trips arriving from 2 PM to 3 PM than from 3 PM to 4 PM. The remaining plant size group curves all seem to have similar patterns. Auto passenger trips show no marked differences.

Figure 48 shows that transit passenger trips peak slightly higher in the morning, and slightly lower in the afternoon and at night, than do auto driver trips. For 43 plants combined, the 7 AM to 8 AM peak accounts for about 33% of the daily trips, the 6 AM to 9 AM peak for about 71%. The 2 PM to 4 PM peak accounts for about 14% of the daily trips, for a total of 85%, somewhat higher than the total for auto driver trips. It should be noted that 3 plants report no transit trips, 12 report less than 100 trips each, and 25 report less than 300 trips each. The patterns shown in Figure 48, therefore, are heavily weighted by the relatively few plants that report a large number of transit trips.

Figure 49 shows that 92% of all truck activity at manufacturing plants occurs during daytime office hours (from 7 AM to 6 PM). Such activity is fairly constant all day, with almost equal peaks in midmorning and midafternoon. Plotted separately for the plant groups in Buffalo, Chicago, Minneapolis-St. Paul, and Pittsburgh, the patterns are consistent.

Travel Times and Distances

Work trips are among the longest made in any urban area. Converting airline distance to over-the-road distance by a factor of about 1.4, the average auto driver trip length for 46 plants was about 6.0 miles (Table 41). For the urban areas considered, most of which are from 20 to 30 miles across, this average does not seem excessive.

The over-the-road travel time averages about 10 min, based where possible on "free" travel time trees and thus

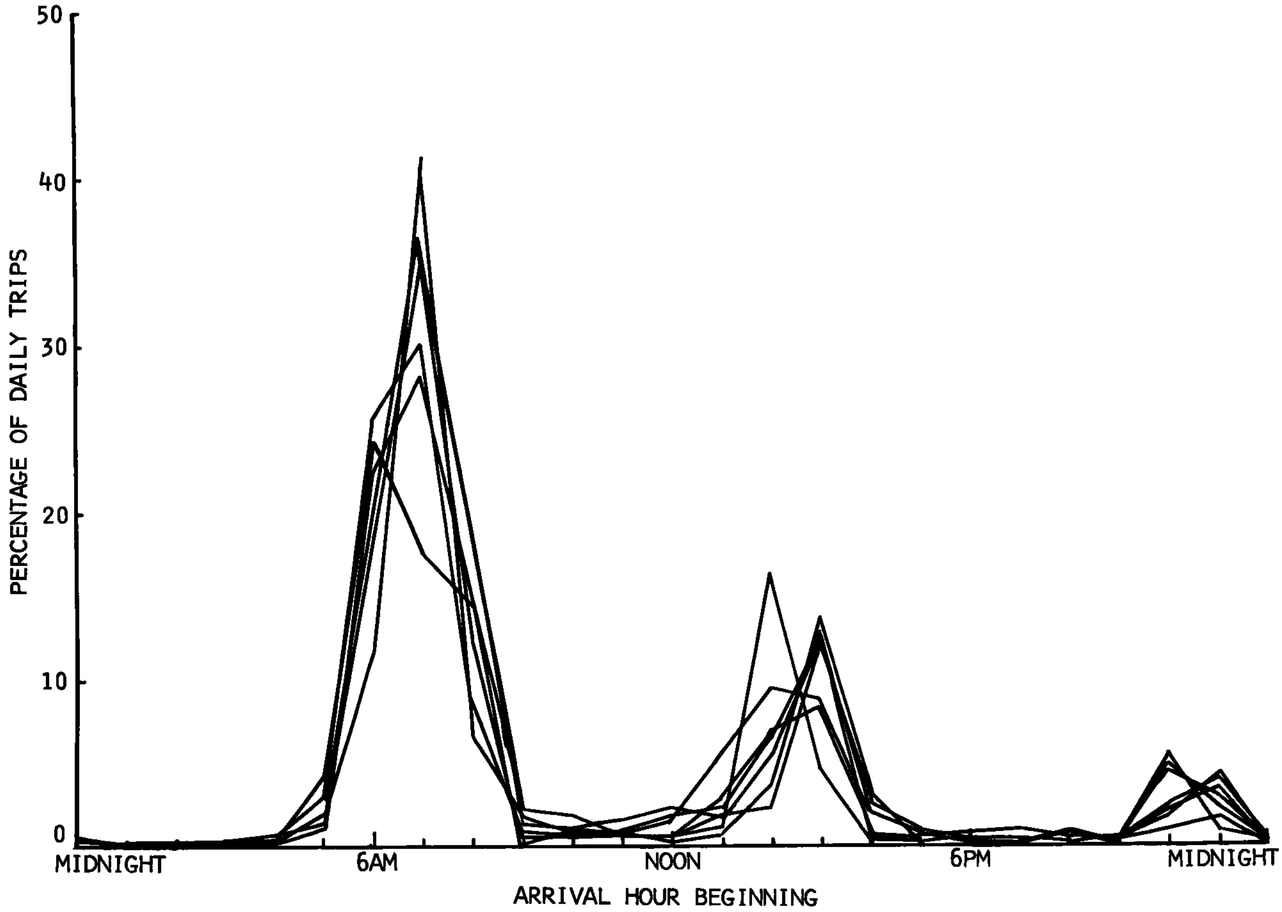

Figure 47. Home interview auto driver trips to work at selected plants, by employment size groupings.

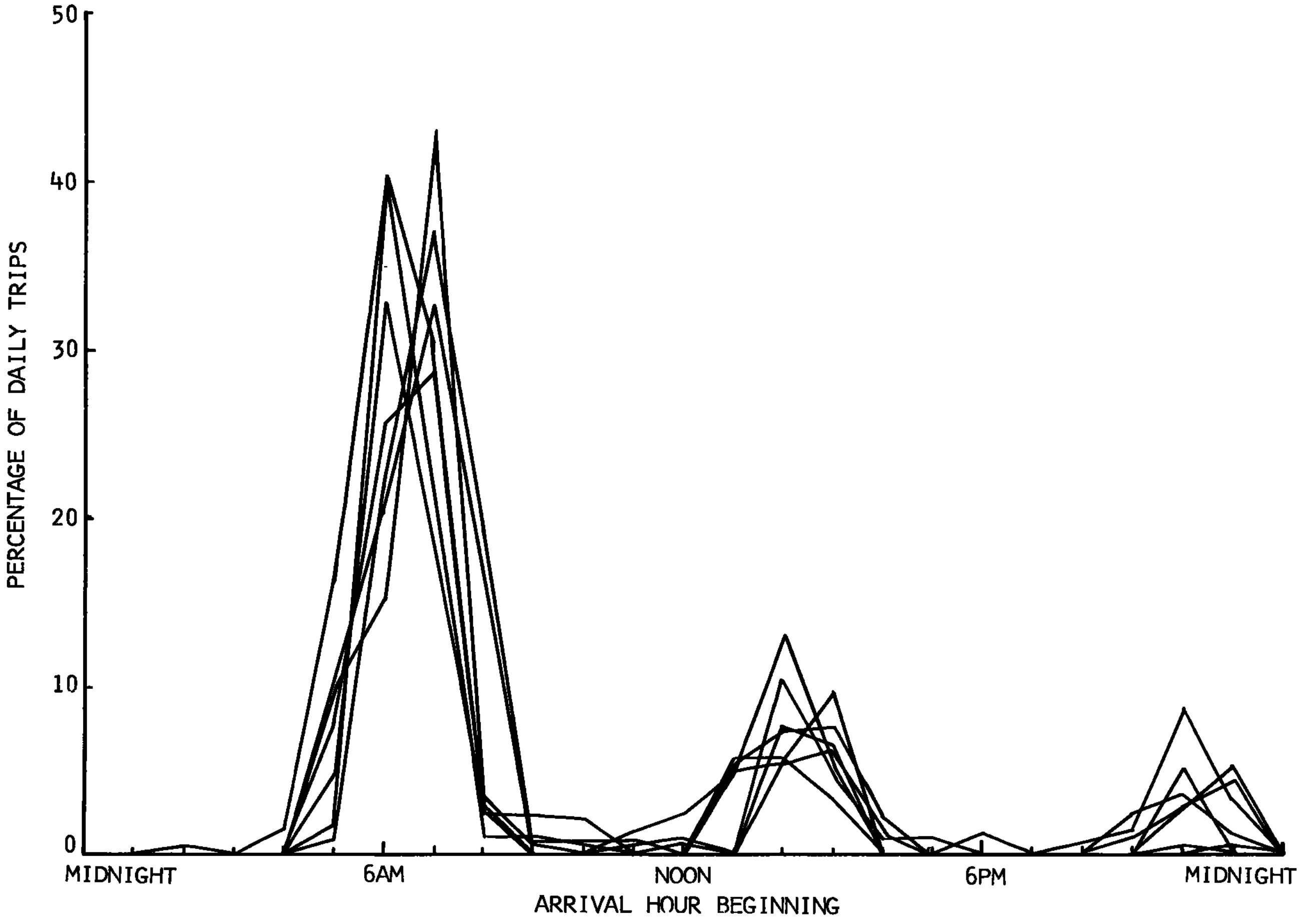

Figure 48. Home interview transit passenger trips to work at selected plants, by employment size groupings.

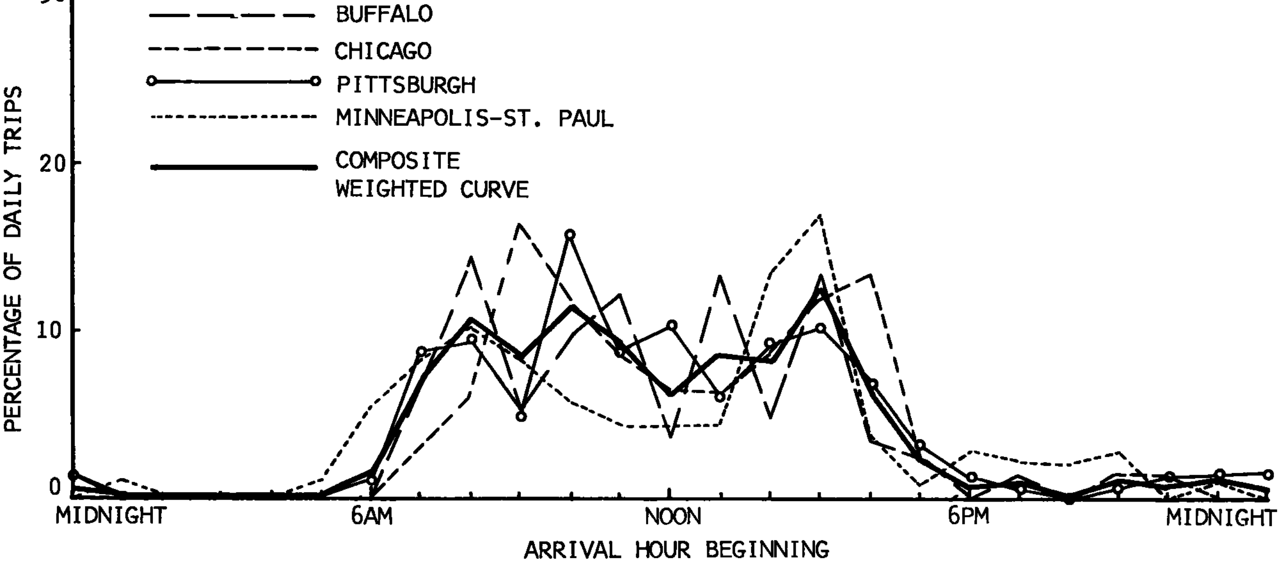

Figure 49. Internal truck trips to selected manufacturing plants.

excluding terminal delays and congestion effects. With additional time allowed for walking to and from the car, for parking maneuvers, and for nominal congestion, the average trip would take closer to 15 or 20 min.

Yet in some respects trip lengths and travel times are surprisingly short. This is because of the large numbers of employees who live almost within walking distance of where they work. The numerous short trips they report tend to balance out the less numerous trips of fellow employees living much farther away. Thus, any discussion of trip lengths and travel times must consider not only averages, but also trip length frequency curves.

Such curves show interesting variations for individual plants. However, when data are aggregated by plant employment group the variations tend to disappear (Fig. 50). A keen eye may discern that the curves for the smaller plant groups are more peaked, and have shorter "tails,"

TABLE 41

TRIP LENGTHS AND TRAVEL TIMES OF HOME INTERVIEW AUTO DRIVER TRIPS TO WORK AT SELECTED PLANTS[a]

PLANT EMPLOYMENT GROUP	TRIP LENGTH (AIRLINE MILES)	ROAD TRAVEL TIME (MIN)
0-999	3.73	11.0
1,000-1,999	4.27	9.1
2,000-2,999	3.92	8.9
3,000-3,999	4.73	8.7
4,000-4,999	4.21	11.0
5,999-9,999	4.47	11.2
10,000-19,999	4.80	NA
Average	4.34	10.1

[a] From transportation study data for various cities.

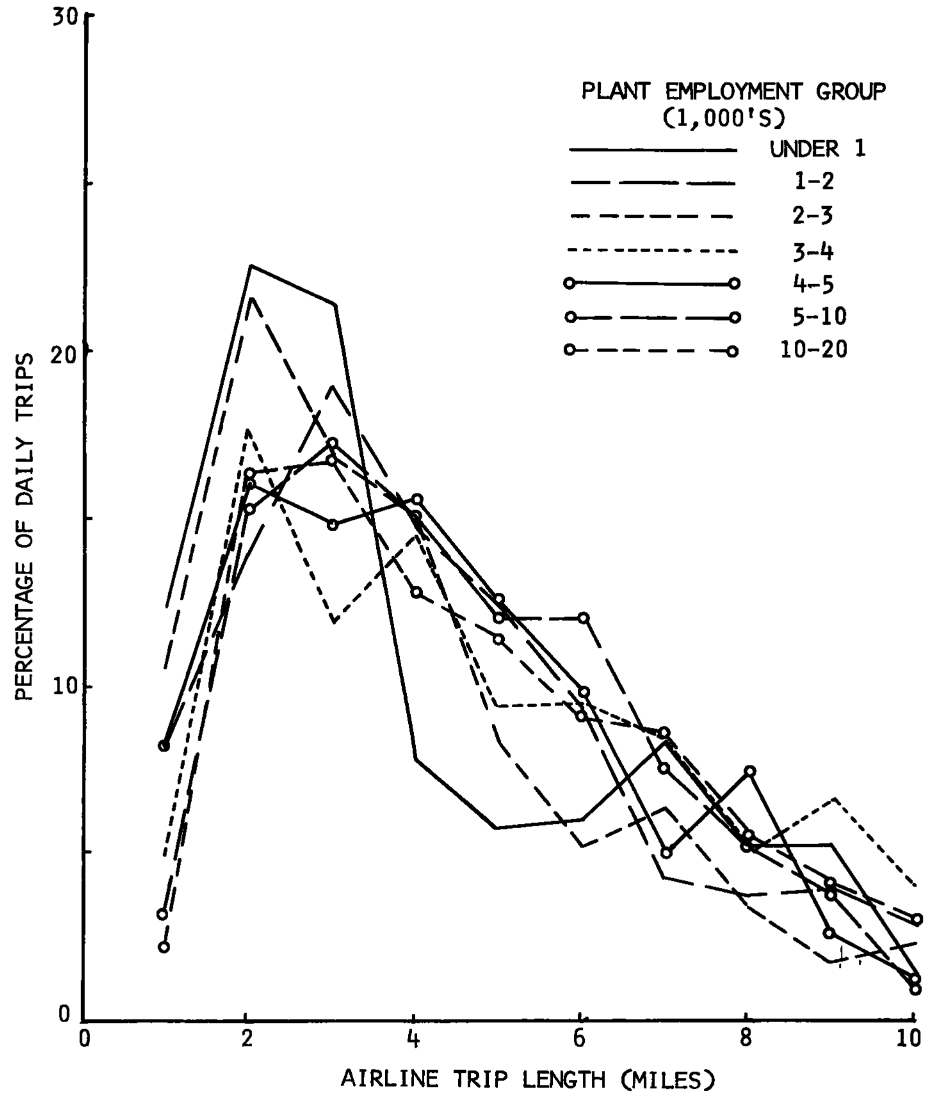

Figure 50. Trip length frequency of home interview auto driver trips to work at selected plants.

than do the curves for the larger plant groups, as would be expected. But it is clear that the composite curves all behave similarly.

Parking and Distances Walked

According to the tripmakers' reports, less than 5% pay for parking. At the subject plants, an average of 84% park free on lots and 10% park free on the streets. Table 42 shows an increasing tendency, as plants grow larger, for workers to park elsewhere than on free lots—perhaps the larger plants simply find it impossible to provide spaces for all employees. It should be noted particularly that 11% of the workers at the two plants employing over 10,000 persons evidently have to park on paid lots. Both of these plants, however, are relatively older plants located in highly built-up areas. Simple observation reveals that most newer plants in suburban locations provide ample free parking for employees.

TABLE 42

HOME INTERVIEW AUTO DRIVER TRIPS TO WORK, BY PLANT EMPLOYMENT GROUP AND TYPE OF PARKING [a]

PLANT EMPLOYMENT GROUP	DAILY TRIPS (%)				
	PARKING ON STREET		PARKING ON LOT		
	FREE	METER	FREE	METER	OTHER PARKING
0-999	1.7	—	94.3	1.3	2.7
1,000-1,999	3.3	—	93.7	1.2	1.8
2,000-2,999	7.3	0.3	89.3	0.6	2.5
3,000-3,999	3.5	1.1	92.5	0.6	2.3
4,000-4,999	22.5	0.7	72.5	2.4	1.9
5,000-9,999	8.0	4.7	83.6	2.2	1.5
10,000-19,999	13.4	—	72.8	11.1	2.7
Average [b]	10.1	1.3	83.7	2.8	2.1

[a] From transportation study data for various cities.

TABLE 43

AVERAGE CAR LOADING FACTOR FOR HOME INTERVIEW AUTO DRIVER TRIPS TO WORK, BY PLANT EMPLOYMENT GROUP [a]

PLANT EMPLOYMENT GROUP	CAR LOADING FACTOR
0-999	1.14
1,000-1,999	1.13
2,000-2,999	1.20
3,000-3,999	1.26
4,000-4,999	1.23
5,000-9,999	1.28
10,000-19,999	1.38
Average [b]	1.24

[a] From transportation study data for various cities.
[b] Weighted.

Nevertheless, in the cross section, even where there may appear to be a parking "problem," few workers report walking any great distance after leaving their cars. More than 90% indicate walking less than a block; 95%, less than two blocks.

CAR LOADING FACTORS

Various studies have shown that the number of persons to a car, or the car loading factor, is variable according to trip purpose. Trips to work have among the lowest factors. Table 43 sets the average for trips to work at the subject plants at 1.24 persons per car. There is considerable variation by plant, however, with individual factors ranging from 1.00 to about 1.50 persons per car. Dealing with averages by plant employment group, it is evident that the factor tends to rise with increasing plant size. This suggests that the greater chance of living near a fellow employee, and, possibly, increasing plant area congestion and shortages of parking spaces, encourages more car-pooling.

Special consideration of the Pittsburgh and Buffalo plants shows that car loading factors also vary according to the tripmaker's sex and the number of cars in his family. For example, male drivers are more apt to have passengers than are female drivers, and both are less apt to have passengers if they come from multi-car families. With increasing auto ownership, average car loading factors are probably declining through time, eventually to reach a figure approaching 1.00 person per car.

TRIP GENERATION

Two trip generation problems might be considered in connection with major industrial plants. The first is where the plant site is described, but nothing is known about employment. The second is where, additionally, the number of employees and certain employment attributes can be described by management.

In the first case, plant site acreage or floor space may be appropriate for predicting both total tripmaking and travel mode distribution. In the second case, which would be far more typical in real situations, total tripmaking is virtually given, and the problem reduces to predicting a modal split in keeping with plant and employee characteristics.

Both problems require a knowledge of plant characteristics, and these were obtained for the present research from three sources. First, questionnaires were sent to 45 of the 49 subject plants. There were 29 replies (see Table B-4). Second, plant site data and data for surrounding land use development were obtained from most transportation studies. Third, most plant sites were field inspected (as were all but a few airports and shopping centers). Although some inconsistencies showed up, these sources supplied the plant descriptions necessary for trip generation analysis.

Employment Unknown

Figure 51 plots, at top, the relationship between total auto driver trips to 24 plants and total plant floor space; at bottom, the relationship between total person trips and total plant floor space. Excepting the three circled points, the

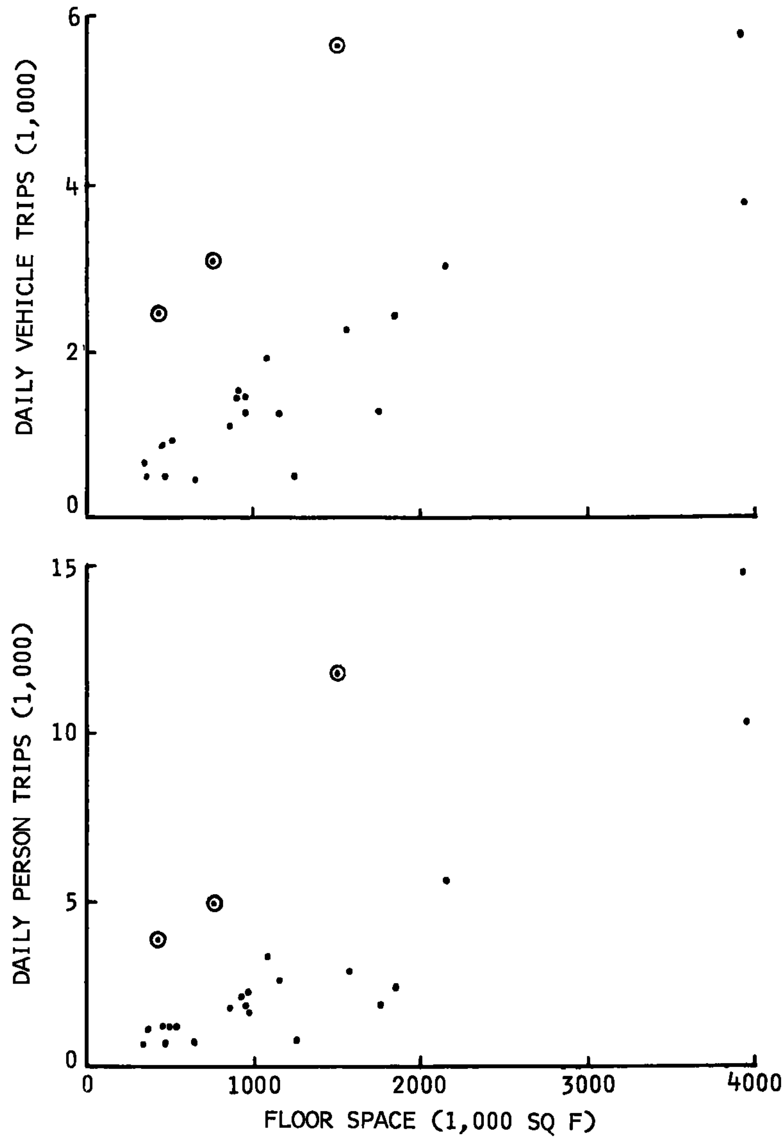

Figure 51. Total person and total vehicle trips to selected plants per 1,000 sq ft of floor space.

relationships are better than were expected. The statistics for auto driver trips are: $r^2 = 0.56$ and standard deviation = 971; with the circled points excluded, $r^2 = 0.84$ and standard deviation = 544. The statistics for person trips are: $r^2 = 0.67$ and standard deviation = 2,284; with the circled points excluded, $r^2 = 0.85$ and standard deviation = 1,345. Although the correlation coefficients are good, the standard deviations may be considered too high for comfort. Comparable work with plant acreage produced worse results.

Floor space is an inconsistent indicator of trip generation for plants of dissimilar types, because it is not all the same. At least four types of floor space can be distinguished: production, storage, office, and service. Each has a distinct function, and may have a variable number of employees per unit area. In an automated steel mill, for example, offices would probably generate trips at a higher rate than would production areas, whereas in an electronics assembly plant the reverse might well be true.

Not only will the generation rates of particular floor space types vary from plant to plant, but so also will the proportional amounts of each floor space type. The average proportions reported by the plants responding to the questionnaire were: production 84%, storage 7%, offices and service 9%. Yet within these averages production ranged from 26 to 99% of the total floor space for any given plant, storage from 9 to 49%, offices and service from 0 to 28%.

In view of these variations, it is not surprising that, where trips to plants cannot be identified by a particular floor space type within a particular site activity code (which is true of all known transportation study land use

coding for trip ends), inconsistent floor area trip generation rates may emerge.

Much the same can be said about plant site areas. Some plants may include a significant amount of vacant and inactive acreage—reserve storage space, railroad sidings, waste dumps, etc. Other plants may include no inactive acreage. Thus, although there may be a positive relationship between tripmaking and plant site area generally, the standard deviation can be quite high.

To summarize, trip generation rates based on plant floor space or plant acreage are not recommended for predicting tripmaking *at specific plants.* Such rates would be difficult to establish for the hundreds of plant types and designs that exist. Even if they could be, they are subject to change as production processes and plant designs change, and application to new plants could prove risky. Finally, where employment is given, they would seem to serve no particular purpose.

Trip generation at the traffic zone, district, ring, or sector level—where aggregation of trips and land areas for a number of like land uses within these larger areas produces trip generation factors at a different scale—is another matter. In this context, floor space or acreage can provide useful indicators of trip generation. The findings in this report, whether for airports, shopping centers, or industrial plants, should not be construed as casting doubt on the effectiveness of this more typical application of the trip generation process. Rather, they consistently refer to the difficulty of using floor space or acreages *as single variables* to predict trip generation *at specific sites.*

Employment Given

Typically, where plant employment exceeds 1,000, average daily work attendance may be taken as 90% of employment. Also typically, about one nonwork trip is reported for every 20 work trips. Therefore, in most situations, total tripmaking can be taken as 95% of the given employment figure. For highway design purposes, the task then is to estimate the resulting number of auto driver trips.

Because many factors bear on selecting the means of travel to work, multiple regression analysis would seem an appropriate approach to assigning them proper weights. Unfortunately, in a sense, a multiple regression analysis of trip generation at any given activity site can turn into a major research project in its own right. Both dependent—that which is to be "explained"—and independent—the "explainer"—variables must be defined and measured, and there may be scores of variables which are pertinent.

Moreover, cause and effect are never proved by such an analysis; only the association between and among variables can be demonstrated. And, although the researcher has a choice of convenient computational programs to draw upon, the search for a practical predictive device depends on judgments as to which independent variables will be used. Often, this comes down to the two or three which "explain" most of the variation in the dependent variable, and which themselves are readily available. Such was the case with the multiple regression analysis of trip generation at industrial plants.

In setting up the analysis, it was anticipated that not all pertinent variables would be available for all subject plants. Therefore, two analytical phases were planned, the first to include only the 25 Pittsburgh and Buffalo plants for which the most complete array of independent variables could be assembled, the second to add the 16 Chicago and Minneapolis-St. Paul plants for which only slightly fewer independent variables (i.e., all but family car ownership and driver licensing data) could be assembled. The first phase was expected to produce the better results, for although statistically there would be fewer degrees of freedom there would be two additional, and presumed strong, predictors.

In the first phase, three computer runs were made. The first run treated two dependent variables: Y_1 = auto driver trips, and Y_2 = transit passenger trips. These and all subsequent dependent variables were expressed as home interview trips to work at the subject plants. Fifteen independent variables were established (Appendix C defines all variables and provides the detailed results of this and subsequent runs). The MANOVA program developed by Seal (*42*) was used. The second run treated identical variables, but used the California biomedical stepwise regression program (*43*). The third run slightly redefined certain independent variables, and added two new dependent variables: Y_3 = percent auto driver trips, and Y_4 = percent transit passenger trips. Only the stepwise regression program was used.

Using the full models—that is, all independent variables—multiple coefficients of determination, R^2, ranged from 0.82 to 0.98. Although this was most encouraging, standard errors of the estimate, as percentages of the dependent variable means, ranged from about 14 to 72%. In other words, the predictive equations were not as good as they might seem.

In the second phase, only one computer run was made, using the stepwise regression program. Two additional dependent variables were treated: Y_5 = auto driver and auto passenger trips, and Y_6 = percent auto driver and auto passenger trips. Based on the previous runs, the number of independent variables was reduced to eleven, with further redefinition.

In general, results of the second phase were better than the first phase. Using the full models, again, R^2 values ranged from 0.63 to 0.97; standard errors of the estimate, as percentages of the dependent variable means, ranged from about 10 to 61%.

Statistically, the more significant variables affecting modal choice were those describing employee attributes; for example, the percentage of white collar workers, the percentage of licensed drivers, the percentage from car-owning households, etc. Contributory area characteristics, such as the net residential density within a 3-mile radius of the plant, the auto ownership rate per 1,000 persons, and so forth, were not very significant. Nor were plant site characteristics such as total plant acreage, employment density in the plant traffic zone, and so forth.

On the whole, the investigation must be considered a modest success. Useful predictive equations were developed, and relative weights for the influence of independent variables were determined.

However, many researchers have pointed out the pitfalls

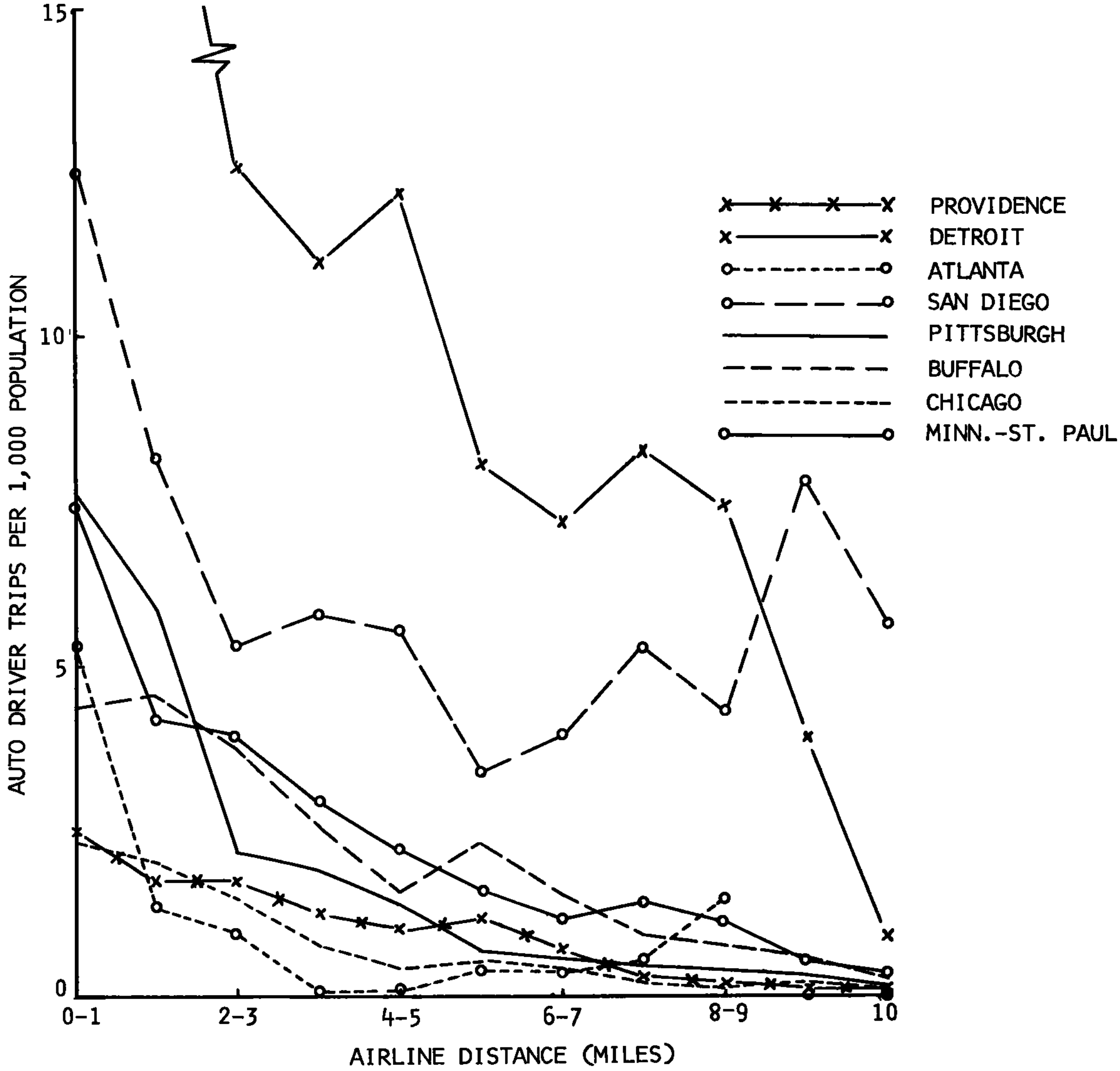

Figure 52. Home interview auto driver work trip rates, by distance, to selected plants.

of applying the results of multiple regression haphazardly. A recent publication by Northwestern University (*47*) is excellent in this respect. This report need only repeat that caution and much common sense are required.

TRIP DISTRIBUTION CHARACTERISTICS

Having developed ways to predict auto trips to industrial plants, the next problem to resolve is how the origins of these trips are distributed. This will determine any traffic imbalance in the approach roads to the plant, and will allow attention to be focused on the critical approach direction.

Trips would be expected to arrive directionally according to the distribution of surrounding population, taking into account the decreasing rates of trip generation at increasing distances from the plant. If this expectation is correct, the problem of apportioning trip origins spatially, and of assigning them to the highway network servicing the plant, will be simplified.

Distance Rates

Where travel times are unavailable, and major travel barriers do not exist, distance provides acceptable results for distributing trip origins. Figure 52 plots the composite curves for subject plants, by city groupings, showing the auto driver trip rates per 1,000 population by distance. The curves tend to have the same shape and slope. Grouping the data, of course, helps smooth out the irregularity in plots of individual plants, and the more plants to a city group, the smoother the curve.

Positioning of the curves relative to the chart's vertical axis is principally the result of differences in the average employment at plants in each city grouping (the surrounding population density is also a factor). By normalizing rates to the common base of 1,000 employees—rates for plants with more than 1,000 employees decreased proportionately; rates for plants with less than 1,000 employees

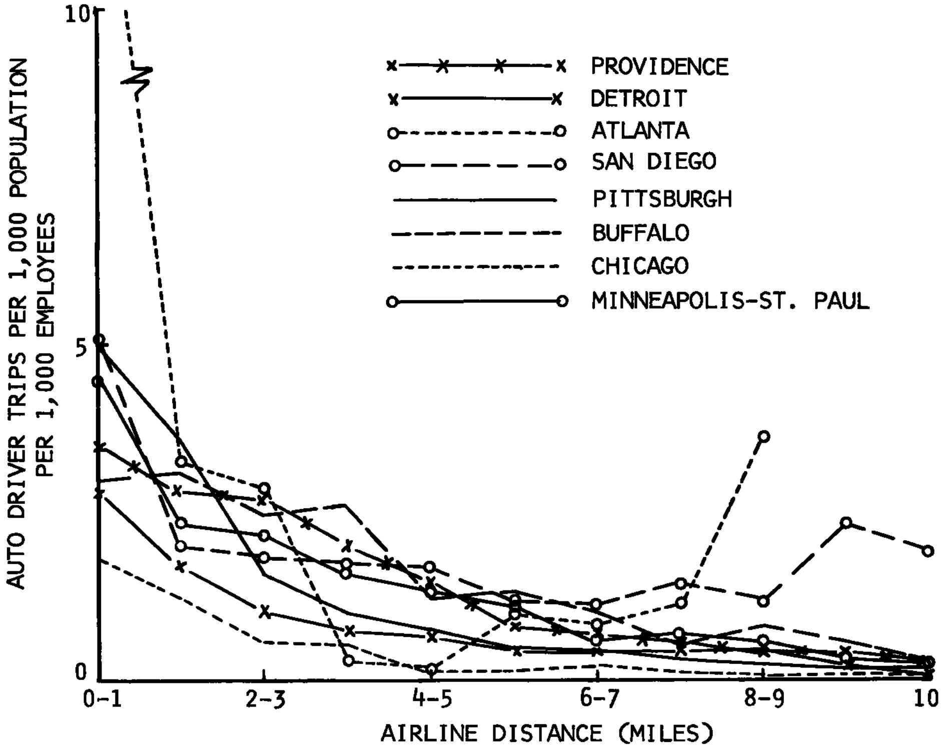

Figure 53. Home interview auto driver work trip rates, by distance, to selected plants, normalized by plant employment.

increased proportionately—the vertical spread between curves is considerably reduced, as shown by Figure 53.

The method used to consider whether or not the curves held good in any direction from any given plant was to back-predict trip origins, and to compare the predicted with the actual, by major travel corridor. From three to six corridors were designated for each plant, generally arranged so that they were traversed by a major travel route to the plant. Because predicted trip origins seldom equaled actual trip origins for each plant, they were prorated to the actual trip origins (maintaining the proportions of predicted trip origins by corridor).

Plots of predicted versus actual trip origins by corridor provide visual demonstration (Fig. 54) that directional predictions were erratic. Pittsburgh proves the worst case. Workers are reluctant to cross major travel barriers—namely the wide river valleys, spanned irregularly by traffic-crowded bridges. Most live on the same side of the valley as the plant, out of proportion to the distribution of population.

Predictions were only slightly better for Minneapolis-St. Paul plants. Actual trip origins appeared to be influenced by river valleys and other natural travel barriers. (This has also been noted in a recent study by Voorhees, *et al.* (*48*)). Trip rates per 1,000 population were higher on the plant side of the river valleys than on the other side. Because the topography is not as irregular as Pittsburgh's, the degree of influence appeared to be less.

Trip rates in Chicago, which is virtually level and has few major travel barriers, appeared simply to be higher on the suburban (farside) than on the CBD (nearside) approach areas of the plant—somewhat the same effect previously noted for trip rates to certain shopping centers. Possibly there is a universal tendency for workers to live on the suburban side—the side opposite the CBD—of where they work. This is where new housing is more readily available, and where most urban growth occurs. To some extent, the farside-nearside effect was discernible in the Twin Cities and Pittsburgh trip origins maps as well.

Why this did not happen with the Buffalo trip pattern is unknown. In any case, when trip origins were back-predicted, using an eyefitted average curve from Figure 53, the results were very good. The correlation between predicted and actual trips, based on about four travel corridors per plant, was $r = 0.97$. This tends to show that, in Buffalo at least, trip rates are about the same in any direction from each plant.

In an attempt to improve the results in the other three cities, the actual trip rate curves were reformulated, distinguishing between farside-nearside (of CBD) in Chicago and between plantside and otherside (of major river valleys) in Pittsburgh and the Twin Cities. The results (Fig. 55) indicate a definite and consistent difference between the two types of rates.

Applying the weighted average curves, one representing the higher rates and the other the lower rates, in a back-prediction (as previously described) improved the Pittsburgh, Twin Cities, and Chicago predictions significantly (Fig. 56), but not the Buffalo prediction. Although time was not taken to refine this technique further, there is clear indication that in some cities special consideration must be

given both to major travel barriers and to nearside-farside differences.

Time Rates

"Free" travel time trees were available for only one-half the plants in the cross section—the 25 in Pittsburgh and Buffalo. "Restrained" trees were available for the three Atlanta plants, but because travel times would not be comparable to the others the Atlanta plants were not combined with those in Pittsburgh and Buffalo.

Figure 57 shows auto driver trips to work per 1,000 population, normalized to a constant base of 1,000 employees per plant, at successive 2-min time intervals from the Pittsburgh and Buffalo plants. Pittsburgh's higher rates at travel times under 4 min probably reflects its "milltown" developments, where densely built-up valley communities surround older steel mills (6 of the 11 Pittsburgh plants produce basic metals, and definitely weight this subsample).

Theoretically, travel time curves might make adjustments for travel barriers, and any nearside-farside differentials, unnecessary. A backcheck prediction bears this out for Buffalo, but not for Pittsburgh (Fig. 58). The Buffalo result is very good; the Pittsburgh result is very bad. It was necessary to re-investigate the influence of travel barriers in Pittsburgh, over and above the obvious effects on travel time.

Figure 59 breaks down the Pittsburgh time trip rate curve by a plantside-or-otherside-of-travel-barrier distinction (nearside-farside, for simplicity). The upper half of the figure shows the difference on the familiar population base; the bottom half, the difference using total resident work trip origins as a base (the relationship to total population is not constant).

Both nearside and farside curves reveal, on both bases, that at 6 to 8 min travel time and beyond, trip rates are nearly the same. However, at lesser travel times the differences are significant. It would appear, therefore, that

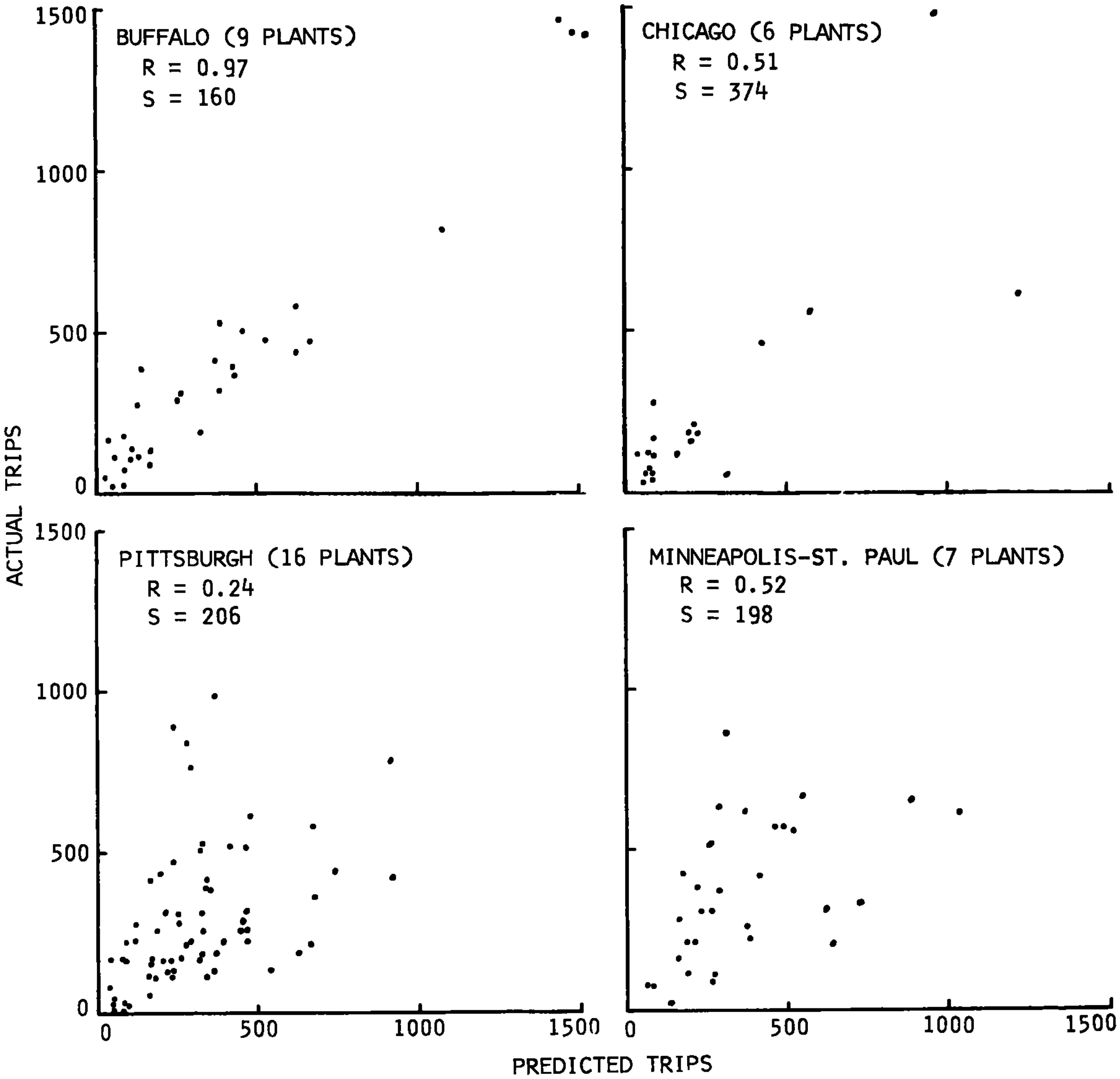

Figure 54. Actual vs predicted auto driver trips to work, by study area corridors, prediction on distance.

workers living in towns just across the valleys from the plants prefer not to cross the rivers, while workers who live across the valleys but beyond the first ridge of valley hills are willing to do so. Plots of blue-collar versus white-collar trip origins (of which Fig. 60 is an example) suggest that proportionately more white-collar workers will cross the rivers from the more distant suburbs.

Having shown that trip distributions could be predicted reasonably for plants in the Buffalo, Chicago, and Twin Cities areas, additional work to refine the complicated distributional pattern in Pittsburgh did not seem warranted. Kochanowski (*49*) has noted that the shape of trip distribution patterns may be

> . . . . . more a result of historical development and employment tradition than it is of the existing transportation system or other current factors. In older mill towns like Southside, Homestead, Lawrenceville, etc., most mill workers are traditionally sons of fathers who worked in the same mill and lived several blocks away. Even though areas around these mills have developed, I think that the mills still draw the majority of their labor forces from their traditional 'residential shed.'

Distributional Models

Several reviewers have correctly questioned why more vigorous trip distribution models, such as the "intervening opportunities" model (*50*), have not been brought to bear. One posed the example where a major manufacturing plant is surrounded by a vast swamp. In this case, both the distance and travel time trip rate curves presented previously might yield too few trips, because trip rates would have decreased seriously before residential areas were reached. This would not happen with the intervening opportunities model, for example.

Perhaps the principal justification for avoiding models is that they tend to get unduly complicated. Sending trips from plants to residential areas would require identification

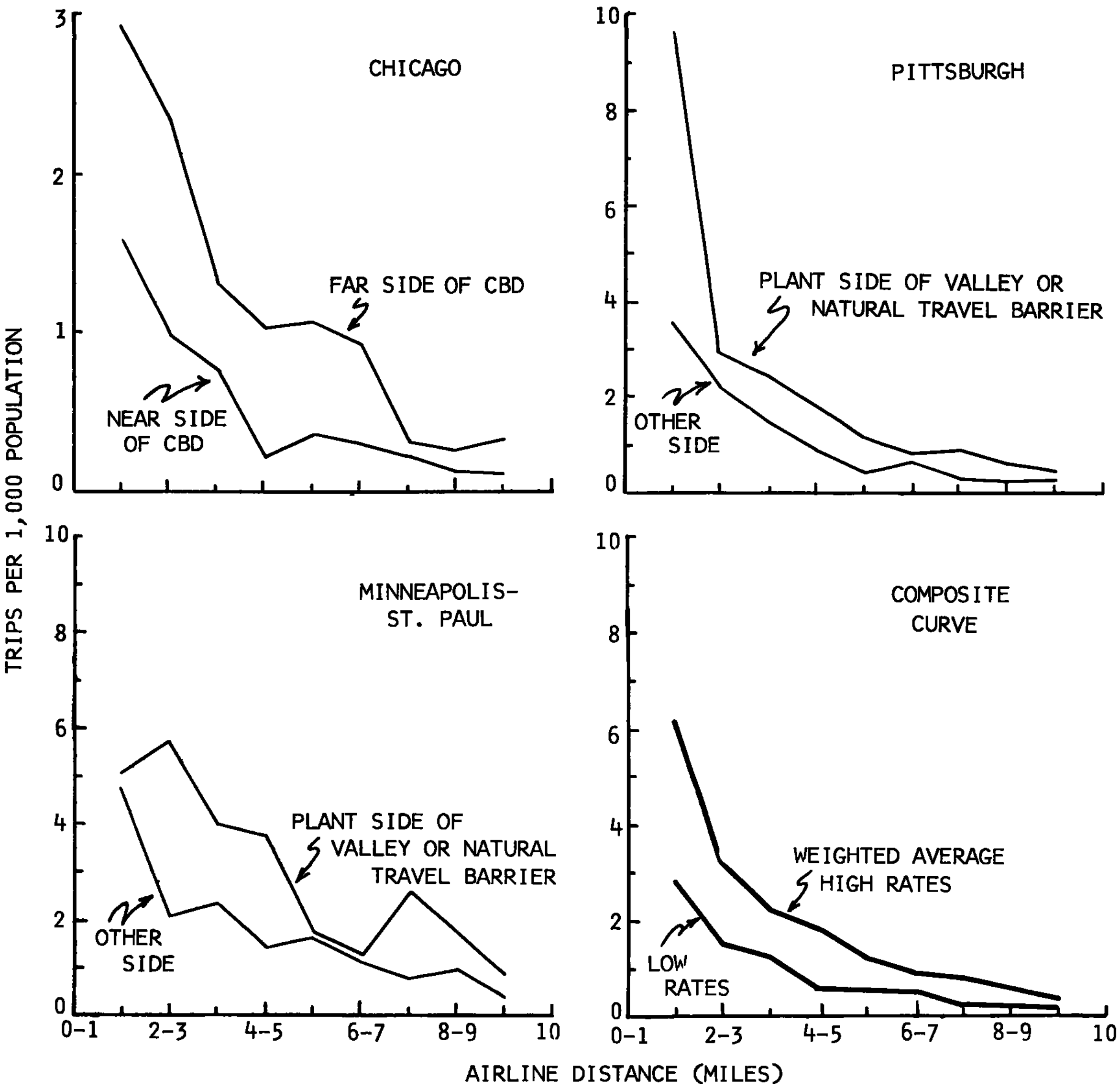

Figure 55. Home interview auto driver work trip rates, by distance, to selected plants, by "inside-outside" location.

of "opportunities" in the latter areas, perhaps in terms of total work-to-home trip destinations; sending trips from residential areas to plants might require identification of total home-to-work trip destinations. Moreover, there are problems of calibrating *L*-values, or gravity model *K*-factors, etc. Probably, the results would be improved. Yet trip rate curves based simply on population would seem appropriate enough in most situations, and require only census data. It should be remembered that the resulting trip predictions must always be prorated up (or down) to the predetermined total trip generation, and therefore only the directional proportioning of trips has any real consequence.

TRAVEL IMPACT ON HIGHWAY NETWORK

Travel Impact

The vehicle-miles of travel attracted by any single plant represent only a very small proportion of the total vehicle-

TABLE 44

TRAVEL IMPACT OF VEHICULAR TRIPS TO SELECTED MANUFACTURING PLANTS IN PITTSBURGH [a]

PLANT	TRAVEL (%) IN STUDY AREA	TRAVEL (%) IN PLANT ZONE	DESIGN CAPACITY USED (%) ZONAL ART. STREET 24 HR	ZONAL ART. STREET 7-8 AM	MAIN ACCESS ROAD 24 HR	MAIN ACCESS ROAD 7-8 AM
1	0.08	7	9	24	25	70
2	0.31	5	10	36	31	110
3	0.17	43	20	78	34	128
4	0.34	10	19	60	16	100
5	0.26	15	22	70	45	147
6	0.20	13	11	22	12	75
7	0.38	10	13	102	62	220

[a] From Pittsburgh Area Transportation Study trip tabulations and street inventory data (52).

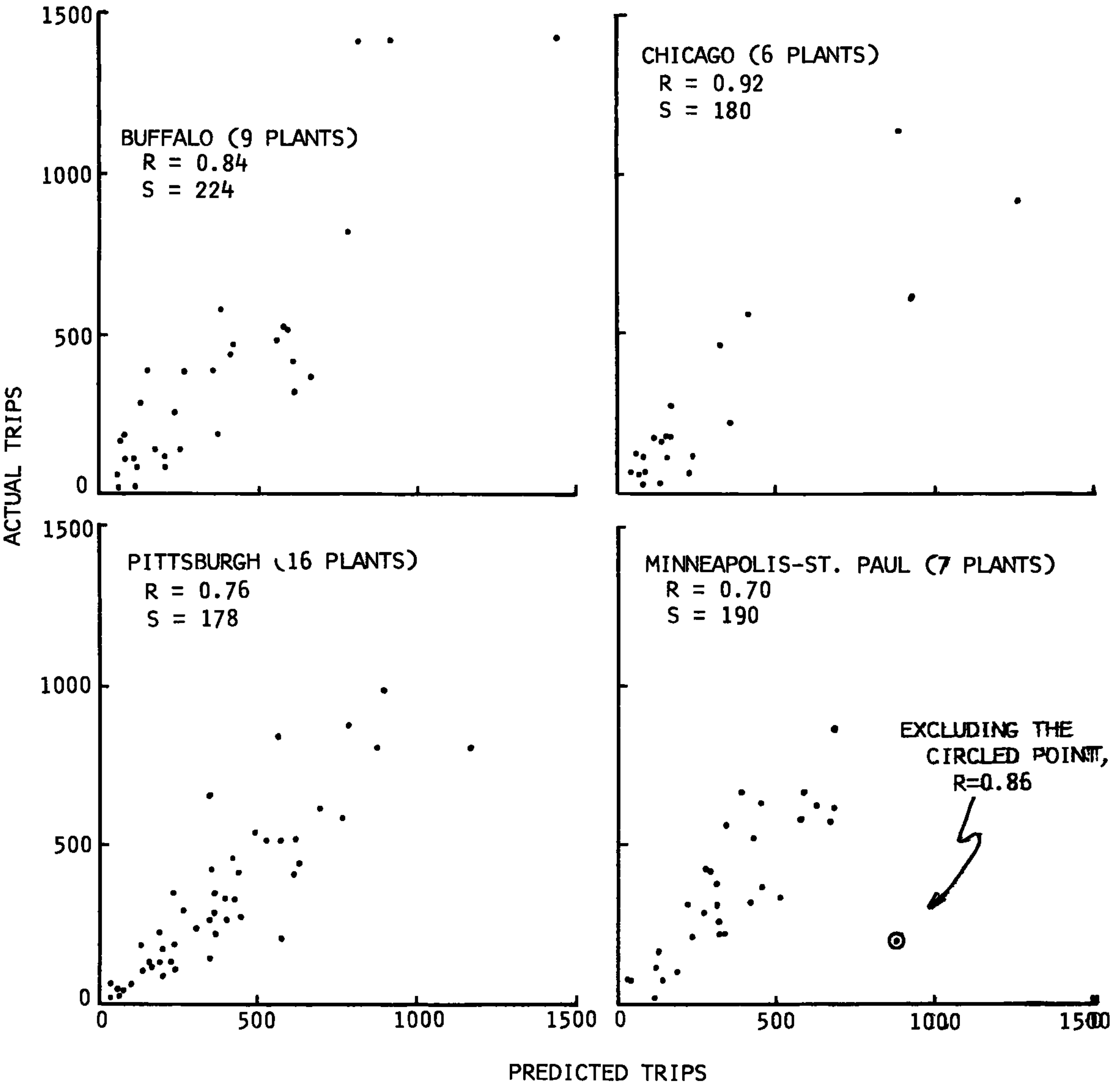

Figure 56. Actual vs predicted auto driver trips to work, by study area corridors, prediction on distance, using "inside-outside" rates.

miles of travel in an entire metropolitan area. Selected plants in Pittsburgh provide useful illustration: the largest single-site employer in the Pittsburgh area, plant 7, attracts only 0.38% of the total metropolitan travel (Table 44). Plant 1, by no means a small employer, is responsible for less than 0.1%. All seven plants together attract less than 2% of the total travel. Because the total travel is so great —on the order of 10 million vehicle-miles daily (*51*)—any similar comparison for the Pittsburgh area, whether for large plants, department stores, shopping centers, or even sports stadia, will result in such small proportions as cited.

Travel impact is first felt in the immediate area of the plant site. Table 44 shows that a single plant can account for nearly one-half of the total vehicle-miles of travel within the traffic zone in which it is located (plant 3, 43%). This proportion represents all trips to and from the plant in a 24-hr day. Because size and content of zones vary, the proportion of zonal traffic accounted for varies, most often ranging from 5 to 15%. All seven plants together average 12%.

Of course, where arterial streets in the plant's traffic zone provide adequate capacity, the plant might account for nearly all of the travel within the zone without creating any particular problem. For example, although plant 3 creates 43% of the travel in its zone, it nevertheless requires only 20% of the available arterial street capacity.

On the whole, however, because capacity is usually a problem in industrial corridors, it is the other way around; the plant requires a higher proportion of the daily capacity available than the proportion of the daily travel it creates. Moreover, on a 7 to 8 AM peak-hour basis, the proportion of arterial street capacity required may exceed 100% (plant 7, 102%). During this typical morning peak hour, the seven plants require an average of 56% of the available capacity. The lowest proportion is 22%, still sizeable.

Possibly the key comparison is the percentage of main access road capacity required; that is, travel to and from the plant on the main access road compared to its capacity. Table 44 shows that on a 24-hr basis this varies from 12 to 62%; on a peak-hour basis, from 70 to 220%. By the Pittsburgh definition of design capacity (52), anything over 140% represents severe overloading and extremely poor quality of travel service, for employee traffic as well as for through traffic.

In concentrated industrial corridors, plant congestion often overlaps. Parts of the major river valleys in Pittsburgh, for example, are virtually lined with plants all served by a single main access road. In selecting sample plants, physically separate rather than contiguous sites usually were taken to minimize the effects of competition for the same street space. However, one such case was accepted for the purpose of scaling the traffic consequences of the problem.

Plants 2 and 4 are contiguous within the same traffic zone. By adding together values from Table 44, combined travel is shown to represent 15% of the total travel in the zone; to require 29% of the available arterial street capacity on a daily basis, and 96% on a 7 to 8 AM peak-hour basis; to require about 47% of the main access road capacity on a daily basis, and about 210% on a 7 to 8 AM peak-hour basis. Such percentages suggest the critical travel impact that two major adjacent plants can have, particularly when served almost exclusively from the same main access road.

There is no escaping the fact that workers at any given plant may commute past other plants which employ workers with the same skills. This was seen by comparing trip origin maps for each plant. (It is obvious that if there were only three plants served by one main access road, it would follow that all of the employees of the middle plant would have to drive past one of the other plants.) Thus there is some sense of competing for the same road space at the same time.

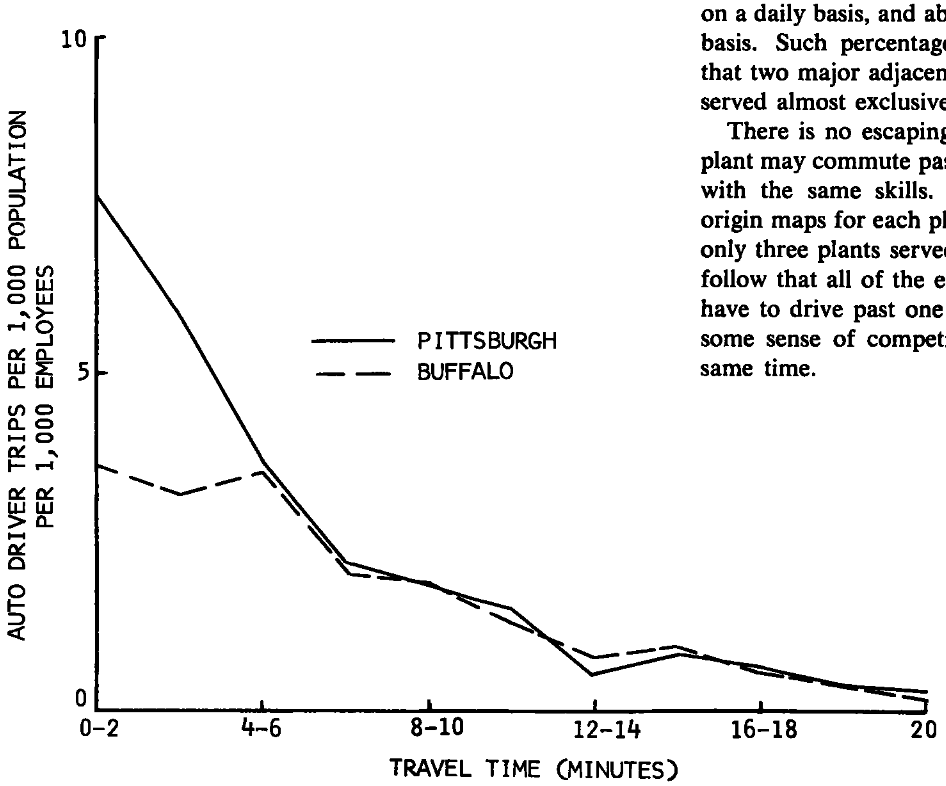

Figure 57. Home interview auto driver work trip rates, by travel time, normalized by plant employment.

Reducing Travel Impact on Highway System

Although staggered work hours would alleviate such competition, they are difficult to arrange where more than one management is concerned. With a single management, such as the Federal Government in Washington, D. C., the arrangement may be more feasible. Even there, however, differentials of 15 to 30 min do not fully space out the troublesome traffic peaks. Apparently differentials of an hour or more are needed, and it seems questionable whether they can ever be provided.

Competition might better be reduced by spacing out plant locations. In some metropolitan areas, however, this principle will often be defeated by a scarcity of satisfactory manufacturing sites. In Pittsburgh, for example, many plants had to be located just as they were. There was little choice—large level sites, with access to water and rail transportation, could be found only in the valley flats. In similar situations, no amount of planning or zoning can really dictate plant locations.

Of course, with the newer manufacturing plants, particularly those classed as light industry, site selection is less limited. Plants that are not rail- or water-oriented can be located almost anywhere. With this kind of plant, two locational alternatives might be considered. First, instead of restricting industrial development to a limited number of large areas, as is typical of some master plans, there might well be a scattering of light industrial plants throughout the residential suburbs. Second, if concentration of like activities must be the goal, master plans might make more use of the industrial park concept.

Through controlled development, manageable ceilings could be imposed on the amount of tripmaking created. This would permit highway planners to anticipate peak loads and to provide added highway capacity as needed. Both scattered light industry and industrial parks could have a maximum allowable size, and could be widely spaced, rather than contiguous.

Design Implications

The previous section attempted to show that although trip generation at a particular plant may not be sufficient to affect the design of areawide systems of major travel facilities such as freeways, it certainly does affect the local traffic problem.

What values can be developed which will directly assist the highway designer in meeting this problem? First, there are predictive equations which will suggest to him the daily number of auto driver work trips to a particular plant. Second, there are alternative trip rate curves which will suggest the directional orientation of the resulting auto driver trip origins. Finally, there are the peak-hour traffic percentages of automobile and truck trips, and the directional tendency of traffic (Table 45). Although none of these values can be applied to any given problem to get a design answer, altogether they may provide perspective.

Table 45 shows, for example, that when averages are taken by plant employment group the peak-hour proportion of daily passenger car units (light trucks and taxis counted as cars) attracted is consistently around 36 to 45%. Table 45 also shows that medium and heavy trucks are consistently only 3 to 7% of the total daily vehicles attracted. For the cross-section plants, at least, such percentages should be reasonably accurate because they are based on relatively large samples. Truck trips during the peak traffic hour range from 0 to 11% by plant group, but such percentages are based on relatively smaller samples and may not be entirely accurate.

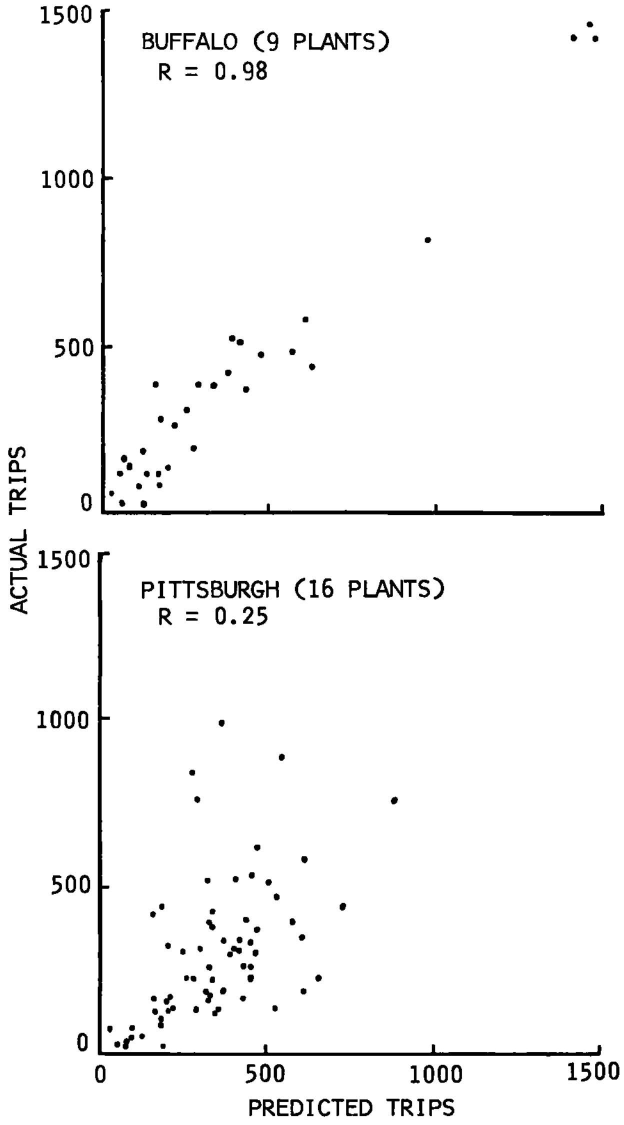

Figure 58. Actual vs predicted auto driver trips to work, by study area corridors, prediction on travel time.

Directional tendency, or the proportion of total vehicle trips in the dominant direction of travel during the peak hour, is derived by assuming that all auto-driving employees reporting to work for the night shift will be leaving during the morning peak. Derivation was necessary because trips *from* plants were not obtained from the transportation studies. Using this technique, Table 44 shows that between 79 and 94% of the two-way morning traffic is moving to the plants.

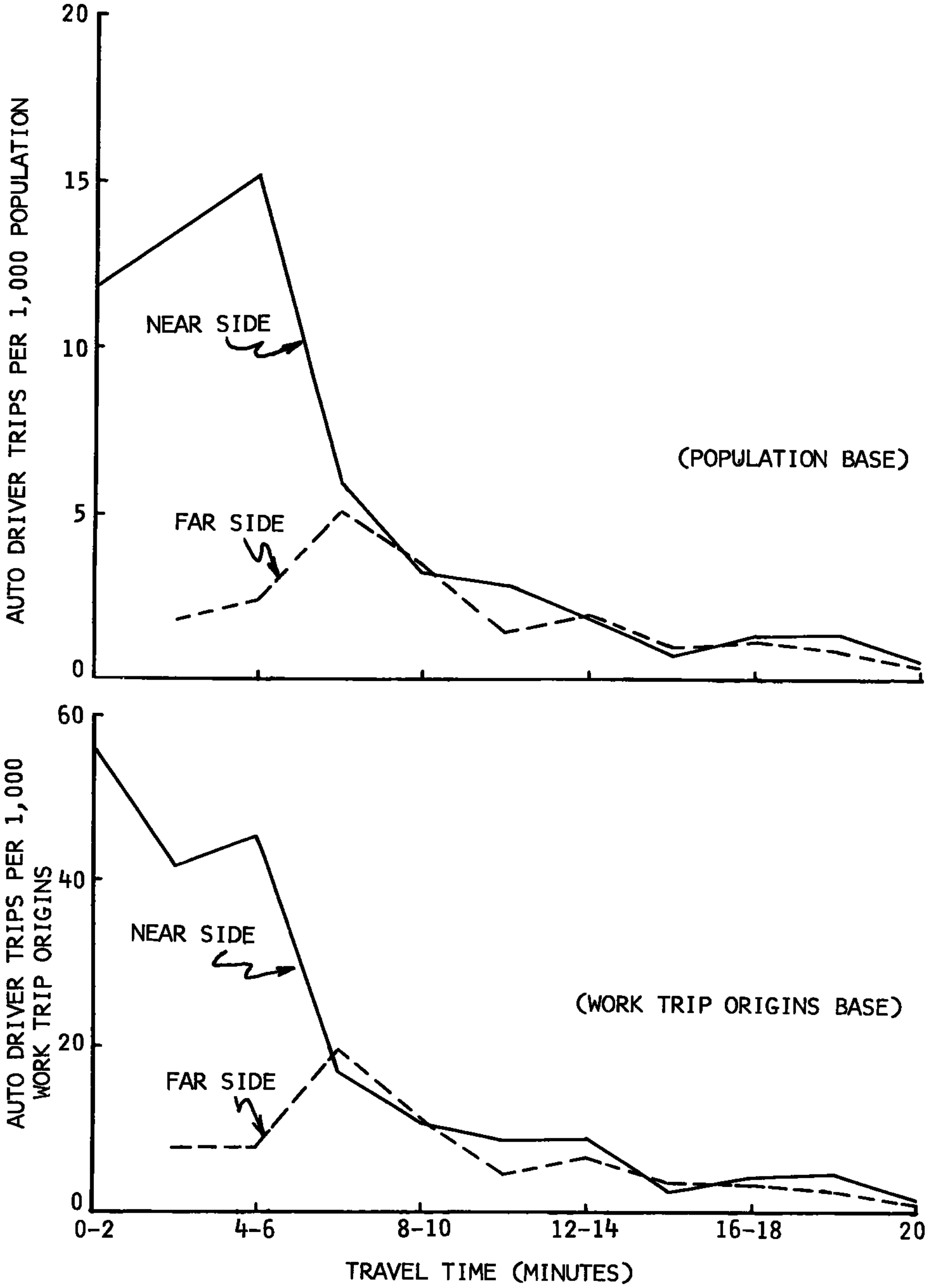

Figure 59. Home interview auto driver work trip rates, by travel time, to selected manufacturing plants in Pittsburgh (seven plants only).

Projecting design factors into the future, of course, raises additional problems related to trends. Changes in production patterns could affect the relative proportions of workers on each shift, and thus the peak-hour percentage, and the directional tendency. Changes in shipping patterns could affect the percentage of trucks during the peak traffic hour, and so forth. Such design factors as found in this report, representing existing or historical patterns, cannot directly anticipate all of the problems of projection.

A major development of distinct concern is the industrial park. In effect, the problem of providing good access to a new industrial park is the same problem as providing good access to a collection of separate plants, except that they all share a common location. Although no industrial parks were included in the present cross section, it can be speculated that, to some extent, each would represent a unique case, reflecting the mixture of industrial activities it contained. Therefore, the best approach might be to summarize the trip generation and trip distribution characteristics of each component.

PREDICTING AND TESTING RELATIONSHIPS

One way to test the effectiveness of the relationships suggested in this chapter is to apply them to a new situation —to attempt to predict the existing tripmaking at several plants not in the cross section from which the relationships were derived. This would not prove or disprove the relationships (because they are already factually based) but would tend to determine whether they had general application, and to point up remaining problems.

For this purpose, data on tripmaking to five maunfacturing plants in the Wilmington, Del., area were obtained from the New Castle County Program (land use-transportation study). Although this reported tripmaking itself is subject to sampling variability, it should be sufficiently accurate for use as a reliable benchmark of actual tripmaking. The following section summarizes the results (see Appendix C for further detail).

Essentially, predictions were made "at arm's length" (that is, without any on-the-ground studies, or direct contact with the plants involved). For example, trip rates for trip distribution were based on distance, rather than special travel time studies; transportation study data were used to fix plant employment and employee characteristics, rather than data obtained directly from the plants. Moreover, only one out of several dozen possible modal split regression formulas was used. In effect, this was a very quick look

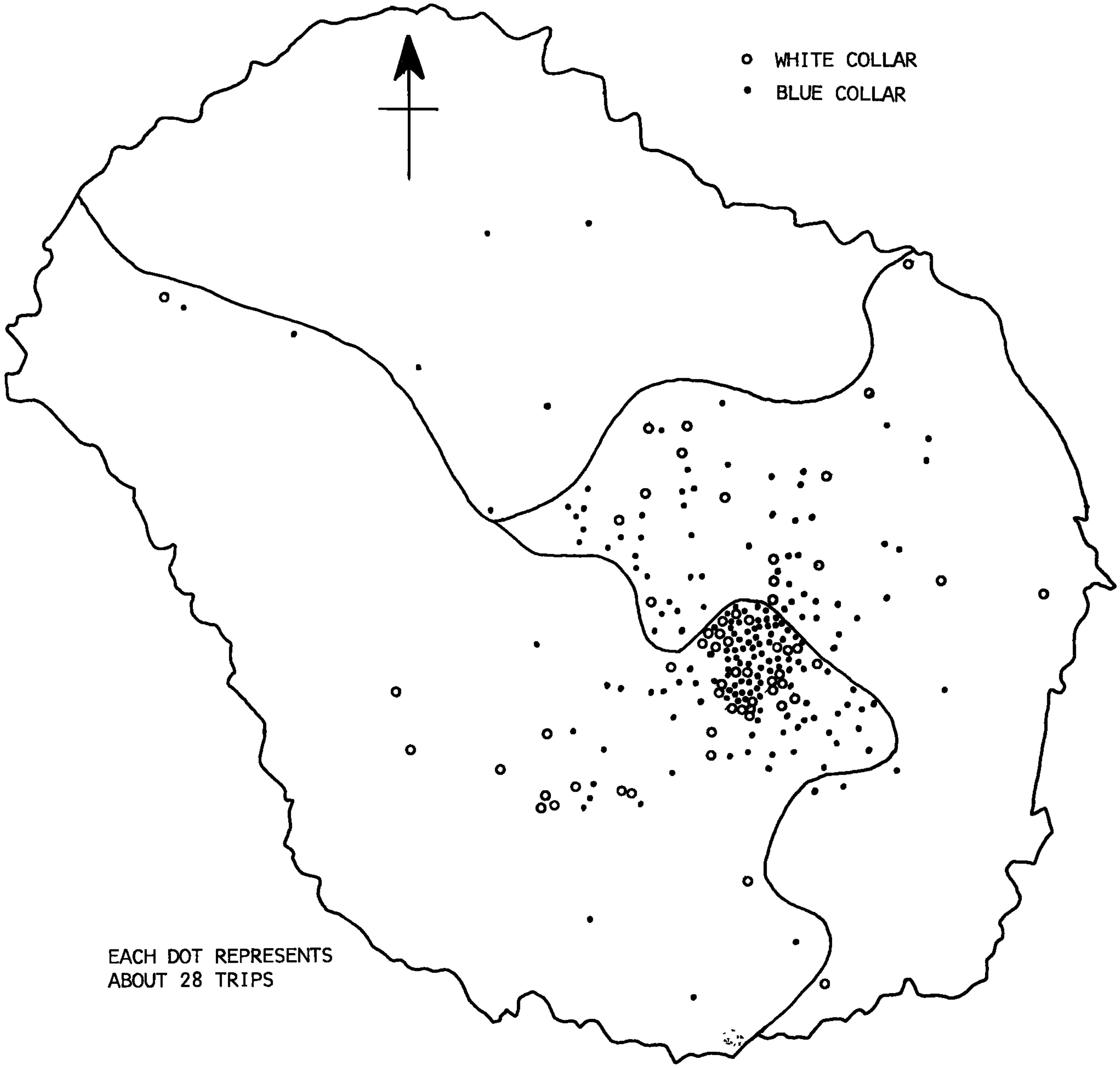

Figure 60. Home interview person trips to work at Plant 4, Pittsburgh, blue collar vs white collar trip origins.

at principal relationships. In practice, additional work might be expected, and possibly better predictive results.

Total auto driver work trips were predicted reasonably well, the proportion of predicted to actual trips for each plant calculating to 102, 146, 92, 90, and 99%, respectively. The proportions of trips from the highest trip generating sector of the study area were predicted less well, the ratios of predicted to actual trips computing at 67, 110, 170, and 112%, respectively. Comparable percentages for predicting the peak traffic hour were 69, 112, 67, 123, and 93, respectively.

The combined results, including separate predictions of truck trips, producing an estimate of total vehicle trips approaching each plant from the "critical" direction at the peak traffic hour, were not very good. The predicted versus actual volumes were: to plant A, 109 trips as against 235; to plant B, 151 against 83; to plant C, 341 against 550; to plant D, 177 against 93; and to plant E, 543 against 520.

TRENDS

Several concurrent developments make it likely that at most new manufacturing plants there will be a higher proportion of auto-driving employees than at many of the older plants considered in this report. The proportions of employees walking, taking transit, or riding as auto passengers will decrease. This will primarily be the result of a continued rise in real family income, and a corresponding increase in auto ownership.

Moreover, auto driving will be encouraged by the new style of manufacturing plant; located on larger, suburban sites, with landscaping and spacious parking lots, the new plants may actually be inaccessible to potential transit riders or walkers. Car pools will probably persist, but with less popularity, and car loading factors will continue to decrease.

Changes in the number of days and hours worked each week per employee seem certain (*53*). How this may affect peak traffic hours, however, is uncertain. Wherever shift work is the rule, there may be no substantial change in present peaking characteristics. In one-shift industries, however, peak hours may occur later in the mornings, or earlier in the afternoon, or both.

Perhaps the most difficult change to predict is the relocation of industry itself. Much has been written about the movement from city to suburbs (*54*). Now there appears a further movement from suburbs to "exurbs," a recent *New York Times* article (*55*) indicated that the largest planned industrial community (129 plants) in the United States has sprouted in Texas "where only eight years ago cattle chomped range grass and rabbits shared burrows with field mice." Another *Times* article (*56*) calls attention to a 520-acre, $250-million industrial park to be built on Long Island, complete with its own harbor.

Clearly, such developments may make present concentrations of industry near freeway interchanges seem insignificant. It would appear that such industrial "cities" might need exclusive freeway service to handle the vast amounts of traffic to be created. In any case, the new individual plants, and the new industrial parks, will likely place heavier demands on highway agencies than ever did any industrial development in its early history.

To anticipate every trend is impossible; the purpose of introducing the problem is to stress the need, in providing for efficient transportation to manufacturing plants, for looking ahead rather than looking back. To use any relationship developed in this report, without anticipating change, for example, would be looking back. Like airport and shopping center activity, manufacturing activity is dynamic and changeable, and trends will deserve careful and continued scrutiny.

TABLE 45

PEAK DISTRIBUTION AND DIRECTIONAL TENDENCY OF TRIPS TO SELECTED MANUFACTURING PLANTS, BY PLANT EMPLOYMENT GROUP [a]

	PASS. CARS [b]			TRUCKS [d]			
PLANT EMPLOYMENT GROUP	DAILY TRIPS (NO.)	PEAK TRIPS [c] (NO.)	PEAK VOL. (%)	DAILY TRIPS (NO.)	DAILY VOL. (%)	PEAK VOL. (%)	*D* [e] (%)
0-999	5,021	1,866	37	319	6.5	6.6	79
1,000-1,999	14,107	5,235	37	891	6.3	10.9	88
2,000-2,999	14,088	6,169	44	499	3.4	5.0	87
3,000-3,999	9,840	4,422	45	256	2.5	1.6	86
4,000-4,999	17,465	7,129	41	1,234	6.6	2.9	86
5,000-9,999	16,024	6,622	41	870	5.1	—	85
10,000-19,999	6,730	2,423	36	303	4.3	—	94
Average	83,275	33,867	41	4,372	5.1	4.2	86

[a] From transportation study data for various cities (see Table B-2 for individual plant values).
[b] Includes automobiles and light truck (4-tired vehicles) trips from home interview, truck-taxi, and roadside interview surveys.
[c] Based on single highest hour, whenever it occurs.
[d] Medium and heavy truck (over 4-tired vehicles) trips from truck-taxi and roadside interview surveys, where available.
[e] Proportion of total vehicle trips in dominant direction (to plant) at peak hour.

CONCLUSIONS

A major manufacturing plant is also a major trip generator. Two of the plants in this cross section each employed nearly 20,000 persons during the trip surveys year. Another (whose analysis was de-emphasized for lack of complete tripmaking data) employed more than 30,000 persons. Considering the number of automobile trips created at shift-change hours, the crowding and congestion that can occur on access highways is easy to imagine.

Practically all of the highway impact is the result of employee travel. About 95% of the daily tripmaking to most plants consists of trips to work. The remainder are generally for personal business—trips to apply for a job, to pick up a check, etc. There may be some visitors for social-recreation purposes. Truck traffic is not often the major factor it might seem.

About 10% of the employees of older plants, located in the highly built-up central cities, may walk to work. A still larger number, perhaps 20%, may take transit. But most, if not all, employees of newer, suburban plants will get to work by automobile. In general, car pooling is not popular, and as more employees own cars, the average car loading drops.

Most work trips are relatively long. The average approaches 5 to 6 miles and 20 to 30 min travel time. Residences are highly scattered, even around mill towns where once most employees could walk to work. There appears to be a reluctance, however, to cross major travel barriers such as river valleys—employees tend to live on the same side as their place of employment. They also tend to live on the suburban rather than the CBD side of their plant.

Although a single plant can impose heavy demands on an industrial highway, a combination of plants in an industrial corridor (as along a river valley in a mountainous area) can create multifold demands. Looking ahead to continued construction of industrial parks, on less limited sites, containing scores of modern plants, whose employees will almost all want to drive to work, the eventual need for special freeway service may be seen.

This chapter has attempted to provide factors and relationships that will prove useful in this more typical situation: when a new plant is to be built at a designated location in an existing system of highway facilities, the contours of new demand can be plotted over the contours of existing demand. This, although crude in its values, will show roughly where new capacity may be needed and where problems may be expected to develop.

CHAPTER FIVE

APPRAISAL AND APPLICATION

This chapter is intended to answer such questions as what do the findings mean—how can they be used in standards, specifications, policies, and procedures? What do they add to our understanding? What effect do they have on economy, safety, amenities, convenience, or other desirable attributes of transportation? It is intended, also, to appraise —in retrospect—the reliability and completeness of the findings themselves.

APPRAISAL OF FINDINGS

The findings are subject to the advantages and disadvantages inherent in transportation study data. Some of these were mentioned in Chapter One; others will have become apparent throughout the succeeding chapters. It is felt, finally, that selected types of major traffic generators can be examined successfully by using areawide transportation study data.

The findings are, however, incomplete in certain respects. The most notable gaps are: (1) The various studies represent single points in time, in some cases already somewhat remote; (2) Weekend activity can only be guessed at (this does not so much affect the analyses of airport and industrial plant tripmaking, but it is unfortunate with respect to shopping center travel); (3) Nonresident air traveler trips are not available (although nonstudy sources might have been elaborated, they would not have been comparable to the primary data source).

Nevertheless, many new aspects of tripmaking to the subject generators have been revealed. There is reason to believe that this is the first research project to put together data from more than a dozen transportation studies on specific site activities. As such, it provides a perspective hitherto lacking—a documentation of likenesses and differences as they exist from city to city. Previously, any such comparison would have had to rely on scattered sources of data inconsistently collected and variously analyzed.

Despite the length of this report, much detailed analysis has been summarized. The Pittsburgh pilot study (*29*) results, only briefly referred to earlier herein, are a good example. Considering the quantity of data assembled, many similar reports might have been prepared. This report presents major findings only.

In presenting these findings simplification has been the rule. Complicated "models" and excessively complex interrelationships have been avoided. Speculation was subordinated to reporting the facts as they were found. Scholarly dissertations on theoretical relationships are sometimes of little help in solving everyday problems. The objective throughout has been to provide relationships that can be applied to real situations.

APPLICATION OF FINDINGS

The findings may have first application to highway design problems. Given a new airport, shopping center, or manufacturing plant, the factors and relationships presented here may give guidance to highway engineers concerned with providing efficient highway service to these as well as to existing activities; in effect, to answer the question of how much additional highway capacity will be needed.

With shopping centers, particularly, state highway departments are often confronted by developers inquiring about access improvements for possible new centers. Somewhat the same situation may exist with respect to manufacturing plants or industrial parks. Inquiries may be predicated on little more than a guess at vehicular trip generation, its distribution in time and space, and its impact on the adjacent highway system. Even where traffic estimates have been made by the developer's consultants, the prudent state highway department will typically review those estimates for reasonableness. This report should furnish some guidelines for such reviews.

Because airports are public rather than private enterprises, they should pose fewer communications problems between developers and highway agencies. However, the literature suggests that airport agencies do not make extensive studies of the impact of airport development on the adjacent highway system. In a sense, this report may help bridge the gap between what they know about airport activities and what state highway departments know about requirements for safe and convenient ground transportation.

In all three instances, the traffic effects of highly concentrated trip generators may suggest the need for various means of controlling land use development to maintain efficient traffic flow. For example, "pirate" commercial activity in strip development at or near a shopping center might be banned as creating, with the center, too many cross movements for traffic safety. Similarly, too many plants in a particular industrial corridor, or too large an industrial park, or too much activity of any kind near major airports, might be prohibited by zoning controls. Certainly, there might be those who would not share this viewpoint. In any case, the traffic consequences of permitting or prohibiting concentrated development should be apparent from the ranges of trip generation established in this report.

Its findings may also have utility for transportation study analysts. Seldom do they have the opportunity of looking closely at particular traffic generators, but rather they are concerned with patterns of land use types through entire metropolitan areas. Still, in long-range planning, such dynamic generators as airports and regional shopping centers should have close scrutiny, because they can create as many trips as most entire traffic zones. Upper values presented here may be suggestive of the traffic growth potential at airports and shopping centers.

It seems possible, though perhaps not probable, that transportation studies in the future will concentrate more attention on specific major generators. One reviewer of the draft of this report, involved in the preparation of a prospectus for a new study in his city, commented that it had provided him with certain ideas for adapting his study design toward better coverage of major generators generally, particularly where standard home interview techniques could be improved for the purpose. The report may be similarly useful to others, particularly highway planning divisions active in the design and supervision of new transportation studies.

Traffic divisions, too, may find applications in the hourly and directional traffic data ranges provided. Although precise traffic counts are not available in this report, various percentages have been presented, and these should have an acceptable accuracy for problem-scaling purposes. City-to-city comparisons show that many traffic patterns are much the same, consistent with the differences in the metropolitan areas themselves. Citation of such patterns might dispel the frequent argument that "our situation is different and special."

The principal application of the findings of this report might be thought of as informational. There were no physical problems concerning structures or materials to be solved; there were no geometric design problems concerning cross sections or interchanges to be solved. Rather, the objective was to explore the relationships between travel to three specific types of land uses and the various factors that influence such travel. The resulting relationships should have a variety of applications.

CHAPTER SIX

CONCLUSIONS AND SUGGESTED RESEARCH

The application of transportation study data in an examination of land use-travel relationships for specific major traffic generators is perhaps unusual. The approach takes advantage of vast amounts of data already available—always an attractive concept. The data are more complete in many respects than those obtainable through parking lot interviews or various return postcard techniques. Treatment provides broad perspectives about different parts of the trip generation-trip distribution problem, ranging from trip-maker attributes to actual traffic on the highways.

Transportation study data were not, however, designed for this type of examination. As a result, there are gaps in the sequence of relationships—unknowns left to be puzzled over. Where significant questions cannot be answered from other sources, they merit identification as topics for further research. By way of supplementing previously presented conclusions, the remainder of this chapter sets forth suggestions for continued research.

AIRPORT TRIPMAKING

Permanent Counter Installations

To the best of knowledge, there are no permanent counter installations at any major airport. Continuous mechanical counts, supplemented periodically by manual classification counts, are an obvious means of directly relating traffic to other airport activity, notably air passenger counts available on a daily (and sometimes hourly) basis from the airport management. Such counts would permit the establishment of monthly, daily, and hourly factors useful for highway design purposes, and would facilitate an examination of trends.

Expanded Air Passenger Surveys

Surveys of air travelers—now commonplace at many major airports—should be augmented by simultaneous surveys of employees and visitors. Terminal approach driveway and parking lot interviews might successfully sort out visitors from air passengers; employees might best be enumerated by employers. Whatever the techniques, this seems necessary to obtain a fully rounded picture of total airport activity, now largely lacking.

Predicting SMSA Air Travelers

Further multiple regression work along the approach taken by this report (and others) would appear potentially rewarding. Time-series analyses for given SMSA's should point up trends. For example, using census data for 1940, 1950, and 1960, and estimated data for intercensile years, might demonstrate through multiple regression what effect changing institutional employment (or any other significant variable) may have on changing air travel generation.

Predicting Air Traveler Ground Origins

In this report, it has been said that the distribution of population by travel time or distance from the airport is sufficient to determine the distribution of resident air traveler trip origins. This is correct only within certain limits of accuracy. For better results, subarea population characteristics (income, occupation, sex, race, age, etc.) warrant further exploration. This information is usually obtained in air passenger surveys, and need only be more rigorously related to subarea population characteristics in the air traveler's home neighborhood. Interrelationships with mode of travel to the airport should be part of the same investigation.

SHOPPING CENTER TRIPMAKING

Changes in Trip Generation Rates

Further analysis is needed to determine the causes of changes in shopping trip generation rates as time passes. Market surveys indicated that the number of centers visited by shoppers tended to increase with the passage of time. Study of trip rates by car ownership groups suggested that trip rates change, and the regression analysis provided confirmation. The land use aspects have not been explored, however, and the specific causes and effects have not been evaluated.

Measuring Impact of New Shopping Center

In addition to studying problems of trip estimation and distribution, examination of trip diversion and re-orientation from existing retail activities could be valuable to highway agencies. Studies of shopping travel patterns before and after the opening of a new center would provide data for many travel characteristics bearing on trip estimation. Such studies could be made in urban areas where two home interview studies have been made within a relatively short span of years.

Shopping Center Trip Generation

Improved trip generation estimates may result from the use of more sophisticated traffic models. On the other hand, the increase in refinement may not be warranted by the data, manpower, and costs incurred, especially where the usual problem is evaluating the potential impact of only one shopping center on the highway system. Further research would, therefore, be justified to determine both the degree of estimating improvement and the increment of cost that would result from using more sophisticated methodology.

Benefits to Retail Centers from Highway Improvement

Cursory examination suggests that uniform improvements in urban highway services confer greater benefits to suburban than to core areas. Further examination, with respect to retail centers, needs to take into account income and mobility factors, as well as typical residential density and highway service levels. If the effects are borne out factually, parallel situations may be found and studied for other land use categories.

Volume Counts at Shopping Centers

To derive up-to-date information for design hour volume factors, more traffic volume counts are needed. Weekdays and Saturday conditions, by hour of the day, and by seasons of the year, are necessary to develop data for the 100 highest hours. Relationships among the high-ranking hours must be known before design hour percentages of daily traffic can be selected.

INDUSTRIAL PLANT TRIPMAKING

Industrial Parks

The present report did not consider planned industrial parks. Because they are "super" plants, in effect, and because they are rapidly becoming more common throughout the country, separate study seems warranted. A key consideration might be the different mixtures of activities represented, and their implications for peak traffic hours.

Small to Medium-Size Plants

At the opposite extreme of the planned industrial parks are the unplanned conglomerations of small and medium-size plants, generally new, that occur near airports, along major highways, and at freeway interchanges. Because of high sampling variability with small numbers of employees, transportation study could not be brought to bear on individual plants of this size group. Still, in the aggregate, they can have considerable impact on servicing highways, and they merit study.

Employment Trends

Various aspects of long-term and seasonal fluctuations in plant employment remain unknown. For a given plant layout, what employment changes occur through time as a result of plant improvements, automation, shift changes, product changes, decreasing or increasing product demand, etc.? Possibly, plants are too often considered to be static traffic generators, when in fact there are significant variations throughout their life cycles. Case histories might shed light on this.

Plant Entrance Practices

Congestion may occur at major plant entrances during shift-change hours for lack of proper design and control. Observation of many plant entrances suggests that through traffic is delayed unduly by uncontrolled vehicular and pedestrian activity. Although this is largely an operations problem, it may affect the planning and design of the main access highways on which it tends to occur. In lieu of adding highway capacity to alleviate such problems, the preparation of guides to help plant officials provide efficient ingress and egress would seem potentially rewarding.

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APPENDIX A

TRAFFIC GENERATION AND TRAVEL PATTERNS AT AIRPORTS, SHOPPING CENTERS, AND MANUFACTURING PLANTS: AN ANNOTATED BIBLIOGRAPHY

There have been many publications describing the planning, design, and operation of airports, shopping centers, and manufacturing plants. Most have dealt either with the broader problems relating to city and regional planning, social and economic impact, and esthetics, or with the more detailed problems of on-site design and development. Relatively few have dealt directly with traffic generation and travel impact on adjacent transportation facilities. This bibliography attempts to concentrate on the latter, providing an annotated sampling of pertinent reports from all sources.

The bibliography has four major parts dealing, respectively, with airports, shopping centers, manufacturing plants, and more generally with trip generation techniques covering all types of land uses.

AIRPORTS

1. AMER. ROAD BUILDERS' ASSN., *Expressways to Airport Vital to Civil Defense.* Tech. Bull. No. 176 (1951); also *Influence of Close-In Airports on City-to-Airport Travel Costs.* Report of ARBA Committee on Access Roads to Airports (1952).

   Represent early efforts in ARBA's continuing interest in promoting improved airport access, citing economic reasons for reducing ground travel costs.

2. BARTON-ASCHMAN ASSOC., *Proposed Circulation and Parking, Logan International Airport, Boston, Mass."* (Prepared for Perry, Show, Hepburn and Dean, and the Massachusetts Port Auth.) Evanston, Ill. (1963).

   An example of a traffic consultant's report on the methodology of identifying the future space requirements for the various vehicle functions that must take place in the terminal building area at Logan International Airport, and converting these requirements into a roadway and parking design concept that is fully integrated with the current designs of terminal buildings. Presents selected results of interviewing 4,400 persons regarding their air trip (if one), ground transportation, and other travel characteristics.

3. BROWN, JOHN F., "Airport Accessibility Affects Passenger Development." *Jour. Aero-Space Transp. Div., Proc. ASCE,* Vol. 91, AT 1 (Apr. 1965).

   Reviews the history of studies examining whether air travel rates decrease with increasing distance from the airport, concluding ". . . a substantial and conclusive body of data has been amassed supporting the finding that airport accessibility does have an effect on air passenger generation, that the effect is in the expected direction, and that the effect is substantial."

4. BUCKLEY, JAMES C., "The Effect of Airport Distance on Traffic Generation." *Jour. Air Transp. Div., Proc. ASCE* (May 1956).

   Reports changes that occurred when, in 1947, scheduled airline operations at Detroit were moved from the Detroit Municipal Airport, 6 miles northeast of downtown Detroit, to the Willow Run Airport, 11 miles west. General conclusion: air passenger traffic did not decline until three years later, and then a "normal" rate of development took over from the reduced level.

5. CIVIL AERONAUTICS ADMINISTRATION, *City to Airport Highways.* (1963).

   Discusses importance of airport access and ways to improve it, concentrating on traffic engineering techniques, rather than the construction of new highways.

6. CLARE, KENNETH G., *Southern California Regional Airport Study.* Stanford Res. Inst. California Labs., S. Pasadena (1964).

   Along with specific discussion of California problems, presents an interesting general discussion of various levels of airport "capacity." In the order typically reached, these levels relate to vehicle parking, terminal access, runways, airspace, and terminal building. The report suggests that, although terminal access can be improved to some extent by means of freeways, rapid transit, and feeder air services, an additional airport is often the required solution in a major urban center.

7. CULBRITH, WILLIAM J., JR., "The Future of Airline Ground Transportation." *Jour. Air Transp. Div., Proc. ASCE* (July 1959).

   Discusses problems and possible solutions of ground transportation as seen by the Airport Ground Transportation Association.

8. FEDERAL AVIATION AGENCY, *Air Traffic Patterns and Community Characteristics.* Air Traffic Serv., Program Control Div. (1963).

   Reports that the number of resident air passengers generated by a given metropolitan area depends on its population class, and whether it can be considered a center for industry, marketing, or institutions-government. Rates increase with increasing population, decrease with increasing industrialization. Range of

rates is provided for five population classes. (Supersedes *Community Size and Economic Character,"* staff study, Civil Aeron. Admin., 1953.)

9. FEDERAL AVIATION AGENCY, *Airport Terminal Buildings,* and *Airport Design.* Bur. of Facilities and Material, Airports Div. (Supersedes similar publications of 1953 and 1949, respectively.)

   Notable in that neither the old nor the new editions provide much information on the requirements for servicing ground travel.

10. FEDERAL AVIATION AGENCY, *National Airport Plan.*

    Published annually to indicate where improvements to existing airports, and new airports, are needed. Provides cost estimates.

11. FEDERAL AVIATION AGENCY, *Statistical Handbook of Aviation.* (Publ. annually).

    A valuable handbook providing statistical time series on a broad range of airport and air industry activities. Near-counterpart of *Highway Statistics* series.

12. FENN COLLEGE, *Outbound Air Travelers of Cleveland Hopkins Airport, November 18-25, 1956.* Bur. of Bus. Res., School of Bus. Admin., Cleveland, Ohio (1958).

    Presents findings from interview survey (patterned after that reported in "New York's Air Travelers") of 5,111 outbound air passengers.

13. GILBOA, ISRAEL, "Parking and Circulation of Vehicular Traffic at Airports." *Jour. Air Transp. Div., Proc. ASCE* (Aug. 1961).

    Describes study at San Francisco International Airport and shows chart of hourly vehicle arrivals and departures at parking places.

14. GILFILLAN, WALTER E., *A Study of Access Guidance to California General Aviation Airports.* Spec. Report, Inst. of Transp. and Traffic Eng., Univ. of California (1964).

    An interesting investigation of aviation activity and related ground access problems at 18 smaller California airports, emphasizing the adequacy of airport directional signing on the airport-serving highways.

15. HOMBURGER, WOLFGANG S., and EAGER, WILLIAM R., "Automobile Parking Requirements at Airports." Paper presented at 4th Natl. Airport Conf., Aero-Space Transp. Div., ASCE, San Francisco, Calif. (1964).

    Looks at long-range parking needs of "tomorrow's" airports: "The rate of technical progress in aircraft design has been rapid over the past 25 years, and may reach an almost fantastic pace hereafter. The design of airport parking facilities also needs to take advantage of new technologies and concepts, so that these facilities will not be the bottleneck but a smoothly functioning link in the entire airport system."

16. HARRIS, ROBERT W., and MICHALSKI, CHARLES S., "Planning and Design of Airport Terminal Parking Facilities." *Proc. 29th Ann. Meeting, Inst. of Traffic Eng.* (1959).

    Reviews studies of airport terminal populations (air passengers, visitors accompanying or meeting air passengers, airport employees, sightseers, business and miscellaneous visitors), modes of ground transportation, hourly and daily fluctuations in parking demand, as well as stopping and standing at terminal doors. Studies represent then-recent data for New York's LaGuardia and International airports, Chicago's Midway airport, and data for airports in Dallas, Fort Worth, Nashville, and Newark.

17. HUMAN SCIENCES RESEARCH, *Airport Transportation: A Study of Transportation Means Between Airports and the Metropolitan Areas They Serve.* Prepared for Bur. of Res. and Devel., Fed. Av. Agency, Natl. Aviation Facil. Exper. Center, Atlantic City, N. J. (1961).

    Important and detailed (289 pages, plus appendices), this report presents an overview of all problems related to airport ground transportation. Includes comprehensive case studies of New York, Chicago, San Francisco, and Washington airport travel. Includes a 461-item bibliography. Valuable reference.

18. IRWIN, ROBERT L., "Person Trips to Greater Pittsburgh Airport." Pittsburgh Area Transp. Study *Research Letter,* Vol. IV, No. 6 (1962).

    Presents a review of the general characteristics of travel of Greater Pittsburgh Airport, one of the nation's major air travel centers. Considers trip origins, trip purposes, modal split, diurnal pattern, and sex-age-occupation distributions of the tripmakers.

19. JORDAN, RICHARD H., *Airport Location in Relation to Urban Transport.* Staff paper, Inst. of Transp. and Traffic Eng., Univ. of California, Berkeley (1961).

    Presents reasoning, based on comparative air trip lengths and ground travel times, favorable to a large metropolitan area's having a long-haul jet airport relatively distant from the core, and a number of smaller fields around the central business district in the direction of the future centers of suburban growth.

20. KESSLER, DAVID S., "Relationships Between Intercity Air Passengers and Economic and Demographic Factors—A Multiple Linear Regression Analysis." M.S. thesis, Princeton Univ. (Jan. 1965).

    Various factors which affect intercity air passenger traffic were examined by multiple linear regression analysis. Considered were population, distance, wealth, economic characteristics of cities, proximity of cities to larger metropolitan centers, household income, and transient ratio. The influence of each factor on the amount of point-to-point air traffic is discussed. A method of predicting intercity air passenger traffic

is presented. Reviews various interactance models used to date.

21. LAWLER, CHARLES A., "Trends in Automobile Parking at Airports." *Jour. Aero-Space Transp. Div., Proc. ASCE* (Oct. 1964).

The question for the future does not concern the amount of land needed for parking lots; rather, it involves the amount of structure required for parking garages now and in the future, and the most favorable location for this structure so that it will best serve the terminal without being hemmed in. There is a limit to the amount of parking that can be provided near the terminal area.

22. LEIGH FISHER & ASSOC., *A Survey of Air Carrier Airport Requirements for the City of San Diego.* Prepared for the Mayor and City Council of San Diego (1956).

Example of an airport planning consultant's comprehensive report of long-range airport needs. Such reports should prove valuable to highway engineers concerned with airport ground access, because they provide not only historic trends in all types of airport activity, but also forecasts of future activity from which ground travel requirements can be derived. Comparable studies are available for most major airports.

23. MIKOLAJCZYK, M., *Seasonal Adjustment of Domestic Trunk Air-Passenger Traffic Data: 1951-1961* (prelim.) Staff Res. Rep. No. 3, Res. and Stat. Div., Office of Carrier Accts. and Stat., Civil Aeron. Bd. (Feb. 1963).

Considers necessity and technique of dealing with seasonal (monthly) variations in air passenger statistics. Provides adjustment factors based on national cross section for the years 1951 through 1959. Shows that seasonal patterns have shifted somewhat over the years, and that patterns for domestic-trunk, domestic-local, and international patterns are markedly different.

24. MORROW, COLE, "Planning a National Airport System to Serve the Seventies." Paper presented at ASCE Transp. Eng. Conf., Minneapolis (May 1965).

Reviews probable long-range needs and suggests procedures for planning the national airport system as part of an integrated over-all transportation system. Startling increases in air travel explained.

25. NUNN, BEN E., "Auto Parking for Efficiency and Revenue at Airports." *Jour. Air Transp. Div., Proc. ASCE* (July 1959).

Stresses the revenue producing role of airport parking facilities.

26. PORT OF NEW YORK AUTH., *Air Travel Forecasting.* Aviation Dept., Forecast and Analysis Div. Publ. by the Eno Foundation for Highway Traffic Control (1957).

Based on results of a national travel market survey by the Survey Research Center, Univ. of Michigan, criteria were established by the Port Authority to forecast 1965 and 1975 national air travel, first by forecasting national population characteristics such as age, education, occupation, and income, for business as distinguished from person travelers, and second, by applying survey year (1957) air trip rates per thousand population, as adjusted upwards to account for continuing conversion from ground transportation and for increased trip frequency of confirmed air travelers, to the forecasted population. The 1965-1975 travel demand at Port Authority airports was derived as a share of the national travel demand. Backchecks for 1955 and 1950 indicated a good accuracy.

27. PORT OF NEW YORK AUTHORITY, *New York's Air Travelers.* Publ. by the Eno Foundation for Highway Traffic Control (1956).

Summarizes the returns of an in-flight questionnaire survey conducted by the Port of New York Authority with the collaboration of all domestic air carriers serving New York city airports, and Air France.

28. PORT OF NEW YORK AUTHORITY, *New York's Domestic Air Passenger Market.* Aviation Econ. Div. (1965).

A significant new report—comparable in content to that publishing the results of the first survey in 1956/57—which conclusively establishes a number of important long-range trends. A relatively brief text presentation is followed by about 100 pages of tabularized appendix data.

29. RANDOLPH, JENNINGS, "Airport-to-Downtown Bottleneck." *Traffic Quart.* (Jan. 1956).

Cites probable long-range increase in air travel and, hence, need for improved access to major airports. Considers possibility for helicopter service, monorail, and other rapid transit, and concludes that expressways will be the only real solution.

30. ROGGEVEEN, VINCENT J., and HAMMEL, LAWRENCE V., "Ground Transport of People to and from the Civil Airport." *Jour. Air Transp. Div., Proc. ASCE* (July 1959).

Presents results of questionnaire sent to 50 large airports. Mode breakdown, distance and travel time to CBD, and estimated origins and destinations by mode are tabularized for selected cities.

31. SEATTLE PORT COMMISSION, *Seattle-Tacoma International Airport and Its Impact Upon the Economy of King County.* Dept. of Planning and Indus. Devel. (1962).

Provides statistical review of activity at Seattle-Tacoma International Airport, tracing vital importance of the airport to the communities it serves.

32. SCOTT, ROBERT S., and MCCULLOUGH, DAVID R., *Optimizing Common Carrier Terminal Locations.* N.Y.

State Off. of Transp. in cooperation with N. Y. State Dept. of Pub. Works, Subdiv. of Transp. Planning and Programming (Oct. 1965).

Describes method for determining optimum location of an airport from the standpoint of passenger time, cost of relocation, "sunk" investment, land use, and coordination with other forms of transportation.

33. WALL, ROBERT F., "Ground Transportation." *Jour. Air Transp. Div., Proc. ASCE* (July 1959).

Discusses various limitations and regulations affecting taxicabs, limousines, and airport buses. Also discusses how the complex downtown circulation pattern of airport buses and limousines can appreciably add to total airport-downtown travel time.

34. WEIN, HAROLD H., *Domestic Air Cargo: Its Prospects.* Occasional Paper No. 7, Bur. of Bus. and Econ. Res., Grad. School of Bus. Admin., Michigan State Univ. (1962).

Representative of many recent reports anticipating strong growth in this aspect of air transport. What freights are most likely to be moved by air, and where, involves rather complicated transportation economics, in which the relative costs of ground transport (access) to airports is highly critical. This report considers various decisions that must be reached by air cargo shippers and carriers.

SHOPPING CENTERS

1. BAKER, GEOFFREY, and FUNARO, BRUNO, *Shopping Centers: Design and Operation.* Progressive Arch. Lib., Reinhold Publ. Corp., New York (1951).

Although now dated, this basic text for shopping center developers poses many of the same problems that still exist and are often ignored. Particularly interesting discussion of mechanized goods handling, possibilities of TV application, and minimization of parking areas is still appropriate in considering future developments.

2. BARTON-ASCHMAN ASSOC., *Traffic Appraisal, Dark Hollow and Springhill Shopping Center Sites.* Report for John Matthews Co., Little Rock, Ark. (1963).

Another example of a consultant's approach to the problem of determining site accessibility and the adequacy of ingress and egress. A carefully illustrated report, it shows the results but not the detailed methodology of making traffic assignments to the adjacent highway network. This is true of almost all consultant reports of this type.

3. BECKET, WELTON, "Shopping Center Traffic Problems." *Traffic Quart.* (Apr. 1955).

General discussion of the traffic planning problems that existed in 1955 and still exist today. The literature includes many articles of this nature, valuable not because of any facts presented, but because they provide a composite image as seen through the eyes of leaders in the field.

4. BERRY, BRIAN J. L., *Commercial Structure and Commercial Blight.* Univ. of Chicago, Dept. of Geography Res. Paper No. 85 (1963).

Analyzes the characteristics of commercial activities in Chicago in 1958, with particular reference to the various types of retail activities and their long-term trends. Discussions are presented on the types of establishments, the trade areas as evident from trip data obtained from the Chicago Area Transportation Study, and the dynamics of retailing. Models are given for fitting the level of retail activities to regional population and income characteristics.

5. BERRY, BRIAN J. L., and TENNANT, ROBERT J., *Chicago Commercial Reference Handbook.* Univ. of Chicago, Dept. of Geography Res. Paper No. 86 (1963).

A statistical supplement to the preceding study and contains data on specific outlying business centers within the City of Chicago for 1958. There are also related summaries based on the 1958 Census of Business.

6. BORTON, THOMAS, "Trip Generation Characteristics of Retail Commercial Land Use." Chicago Area Transp. Study *Research News,* Vol. 5, No. 4 (Sept. 27, 1963)

Considers two-digit commercial land use person trip generation rates by analysis district (group of analysis zones) as affected by the net residential density, the type of mixture of commercial land uses, and the intensity of commercial development in the district. Correlations were generally poor. Although type and condition of physical facilities and type of goods and services offered were not considered, the author speculates that they are not unimportant.

7. CASEY, HARRY J., JR., "The Law of Retail Gravitation Applied to Traffic Engineering." *Traffic Quart.* (July 1955).

Presents a theoretical case testing "Reilly's Law" and makes clear that the approach deals with dollar-sales, not necessarily with vehicular trips (*not* a trip distribution model).

8. *Chicago Tribune,* "How Chicago Shops." Research and Marketing Div. (1964).

The findings of a survey of more than 2,000 Chicago shoppers are primarily oriented to marketing and advertising activities. However, the study describes trade areas between outlying shopping centers, and the mobility of suburban shoppers is evident from their reported periodic visits to several centers for shopping. Because of this, the survey has more than just local interest.

9. CLEVELAND, DONALD E., and MUELLER, EDWARD A., *Traffic Characteristics at Regional Shopping Centers.* Bur. of Highway Traffic, Yale Univ. (1961).

This study of 14 regional shopping centers by staff members and graduate students over a period of about 6 years provides a record of the total traffic entering and leaving; traffic variation by hour, by day of week, and by season; the parking accumulation and parking loads; and relates sales to volumes as a possible traffic predictor. Should be of particular interest to traffic engineers and traffic planners.

10. CUYAHOGA COUNTY REGIONAL PLANNING COMMISSION, *Suburban Business Centers, An Inventory, Analysis, and Projection of Outer Urban and Suburban Business Centers in Metropolitan Cleveland.* (1959).

An important report describing results of interviewing some 35,000 shoppers in stores at 78 of 98 business centers in the Cleveland area, 31 of which were "integrated shopping centers; a shopping development built as a unit with off-street parking." The principal objective was to relate center areas to the populations served, as a means of predicting future needs of future families. For all centers, there was a close relationship at around 23-27 sq ft per family. Also, extensive facts on parking, travel mode, mileage distributions, etc.

11. CYSEWSKI, G. R., "Portland's Lloyd Center." *Traffic Eng.,* (Dec. 1958).

Lloyd Center, with its more than 3,600,000 sq ft of area and three-level parking for over 8,500 cars, is the world's largest shopping center. This article describes the complex traffic planning that was required.

12. DELANCEY, D. J., *Traffic Studies at a Suburban Shopping Center.* Unpubl. thesis, Yale Bur. of Highway Traffic (1957).

An intensive study of traffic patterns based on a series of special traffic counts at Hamden Plaza (a regional shopping center near New Haven, Conn.)

13. *Denver Post,* "Consumer Analysis." (1961).

This study, made for and published by a newspaper, is a survey of shopper habits, also oriented toward marketing and sales promotion. Some information is provided on trip characteristics, and centers visited in Denver. Reports of this type are frequently available from leading newspapers in major metropolitan areas.

14. DICKEY, JOHN W., *A Model of the Maximum Generation of Traffic to Planned Shopping Centers.* Prelim. unpubl. report, The Transportation Center, Northwestern Univ. (1965).

Because of the difficulties found in the past in attempting precise trip generation figures for shopping centers, the author proposes a method of predicting a maximum volume that permits refinement if further data can be applied to the problem. Past methods of trip generation are discussed and evaluated.

15. FAIRMAN, GIBSON W., INUZUKA, TSUNEO, and MCBRIDE, JAY W., "LARTS Shopping Center Study—Preliminary Results." *Proc. 14th Calif. Street and Highway Conf.* (1962).

Presents detailed results of interviewing about 10% of the customers at five regional and one community shopping center in the Los Angles area. Various trip generation rates and predictive equations are presented.

16. GRUEN, VICTOR, and SMITH, LARRY, *Shopping Towns USA: The Planning of Shopping Centers.* Reinhold (1960).

A basic reference covering all aspects of shopping center planning.

17. HARDING, C. H. V., *Shopping Centers: Planning and Design for Traffic and Traffic Generation.* Grad. report, Inst. of Traffic and Transp. Eng., Univ. of California (1960).

Condensing an MS thesis, this report describes the operation of several regional shopping centers in the San Francisco Bay area.

18. HOYT, HOMER, "Suburban Shopping Center Effects on Highways and Parking." *Traffic Quart.* (Apr. 1956).

Represents a typical broad statement of the problem with corresponding absence of concrete data and methodology.

19. JOHNSON, H. WEBSTER, *Summary Report of East Jefferson Shopping Area Survey.* City of Detroit Mayor's Comm. for Indus. and Commercial Devel. 1959); and *Shopping Survey of Families in the Harper Avenue Area.* Bur. of Bus. Res., School of Bus. Admin., Wayne State Univ. (1960).

Two reports, both based on home interviews in an area losing retail trade to the Eastland Shopping Center, describing shopper attitudes and attributes.

20. JONASSEN, C. T., *The Shopping Center Versus Downtown: A Motivation Research on Shopping Habits and Attitudes in Three Cities.* Ohio State Univ. (1955).

Reports results of interviewing in depth 600 respondents in Seattle and Houston, and 100 in Columbus. It suggests the probabilities of shoppers' choices between suburban shopping centers and downtown, by relating their personal attributes to the costs, quality, and choice of merchandise offered and the questions of access.

21. KELLEY, EUGENE S., *Shopping Centers: Locating Controlled Regional Centers.* Eno Foundation for Highway Traffic Control, Saugatuck, Conn. (1956).

An excellent book providing insights into locational theory problems, and presenting case histories of such regional centers as Shoppers' World, Cross County, Roosevelt Field, Garden State Plaza, Bergen Mall, and Northland. An extensive bibliography, slanted to the businessman's interests, is included.

22. KROGER CO., *Selected Annotated Bibliography on Shopping Centers.* Annotated by Saul B. Cohen, Cincinnati, Ohio (1957).

    Now dated, this bibliography stresses the market considerations that were given closest attention in the early days of shopping center development. Contains few specifically traffic-oriented citations.

23. LEVINSON, HERBERT J., MUELLER, EDWARD A., and MCGRATH, WILLIAM R., "Panel Discussion on Shopping Centers." *Traffic Eng.* (Oct. 1955).

    Of interest primarily as it views traffic engineering considerations at shopping center entrances and approaches. Various viewpoints presented, but without citing specific studies.

24. MADISON AREA TRANSPORTATION STUDY, *Special Generator Study No. 1, Westgate Shopping Center.* State Highway Comm. of Wisconsin (1965).

    A license plate survey of visitors to a large shopping center was made to determine the total trip generation, the size of the market area, and also the effectiveness of the license plate survey. Arrival and accumulation characteristics are presented. The study would be helpful to others contemplating such an undertaking.

25. MICHIGAN STATE HIGHWAY DEPT., *City of Wayne State Trunkline Plan* (1962).

    An example of how a highway department altered an existing state highway to key on a shopping center, and spent money for improvements "solely to satisfy local development plans."

26. MINNESOTA HIGHWAY DEPT. *Golden Rule Shopping Center* (May 1961); and *Traffic Analysis of a Regional Shopping Center* (Oct. 1961). Planning and Programming Div., Planning Res. Sect., Metropolitan Area Study Unit.

    Excellent examples of the technique employed by a progressive state highway department to review the traffic forecasts supplied by a shopping developer, and to assess the need for highway department actions to improve site accessibility while at the same time providing adequately for through traffic service.

27. NATIONAL RESEARCH BUREAU, *Shopping Center Directory.* Chicago (Publ. annually since 1957).

    Provides detailed physical facts for more than 8,000 shopping centers throughout the United States.

28. NEW JERSEY STATE HIGHWAY DEPT., *Route 4 and 17 Shopping Center Study* (1963).

    Shows the impact of a regional shopping center and a nearby major department store on two suburban arterial highways and their mutual cloverleaf interchange. Shopping center traffic is shown as a proportion of all volume for individual hours and an average day.

29. PHILLIPS, WILLIAM T., *Traffic Characteristics and Parking Requirements at Regional Shopping Centers.* Res. Report, Univ. of California School of Bus. Admin., Berkeley (1964).

    Discussion of the variables that should be considered in estimating the need for parking spaces at planned shopping centers. Data are presented on parking characteristics. Trip generation is presented in the context of developing parking space requirements rather than from the viewpoint of traffic volumes on approach highways.

30. REID, LLOYD B., *People and Cars at Eastland.* A report for Eastland Shopping Center, Detroit, Mich. (1958).
    ———, *Cars and People at Northland.* A report for Northland Center, Detroit, Mich. (1959).

    Two reports representative of this consultant's methods and results in measuring actual travel to and from existing shopping centers.

    ———, *Traffic Feasibility of a Shopping Center Site on Manhattan Boulevard, Toledo, Ohio* (1962).

    An example of this consultant's techniques for converting a "trading area" report by an economic consultant into a traffic report and test of traffic accessibility to a specified site. The analysis of main access road capacity demand imposed by shopping center patrons is perhaps typical of that employed by most traffic planning consultants.

31. RICE, SHELDON, *Traffic Characteristics of a Regional Shopping Center.* Thesis, Yale Bur. of Highway Traffic (1959).

    The purpose of this report was to investigate seasonal, weekly, and daily traffic volume characteristics at a regional shopping center. Both manual and machine counts were taken on 20 different dates from Nov. 1958 through Mar. 1959.

32. RICHTER, JACQUES, *A Study of Parking Demand at a Suburban Shopping Center.* Unpubl. thesis, Yale Bur. of Highway Traffic (1957).

    Presents an interesting technique for relating customer demand in "store-minutes" to parking demand in "car-minutes."

33. SATO, N. G., "Technical Memorandum—Subject—Trips by Purpose: Shopping." Unpubl. Chicago Area Transportation Study (1965).

    Report on a series of tests relating vehicle shopping trips to population and other regional characteristics in Chicago. The difficulties of relating shopping trip

generation by district to retail activity in the same district are cited.

34. Sharpe, Gordon B., "Travel to Commercial Centers of the Washington Metropolitan Area." *HRB Bull. 79,* pp. 1-15 (1953).

    Based on 1948 Washington, D. C., O-D survey, this paper reports various relationships between 14 selected suburban shopping centers (only a few of which are planned centers) and the Washington CBD.

35. Silver, Jacob, "Trends in Travel to the Central Business District by Residents of the Washington, D. C., Metropolitan Area, 1948 and 1955." *Pub. Roads,* Vol. 30, No. 7.

    One of the few studies that can demonstrate factually (based on O-D data) the changes that have occurred in downtown shopping: "This decline (9%) in the volume of CBD shopping trips, however, does not so vividly illustrate the decreased importance of the CBD for shopping as does the comparison between 1948 and 1955 of the percentage of total area shopping trips destined to the CBD (31 per cent in 1948 and 16 per cent in 1955)."

36. Silver, Jacob, and Hansen, Walter G., "Characteristics of Travel to a Regional Shopping Center." *Pub. Roads,* Vol. 31, No. 5.

    A significant study of reported travel characteristics at the Seven Corners Shopping Center near Washington, D. C. The trip attraction rates "inboard" (toward CBD) and "outboard" (toward suburbs) were found to vary regularly even at comparable time-distance bands. Shopping goods trips were found to be generated at a greater rate, considering floor area, than convenience goods trips, and various trip generation rates are given. Hourly and daily patterns of movement are described. Other valuable relationships are presented.

37. Sullivan, Sheldon W., "Shopping Center Trip Characteristics." Pittsburgh Area Transportation Study *Research Letter,* Vol. III, No. 6, 1962.

    Presents a thorough review of the general characteristics of shopping center tripmaking in the Pittsburgh metropolitan area.

38. Thabit, Walter, and Lobe, Nathalie, "Shopping Origins and Destinations." *Traffic Quar.* (Jan. 1957).

    Reports theoretical method of estimating where people shop and how they get there, without origin and destination survey, but using available data with statistics on sales and income.

39. Urban Land Institute, *Mistakes We Have Made in Developing Shopping Centers.* Tech. Bull. No. 4 (1946).

    ————, *Shopping Centers: Principles and Policies.* Tech. Bull. No. 2 (1953).

    ————, *Shopping Habits and Travel Patterns.* Tech. Bull. No. 24 (1955).

    ————, *Shopping Centers Restudied.* Tech. Bull. No. 30 (1957).

    ————, *A Re-Examination of the Shopping Center Market.* Tech. Bull. No. 33 (1958).

    ————, *The Community Builder's Handbook.* (1960).

    ————, *Operation Shopping Centers.* (1962).

    ————, *Urban Land* (monthly publ.), various articles.

    The many Urban Land Institute publications dealing with shopping centers represent perhaps the most detailed and most practical source of shopping center data available. It would be difficult to recapitulate the significant contents of each. Taken in chronological order, they trace the rapid development within the field, and document the ULI leadership in establishing standard terminology and improved planning/operation techniques. Any serious student of shopping center development, including highway officials concerned with related traffic problems, should consider them required reading.

MANUFACTURING PLANTS

1. Adams, Leonard P., and Mackesey, Thomas W., *Commuting Patterns of Industrial Workers: A Study of Experience Since 1940 in the Northeast Region.* Housing Res. Center, Cornell Univ. (1955).

    A report for the U. S. Housing and Home Finance Agency directed toward "bringing together from World War II experience, from more recent labor market and transportation studies, and from a first-hand investigation made in the fall of 1951 in several upstate New York industrial areas, information on commuting paterns of *industrial production* workers," and, secondly, toward developing techniques and methods for measuring and analyzing other commuting patterns. Extensive statistical time series, and an 87-item bibliography make this report a valuable reference.

2. Alexandersson, Gunnar, *The Industrial Structure of American Cities.* Univ. of Nebraska Press (Almquist and Wiksell: Stockholm, 1956).

    First distinguishes urban and rural industries (the book concerns urban industries only); then distinguishes "sporadic industries" and "ubiquitous industries"; and, finally, distinguishes "city forming" and "city serving" (for example, calculates that 1.5% of the 28% in Detroit's automobile employment is city serving, the rest city forming). Using 1950 census data, shows dot maps of employment categories across the United States, and provides other "overview" material well suited for background reading on industrial employment. All of the many, many books on this subject, in effect, consider industrial area trip generation, since employment virtually equals trip generation.

3. Barton-Aschman Assoc., *Traffic Movement Requirements: The Boeing Company, Seattle, Wash.* (1962).

An example of a traffic consultant's study of the extreme congestion on highways adjacent to a plant employing 35,000 employees. The study includes an assignment of trips to main access routes and an analysis of capacity requirements. Interesting because it illustrates the severe problems that do exist.

4. Black, Alan, "Manufacturing Trip Rates." Chicago Area Transp. Study *Tech. Memo. No. 10206* (1963).

An excellent and detailed discussion of difficulties inherent in generalizing about trip generation at manufacturing plants. Extensive regression analyses relating trip generation to net and gross population density, percentage of developed land in streets, percentage of developed land in residential use, percentage of usable land vacant, percentage of developed land in commercial use, and to other independent variables, is evaluated. Leads provided for continued research.

5. Black, Alan, "Comparison of Three Bases for Trip Generation." Chicago Area Transp. Study *Tech. Memo. No. 02206* (1963).

Considers the efficacy of predicting trip generation from (1) land area, (2) floor area, and (3) employment. Section on manufacturing reports that employment is the best predictor because there are relatively few nonwork trips to manufacturing.

These two memoranda by Black, along with CATS' *Land Use Forecast* by Hamburg and Sharkey (see entry elsewhere), and several other technical memoranda ("Comparison of CATS Data on Employment and Work Trips" (1963); "Distribution of 1980 Non-Residential Trips" (1963); "Estimating Trips to Industrial Land Given Employment" (1961); "Estimating 1980 Total Person Trips" (1963)), represent thorough documentation of trip generation procedures used by one of the major transportation studies.

6. Browning, Clyde E., "Industrial Worker Densities in the CATS Area." CATS *Res. News,* Vol. 2, No. 8 (1958).

Representative of many articles on the subject of employment densities, this article discusses the relationship with distance from the CBD. Since tripmaking to industrial areas is highly worker-oriented, a consideration of such density rates is virtually tantamount to a consideration of trip generation rates.

7. Dept. of City Planning, City of Chicago, *Locational Patterns of Major Manufacturing Industries in the City of Chicago.* Economic Base Study Series, Study No. 2, Research Div. (Nov. 1960).

In Chicago, as in many major metropolitan areas, locational patterns for industry are changing. This study reports the changes that occurred between 1940 and 1958, such changes having various, but significant, effects on trip generation and travel mode selection.

8. Hoel, Lester A., "Characteristics of Truck Travel in the Los Angeles Metropolitan Area." Unpubl. paper prepared for HRB (1963).

Based on a special study by the California Division of Highways for the Los Angeles Regional Transportation Study, this paper provides a brief description of several alternative ways of predicting truck trip generation at industrial land. Additional work was anticipated.

9. Horn, John W., "Impact of Industrial Development on Traffic Generation in Rural Areas of North Carolina." *HRB Bull. 347,* pp. 133-142 (1962).

Traffic problems are created by rural industry as well as by urban industry. This paper shows that even in essentially rural areas people live fairly close to their jobs. Data presented on trip lengths and trip distribution.

10. Inst. of Traffic Engineers, *Industrial Plant Parking.* Washington (1959).

This report, developed by a Technical Committee, was approved by the Board of Direction as a "Recommended Practice." It covers pedestrian-vehicle circulation requirements at typical industrial plants, both on the plant premises and on neighboring streets. It includes an outline of traffic engineering studies that should be made wherever a problem exists, and a discussion of steps that can be taken to expedite the flow of traffic at shift-change traffic peaks.

11. Keefer, Louis E., "1980 Truck Trips." Pittsburgh Area Transportation Study *Tech. Paper No. 11* (1961).

Technical documentation of the methods considered for predicting truck trip generation in Pittsburgh by various land use categories, particularly to industrial land. Land use area trip rates and truck/person trip rate ratios are compared. Discusses final forecast results, and includes both tabular and graphic trip rate details.

12. Lansing, John B., Mueller, Eva, and Barth, Nancy, *Residential Location and Urban Mobility.* Survey Research Center, Inst. for Social Research, Univ. of Michigan (June 1964).

A report prepared for the U. S. Bureau of Public Roads dealing, in part, with the question "When you were looking for a new home, how important to you was it to live closer to the place where you (or your husband) works?" Of 370 sample cases, 44% said "Made no difference—not important"; 24% said "Somewhat important"; 32% said "Very important." Further ramifications explored, particularly those bearing on selection of travel mode to work.

13. Little, Arthur D., *The Usefulness of Philadelphia's Industrial Plant: An Approach to Industrial Renewal.* (1960).

Includes general discussion of the different kinds of

transportation accessibility required by different kinds of industry.

14. McCarthy, James F., *Highways, Trucks and New Industry: A Study of Changing Patterns.* Dept. of Res. and Transport Economics, American Trucking Assoc. (May 1963).

According to questionnaire returns, "More and more plants are using truck transport for the movement of nearly all of their freight traffic." Moreover, "Most survey respondents either received or shipped 90% or more of their freight by truck and, in the case of nearly half of the responding firms, 90% or more of both inbound and outbound freight movement was by truck." Generally confirms increasing truck trip generation at newer industrial locations.

15. McKie, John, *Home Location Patterns of Industrial Workers in the Detroit Region.* Detroit Metro. Area Regional Planning Comm. (Dec. 1955).

An infrequent example of a planning commission's use of transportation study data (Detroit Metropolitan Area Traffic Survey) to examine commuting patterns to selected major plants in a metropolitan area as part of its comprehensive planning effort. General analyses, comparable to those forming the basis for the present report, were seen as highly useful. Suggests that other planning agencies should make comparable use of such data.

16. Muncy, Dorothy A., "Land for Industry." *Readings in Urban Geography,* edited by Harold M. Mayer and Clyde F. Kohn, Univ. of Chicago Press (1959).

The purpose of this paper was to explore ways in which business and community leaders can provide space for industrial growth. General discussion of access requirements.

17. Pasma, Theodore K., *Organized Industrial Districts.* U. S. Dept. of Commerce, Office of Tech. Serv., Area Development Div. (1954).

An early guide, summarizing types of district development, but relatively little on traffic planning.

18. Pittsburgh Regional Planning Assoc., *Steel Valley District: A Long-Range Development Plan* (for the Boroughs of Homestead, Munhall, West Homestead, West Mifflin, and Whitaker). (Jan. 1961).

An excellent example of a comprehensive planning report which deals extensively with both general planning and traffic problems created by industrial concentrations.

19. Urban Land Institute, "Planned Industrial Districts: Their Organization and Development." *Tech. Bull. No. 19* (1952).

Discusses the historical and then-current development of planned industrial districts. A good general primer on all phases of planning and operation, but weak on traffic requirements, as were most of the early publications dealing with the subject.

20. Urban Land Institute, "Space for Industry: An Analysis of Site and Location Requirements." *Tech. Bull. No. 23* (1954).

A landmark study of 220 plants, built mostly between 1940 and 1944, as to site specifications such as land areas, structure area, floor space, distance from CBD, floor space per employee, employees per acre, employees per parking space, transportation facilities, and other details. Findings provide a good general picture of the relative sizes of industrial operations across the country (although now obviously dated). Includes various planning considerations for transportation.

21. Urban Land Institute, "Redevelopment for Industrial Use." *Tech. Bull. No. 25* (1955).

Discusses land requirements for industry, and some of the reasons why industry is decentralizing and building different kinds of plants than formerly. No specifics on transportation planning.

22. Williams, T. E. H., Latchford, J. C. R., and Dobson, G. G., "Road Traffic Generated by Households and Factories." Paper presented at Seventh Internat. Study Week in Traffic Eng., London (Sept. 1964).

"Mobile industries," the locations of which were not tied to natural geographic features or material resources, were studied in the North-East of England. Most were "mechanical engineering" factories. Traffic flows recorded on site, and site data obtained by questionnaire, for factories employing from 100 to 3,000 people, were reduced to a series of regression equations for trip generation studies.

23. Wrigley, Robert L., Jr., "Organized Industrial Districts," *Readings in Urban Geography,* edited by Harold M. Mayer and Clyde F. Kohn, Univ. of Chicago Press (1959).

Interesting review of the large industrial districts in Chicago, among the oldest in the country. Some discussion of transportation requirements.

GENERAL REFERENCE

1. Campbell, M. Earl, and Schmidt, Robert E., *Highway Traffic Estimation.* The Eno Foundation for Highway Traffic Control (1956).

A basic text interesting for its treatment of the broad aspects of trip generation and traffic estimation.

2. Chicago Area Transportation Study, *Final Report, Volume 1: Survey Findings, Volume 2: Data Projections, and Volume 3: Transportation Plan* (1959, 1960, and 1962).

Together, these three volumes detail the transportation planning process developed to attack the transportation problem in America's second largest metropolitan area, and are "must" reading for any student of trans-

portation planning. As with the earlier Detroit report, there is a thoughtful analysis of land use trip generation.

3. Detroit Metropolitan Area Traffic Study, *Final Report, Parts I* and *II* (1955 and 1956).

   The first major transportation study to delve deeply into the traffic generating characteristics of different land uses, the Detroit final reports offer much pertinent land use-traffic data.

4. Hall, Edward M., "Traffic Generator Studies in San Diego." *Traffic Eng.* (Feb. 1960).

   Based on factual studies of 1952-1953 travel characteristics in San Diego, this article presents various trip generation rates used by the San Diego Metropolitan Area Transportation Study.

5. Hamburg, John R., "Summary Comparison of Trip Generation for Chicago and Detroit." Chicago Area Transp. Study *Res. News,* Vol. 2, No. 11 (1958).

   Summary comparison of per-acre land use person trip generation rates developed by the Chicago and Detroit transportation studies.

6. Hamburg, John R., "A Comparison of Vehicle and Person Destinations by Land Use." Chicago Area Transp. Study *Res. News,* Vol. 2, No. 13 (1958).

   The important conclusion is that there are significant differences in the proportions of trips generated by different land use activities as between person trips and vehicle trips. For example, "the proportion of total commercial vehicle destinations to non-residential land, particularly commercial, is much higher than the proportion of total person trips destined to non-residential land."

7. Hamburg, John R., and Sharkey, Robert H., "Land Use Forecast." Chicago Area Transp. study *Tech. Manual 32.610* (1961).

   A book-length account of the procedures used to forecast and distribute spatially the additional land to be brought into use between 1956 and 1980 in the 1,250-sq-mi Chicago study area. Of importance to any student of trip generation, since the determinants of where and how land will be used are also, generally, the determinants of its level of trip generation. See particularly Chapter VI, "The Future Development of Non-Residential Land-Manufacturing." For comparisons with the Pittsburgh procedures, see Arthur Schwartz, *Land Use Forecast,* PATS *Tech. Paper No. 16* (1960), and particularly *Distributing Future Industrial Land,* PATS *Tech. Paper No. 15* (1959) (not entered).

8. Pittsburgh Area Transportation Study, *Final Report, Volume 1: Study Findings* and *Volume 2: Forecasts and Plans* (1961 and 1963).

   Styled after the Chicago report, the Pittsburgh volumes contain detailed studies of trip generation with special attention to land use area trip generation rates and their shortcomings for the prediction of future travel production. Chapter III (Future Tripmaking by Auto and Truck) of Vol. 2 demonstrates the probability for a significant underestimation of trips if present trip rates are applied to future land use areas.

9. Penn-Jersey Transportation Study, *Final Report, Vol. 1: The State of the Region; Vol. 2: 1975 Projections—Foreground of the Future; and Vol. 3: 1975 Transportation Plans* (1964 and 1965).

   This most recent of final reports by major transportation studies provides a wealth of detail about trip generation in the Philadelphia area. Generally confirming the basic relationships with land use found by predecessor studies, the Philadelphia experience is valuable, in that it also shows that differences in trip generation can persist from city to city.

10. Row, Arthur T., "Land Use Planning Related to Traffic Generation and Estimation." *Proc. 28th Ann. Meeting Inst. of Traffic Eng.* (1958).

    Reviews the inseparableness of land use and transportation planning and cites certain implications of planning vs predicting land uses.

11. Sharkey, Robert H., "Trip Origins by Type of Land Use in the CATS Area." Chicago Area Transp. Study *Research News,* Vol. 12, No. 12 (1958).

    Provides useful scale to the percentage of total study area person trips generated by 83 different land use categories.

12. Shuldiner, Paul W., DeSalvo, Joseph, Dickey, John, and Horton, Frank, *Non-Residential Trip Generation Analysis.* Northwestern Univ. (Nov. 1965).

    A research project sponsored by the U. S. Bureau of Public Roads exploring the role of land use in trip generation analysis, variables used in generation analysis, methodological approaches (particularly multiple linear regression), and various other aspects of trip generation. Excellent review of techniques used by selected transportation studies. Extensive bibliography.

13. Sullivan, Sheldon W., "Land Use Trip Generation Rates." Pittsburgh Area Transp. Study *Tech. Paper No. 12* (1961).

    A summary presentation of all two-digit person and vehicle land use area trip generation rates, by ring, for the Pittsburgh area, 1958. Explains calculation of rates.

14. Twin Cities Area Transportation Study, *Final Report, Vol. 1: Study Findings* (1962).

    Chapter IV, "Trip Generation and Land Use," includes a special look at industrial land use and provides trip generation rates both by floor area and by ground area. Another important report for comparison purposes.

APPENDIX B

SUMMARIES OF SHOPPING CENTER AND MANUFACTURING PLANT PEAK TRAFFIC DATA, TRANSPORTATION STUDY TRAVEL SURVEY CHARACTERISTICS, AND PLANT QUESTIONNAIRE RETURNS

TABLE B-1

SHOPPING CENTER PEAK-HOUR VOLUMES[a]

	ENTERING TRAFFIC DURING		
	HWY. PEAK HOUR[b]	CENTER PEAK ENTERING HOUR	
CENTER	(%)	(%)	TIME
A	6.3	26.4	7-8PM
B	6.3	22.5	7-8PM
C	6.3	26.0	7-8PM
D	6.5	20.7	7-8PM
E	8.3	17.5	7-8PM
F	5.7	13.8	7-8PM
G	4.6	12.2	6-7PM
H	6.0	13.6	7-8PM
J	5.9	18.0	7-8PM
K	5.1	16.0	7-8PM
L	11.5	16.9	3-4PM
M	9.2	12.0	2-3PM
N	6.8	12.0	12-1PM
O	7.0	12.7	1-2PM
P	6.6	11.3	10-11AM
Q	6.3	11.2	1-2PM
R	4.8	11.7	7-8PM
S	5.6	11.3	7-8PM
T	5.0	15.0	2-3PM
U	8.6	9.6	7-8PM
V	8.9	12.5	1-2PM
W	8.3	11.0	12-1PM
X	6.7	12.4	1-2PM
Avg.	6.8	15.1	

[a] From transportation study data for various cities.
[b] Average of two hours between 4 and 6 PM.

TABLE B-2

PEAK AND DIRECTIONAL CHARACTERISTICS OF TRIPS TO SELECTED MA "'FACTURING PLANTS [a]

	PASS ·RS				TRUCKS			
		PEAK						
PLANT	DAILY TRIPS [b] (NO.)	TRIPS [c] (NO.)	HOUR	(%)	DAILY TRIPS [d] (NO.)	DAILY TRIPS (%)	PEAK (%)	D [e] (%)
1	1569	565	7-8	36	31	1.9	—	80
2	1940	931	6-7	48	38	1.9	—	71
3	3072	1536	7-8	50	305	9.0	1.6	78
4	4280	1840	7-8	43	154	3.5	—	75
5	2802	1205	7-8	43	341	10.8	1.5	88
6	2345	1079	7-8	46	175	6.9	—	92
7	3795	1784	7-8	47	452	10.6	—	90
8	1294	479	7-8	37	67	4.9	16.4	84
9	2279	661	3-4	29	55	2.4	—	70
10	1110	644	7-8	58	32	2.8	—	100
11	899	288	6-7	32	11	1.2	—	78
12	4937	1432	6-7	29	99	2.0	—	85
13	2596	779	6-7	30	253	8.9	3.2	89
14	916	705	7-8	77	33	3.5	33.3	100
15	1728	760	7-8	44	63	3.5	—	89
16	1432	387	7-8	27	149	9.4	9.4	62
17	5680	NA	NA	NA	NA	NA	NA	NA
18	3080	NA	NA	NA	NA	NA	NA	NA
19	894	295	7-8	33	30	3.2	—	82
20	6730	2423	7-8	36	303	4.3	—	94
21	1042	636	7-8	61	47	4.3	—	90
22	3012	1566	6-7	52	165	5.2	—	94
23	850	221	3-4	26	96	10.1	17.7	84
24	321	71	7-8	22	16	4.7	—	100
25	1655	828	7-8	50	33	2.0	30.3	79
26	3186	1274	7-8	40	124	3.7	—	75
27	2110	1118	7-8	53	116	5.2	8.1	91
28	1274	637	6-7	50	90	6.6	—	93
29	4380	NA	NA	NA	NA	NA	NA	NA
30	5878	NA	NA	NA	NA	NA	NA	NA
31	33078	NA	NA	NA	NA	NA	NA	NA
32	1648	824	7-8	50	89	5.1	—	98
33	1155	520	8-9	45	6	0.5	33.3	94
34	1639	377	6-7	23	272	14.2	7.0	78
35	1461	453	6-7	31	164	10.1	14.0	100
36	3466	1352	7-8	39	160	4.4	11.3	83
37	2446	856	7-8	35	59	2.4	6.8	100
38	2268	1361	7-8	60	35	1.5	—	100
39	560	196	6-7	35	67	10.7	14.9	93
40	549	165	6-7	30	82	13.0	6.1	80
41	1218	475	6-7	39	96	7.3	5.2	89
42	632	240	8-9	38	—	—	—	100
43	2408	867	7-8	36	—	—	—	100
44	3184	1178	7-8	37	—	—	—	91
45	257	193	7-8	75	18	6.5	—	100
46	522	172	6-7	33	46	8.1	13.1	64
47	504	116	6-7	23	—	—	—	84
48	888	302	7-8	34	NA	NA	NA	100
49	402	76	6-7	19	NA	NA	NA	64

[a] From transportation study data for various cities.

[b] Automobile plus light truck (4-tired vehicles) trips from home interview, truck-taxi, and roadside interview surveys.

[c] Based on single highest hour, whenever it occurs.

[d] Medium and heavy truck (over 4-tired vehicles) trips from truck-taxi and roadside interview surveys, where available.

[e] Proportion of total vehicle trips in dominant direction (to plant) at peak hour.

TABLE B-3

FACTSHEET FOR TRANSPORTATION STUDIES FURNISHING BASIC TRAVEL DATA[a]

STUDY	HOME INTERVIEW DATA		STUDY AREA DATA		SAMPLE SITES ANALYZED (NO.)		
	PERIOD SURVEY	SAMPLE SIZE (%)	AREA (SQ MI)	POPULATION (MILLIONS)	SHOP CTRS.	AIRPORTS	MFG. PLANTS
Atlanta Area Transportation Study[b]	2/61-7/61	5	200	0.6	3	1	3
Chicago Area Transportation Study[b]	4/56-10/56	3.33	1236	5.2	2	1	5
Denver Metropolitan Area Transportation Study	6/59-8/59	14[c]	410	0.8	1	0	1
Detroit Metropolitan Area Traffic Study[d]	8/53-12/53	4 and 10	682	3.0	0	0	3
Miami Area Transportation Study	3/64-4/64	5	400	1.1	3	1[e]	0
New Castle County Planning Program	9/64-11/64	6.67	437	0.4	3	0	5[e]
Niagara Frontier Transportation Study	6/62-8/62	4	810	1.3	4	1	7
Penn-Jersey Transportation Study	6/60-11/60	4 and 10	1175	4.0	2	1	0
Pittsburgh Area Transportation Study	9 58-11/58	4	420	1.5	4	1	16
Puget Sound Regional	11/61	10	1269	1.5			
Transportation Study	7/61-	4 and			3	1	0
Rhode Island Statewide Traffic Survey	1/61-8/61	5 and 10	295	0.8	1	1	2
Salt Lake Area Transportation Study	10/59-9/60	6.67 and 10	350	0.4	0	1[e]	0
San Diego Traffic Survey[f]	10/52-3/53	5	430	0.6	0	1	2
Twin Cities Area Transportation Study	7/58-11/58	5	890	1.4	2	1	7
Washington Metropolitan Area Transportation Study	1/55-12/55	3.33 and 10	233	1.6	0	1	0
All					28	12	51

[a] From various transportation study published documents.
[b] Home interview and truck-taxi travel data only.
[c] Varied by zone; average sample size 14%.
[d] Home interview travel data only, from secondary source.
[e] Backcheck site.
[f] Home interview travel data only.

TABLE B-4
SUMMARY OF MANUFACTURING PLANT QUESTIONNAIRE RETURNS[a]

PLANT[b]	SITE AREA (ACRES)	FLOOR SPACE (1,000 SQ FT) PRODUC-TION	WARE-HOUSING	OFFICES & LABS	TOTAL	TRUCK FREIGHT[c] %	PARKING AREA (ACRES)	ON-SITE SPACES	AVERAGE DAILY ATTENDANCE
1	97	875		39	914	60/95	NF	1,000	2,237[d]
2	40-50	1,090			1,090[e]	NA	NF	NF	2,900[d]
7	76	3,791		545	4,336	NA	NF	1,500	10,422[d]
8	208	1,705		48	1,753	NF	(2)[f]	1,119	3,109[d]
9	89	1,507	32	55	1,594	NF	(4)[f]	1,900	3,294[d]
10	32	770		80	850	NF	(5)[f]	900	1,728[d]
11	14	334	61	60	455	NF	NF	785	1,410[d]
14	40	400		100	500	NF	(2)[f]	2,000	1,395[d]
15	NA	NA	NA	NA	NA	NA	NA	NA	2,187[d]
16	45	946		18	964	NF	(5)[f]	620	1,450[d]
17	112	1,500			1,500	NF	(8)[f]	NF	24,221
18	40	730	20		750	NF	(2)[f]	NF	3,250
20	136	4,360		340	4,700	30/50	21	NF	17,082[d]
22	68	1,996		178	2,174	7/70	10	1,353	7,577[d]
28	72	775		175	950	70/5	NF	950	1,773
32	33	360	227	315	902	10/95	6.9	774	1,500
34	NF	185			185[e]	10/65	NF	800	1,500
35	42	347	282	70	699	80/11	2.9	586	1,715
36	NA	NA	NA	NA	NA	NA	NA	NA	4,797[d]
37	26	402			402[e]	100/100	16.2	2,242	3,000
38	NA	NA	NA	NA	NA	NA	NA	NA	NA
39	2	350		1	351	100/20	0.3	NF	NF
40	44	613		43	656	NF	2.8	NF	NF
41	40	922		243	1,165	90/10	NF	925	NF
42	103	265		48	313	100/100	5.5	NF	NF
43	22	483	908	444	1,835	50/50	NF	1,022	2,860[d]
46	18	600	600	60	1,260	NF	(3)[f]	500	1,625
47	26	275	215		490	NF	(3)[f]	830	1,140
48	33	225	137	138	500	80/80	NF	800	1,030

[a] NA = not available; NF = not furnished.
[b] Missing numbers through 49 indicate no return.
[c] Inbound/outbound.
[d] From transportation study source.
[e] No breakdown furnished.
[f] Number of parking lots.

APPENDIX C

REGRESSION AND BACKCHECK RESULTS

REGRESSION RESULTS

Airports

With the objective of developing relationships to "explain" the number of air travel trips generated annually by each Standard Metropolitan Statistical Area (SMSA) throughout the United States, two multiple regression runs were made. The first dealt with all SMSA's having airport service; the second excluded certain SMSA's having either very high or very low air travel rates. For example, Las Vegas and Miami were excluded because of high rates not attributable to SMSA socio-economic characteristics. Likewise, Wheeling, W. Va., and Bridgeport, Conn., were excluded because of the "shadow effect"; that is, many of their air travelers using the Pittsburgh or New York airports. Results of the second run were better statistically because they were representative of more typical relationships.

Explorative variables were limited to those readily available from census sources (specifically, those published in the *County and City Data Book*). Although it was recognized that many additional variables might have important influence on air travel, the limitations on both time available and the purposes of this project precluded further refinements. All the variables considered are defined in Table C-1.

It is impossible in this report to reproduce the full com-

TABLE C-1

DEFINITION OF VARIABLES USED IN MULTIPLE REGRESSION, AIRPORTS

VARIABLE TYPE	SYMBOL	DEFINITION	REFERENCE
Dependent	Y_1	Total aircraft departures performed in scheduled service, calendar year 1960	a
	Y_2	On-line revenue passenger originations in scheduled service, calendar year 1960	a
	Y_3	Y_2/100,000 SMSA population	
Independent	X_1	Population, thousands	b, Col. 3
	X_2	Population, per square mile	b, Col. 4
	X_3	Nonwhite population, 0.1%	b, Col. 9
	X_4	Median age, 0.1 year	b, Col. 13
	X_5	Families with incomes over $10,000, 0.1%	b, Col. 24
	X_6	High school graduates, 0.1%	b, Col. 28
	X_7	Manufacturing employment, hundreds	b, Cols. 40, 41
	X_8	Transportation employment, hundreds	b, Col. 42
	X_9	Trade employment, hundreds	b, Col. 43
	X_{10}	Institutional employment, hundreds	b, Cols. 44, 45, 46
	X_{11}	Manufacturing establishments with at least 100 employees	b, Col. 88
	X_{12}	Services receipts, $million	b, Col. 122
	X_{13}	Unemployment rate	b, Col. 35

[a] *Airport Activity Statistics of Certified Route Air Carriers, Twelve Months Ended Dec. 31, 1960.* Joint publ. of U.S. Civil Aeronautics Board and Federal Aviation Agency.
[b] "Table 3—Standard Metropolitan Statistical Areas." *County and City Data Book* (for 1960 census data), U.S. Bureau of the Census, pp. 432-55 (1962).

puter outputs. However, Table C-2 gives (a) the predictive equations having the lowest standard error of the estimate (not necessarily the highest multiple coefficient of determination), (b) the standard error for each term, and (c) the correlation coefficient (R^2). Table C-3 gives, for each dependent variable, all independent variables by rank importance, showing the increase, if any, in R^2 by adding each to the predictive equation.

Shopping Centers

Figures 32 and 33 show the relationship between certain tripmaking categories and shopping center characteristics of employment and floor space. Table C-4 gives the associated simple linear equations, together with their coefficients of correlation and standard errors of estimate. Two other equations are given—for person work trips and total vehicle trips, both related to total floor space.

None of these simple linear regression equations would produce highly reliable predictions of trips to shopping centers. Therefore, the prospects of developing better relationships led to the application of multiple linear regression techniques. The procedure followed was to develop regression equations with data from 23 shopping centers, and then to test the equations against observed data for three shopping centers in Wilmington, Del.

Equations were derived for up to five dependent variables, with as many as fourteen independent variables. Table C-5 defines those used in the equations tested with the Wilmington shopping center data (note redefinitions between runs).

Auto driver trips to work were not included as a dependent variable because person work trips were used to represent shopping center employment at the time of study. "Other" trips include personal business, social-recreation, eat meal, school, medical-dental, and serve passenger purposes. In computer run 2 "other" trips excluded serve passenger trips, and travel speed was cubed. Because work trips are excluded, shopping and "other" trips do not equal all auto driver trips. It should also be noted that truck trips are not treated, and must be added later—presumably as a uniform proportion of predicted tripmaking—to obtain total vehicle trips.

In addition to the variables given in Table C-5, other slightly modified variables were employed to test the need for seasonal adjustments. This question was resolved by parallel testing with and without monthly trip factors for the different seasons represented in the various studies. Comparison of the regression results showed no improvement with the factors.

Other variable changes were made when the initial tests showed market area variables to be insignificant. The dependent variables were modified to shopping and other trips originating within 3 miles of the center, and those from more than 3 miles. At the same time, population and car ownership variables were also adjusted to 3-mile limits. The resulting analysis confirmed that the significant variables were those of the shopping center, not the market area.

An analysis technique described by Seal (*42*) was employed to determine the best fitting linear equation using the fourteen variables, and to determine variances about the general mean and the model. A stepwise linear regression analysis program of the University of California School of Medicine (*43*) was used primarily to identify variables by order of their significance. This procedure permitted the selection of the most significant hypotheses (or groups of variables) for analysis of variance. Equations showing the lowest standard error in the stepwise program were tested with the other technique to determine whether the differences in variance between the full model and simpler models

TABLE C-2

SELECTED MULTIPLE REGRESSION RESULTS, AIRPORTS

RUN	N	EQUATION [a]	R^2	STD. ERROR [b]
1	176	$Y_1 = -63 + 0.17X_3 + 0.78X_5 - 0.06X_7 + 0.76X_8 + 0.19X_9 - 0.43X_{12} - 0.62X_{14}$ (0.07) (0.19) (0.02) (0.14) (0.07) (0.07) (0.48)	0.86	60
		$Y_2 = -2{,}977 - 3.36X_1 + 2.50X_3 + 16.43X_5 - 2.27X_7 + 12.32X_8 + 13.06X_9 - 2.09X_{10} - 3.09X_{12}$ (3.45) (1.54) (4.06) (1.02) (3.09) (3.07) (1.38) (1.72)	0.92	73
		$Y_3 = -944 - 0.06X_2 + 0.69X_3 + 1.49X_4 + 3.01X_5 + 0.58X_6 - 0.48X_7 + 0.95X_9 - 0.41X_{10} + 0.33X_{11}$ (0.07) (0.25) (0.79) (0.75) (0.45) (0.10) (0.21) (0.12) (0.33) $+ 0.30X_{12} + 1.51X_{14}$ (0.18) (1.54)	0.35	83
2	157	$Y_1 = -75 - 0.16X_1 - 0.19X_3 + 0.92X_5 + 0.82X_8 + 0.25X_9 + 0.06X_{10} - 0.44X_{12} - 0.62X_{14}$ (0.10) (0.08) (0.23) (0.14) (0.14) (0.04) (0.08) (0.57)	0.87	56
		$Y_2 = -3{,}365 - 2.94X_1 + 2.75X_3 + 18.88X_5 - 1.82X_7 + 12.93X_8 + 11.29X_9 - 1.63X_{10} - 3.75X_{12}$ (3.57) (1.60) (4.74) (1.08) (3.09) (3.11) (1.45) (1.80)	0.93	67
		$Y_3 = -72 - 0.49X_1 + 0.07X_2 + 0.27X_3 + 0.23X_4 + 0.49X_5 + 0.51X_6 - 0.14X_7 + 0.76X_8 + 0.99X_9$ (0.21) (0.05) (0.16) (0.54) (0.55) (0.30) (0.06) (0.28) (0.26) $- 0.29X_{11} - 0.53X_{12} - 1.76X_{14}$ (0.22) (0.15) (1.11)	0.47	52

[a] Value in parentheses ( ) is standard error of term above.
[b] As percentage of $\overline{Y}$.

TABLE C-3

RANK ORDER OF INDEPENDENT VARIABLES AND INCREASING R^2 AS EACH IS ADDED TO THE PREDICTION EQUATION[a], AIRPORTS

	RUN 1 ($N=176$)						RUN 2 ($N=157$)					
	Y_1		Y_2		Y_3		Y_1		Y_2		Y_3	
RANK ORDER	VAR.	R^2	VAR.	R^2	VAR.	R^2	VAR.	R^2	VAR.	R^2	VAR.	R^2
1	X_9	0.78	X_9	0.89	X_5	0.14	X_9	0.79	X_9	0.90	X_5	0.14
2	X_5	0.80	X_1	0.90	X_3	0.17	X_5	0.91	X_1	0.91	X_{14}	0.19
3	X_7	0.82	X_5	0.91	X_6	0.21	X_3	0.83	X_5	0.92	X_3	0.22
4	X_{12}	0.83	X_8	0.91	X_4	0.23	X_1	0.83	X_8	0.92	X_6	0.25
5	X_8	0.85	X_{12}	0.92	X_2	0.24	X_8	0.84	X_{12}	0.93	X_4	0.27
6	X_3	0.86	X_7	0.92	X_8	0.24	X_{12}	0.86	X_3	0.93	X_8	0.28
7	X_{14}	0.86	X_3	0.92	X_7	0.28	X_{10}	0.87	X_7	0.93	X_{12}	0.35
8	X_1	0.86	X_{10}	0.92	X_9	0.30	X_{14}	0.87	X_{10}	0.93	X_7	0.40
9	X_6	0.86	X_{11}	0.92	X_{10}	0.34	X_7	0.87	X_{11}	0.93	X_9	0.44
10	X_2	0.86	X_6	0.92	X_{12}	0.35	X_6	0.87	X_{14}	0.93	X_1	0.46
11	X_{11}	0.86	X_2	0.92	X_{14}	0.35	X_2	0.87	X_6	0.93	X_2	0.46
12	X_4	0.86	X_{14}	0.92	X_{11}	0.35	X_{11}	0.87	X_2	0.93	X_{11}	0.47
13	X_{10}	0.86	X_4	0.92			X_4	0.87	X_4	0.93		

[a] See Table C-2.

TABLE C-4

SUMMARY OF SIMPLE LINEAR REGRESSION, SHOPPING CENTERS

REGRESSION	REF.	EQUATION	r	S
1. Total vehicle trips vs person work trips	Fig. 32	$Y = 1{,}090 + 4.73X$	0.82	1,520
2. Auto driver trips to shop vs person work trips	Fig. 32	$Y = 824 + 3.36X$	0.77	1,295
3. Convenience goods auto driver trips vs convenience goods floor space	Fig. 33	$Y = 578 + 9.13X$	0.45	419
4. Shopping goods auto driver trips vs shopping goods floor space	Fig. 33	$Y = 1{,}040 + 7.7X$	0.60	1,560
5. "Other" auto driver trips[a] vs "other" floor space[a]	—	$Y = 394 + 6.66X$	0.48	408
6. Person work trips vs total floor space	—	$Y = 137 + 2.16X$	0.73	316
7. Total vehicle trips vs total floor space	—	$Y = 1{,}512 + 10.83X$	0.65	2,040

[a] Includes personal business, social-recreational, school, and medical-dental.

TABLE C-5

DEFINITION OF VARIABLES USED IN MULTIPLE REGRESSION, SHOPPING CENTERS

VARIABLE			
	SYMBOL		
TYPE	RUN 1	RUN 2	DEFINITION
Dependent	Y_1	Y_1	All auto driver trips
	Y_2	Y_2	Auto driver trips to shop
	Y_3		Auto driver trips to shop for convenience goods
	Y_4		Auto driver trips to shop for shopping goods
	Y_5	Y_3	Other auto driver trips
Independent	X_1		Number of establishments
	X_2		Total site area, acres
	X_3	X_1	Number of parking spaces
	X_4	X_2	Total person work trips
	X_5		SMSA median family income
	X_6	X_3	Distance from major competition, 0.1 mile
	X_7	X_4	Age of study data, years
	X_8		Population within 5-mile radius, thousands
	X_9	X_5	Age of center at time of study, years
	X_{10}	X_6	Reported travel speed of tripmakers, mph
	X_{11}		Autos owned per 1,000 population within 5 miles
	X_{12}	X_7	Floor space for convenience goods, 1,000 sq ft
	X_{13}	X_8	Floor space for shopping goods, 1,000 sq ft
	X_{14}	X_9	Floor space for other uses, 1,000 sq ft

were statistically significant. If not, the simpler models were accepted. Table C-6 summarizes the effectiveness of selected models in reducing the unexplained variance. (The five-variable model given included work trips, age of center, and the floor space measures.)

It is evident that tripmaking must be subject to the influence of other unspecified variables, inasmuch as the models leave from 20 to 40% of the original variance unexplained (60% or more for convenience goods trips).

The equations for computer run 2 in Table C-7 are those producing the lowest standard error in stepwise regression tests incorporating the nine variables listed for computer run 2 in Table C-5. Because the unexplained variance for these equations was not significantly different from that using all the variables, the simpler equations were used in the subsequent Wilmington test. Table C-7 also gives for each equation the standard error (as percent of the dependent variable mean), the value of R^2, and the standard error for each individual regression coefficient. Differences in the input data between the first and second runs, most notably the dropping of serve passenger trips, are particularly reflected in the lowered standard error of estimate for "other" trips.

TABLE C-6

REDUCTIONS IN VARIANCE USING 14- AND 5-VARIABLE MODELS

	VARIANCE		
DEPENDENT VARIABLE	ABOUT GENERAL MEAN	AROUT 14-VAR. MODEL	ABOUT 5-VAR. MODEL
All trips, Y_1	$(2{,}859)^2$	$(1{,}175)^2$	$(1{,}391)^2$
All shopping trips, Y_2	$(2{,}070)^2$	$(980)^2$	$(1{,}111)^2$
Conven. goods trips, Y_3	$(515)^2$	$(395)^2$	$(468)^2$
Shop. goods trips, Y_4	$(2{,}025)^2$	$(965)^2$	$(1{,}108)^2$
Other trips, Y_5	$(695)^2$	$(290)^2$	$(465)^2$

Manufacturing Plants

This summary describes the major statistical results of three computer runs utilizing the "stepwise regression" program developed by the Health Sciences Computing Facility, UCLA (*43*). The first two runs were based on the 25 plants in Pittsburgh and Buffalo. The third run added 6 plants in Chicago, 7 plants in Minneapolis-St. Paul, and 3 plants in Wilmington, Del.

The principal purpose was to develop a modal split model, not a model to predict total trip generation. The primary concern throughout was the number or percentage of auto driver trips produced by a plant of given employment. Although expressed variously, all dependent variables were designed for this goal. Table C-8 defines all variables as used in the three computer runs (note redefinitions between runs). Unless otherwise noted, all variables are expressed in terms of daily home interview work trips to each plant.

From this array, computer outputs provided 144 predictive equations and various statistical measures of "goodness." Because it is hardly possible to reproduce the entire output, Table C-9 summarizes only selected results— specifically, the equation having the lowest standard error of the estimate (S_E) for each dependent variable for each run; its multiple coefficient of determination (R^2); its

TABLE C-7

SELECTED MULTIPLE REGRESSION RESULTS, SHOPPING CENTERS

RUN	EQUATION [a]	R^2	STD. ERROR [b]
1	$Y_1 = -4{,}453 + 60.07X_1 - 11.36X_2 + 0.247X_3 + 3.68X_4 + 1.32X_5 + 138.6X_6 - 225.8X_7 - 1.06X_8 + 159.9X_9$		
	(34.3) (19.1) (0.25) (1.22) (0.91) (118.5) (139.0) (2.01) (126.0)		
	$-225.0X_{10} - 21.47X_{12} - 0.58X_{13} - 33.6X_{14}$	0.934	19
	(185.8) (17.03) (3.16) (10.5)		
	$Y_2 = -3{,}022 + 56.33X_1 - 21.58X_2 + 0.137X_3 + 2.16X_4 + 0.74X_5 + 129.2X_6 - 196.2X_7 - 0.38X_8 + 85.3X_9$		
	(30.7) (19.7) (0.23) (1.23) (0.81) (126.6) (124.0) (1.95) (121.4)		
	$-100.9X_{10} + 2.10X_{11} - 17.90X_{12} - 2.56X_{13} - 35.6X_{14}$	0.919	24
	(169.2) (7.35) (16.98) (3.88) (9.36)		
	$Y_5 = -675 + 10.65X_2 - 0.15X_3 - 0.311X_4 + 0.34X_5 - 0.31X_8 + 112.9X_9 - 74.3X_{10} - 2.75X_{11} - 8.36X_{12}$		
	(4.25) (0.06) (0.22) (0.18) (0.47) (26.9) (41.5) (1.38) (3.70)		
	$+0.71X_{13} - 2.37X_{14}$	0.936	36
	(0.92) (2.10)		
2	$Y_1 = 3{,}875 + 5.35X_2 + 291.9X_3 - 578.5X_4 - 0.65X_6 - 22.31X_9$	0.920	21
	(0.522) (128.1) (119.9) (0.24) (7.35)		
	$Y_2 = 2{,}841 + 3.23X_2 + 241.4X_3 - 410.8X_4 - 0.34X_6 - 10.45X_7 + 4.32X_8 - 25.70X_9$	0.892	25
	(1.02) (150.5) (124.5) (0.30) (13.10) (4.77) (7.34)		
	$Y_3 = 801 + 0.06X_1 + 0.90X_2 + 31.2X_3 - 108.0X_4 + 35.7X_5 - 0.18X_6 - 1.47X_7 - 2.36X_8 + 1.67X_9$	0.985	14
	(0.04) (0.13) (15.5) (14.8) (10.7) (0.03) (1.37) (0.52) (0.70)		

[a] Value in parentheses ( ) is standard error of term above.
[b] As percentage of $\overline{Y}$.

TABLE C-8

DEFINITION OF VARIABLES USED IN MULTIPLE REGRESSION, MANUFACTURING PLANTS

VARIABLE				
	SYMBOL			
TYPE	RUN 1	RUN 2	RUN 3	DEFINITION
Dependent	Y_1	Y_1	Y_1	Auto driver trips
	Y_2	Y_2	Y_2	Transit passenger trips
		Y_3	Y_3	Auto drivers, %
		Y_4	Y_4	Transit passengers, %
			Y_5	Auto drivers and auto passengers, %
			Y_6	Auto drivers and auto passengers, number
Independent	X_1			Population within 5-mile radius, thousands
	X_2			Automobiles within 5-mile radius, thousands
	X_3			Residential land within 5-mile radius, 0.1 acre
	X_4	X_5	X_3	Net residential density in plant zone, persons/acre
	X_5	X_6	X_4	Net manufacturing density in plant zone, persons/acre
	X_6	X_7	X_5	Plant site area, acres
	X_7	X_8	X_6	Prime shift percentage, three highest morning hours
	X_8	X_1		Employees from car-owning households
	X_9	X_2	X_{11}	Employees not licensed to drive
	X_{10}	X_3	X_1	White-collar employees
	X_{11}	X_4	X_2	Male employees
	X_{12}			CBD-plant distance/CBD-cordon line distance
	X_{13}	X_9	X_7	Average distance, home to work, 0.01 miles
	X_{14}	X_{10}	X_9	Total work trips to plant
	X_{15}			Total manufacturing work trips, plant zone
		X_{11}		Net residential density within 5-mile radius, persons/acre
		X_{12}		Autos per 1,000 population within 5-mile radius
			X_8	Autos per 1,000 population within 3-mile radius
			X_{10}	Net residential density within 3-mile radius, persons/acre

standard error of the estimate expressed as a percentage of the dependent variable mean ($\bar{Y}$); and the standard errors for each of its individual coefficients.

BACKCHECK RESULTS

Airports

Table C-10 summarizes the results of predicting current resident tripmaking to the Salt Lake City and Miami airports. Reported data were provided by the transportation studies for those areas. Table C-11 summarizes the estimated and reported trip distributions by directional orientation.

Shopping Centers

The value of the multiple regression equations as predictive devices can be tested by application to shopping center data not employed in their development. The proposed technique for simulating the distribution patterns may also be tested with the same shopping center data. The results of these evaluations, using data from Wilmington (Del.) shopping centers, are discussed in this section.

Three categories of trips to shopping centers were predicted, using the results of the last regression series, specifically those equations showing the least standard error (see previous discussion on "Regression Results, Shopping Centers"). Table C-12 gives the computed and survey values for the three trip categories for each of the three shopping centers. For comparison, the 14-variable model results are also given with survey volumes that include "serve passenger" trips. It is evident that neither the most broadly based model nor the more practical model (with fewer variables) is a highly reliable predictor, even though the test centers have characteristics well within the data ranges used to construct the models.

As a final check, trips to three centers in Roanoke, Va., were estimated and compared with unpublished survey data provided by the Virginia Department of Highways. The estimates for all auto driver trips were 95, 92, and 78% of survey volumes. Trips to shop were similarly proportioned, but "other" trips were considerably lower than the survey volumes, even though an adjustment was made for "serve passenger" trips. It must be noted that because travel speeds were not known the mean value for all shopping centers was employed in this particular analysis.

It is worth noting, however, that the minimum variable equation for all auto driver trips reproduced the survey volumes within 10% for 9 of 17 centers, and within 20% for 14 of 17 centers. Nevertheless, accurate trip prediction

TABLE C-9

SELECTED MULTIPLE REGRESSION RESULTS, MANUFACTURING PLANTS

RUN	EQUATION [a]	R^2	STD. ERROR [b]
1	$Y_1 = 1.449 - 3.02X_4 + 1.34X_5 + 1.18X_6 - 9.46X_7 - 0.97X_8 - 1.58X_9 - 0.79X_{10} - 0.62X_{11} - 0.64X_{12}$ (3.00) (2.42) (0.74) (4.35) (0.62) (0.55) (0.24) (0.42) (3.32) $-1.22X_{13} + 2.32X_{14} - 0.01X_{15}$ (0.70) (0.90) (0.05)	0.98	13
	$Y_2 = -287 + 0.78X_8 + 0.43X_{10}$ (0.20) (0.12)	0.82	64
2	$Y_1 = 1{,}084 - 0.92X_1 - 1.54X_2 - 0.74X_3 - 0.69X_4 + 1.04X_7 - 9.00X_8 - 1.16X_9 + 2.30X_{10} + 0.69X_{12}$ (0.52) (0.53) (0.16) (0.31) (0.57) (3.97) (0.54) (0.72) (1.27)	0.98	12
	$Y_2 = -380 + 0.23X_2 + 0.43X_3 + 0.12X_4 + 7.77X_8 + 1.33X_9 - 3.22X_{12}$ (0.32) (0.13) (0.07) (5.35) (0.77) (1.75)	0.86	53
	$Y_4 = 9.99 + 0.02X_1 + 0.02X_2 + 0.16X_8 - 0.01X_{10} + 0.16X_{11} - 0.08X_{12}$ (0.01) (0.01) (0.10) (0.01) (0.15) (0.05)	0.79	43
3	$Y_1 = 116 - 0.28X_1 + 0.22X_2 + 1.01X_4 + 0.99X_5 - 3.25X_6 + 0.59X_7 + 0.33X_8 + 0.48X_9 - 0.78X_{11}$ (0.15) (0.20) (0.71) (0.80) (4.72) (0.36) (1.01) (0.23) (0.33)	0.95	8.3
	$Y_2 = -259 + 0.12X_1 - 0.35X_2 - 0.37X_7 + 0.44X_9 + 2.24X_{10} + 0.63X_{11}$ (0.14) (0.17) (0.29) (0.20) (2.27) (0.28)	0.94	57
	$Y_3 = 103 - 0.23X_3 + 0.03X_4 - 0.40X_6 - 0.01X_{11}$ (0.06) (0.02) (0.14) (0.003)	0.58	16
	$Y_4 = -1.20 + 0.09X_3 + 0.15X_6 - 0.01X_7 - 0.02X_8 + 0.13X_{10} + 0.01X_{11}$ (0.06) (0.08) (0.006) (0.02) (0.07) (0.002)	0.73	50
	$Y_5 = 106 - 0.01X_1 - 0.01X_2 - 0.20X_3 - 0.04X_5 - 0.13X_6 + 0.02X_7 + 0.01X_9 - 0.23X_{10} - 0.02X_{11}$ (0.004) (0.005) (0.09) (0.02) (0.11) (0.008) (0.006) (0.10) (0.008)	0.82	9.4
	$Y_6 = 532 + 0.30X_2 - 2.04X_3 - 0.34X_5 - 4.90X_6 + 0.56X_7 + 0.51X_8 + 0.60X_9 - 1.11X_{11}$ (0.20) (2.70) (0.91) (5.01) (0.34) (1.22) (0.21) (0.37)	0.96	16

[a] Value in parentheses ( ) is standard error of term above.

[b] As percentage of $\bar{Y}$.

TABLE C-10

SUMMARY COMPARISON OF PREDICTED AND REPORTED CURRENT RESIDENT TRIP GENERATIONS AT SALT LAKE CITY AND MIAMI AIRPORTS

FACTOR COMPARED	SALT LAKE CITY PREDICTED	SALT LAKE CITY REPORTED	MIAMI PREDICTED	MIAMI REPORTED
1. Air travel trips:				
(a) Int. pers. trips (no./1,000 pop.)	1.33 [a]	1.56	4.52 [b]	3.09
(b) Int. transit trips (%)	4.8 [c]	0.0	16.7 [d]	1.6
(c) Int. avg. car loading (no./car)	1.68 [c]	1.31	1.68 [e]	1.47
(d) Ext. total trips (%)	20 [f]	24	10 [f]	25
(e) Total auto trips (no.)	371	621	2,785	3,107
2. Social-recreation trips:				
(a) Int. pers. trips (no./1,000 pop.)	1.02 [a]	2.51	2.04 [b]	2.17
(b) Int. transit trips (%)	0.2 [c]	0.0	5.0 [g]	0.0
(c) Int. avg. car loading (no./car)	2.43 [c]	3.69	2.43 [e]	3.29
(d) Ext. total trips (%)	20 [f]	7	5 [f]	33
(e) Total auto trips (no.)	206	287	939	1,109
3. Work trips:				
(a) First work trips (no.)	1,125 [h]	1,184 [i]	14,292 [j]	—
(b) Int. transit trips (%)	1.0 [c]	0.0	7.3	1.8
(c) Int. avg. car loading (no./car)	1.14 [c]	1.15	1.14 [e]	1.11
(d) Ext. total trips (%)	20 [f]	12	5 [f]	11
(e) Total auto trips (no.)	1,221	1,302	10,386	13,980
4. Truck and taxi trips:				
(a) Int. trk. trips (no./100 auto trips)	10.0 [k]	19.6	10.0 [k]	11.0
(b) Ext. trk. trips (% of total)	20 [f]	10	20 [f]	13
(c) Int. taxi trips (no./100 auto trips)	12.0 [k]	9.0	10.0 [k]	6.2
(d) Total trk. and taxi trips (no.)	353	581	2,986	2,942
5. Total vehicle trips	2,151	2,791	17,096	21,138

[a] Average from Table 14.
[b] Twice highest rate in Table 14.
[c] Average taxi rate from Tables 3 and 2; no scheduled transit service to airport during survey year.
[d] The San Diego rate from Table 14.
[e] Average from Table 11.
[f] Estimated from Table 16.
[g] Twice average rate in Table 2.
[h] 0.95 of reported employment.
[i] Reported employment.
[j] Reported work trips, excluding certain industrial employment on airport site.
[k] Estimated from Table 6.

TABLE C-11

COMPARISON OF ESTIMATED AND REPORTED TRIP DISTRIBUTIONS BY DIRECTIONAL ORIENTATION

ESTIMATION BASE	TRIP PURPOSE	TRIPS ORIGINATING IN STUDY AREA SEGMENT (%) NORTH AND NORTHEAST	EAST	SOUTH, SOUTHEAST AND SOUTHWEST
Travel time	Work	18	12	70
	Soc.-recr.	19	13	68
	Air travel	19	11	70
	All	18	12	70
Distance	Work	29	10	61
	Soc.-recr.	12	12	76
	Air travel	25	9	66
	All	27	10	63
Reported	Work	19	19	62
	Soc.-recr.	21	22	57
	Air travel	14	15	71
	All	18	19	63

TABLE C-12

COMPARISON OF PREDICTED AND SURVEY TRAFFIC VOLUMES AT WILMINGTON SHOPPING CENTERS

TRIP CATEGORY	SHOPPING CENTER	NUMBER OF TRIPS: 14-VARIABLE MODEL: SURVEY	PREDICTED	REDUCED-VARIABLE MODEL: SURVEY	PREDICTED
All auto drivers	AA	4,723	6,310	4,581	4,670
	BB	5,026	5,879	4,757	6,257
	CC	2,611	2,235	2,534	2,912
All auto drivers to shop	AA	3,382	4,271	3,382	3,670
	BB	3,779	4,520	3,779	5,508
	CC	2,156	1,616	2,156	2,150
All auto drivers to other[a]	AA	591	1,671	449	750
	BB	422	340	153	206
	CC	302	909	225	543

[a] Except work trips.

can hardly be expected when the unexplained variance is as large as it was earlier shown to be.

The trip distribution procedure was predicated on a general trip rate curve derived from shopping trip characteristics in seven metropolitan areas. The curve shown in Figure 45 can be expressed by

$$y = 66.4/1.26^{x} \qquad \text{(C-1)}$$

where y = auto driver trips to shop at shopping centers, per 1,000 population; and
x = travel time from the shopping center, in minutes.

Thus, basic trip rates may be computed for each origin zone. These, however, require adjustments due to competition from other retail centers. The Pittsburgh pilot study developed a technique which was found equally valid in other areas. The adjustment factor is based on the travel time between the shopping center and its competitor and that between the zone whose trip rate is being adjusted and the competing center. (Generally, the competition will be the central business district, although a nearby center of equal or greater size also qualifies.) The factor was empirically derived as being the number whose natural logarithm is

$$(T_z - T_s)/T_s \qquad \text{(C-2)}$$

where T_z = time from zone to CBD; and
T_s = time from shopping center to CBD.

For example, if the origin zone is only one-half the travel time from the CBD as is the shopping center, the adjustment factor will be 0.61. If the origin zone is twice as far from the CBD as is the shopping center, the adjustment factor will be 2.71. Of course, if times are equal the adjustment factor is 1.00.

After the adjusted trip rates are computed for each zone, trip volumes are calculated from the population data and totaled. Because the initial trip rate curve is a general one, the resulting total will differ from an independently determined estimate of shopping trips to the center. Consequently, trips computed for each origin zone must be factored uniformly so that the totals will agree. At this point, the problem of "other" trips arises. Because this latter category of trips lumps together an assortment of trip purposes, which may be home- or nonhome-based, no explicit procedure for their distribution was proposed in this research. Thus, the normalization process, or uniform factoring of the trips at the origin zones, must be applied to bring the total of distributed trips to that of the estimated total generation.

As a method, the procedure oversimplifies the travel characteristic simulation, inasmuch as all trips are distributed according to only one trip rate curve. The alternatives, however, are to deal with a variety of trip purposes (whose trip volumes could not be precisely estimated for any one center) and to relate these subcategories to population and probably other trip rate bases. The additional data and refinements are probably not warranted for merely determining approach volumes by direction on highway links adjacent to the center.

In the backcheck on the Wilmington shopping center, the results shown in Figure 45 indicate that the trip rate curve and modifying adjustments reproduced both the time and geographic distribution of trip origins. Table C-13 gives a similar summary for trips to Center N.

In this case, two sets of adjustments were made, to allow for the competing effect of Center L as well as the CBD. Center L, although much smaller, is within 6 min travel time of Center N. As a result, trip distribution using only the CBD adjustment overestimated tripmaking near both shopping centers, and (through the normalizing process) underestimated trips at greater distances. Calculating and averaging adjustment factors due to both the CBD and Center L simulated actual trip distribution better, although equal weight for both competing retail areas has exaggerated the influence of Center L.

Table C-13 does show that approach highway volumes could be estimated with reasonable accuracy from this trip distribution process. Thus, the effect of a competing center on travel patterns to the center under study can be estimated. The accuracy is well within reasonable limits considering both the sample survey data and the accuracy levels attainable with the best of trip generation methods.

TABLE C-13

COMPARISON OF PREDICTED AND SURVEY TRAFFIC VOLUMES BY TIME INCREMENT FROM SHOPPING CENTER N

TIME INCREMENT (MIN)	NUMBER OF TRIPS			
	SURVEY		PREDICTED	
	INSIDE	OUTSIDE	INSIDE	OUTSIDE
0-2	483	481	336	316
3-4	273	252	158	214
5-6	378	147	454	182
7-8	21	546	13	534
9-10	672	231	427	305
11-12	399	441	390	479
13-14	399	546	523	334
15-16	126	294	249	151
17-18	273	21	243	18
19-20	168	42	316	36
21-22	84	42	343	69
23-24	126	63	293	85
Total	3,402	3,066	3,746	2,722

Manufacturing Plants

This section appraises how well various manufacturing plant trip generation relationships work when applied to new situations. An important prediction might be the total vehicular traffic to a major manufacturing plant during the peak hour, including the truck percentage, and the proportion of all trips from the dominant direction of travel. To test the prediction, the trips reported by a transportation study are assumed to represent the actual tripmaking.

Five plants in the Wilmington, Del., area were chosen. Three are typical of the cross section described in the report; two are less typical in that they are basically research laboratories. Travel data from the internal, external, and truck-taxi surveys, as well as household characteristic data, land use data, and related information were furnished by the New Castle County Program. Various techniques could be employed to make the basic predictions. The technique actually used is described briefly in the following. Table C-14 summarizes the results.

Employment figures normally would be obtained directly from the plants involved. To avoid complications arising from possible non-comparability of plant-furnished attendance (employment minus absentees) with study-furnished work trips, this step was omitted. Instead, the study figures for total work trips (all modes, including walk-to-work) were taken as a starting point. This does not harm the validity of testing techniques; in effect, it is the same as

TABLE C-14

SUMMARY OF PREDICTIVE BACKCH .CKS FOR FIVE MANUFACTURING PLANTS IN WILMINGTON, DELAWARE

FACTOR COMPARED	PLANT A[a]		PLANT B		PLANT C[a]		PLANT D		PLANT E	
	PRE-DICTED	RE-PORTED	PRE-DICTED	RE-PORTED	PRE-DICTED	RE-PORTED	PRE-DICTED	RE-PORTED	PRE-DICTED	RE-PORTED
1. Total person work trips derived from employment[b] (no.)	1,989[b]	1,989	1,018[b]	1,018	3,342[b]	3,342	1,212[b]	1,212	3,386[b]	3,386
2. Ext. person work trips (no./100 int. person work trips)	30	17	10	4	15	19	5	6	10	48
3. Ext. person work trips (no.)	459	285	93	35	436	531	58	69	308	1,104
4. Ext. auto driver work trips at 1.3 persons per auto (no.)	353	206	72	31	335	359	45	47	236	669
5. Prop. of int. person work trips as auto drivers (%)	64.69	65.02	71.11	47.81	67.79	76.16	69.02	77.69	74.41	82.16
6. Int. auto driver work trips (no.)	990	1,108	658	470	1,970	2,141	796	888	2,290	1,875
7. Total auto driver work trips (no.)	1,343	1,314	730	501	2,305	2,500	841	935	2,547	2,544
8. Heavy truck trips, daily (no.)	41	75	51	26	71	28	57	61	169	283
9. Heavy truck trips, peak hour (no.)	0	2	2	0	0	0	3	0	10	1
10. Trips from critical study area travel corridor (%)	22	33	55	50	40	40	56	33	57	51
11. Auto driver trips at peak traffic hour (%)	37	54	37	33	37	55	37	30	37	40
12. Tot. veh. trips to plant from "critical" direction at peak traffic hour (no.)	109	235	151	83	341	550	177	93	543	520

[a] Research laboratory. [b] Given.

assuming plant employments as given, and converting those figures to average daily attendance by the familiar 0.90 factor.

Multiple regression was used next to predict the modal split—the percentage of internal auto driver work trips. Dozens of possible predictive equations could have been applied, with from one to twelve independent variables (see earlier section on "Regression Results, Manufacturing Plants"). All would have yielded different answers. Rightly or wrongly,

$$Y = 102.36 - 0.024X_2 - 0.078X_6 - 0.371X_8 \quad \text{(C-3)}$$

was selected (subsequent checks showed that other equations would have produced better answers, but there was no way to determine this without knowing the "right" answers in advance). Values for independent variables were taken from transportation study data. Table C-8 defines the variables.

Before applying Eq. C-3, which predicts the internal modal split only, employment for each plant was divided into probable proportions of internal versus external trips. This was a judgment based on the plant's proximity to the cordon line, the degree of development outside the cordon line, the total employment at the plant, and the size and total population of the study area. (Proportions are known for about 30 plants in the cross section, and the average is 12% external. For typically centrally located plants (that is, for plants with a central city or near-suburban location) the average is on the order of 5% external).

Having determined the internal employment, Eq. C-3 was applied to determine the proportion of internal work trips by auto drivers. The external employment was converted to auto driver work trips by assuming an average car loading factor somewhat higher than the average reported for internal trips.

Medium and heavy truck trips were predicted on the basis of Table 38 according to the appropriate plant employment group. Both the daily percentage of truck trips, and the percentage during the peak traffic hour, were taken from Table 45, except that for the two research laboratories smaller percentages were assumed by judgment. The percentages of auto driver trips during the peak hour were also taken from Table 45.

The study area travel corridors in which the largest percentages of auto driver work trips originated were established next. For each plant, a study area traffic zone map was divided into four corridors, where appropriate, following natural travel barriers such as rivers. Population was summarized by corridor by mile distance increment from the plant zone. Auto driver trip rates per 1,000 population were applied by mile distance increment, and the resulting trip origins were summed by corridor. Totals were normalized to the pre-established control of grand total auto driver work trips from all corridors. External auto driver work trips and all truck trips were assumed to have the same directional orientation.

Finally, peak percentages, already mentioned as coming from Table 45, and directional tendencies, also from Table 45, were applied to the total auto driver and truck trips from the subject corridors.

APPENDIX D

SUMMARIES OF SHOPPING CENTER AND SHOPPING TRAVEL CHARACTERISTICS

Tables D-1, D-2, and D-3 give, respectively, summaries of selected shopping center characteristics; trips to shopping centers, by source; and time and speed characteristics of home interview auto driver trips to shop at major shopping centers.

TABLE D-1

SUMMARY OF SELECTED SHOPPING CENTER CHARACTERISTICS[a]

CENTER	TOTAL SITE AREA (ACRES)	FLOOR AREA (1,000 SQ FT)	NO. OF ESTAB-LISH-MENTS	PARKING SPACES	YEAR OF OPENING	RATIO, FLOOR AREA/SITE	PARKING RATIO
A	24	284	61	2,800	1956	0.27	9.7
B	25	241	41	3,700	1954	0.23	15.3
C	32	368	48	3,000	1956	0.26	8.2
D	12	300	46	1,000	1952	0.57	3.3
E	39	421	50	5,000	1952	0.25	11.9
F	29	412	45	2,400	1952	0.32	5.8
G	60	270	41	3,000	1956	0.10	11.1
H	22	282	27	2,000	1953	0.30	7.1
J	75	316	47	5,000	1949	0.10	15.8
K	38	460	54	2,000	1952	0.28	4.4
L	50	240	23	3,000	1957	0.11	12.5
M	22	166	22	1,400	1955	0.25	8.4
N	69	800	70	6,000	1959	0.28	7.5
O	33	280	36	2,500	1955	0.19	9.0
P	90	550	76	5,200	1956	0.14	9.5
Q	53	520	80	5,000	1956	0.22	9.6
R	73	395	65	4,000	1962	0.12	10.1
S	45	500	52	3,000	1960	0.26	6.0
T	22	142	43	1,500	1957	0.15	10.6
U	44	365	33	5,000	1954	0.21	13.7
V	31	317	48	2,500	1946	0 23	7.9
W	60	725	80	5,000	1950	0.28	6.9
X	25	308	33	2,300	1960	0.28	7.5
Mean	42	377	49	3,570	1955	0.23	9.2
Range	12-90	155-800	22-80	1,000-6,000	1946-1962	0.10-0.57	3.3-15.8

[a] From shopping center managements, transportation study data for various cities, and "Directory of Shopping Centers" (28).

TABLE D-2

SUMMARY OF TRIPS TO SHOPPING CENTERS, BY SURVEY SOURCE[a]

	HOME INTERVIEW SURVEY							
CENTER	AUTO DRIVERS (NO.)	AUTO PASS. (NO.)	TRANSIT PASS. (NO.)	TRANSIT TRIPS (%)	ROADSIDE VEH. TRIPS (NO.)	TRUCK AND TAXI TRIPS (NO.)	TOTAL VEH. TRIPS (NO.)	HOME INT./TOT. VEH. TRIPS (%)
A	1,515	1,632	85	3	955	44	2,514	60
B	3,465	2,119	163	3	1,720	158	5,343	65
C	2,570	1,941	54	1	375	68	3,013	85
D	4,673	2,218	608	8	85	24	4,782	98
E	8,484	6,972	784	5	187	209	8,880	96
F	5,712	4,368	28	—	222	121	6,055	95
G	4,144	2,492	56	1	252	154	4,550	91
H	4,480	3,752	280	3	28	220	4,728	95
J	5,551	3,993	125	1	530	75	6,156	90
K	5,959	4,554	1,978	16	N.A.	281	6,240	96
L	1,365	714	42	2	N.A.	138	1,503	N.A.
M	3,381	1,911	—	—	N.A.	234	3,615	N.A.
N	6,972	2,709	231	3	N.A.	312	7,284	N.A.
O	5,094	3,007	11	—	43	164	5,301	96
P	9,965	6,681	493	3	161	315	10,441	96
Q	10,000	7,210	511	3	3,817	450	14,267	70
R	5,012	2,889	59	1	39	137	5,188	96
S	5,795	3,597	334	3	187	123	6,105	95
T	3,431	2,171	94	2	N.A.	N.A.	3,431	N.A.
U	6,498	4,247	308	3	393	258	7,149	91
V	6,350	3,155	100	1	N.A.	N.A.	6,350	N.A.
W	9,293	4,578	181	1	N.A.	N.A.	9,293	N.A.
X	3,004	1,845	69	1	N.A.	N.A.	3,004	N.A.
All	122,713	78,755	6,594	3	8,994	3,485	135,192	88[b]

[a] From transportation study data for various cities.
[b] Excluding those centers lacking roadside vehicle trips.

TABLE D-3

SUMMARY OF TIME AND SPEED CHARACTERISTICS OF HOME INTERVIEW AUTO DRIVER TRIPS TO SHOP AT MAJOR CENTERS[a]

CENTER	REPORTED AVG. ELAPSED TRAVEL TIME (MIN)	CALC. AVG. ROAD TRAVEL TIME (MIN)	CALC. AVG. TERMINAL TIME (MIN)	REPORTED AVG. AIRLINE DISTANCE (MI)	REPORTED AVG. AIRLINE SPEED (MPH)
A	13.95	6.23	7.72	2.33[b]	10.0
B	16.41	8.64	7.72	3.76[b]	13.8
C	14.90	6.76	8.14	2.83	11.4
D	9.69	4.55	5.14	1.72	10.7
Avg.	13.18	6.30	6.86	2.59	11.8
E	15.63	6.64	8.99	2.99	11.5
F	12.74	7.40	5.34	3.32	15.6
G	11.24	6.88	4.36	3.25	17.4
H	11.80	5.69	6.11	2.07	10.5
Avg.	13.40	6.72	6.68	2.56	11.5
J	11.33	4.40	6.93	1.89[b]	10.0
K	17.32	11.04	6.28	4.00	13.9
Avg.	15.14	8.33	6.81	3.15	12.5
L	12.24	11.20[c]	1.04	2.67	13.1
M	12.05	10.35[c]	1.70	2.09	10.4
N	13.33	11.02[c]	2.31	2.91	13.0
Avg.	12.35	10.82[c]	1.53	2.64	12.4
O	16.53	N.A.	N.A.	3.22	11.7
P	17.02	11.18	5.84	3.95	13.9
Avg.	16.83	—	—	3.69	13.2
Q	14.17	9.69	4.48	2.52[b]	10.7
R	16.32	11.40	4.92	4.03	14.8
S	16.63	10.35	6.28	2.98	10.7
Avg.	15.45	10.34	5.11	3.06	11.9
T	12.08	8.76	4.32	2.24	11.1
U	16.15	9.40	6.75	2.82	10.5
V	11.09	N.A.	N.A.	2.78	15.0
W	14.75	N.A.	N.A.	2.89	11.8
X	12.93	N.A.	N.A.	3.24	15.0
Avg.	12.83	—	—	2.92	13.7

[a] From transportation study data for various cities.
[b] Affected by cordon location.
[c] Capacity restrained time.

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