Some Aspects of Future Transportation In Urban Areas

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This paper summarizes some of the basic interrelationships between cities, people, and their transportation requirements and shows how present trends in travel and urban development affect demands and potentials for public and private transportation. It sets forth rationale for predicting travel modes in urban areas both on a daily and peak-hour basis and shows how the characteristics of public and private transportation relate to various predictors. These predictors, in turn, provide a basis for generalizations regarding the role and balance of each form of future urban transportation.

The paper shows some of the fundamental interrelationships between land use, socio-economic status, and transportation mode. Because these elements are interdependent, it suggests that future land use and transportation must be conceived and planned as an integral unit.

• MOBILITY and industrialization have become major factors in the national culture and economy. The growth of transportation and the rise of cities has been parallel. Despite significant technological advances, the continuing expansion of urban areas has made the daily movement of people and goods increasingly complex. There is urgent need for greater efficiency and a better "balance" among the several modes of urban transportation.

This paper sets forth some of the basic problems of future urban transportation. Analyses have been based on information obtained from a series of urban areas varying widely in size, location, and economy. These areas include Chicago, Detroit, Washington, Pittsburgh, St. Louis, Houston, Kansas City, Phoenix, Nashville, Chattanooga, Charlotte, Reno, Tacoma, and Nashville. Questions investigated include:

1. How do present trends in urban development and travel affect demands for public and private transportation?
2. What bases can be developed for predicting the modal distribution of travel within urban areas in terms of today's technology and capability?
3. What are the respective roles of modern public and private transportation?
4. What land use implications are inherent in efforts to achieve a "balanced system" of urban transportation?

TRANSPORTATION AND CITY GROWTH

The history of man's civilization is often told in terms of city development. Early urban settlements developed at the crossroads of caravan commerce or at the edge of the sea, where land transport shifted to water carriers. For centuries, waterways were the principal highways of the trading world, affording the fastest and cheapest transport of people and goods. Land travel, in contrast, was slow and expensive, and cargoes relatively small.

The limited means of transportation restricted development of cities and kept them to a size that could be served by the surrounding agricultural "hinterland" within a few days wagon journey. However, despite these limitations, a few cities grew up to very large size; London, England, reached more than a million persons while still dependent on water travel and horse-drawn land traffic.

The Rise of Cities

The harnessing of steam power, brought on by the industrial revolution, provided urbanization its greatest impetus and quickly influenced transportation. New mechanical power increased agricultural productivity, and the resulting migration of persons to cities created a continuing period of city building that shows no sign of diminishing.

City growth, structure, and function are intimately related to the movement of people and goods; the railroad, horsecar, electric street railway, subway and elevated, motor bus, and private automobile have all served to extend the radius of the urban region. Within the city, the invention of the mechanical elevator has permitted a vertical growth that matches its horizontal expansion.

The central business district is the natural focus of the urban area. Until the early 20th Century, each new form of transportation encouraged concentration at this central point. The greatest concentrations developed in the large American cities where rail rapid transit systems were built—New York, Chicago, Philadelphia, and Boston. The impact of rapid transit on the growth of these centers has been unparalleled—and was accompanied by concentrations of people along the principal routes.

In the history of city development, the automobile is the only personal transport vehicle that has the potential to serve all parts of the city with equal efficiency. Consequently, it has tended to equalize the attractiveness of many different sites within an urban region.

The Individuality of Cities

Transportation plans must be objectively developed and carefully related to other

TABLE 1

DISTRIBUTION OF 1950 AND 1960 POPULATION[1]

Population Range	1950 No of Cities or Areas	1950 Percent of Total	1950 Mean Density (persons per sq mi)	1960 No of Cities or Areas	1960 Percent of Total	1960 Mean Density (persons per sq mi)
(a) Central Cities						
0- 50,000	8	4.6	3,000	25	9.8	2,500
50,000- 100,000	67	38.9	4,500	111	43.7	4,500
100,000- 200,000	45	26.2	6,400	57	22.4	5,100
200,000- 300,000	16	9 2	7,600	19	7.5	5,700
300,000- 400,000	11	6 4	7,500	12	4.7	5,800
400,000- 500,000	7	4.1	7,600	9	3 6	6,300
500,000- 750,000	7	4 1	9,000	11	4 3	8,100
750,000-1,000,000	6	3 5	13,250	5	2.0	10,300
1,000,000-2,000,000	2	1.2		1	0 4	
2,000,000-3,000,000	1	0.6	17,000	2	0 8	11,700
3,000,000-5,000,000	1	0.6		1	0.4	
Over 5,000,000	1	0 6	25,000	1	0.4	25,000
Total	172	100.0	7,788	254	100.0	5,349
(b) Urbanized Areas						
0- 50,000	-	-	-	-	-	-
50,000- 100,000	38	24.2	4,400	62	29 1	3,100
100,000- 200,000	59	37 6	4,300	66	31 0	3,100
200,000- 300,000	18	11.5	3,700	28	13.1	3,200
300,000- 400,000	8	5.1	4,500	14	6.6	3,100
400,000- 500,000	9	5.7	4,600	7	3 3	3,400
500,000- 750,000	9	5 7		12	5 7	
750,000-1,000,000	4	2 5	6,500	8	3 8	4,000
1,000,000-2,000,000	5	3 2		9	4.2	
2,000,000-3,000,000	4	2.6	7,400	2	0 9	5,500
3,000,000-5,000,000	2	1 3		2	0.9	
Over 5,000,000	1	0 6		3	1.4	
Total	157	100.0	5,438	213	100 0	3,752

[1]Source: U.S. Department of Commerce, Bureau of the Census.

urban values and goals. They must recognize the individuality of cities and the desires of people. No single, stereotyped transportation plan can be superimposed on all cities; there is no "one solution" regarding the relative roles of public and private transportation—each urban area is unique in its history, culture, economy, future mission, and transportation requirements.

The interrelationships between population and density within the nation's urban areas (given in Table 1) clearly indicate the individuality of the American city. In 1950, there were 172 central cities in the nation's 157 urbanized areas; the urbanized area population aggregated 69,300,000; central city densities averaged 7,788 persons per sq mi; and urbanized area densities, 5,438 persons per sq mi. In 1960, there were 254 central cities in 213 urbanized areas; the urbanized area population totaled 95,800,000; central city densities averaged 5,349 persons per sq mi; and urbanized area densities, 3,752 persons per sq mi. Thus, within the last decade there has been a lowering of urban densities; at the same time urbanization has sharply increased.

As shown in Table 1, densities tend to increase as cities get larger. Densities increase from about 5,000 to 6,000 persons per sq mi in central cities under 200,000 population, to over 8,000 persons per sq mi in central cities over 500,000, and over 10,000 persons per sq mi in central cities over 1,000,000. (Table 1 also shows that the increases in density in large cities were more rapid in 1950 than in 1960.) Variations in urbanized area densities were less, particularly in 1960. In 1950, urbanized area densities increased from about 4,500 persons per sq mi in areas under 750,000 population, to about 7,400 persons per sq mi in areas over 2,000,000 population. In 1960, urbanized area densities ranged from about 3,000 persons per sq mi in areas under 750,000 to 5,500 persons per sq mi in areas over 2,000,000.

Although large cities are generally more dense than smaller ones, there are many exceptions. These exceptions become more numerous as new major centers emerge.

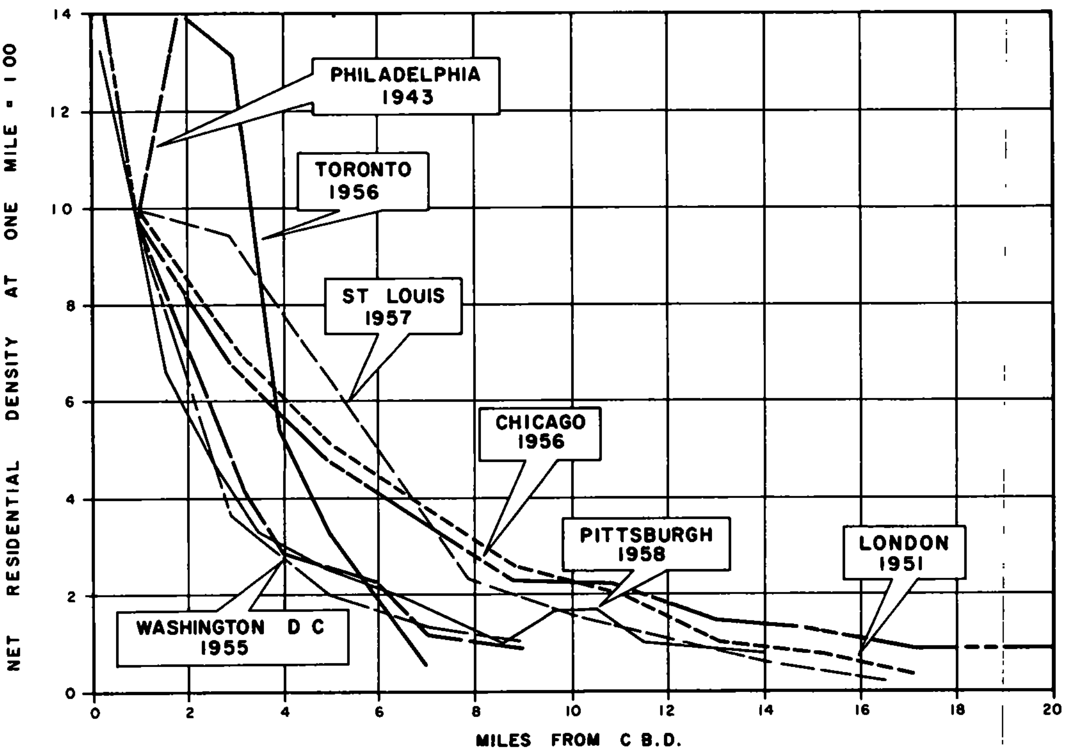


Figure 1. Population densities related to distance from central business district.

Los Angeles, for example, had a 1960 population of nearly 2,500,000, with a density of about 5,500 persons per sq mi.

The greatest concentrations of people are found in the old established cities where rapid transit systems have been operating for years. Of the large central cities in the country with 1960 densities exceeding 14,000 persons per sq mi (New York—Northeastern New Jersey, 23,321; Chicago, 15,836; San Francisco, 15,553; Boston, 14,586; and Philadelphia, 15,743), only San Francisco does not have a rapid transit system. By way of comparison, in both Montreal and Toronto, where rapid transit exists or is being developed, central city densities are about 20,000 persons per sq mi.

GROWTH IMPLICATIONS

Motivated by strong social and economic forces, the modern metropolis is spreading in every direction, in terms of both area and population. Previously remote real estate is now being occupied by people who work, shop, or visit in the neighboring urban center and its environs.

Today, the nation's population is nearly 180,000,000 people—an increase of about 18.5 percent since 1950. Within the last decade, the West grew 38.9 percent, the South 16.5 percent, the North Central area, 16.1 percent, and the Northeast 13.1 percent. The greatest metropolitan area and central city growths, in terms of percentage, were also in the South and Southwest. On the other hand, most of the old-established transit-oriented cities experienced some population decreases.

Density gradient patterns clearly depict the changing aspect of city growth and explain the "low-density" character of suburbia. As shown in Figure 1, density decreases consistently over concentric zones (3, 8, 13). In Chicago, for example, population density 4 mi from downtown is about 60 percent of that at 1 mi; at 10 mi, it is about 20 percent. The pattern in London, England, is strikingly similar to the patterns found in St. Louis and Chicago. Each subsequent zone tends to level off at a somewhat lower over-all density.

Land Use and Travel

As urban areas grow, new patterns of land use and travel emerge. The growing suburbs have precipitated new shopping centers and a dispersal of commercial services and industrial plants, creating new work opportunities in these areas. Dispersal of manufacturing activity from the inner zones of the central city was dominant throughout the nation. Downtown there has been a relative drop in sales and employment, with the central business district becoming more specialized as the center of government, management, and finance. Central business district sales in 55 metropolitan areas decreased 0.1 percent between 1954 and 1958, whereas total metropolitan area sales increased 17.4 percent (4).

All of these developments have created new travel patterns and fostered increased dependence on motor vehicle transportation, both individually and nationally. Today, approximately three of every four families in the United States own cars. Nearly 74 million registered vehicles travel more than 720 billion vehicle-miles annually. Acceptance and use of the motor vehicle have outpaced the building of adequate roads and parking facilities.

Automobile registrations have increased approximately 128 percent, and vehicle-miles 138 percent since 1940. In this same period, public transportation had declined over 30 percent (from 14.1 to 9.3 billion riders annually) and commuter railroads about 3 percent despite the increases in urbanization. Annual transit rides per capita have decreased from over 300 in 1940 to less than 100 in 1960. Within the past few years, rapid transit riding has stabilized and has even shown slight increases. Generally, rapid transit serves high-density and relatively stable service areas that were built along its lines.

Losses in transit patronage have resulted from the increased ownership and use of the private automobile, and from increasing scatteration throughout the urban area. Other causative factors include a shorter working week, changing recreational habits, increased fares, and a lack of transit modernization commensurate with highway improvements.

Within the next two decades, the nation's population is expected to reach 245 million, of which 180 million will live in urban areas—as much as the country's entire population today. Most of the new urban growth will be at population densities of approximately 2,500 persons per sq mi; the amount of land located within expanded urban limits by 1980 will be about double that of today. By 1980, the ratio of private cars to persons will likely increase about 20 percent, with one passenger car registered for every 2.4 persons. Car registration will approximate 120 million; motor vehicle travel, over 1,200 billion vehicle-miles annually.

These trends imply continued dispersion of cities and lower population densities. There will probably be more "second dwellings" at the beach, lake, or forest, resulting in longer commuting distances.

URBAN TRIP GENERATION

Knowledge of the basic characteristics of urban travel is prerequisite for the determination of future transportation requirements. Since 1944, about 150 "metropolitan area" transportation studies of urban travel have been undertaken; most were developed by state highway departments in conjunction with the U.S. Bureau of Public Roads. The current trend is toward increasingly thorough analyses that fully recognize the need to augment inventories of travel facilities and patterns with appraisals of land use, population density, and composition, as well as quality and character of housing.

Summary Patterns

The travel characteristics of residents within a cross-section of the nation's urban areas are summarized in Tables 2 and 3. (Analyses have been based on information contained in the origin-destination studies cosponsored by the U.S. Department of Commerce, Bureau of Public Roads, the respective state highway departments, and local government agencies.) These tables show that (a) the number of daily trips ranges from 1.6 to 2.5 per person, and from about 5 to 8 per dwelling unit; (b) the number of persons per dwelling unit ranges from about 2.2 (in Fort Lauderdale), to about 3.4 (in Charlotte); (c) the number of cars per dwelling unit ranges from about 0.8 (in Fort Lauderdale, Washington, and Chicago) to about 1.1 (in Phoenix and Reno); (d) car occu-

TABLE 2

GENERATION OF TRAVEL BY URBAN RESIDENTS[1]

Area	Year of Survey	Population in Study Area	Trips per Person	Persons per Car	Trips per Dwelling	Persons per Dwelling	Cars per Dwelling
Chicago, Ill.	1956	5,169,663	1.92	3.85	5.96	3.10	0.80
Detroit, Mich.	1953	2,968,875	1.77	3.51	5.88	3.31	0.94
Washington, D.C.	1955	1,568,522	1.67	3.75	5.05	3.02	0.81
Pittsburgh, Pa.	1958	1,472,099	1.61	3.75	5.26	3.26	0.87
St. Louis, Mo.	1957	1,275,454	1.94	3.48	6.05	3.12	0.90
Houston, Texas	1953	878,629	2.22	3.43	7.16	3.22	0.94
Kansas City, Mo.	1957	857,550	2.18	3.26	6.69	3.07	0.95
Phoenix, Ariz.	1957	397,395	2.29	2.87	6.88	3.01	1.05
Nashville, Tenn.	1959	357,585	2.29	3.35	7.52	3.28	0.98
Chattanooga, Tenn.	1960	242,000	2.17	3.32	7.22	3.33	1.00
Ft. Lauderdale, Fla.	1959	210,850	1.69	2.72	3.63	2.15	0.79
Charlotte, N.C.	1958	202,272	2.36	3.28	8.10	3.43	1.05
Reno, Nev.	1955	54,933	2.48	2.43	6.87	2.77	1.14

[1]Compiled from various summaries of origin-destination data for each urban area.

TABLE 3

TRIPS BY URBAN RESIDENTS ACCORDING TO MODE IN STUDY AREAS[1]

Area	Year	Trips								Avg Car Occupancy	Trucks (%)
		Driver (x 10^3)	Passenger (x 10^3)	Transit (x 10^3)	Total Auto and Transit (x 10^3)	In Autos (%)	In Transit (%)	Truck (x 10^3)	Total Veh (x 10^3)		
Chicago	1956	4,811	2,706	2,414	9,931	75 7	24 3	828	5,639	1 56	14 7
Detroit	1953	2,991	1,394	879	5,264	83 3	16 7	495	3,486	1 46	14 2
Washington	1955	1,278	709	639	2,626	75 7	24 3	219	1,497	1 56	14 6
Pittsburgh	1958	1,292	603	482	2,377	79 7	20 3	229	1,521	1 47	15 1
St Louis	1957	1,359	731	387	2,477	84 4	15 6	280	1,639	1 54	17 1
Houston	1953	1,085	616	252	1,953	87 1	12 9	202	1,287	1 57	15 7
Kansas City	1957	1,108	577	185	1,870	90 1	9 9	181	1,289	1 52	14 0
Phoenix	1957	586	266	58	910	93 6	6 4	168	754	1 45	22.2
Nashville	1959	493	263	63	819	92 3	7 7	91	584	1 54	15 6
Ft Lauderdale	1959	238	114	5	357	98 6	1 4	31	259	1 48	12 0
Chattanooga	1960	312	174	39	525	98 6	7 4	64	376	1 56	17 0
Charlotte	1958	303	140	35	478	92 7	7 3	52	355	1 46	14 6
Reno	1955	81	53	2	136	98 5	1 5	22	103	1 65	21 4

[1]Obtained from origin-destination studies in each area.

pancy ranges from 1.4 to 1.7 persons per trip, averaging about 1.5; (e) commercial vehicles accounted for between 12 and 22 percent of vehicle trips; and (f) more than three-fourths of all urban travel is by car.

Figure 2 relates trip generation in these communities to city size and structure. The interplay between city population, density, and trip generation is apparent; the number of daily person trips in vehicles decreases as the size and/or density of the community increases (in large cities like Detroit and Chicago, the urban residents make about 2 trips per day, whereas in smaller cities like Reno, the average is 2½ or more trips per day). These differences may be attributed to greater car ownership and dependence on the private car for transporation, comparative availability of parking spaces, shorter average trip lengths, and the relatively few destinations within walking distance.

Based on the origin-destination data in these cities, urban trip generation has been related to car ownership in Table 4. Inasmuch as car ownership depends largely on economic status, urban trip generation reflects the economic ability to travel. As a result, there is an inverse relationship between trip generation and car ownership; the greater the number of persons per car, the lower the daily trips per person, and the number of trips per car.

Car occupancies for various trip purposes are related to car ownership in Table 5. The occupancies of work and shopping trips increase as the number of persons per car increases (i.e., as car ownership decreases). For example, when there are 1.5 to 2.0 persons per car, the work trip occupancy averages 1.10 persons per auto trip; when there are over 6 per car, work trip occupancy averages 1.60 per auto trip. Social trip occupancies are the same for all levels of vehicle ownership, although fewer social trips are made by families with low car ownership ratios.

These tables provide a basis for estimating the generation of travel by residents in a city; they enable zonal trip ends to be related to the various employment generators, retail sales, and recreational facilities for each zone considered.

Characteristics of Transit Riders

Characteristics of Chattanooga, Tenn., transit riders illustrate the socio-economic and socio-ethnic stratification of transit patrons. During an average 1960 weekday, persons in the Chattanooga area made about 29,300 transit trips (excluding school bus trips); of these, 12,600 (43 percent) were made to and from the central business district.

The distribution of these trips, according to occupation of transit riders, is given in Table 6. Housewives and retired persons made 26.3 percent of the transit trips to the central business district, and 25.3 percent of the central business district transit trips were made by store and office clerks. The remaining 48 percent were distributed among eight other occupation classifications.

The composition of transit trips with both termini in outlying areas of Chattanooga was strikingly different. Personal service workers accounted for 30.7 percent of the non-central business district trips; grammar and high school students, 17.9 percent;

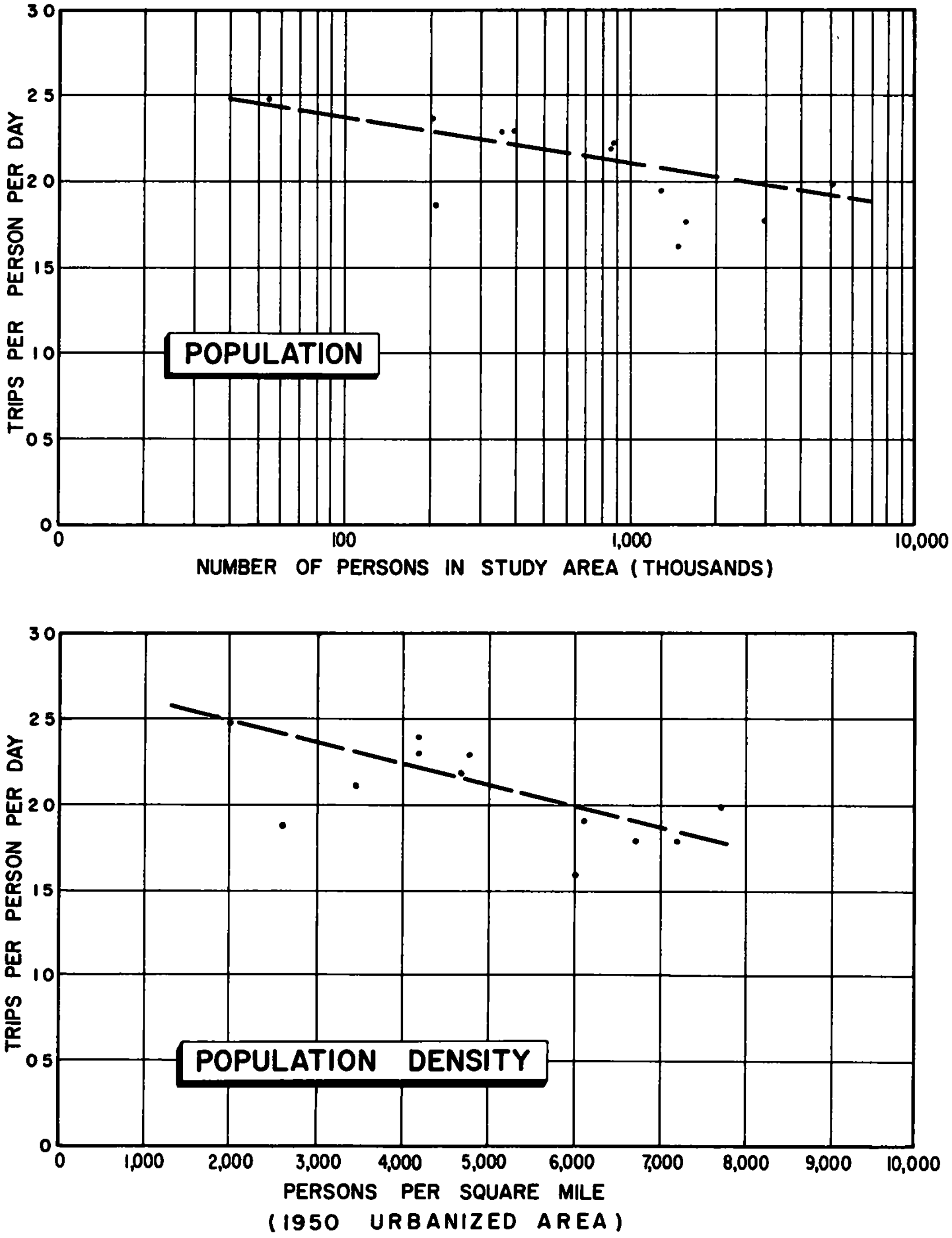


Figure 2. Trip generation related to city size and density.

and operatives and semiskilled workers, 15.5 percent. The remaining 36 percent were distributed among seven other occupational groups.

Personal service workers accounted for 27.3 percent of the total metropolitan area trips; housewives and retired persons, 16.6 percent; grammar and high school students, 15 percent; store and office clerks, 14.7 percent; and operative and semiskilled workers, 12.6 percent.

Most Chattanooga transit riders do not have a car available to them. Similarly, a study of car ownership in Hartford, Conn., showed approximately 39 percent of all bus riders without a car for family use, and, therefore, heavily reliant on bus transportation.

Walking distance patterns of transit riders in Chattanooga clearly show the value and limitations of public transportation. As shown in Table 7, some 72 percent of all transit riders are delivered to within one block of their downtown destination; 90 percent to within two blocks. At the non-central business district end of transit trips, two-thirds of all riders walk one block or less from the bus stop; and about 85 percent two blocks or less. Thus, transit provides "door step" service within the core area, but its service elsewhere is limited to areas within short walking distances of bus stops.

A study of the socio-ethnic composition of Chattanooga transit riders indicates that nearly two-thirds of all transit riders were women. Nonwhite female residents generated nearly a quarter of all transit trips, although they constituted under 10 percent of

TABLE 4

URBAN TRIP GENERATION RELATED TO CAR OWNERSHIP[1]

Avg. No. Persons per Car in Zone	Avg. Daily Trips per Person, All Modes	Driver Trips per Car
1.5 - 2.0	3.2 - 3.6	3.4 - 5.0
2.0 - 2.5	2.6 - 3.2	3.5 - 4.9
2.5 - 3.0	2.2 - 3.0	3.7 - 5.5
3.0 - 3.5	2.0 - 2.5	3.5 - 4.4
3.5 - 4.0	1.6 - 2.0	3.1 - 4.9
4.0 - 5.0	1.4 - 1.9	2.9 - 4.6
5.0 - 6.0	1.2 - 1.6	2.5 - 3.7
6.0+	0.9 - 1.2	2.3 - 3.7

[1]Compiled from origin-destination study in various urban areas.

TABLE 5

URBAN CAR OCCUPANCIES BY TRIP PURPOSE RELATED TO CAR OWNERSHIP[1]

Avg. No. Persons per Car	Average Auto Trip Occupancy for			
	Work	Shopping	Social	All Purposes
1.5 - 2.0	1.10	1.30	2.35	1.4 - 1.6
2.0 - 2.5	1.20	1.40	2.35	1.4 - 1.6
2.5 - 3.0	1.25	1.45	2.35	1.4 - 1.6
3.0 - 3.5	1.30	1.45	2.35	1.4 - 1.6
3.5 - 4.0	1.35	1.45	2.35	1.4 - 1.6
4.0 - 5.0	1.40	1.45	2.35	1.4 - 1.6
5.0 - 6.0	1.50	1.50	2.35	1.5 - 1.7
6.0 +	1.60	1.55	2.35	1.6 - 1.8

[1]Compiled from origin-destination studies in various urban areas.

the entire metropolitan area population. (The Chattanooga standard metropolitan area had a total 1960 population of 283,169 of which 17.5 percent were nonwhite. Of 29,296 transit riders, 24.5 percent were nonwhite female, 39.7 percent white female, 12.7 percent nonwhite male, and 22.7 percent white male.)

MODAL DISTRIBUTION

Knowledge of the factors that relate to the distribution of travel between alternate modes, particularly between transit and automobiles, is prerequisite to the development of a balanced transportation plan.

Principal factors that affect the choice of travel mode include city size, density, and age; the composition, distribution, and economic levels of urban residents; and the quality of existing transportation facilities. Impediments to automobile travel (topographic barriers, high densities, and resulting congestion) for example, may be conducive to transit use.

TABLE 6

OCCUPATION OF TRANSIT RIDERS, CHATTANOOGA, TENNESSEE[1]
(1960 Average Weekday)

Occupation	Central Business District Trips		Non-Central Business District Trips		Total-All Metropolitan Area Trips	
	Total	%[2]	Total	%	Total	%
Professional and semi-professional	562	4.7	413	2.4	975	3.3
Proprietors, managers, and officials	360	3.0	265	1.5	625	2.1
Store and office clerks, inside salesmen, etc.	3,040	25.3[a]	1,263	7.3	4,303	14.7
Traveling salesmen, agents, canvassers, etc.	53	0.4	95	0.6	148	0.5
Craftsmen, foremen, skilled laborers, etc.	276	2.3[b]	710	4.1	986	3.4
Operatives and semi-skilled workers	996	8.3	2,682	15.5	3,678	12.6
Laborers and unskilled workers	679	5.7	1,484	8.6	2,163	7.4
Protective services, policemen, etc.	42	0.3	42	0.2	84	0.3
Personal service workers	1,250	10.4	5,301	30.7	6,551	22.3
Housewives and retired persons	3,168	26.3	1,688	9.8	4,856	16.6
High school and grammer school students	1,313	10.9	3,086	17.9	4,399	15.0
College and business school students	286	2.4	244	1.4	530	1.8
Total trip destinations	12,025	100.0	17,273	100.0	29,298	100.0

[1]Source: Transportation Program—Chattanooga, Tennessee, Wilbur Smith and Associates, 1961. Excludes school bus trips.

[2]Because the data were obtained from an approximate 5 percent sample, they are subject to some sampling variability. The following two examples illustrate this variability: [a]Approximate 95 percent confidence limits are 22.9 and 28.7 percent. [b]Approximate 95 percent confidence limits are 0.7 and 4.9 percent.

Predicting Travel Modes

City size and age are related to travel modes in Table 8. Within the cities listed, the proportion of travel by transit ranges from under 2 percent in Reno to over 24 percent in Washington and Chicago; downtown trips by transit range from about 11 percent in Phoenix to 71 percent in Chicago.

At first glance, transit use appears predominantly a function of city size. This, however, is not necessarily the case. The proportion of travel by transit, especially central business district travel by transit, appears to more closely correlate with 1920 central city population than with current population, as shown in Figure 3. Apparently, the composition and structure of central cities in 1920 is more descriptive of transit use than present population. Thus transit use appears closely related to those parts of urban areas that were developed as a result of, and tributary to, public transport routes. This is not to infer that transit potentials are static; rather, that the basic structure of the "transit-oriented" sections of the central city were well-crystallized by 1920.

Thus, population, per se, is not always representative of transit usage, particularly in light of recent population dispersion in many of the most rapidly growing urban areas.

Two other factors emerge as being significantly related to transit use; car ownership and population density. Car ownership and use, in turn, are related to socio-economic status—the lowest ownership and use of cars are in high-density low-income areas, and conversely.

TABLE 7

WALKING DISTANCE TO BUS STOP, TYPICAL WEEKDAY[1]

Distance from Bus Stop (blocks)	Walking Distance: Within CBD Trips	%	Accum. %	Zone End of CBD Trips	%	Accum. %	Non-CBD Trips	%	Accum %	All Transit Trips Trips	%	Accum. %
1	4,316	71.8	71.8	3,914	65.1	65.1	11,742	68.0	68.0	19,972	68.2	68.2
2	1,114	18.5	90.3	1,040	17.3	82.4	3,029	17.5	85.5	5,183	17.7	85.9
3	466	7.7	98.0	657	10.9	93.3	1,704	9.9	95.4	2,827	9.6	95.5
4	106	1.8	99.8	254	4.2	97.5	479	2.8	98.2	839	2.9	98.4
5	11	0.2	100.0	95	1.6	99.1	181	1.0	99.2	287	1.0	99.4
6	-	-	-	53	0.9	100.0	137	0.8	100.0	190	0.6	100.0
Total trips	6,013	100.0	-	6,018	100.0	-	17,272	100.0	-	29,298	100.0	-

[1]Source: Chattanooga 1960 Origin-Destination Survey (under preparation for U.S. Bureau of Public Roads and Tennessee State Highway Department by Wilbur Smith and Associates). Excludes school bus passengers.

TABLE 8

TRAVEL MODE IN RELATION TO CITY AGE[1]

City	1920 Population	Current Population (study area)	Households per Car	Product Cols. 1 & 3 (thousands)	Product Cols. 2 & 3 (thousands)	Percent of Total Internal Trips by Auto	Transit	Percent of CBD Trips by Auto	Transit
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	
Chicago	2,701,705	5,169,663	1.25	3,777	6,462	75.7	24.3	29.0	71.0
Detroit	993,678	2,968,875	1.06	1,053	3,147	83.3	16.7	54.8	43.2
St. Louis	772,897	1,275,454	1.11	858	1,416	84.4	15.6	53.2	46.8
Pittsburgh	588,343	1,472,099	1.15	676	1,693	79.7	20.3	49.0	51.0
Washington	437,571	1,568,522	1.23	538	1,929	75.7	24.3	56.9	43.1
Kansas City	324,410	857,550	1.05	341	900	90.1	9.9	69.6	30.4
Houston	138,276	878,629	1.06	147	931	87.1	12.9	74.0	26.0
Nashville	118,342	357,585	1.02	121	365	92.3	7.7	79.7	20.3
Chattanooga	57,895	242,000	1.00	58	242	92.6	7.4	83.8	16.2
Charlotte	46,388	202,272	0.95	44	192	92.7	7.3	86.1	13.9
Phoenix	29,053	397,395	0.95	28	378	93.6	6.4	89.3	10.7

[1]Compiled from U.S. Census and origin-destination studies.

Accordingly, a correlated analysis of these variables is developed in Figure 4 and and Table 9. (The curves were developed before the plotting of data for Chattanooga, which conforms closely. Houston, in terms of current transit usage, is about 6 percent, and falls closely onto the curves.) The various scatter diagrams show strikingly consistent relationships between the choice of travel mode, urbanized area population density, and car ownership. The curves were first plotted as straight lines on normal probability paper, indicating that the data may be approximated by a cumulative normal distribution. On cartesian coordinates they plot as a series of ogives, with the steepest points where 50 percent transit use is anticipated.

The curves show that transit use increases rapidly as the number of persons or households per car increase and that it decreases as the cars per household increase. The best fits were obtained when transit usage was directly related to the combined

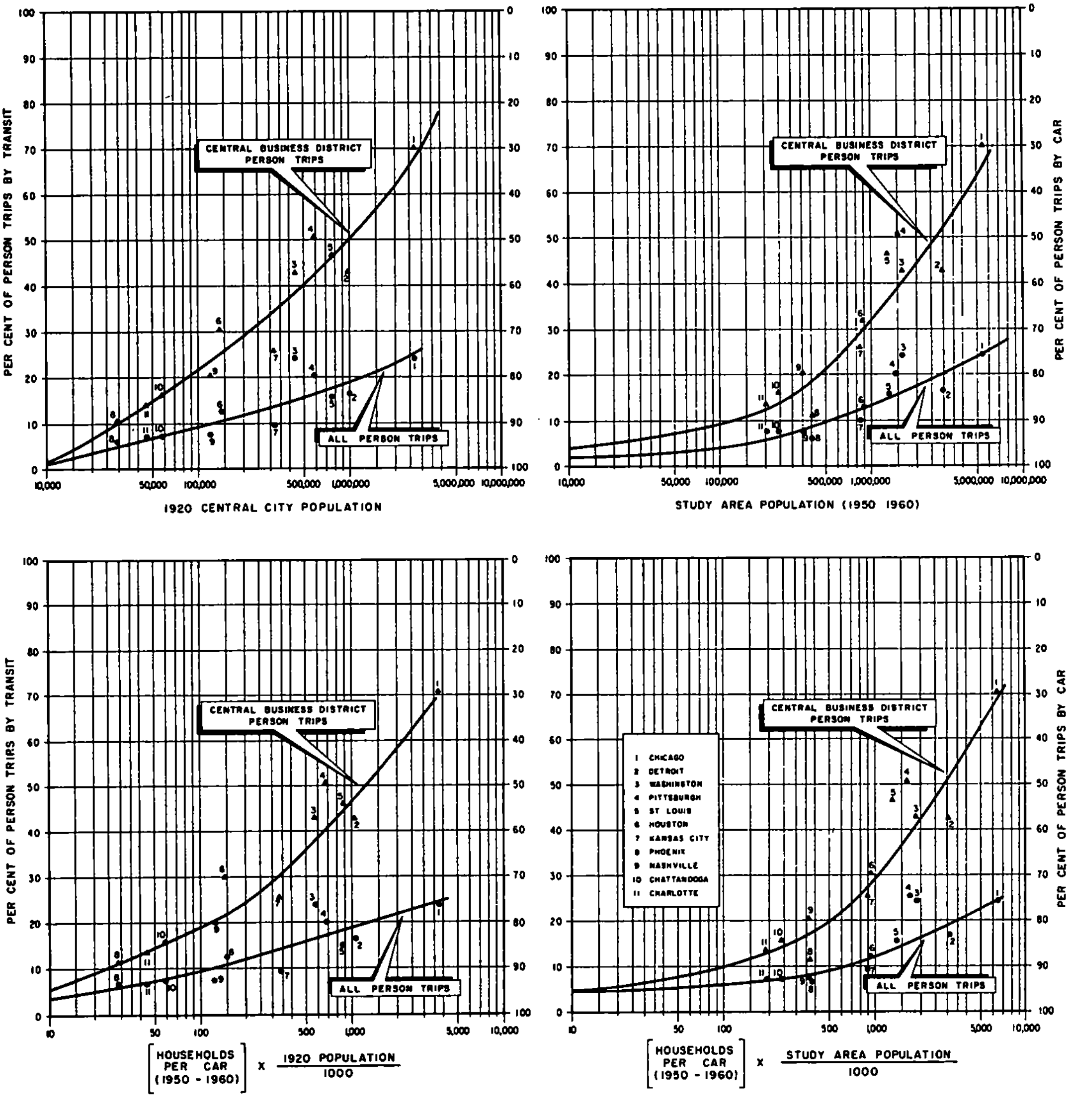


Figure 3. Effect of population on travel mode.

effects of households per car and population density—using both parameters tends to recognize aspects of change within an urban area. These findings are substantiated by the transit use analyses found in the Chicago and Pittsburgh area transportation studies, which indicated that car ownership and net residential density were the two principal determinants of travel mode. A study prepared by the Michigan State University Institute for Community Development and Services showed transit use related to size, age, and density of cities.

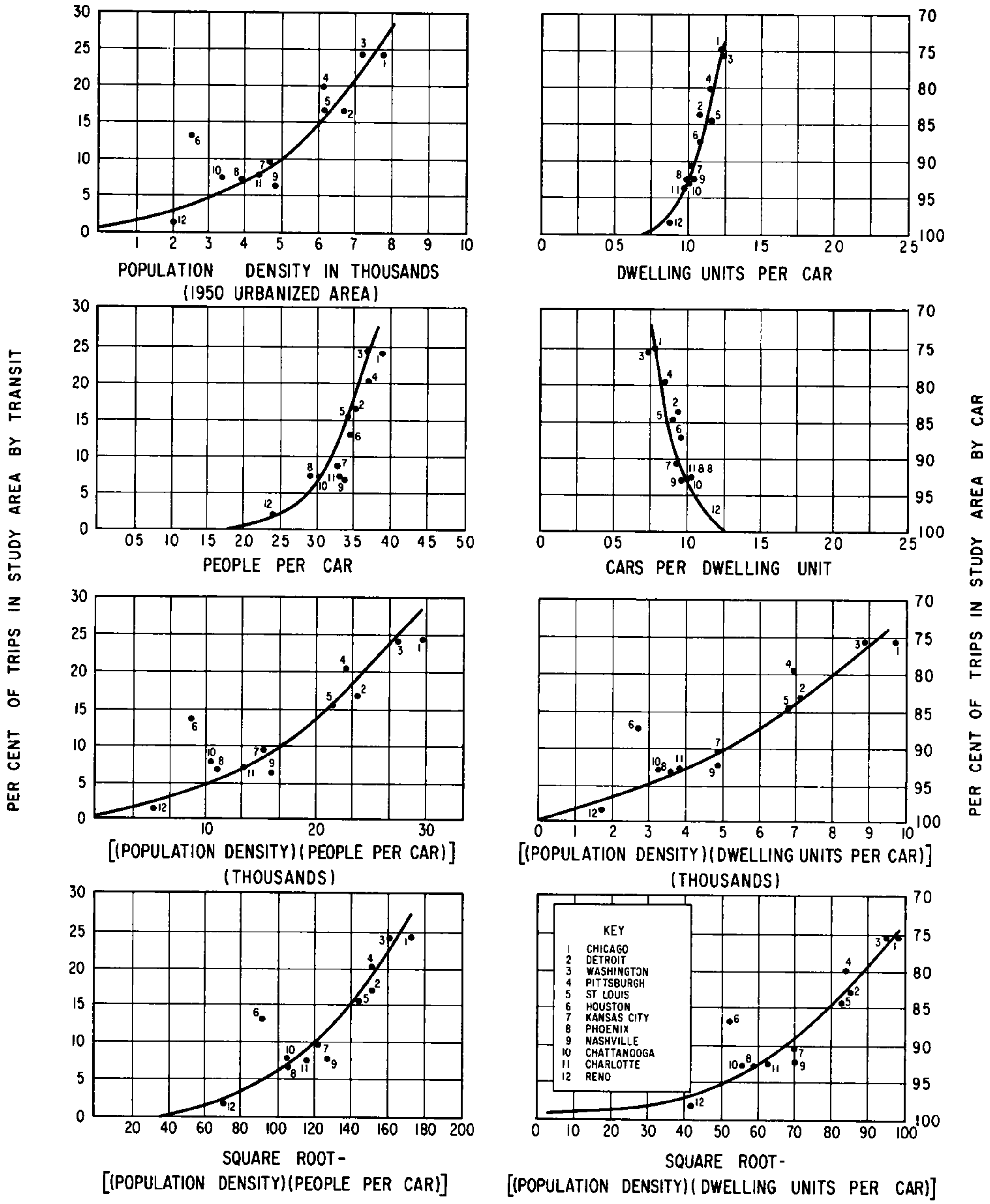


Figure 4. Travel mode relationships.

Similar relationships between the proportion of transit trips to or from the central business district, car ownerships, and population density are shown in Figure 5. The proportion of CBD trips by transit increases as the population density increases and as car ownership decreases, but at a much steeper rate than for all transit trips within an urban area. The curves show the specialized use of transit in serving the central business district, particularly in the large, high-density urban areas.

TABLE 9

TRANSIT USE IN TYPICAL URBAN AREAS[1]

City	1950 Urbanized Area Pop Density	People per Pass Car (study area)	Dwelling Units per Car (study area)	Product (Cols 1 & 2)	$\sqrt{\text{Col } 4}$	Product (Cols 1 & 3)	$\sqrt{\text{Col } 6}$	Percent of Internal Person-Trips by Auto	Percent of Internal Person-Trips by Transit	Percent of CBD Person-Trips by Auto	Percent of CBD Person-Trips by Transit
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		(9)	
Chicago	7,713	3 85	1 25	29,695	172	9,641	98	75 7	24 3	29 0	71 0
Detroit	6,734	3 51	1 06	23,636	154	7,138	84	83 3	16 7	56 8	43 2
Washington	7,216	3 75	1 23	27,060	164	8,875	94	75 7	24 3	56 9	43 1
Pittsburgh	6,045	3 75	1 15	22,669	151	6,952	83	79 7	20 3	49 0	51 0
St Louis	6,146	3 48	1 11	21,388	146	6,822	83	84 4	15 6	53 2	46 8
Houston	2,594[2]	3 43	1 06	3,897	94	2,750	52	87 1	12 9[3]	74 0	26 0
Kansas City	4,687	3 26	1 05	15,280	124	4,921	70	90 1	9 9	69 6	30 4
Phoenix	3,921	2 87	0 95	11,253	106	3,725	61	93 6	6 4	89 3	10 7
Nashville	4,821	3 35	1 02	16,150	127	4,917	70	92 3	7 7	79 7	20 3
Chattanooga	3,329	3 31	1 00	11,019	105	3,329	58	92 6	7 4	83 8	16 2
Charlotte	4,085	3 28	0 95	13,399	116	3,881	62	92 7	7 3	86 1	13 9
Reno	2,000[4]	2 43	0 88	4,860	70	1,760	42	98 5	1 5	NA[5]	

[1]Sources: U S. Department of Commerce, Bureau of Census, origin-destination studies in each area.
[2]Houston about doubled its city limits before 1950 census, thus, area actually urbanized at time of study had much higher density
[3]Reported at 6 percent 1959-60
[4]Estimated.
[5]NA-not available.

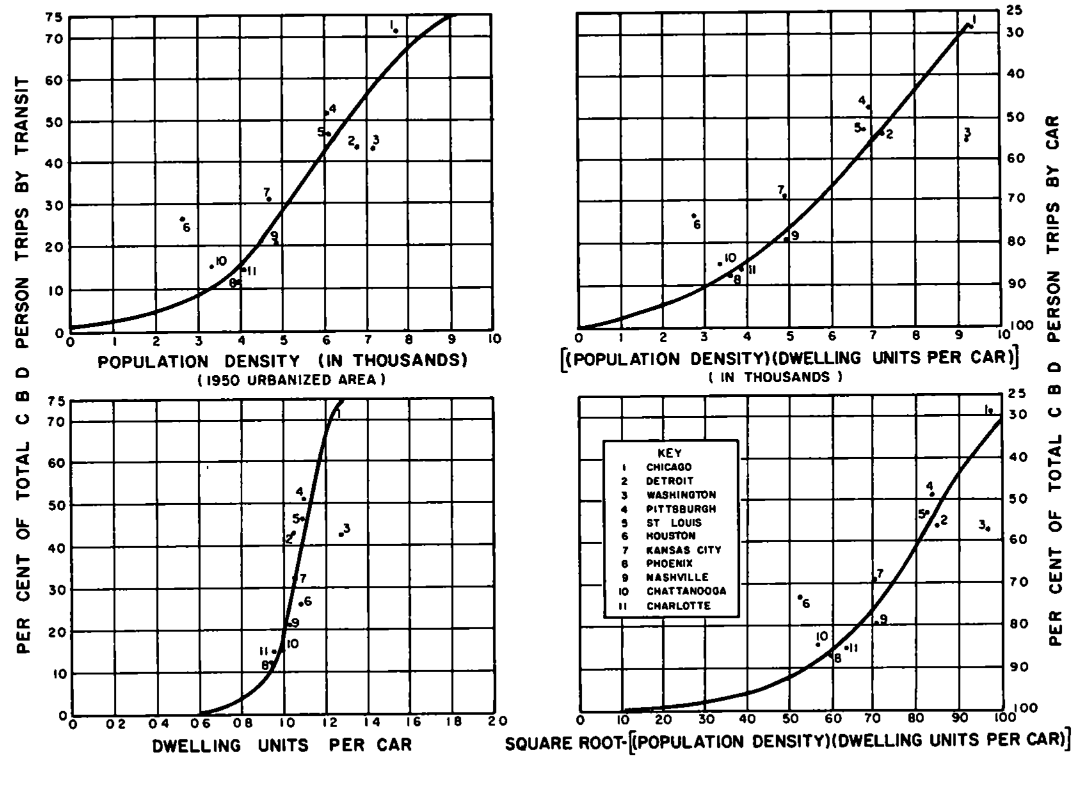


Figure 5. Central business district travel mode relationships.

From these analyses, it is possible to derive a generalized relationship for the predicting of over-all transit or auto use in any urban area. These generalized transit use curves are shown in Figure 6. The "travel mode factor" represents the product of urbanized area population density and households per car divided by 1,000 and is plotted along the x-axis; the percentages of all trips made by transit and auto within the urban area are shown along the y-axis.

Transit use increases as population density and/or the number of households per car increase: the greater the density and the lower the car ownership, the greater the proportion of travel by transit; where two areas have the same densities, the area with the greater car ownership will generally develop fewer trips by mass transit; similarly, where two areas have the same car ownership, the area with the greater population density will generate more transit trips.

Most American cities today have travel-mode factors under 10—the practical range of the curve. New York City, of course, is the notable exception. The curves confirm the thesis that the old, densely populated cities, usually with the low car ownership and large populations, have the greatest proportions of transit travel—their physical layouts, land-use patterns, and central business district intensities were usually crystallized before the widespread use of the automobile. Cities that evolved in the motor age and that are growing rapidly today, are less intensely developed and are more automobile-reliant.

Transit is most widely used in the peak hour. Accordingly, travel-mode curves have also been developed for one-directional and two-directional peak-hour travel; these curves are shown in Figure 7. One-directional peak-hour transit travel has been assumed to be twice as peaked as highway travel, and two-directional peak-hour transit travel has been assumed to be 50 percent more peaked than highway travel. The total travel in the peak hour has been assumed as AT + (100-T) when T is the percent of 24-hr transit travel and A the relative ratio between transit and auto travel. The percent peak-hour transit travel is therefore $\frac{AT}{T(A-1)+100}$. In this regard, of all 24-hr traffic

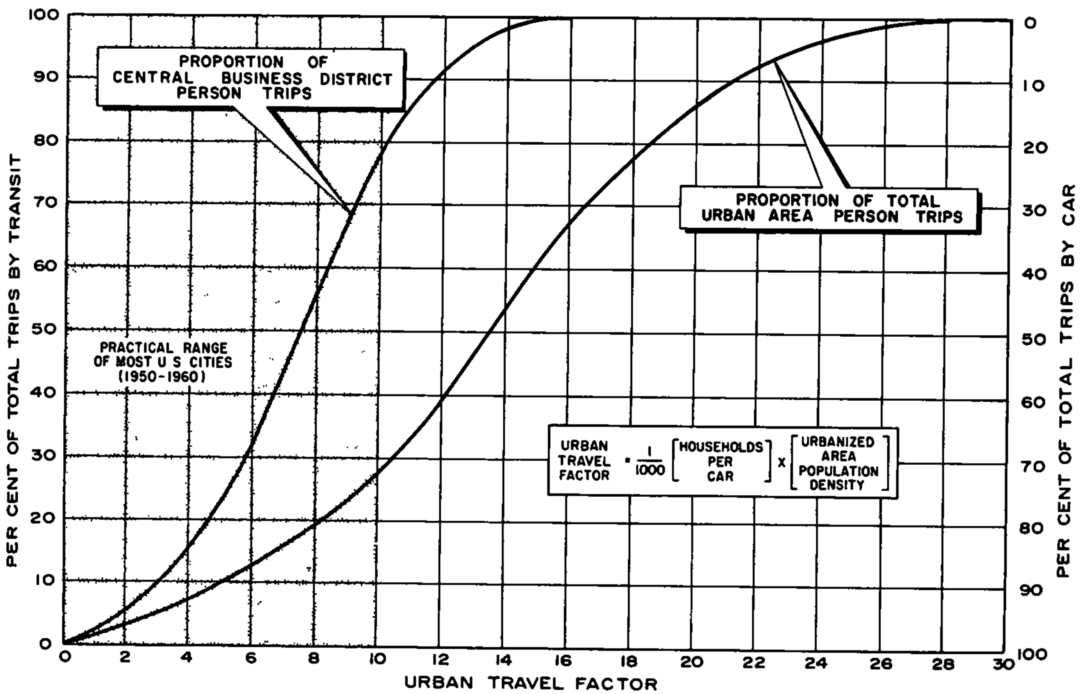


Figure 6. Generalized travel mode curves.

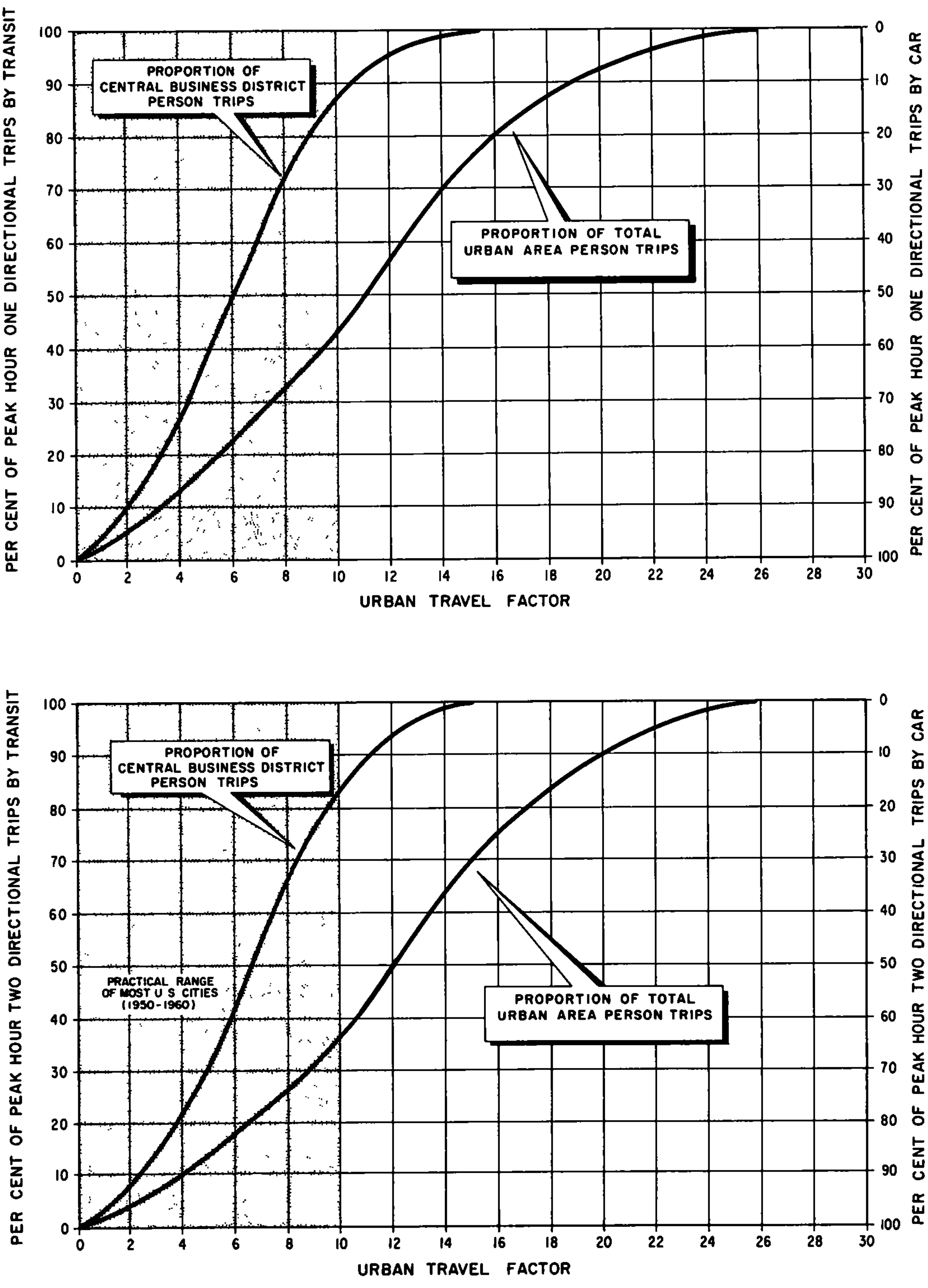


Figure 7. Generalized peak-hour travel mode curves.

leaving St. Louis Central Business District in 1957, 26 percent was by transit, and 42 percent of the peak-hour exist movement was by transit. This corresponds to a value of A equal to 2.

In a large urban area with a transit use-factor of 10 (typical of Chicago, Washington, and Philadelphia), approximately 83 percent of all PM peak-hour trips leaving the CBD would be made by transit. In cities with a transit use-factor of 5, (typical of medium-sized cities like Nashville) about 40 percent of all PM peak-hour trips leaving the CBD would be by transit.

Predicting CBD Travel Modes

Travel modes of trips to or from the central business district are compared with the modal split of all trips in Figure 8. Again, there is a consistent pattern; knowledge of either attribute (i.e., the CBD modal split, or the city-wide modal split) permits estimation of the other. Values obtained from the travel mode curve have been superimposed on the actual data; except for extremities, the trend is linear.

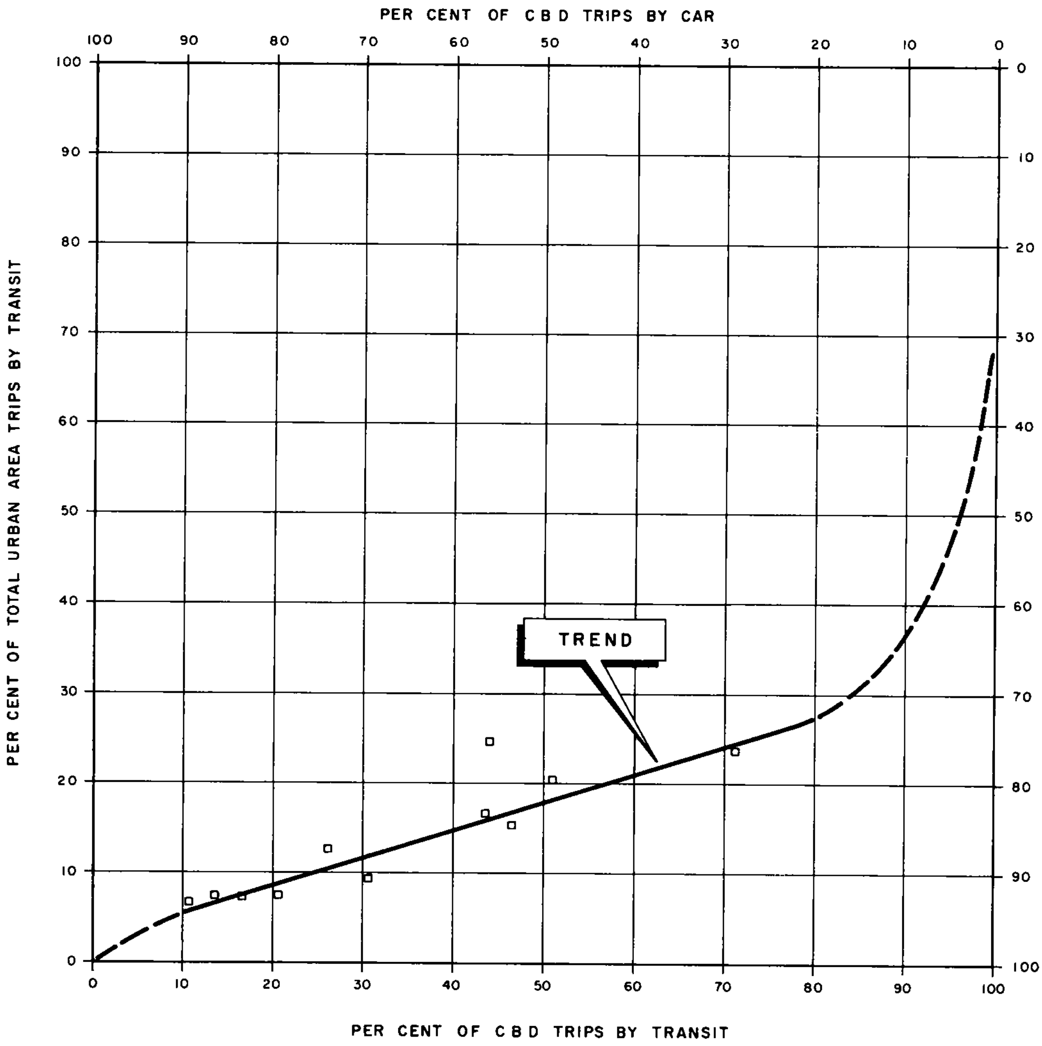


Figure 8. Comparative travel modes, central business district and entire urban area.

As previously indicated, the proportion of CBD trips by transit is generally two or three times as great as all transit trips within an urban area. For example, in Chicago, about 71 percent of all CBD trips are made by transit, whereas only about 24 percent of all trips in the area are made by this mode. In Phoenix, (with a low population density and high auto ownership) about 11 percent of CBD trips are made by transit compared with only 6 percent of all trips within the area; the bulk of both city-wide and CBD trips are made by car.

Travel modes are also influenced by the distribution of population relative to the central business district. Figure 9 shows for four cities (Charlotte, Houston, Tacoma, and Honolulu) the relative proportion of CBD trips per thousand persons decreases as distance from downtown increases. Transit trips decrease more rapidly than total trips per unit of population, dropping to zero at the limits of the service area.

In the four cities graphed there is a general similarity in patterns—the CBD trip generation curves decay at about the same rate. Here, the "interactance" effect of competing generators is at work; as travel time-distance downtown becomes longer, more opportunities exist for interception or attraction of travel by other areas.

The modal split of CBD trips at various distances from the central area (Fig. 10) clearly reflects the importance of close-in areas to transit. In Charlotte, Tacoma, and Houston there is a consistent decline in the proportion of CBD trips by transit as distance from downtown increases. Topography, in restricting developmental corridors, has placed a large transit-oriented populace about 5 mi from downtown Honolulu.

There is another striking aspect about these curves. The proportion of CBD trips by transit is greatest in 1947 (Honolulu) and least in 1958 (Charlotte). Again, the impact of increasing car ownership and population density on travel mode, in particular on transit patronage, is apparent.

From the preceding analyses, it is evident that the magnitude and modal distribution

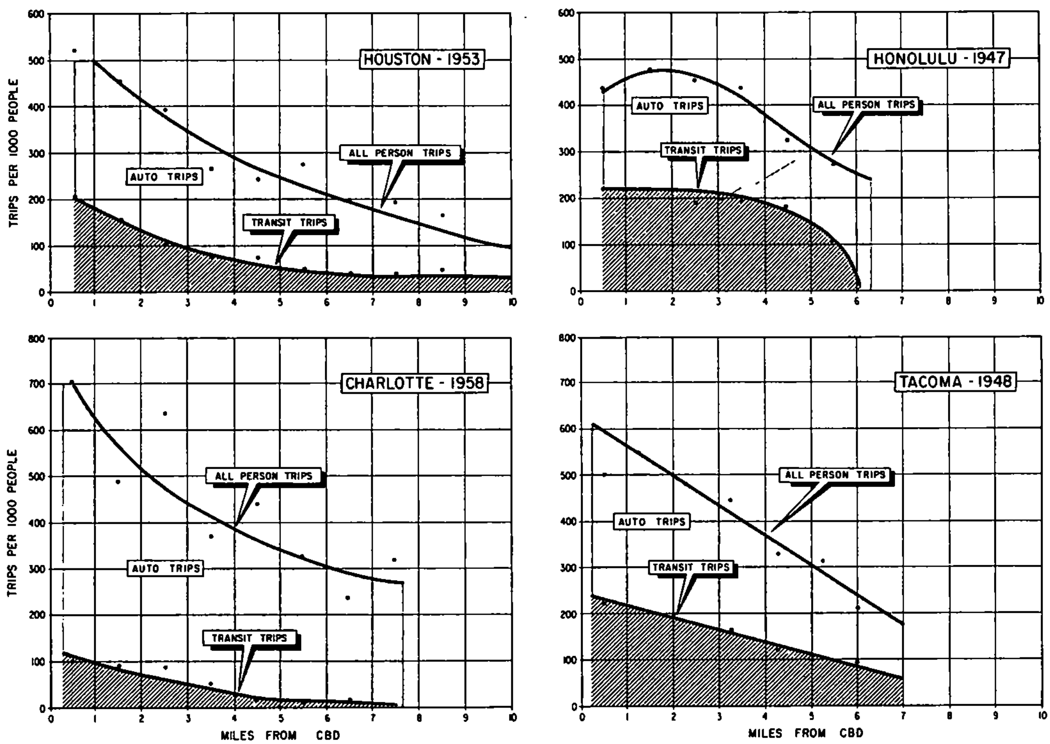


Figure 9. Central business district trip attraction.

of central business district trips depend on the nature and intensity of downtown development. To some extent, this is a function of size and age of the central city; more significantly, it depends on the density of destinations within the downtown area, and on the concentration of work trips.

An exploratory analysis of the relation between travel mode and CBD land use showed a general increase in transit usage as office space (or office space per capita) increased. A somewhat more significant relationship was found when the density of CBD origins and destinations was related directly to travel mode (see Table 10). Symbolically, this may be written as:

$$P = f\left(KS^{X}\frac{(PH)^{Y}}{(AC)}D^{Z}\right)$$

$$= f(KS^{X}F^{Y}D^{Z})$$

in which

- P = percent of trips by transit;
- A = square miles;
- S = transit service factor;
- H = households in urban area;
- C = cars in urban area;
- D = downtown concentration factor;
- K, X, Y, Z = constants; and
- F = travel mode factor.

For example, Chicago has about 9,000 CBD person trip-ends per sq mi; Detroit and Washington, 450; Charlotte, 150. In Table 10, the areas of the central business districts conform with those defined in the origin-destination studies, and do not, therefore, fully reflect relative intensities with the core areas; nonetheless, experimental plots indicate that this data, used in conjunction with population density and car ownership, tend to improve the predictability of central business district transit trips. Accordingly, this leads to the following generalized model for the prediction of downtown modal distribution of travel; transit usage is proportional to the products of population

TABLE 10

DENSITY OF TRAVEL TO AND FROM TYPICAL CENTRAL BUSINESS DISTRICTS

Survey Area	Population	Area of Central Business District[1] (sq mi)	CBD Person-Trips[2] (thousands)	CBD Person-Trips per Sq Mi of CBD (thousands)	Percent of CBD Person-Trips by	
					Auto	Transit
Chicago	5,169,663	1 0[3]	932	932	29.0	71.0
Detroit	2,968,875	1.1	511	465	56 8	43.2
Washington	1,568,522	2.0[3]	883	442	56.9	43.1
Pittsburgh	1,472,099	0.5	154	308	49.0	51.0
St. Louis	1,275,454	0.7[3]	250	357	53.2	46.8
Houston	878,629	0.9	351	390	74.0	26.0
Kansas City	857,550	0.9	213	236	69.6	30.4
Phoenix	397,395	0.7	130	186	89.3	10.7
Nashville	357,585	0.6	128	213	79.7	20.3
Chattanooga	242,000	0.3	76	253	83.8	16.2
Charlotte	202,272	0.7	105	150	86.1	13.9

[1]Source: origin-destination surveys in each area.
[2]Trips to or from central business district.
[3]Excluding mall, riverfront areas, and lakefront areas.

density, households per car, and density of downtown destinations, as influenced by the transit service afforded.

Studies now under way in Baltimore and Norfolk are further exploring these relationships by analyzing data from individual zones and by very clearly delineating core, frame, and fringe within the central business district.

Summary and Interpretation

The most significant aspect of the modal distribution analyses is the close relationship between car ownership, population density, and mode of travel. These interrelationships are further emphasized by the summary of person-trip generation shown in Figure 11. This curve shows how transit, auto, and pedestrian trips vary as a function of the travel mode factor: transit and auto trips are based on the information obtained in the cities studied, whereas pedestrian trips have been estimated.

The number of transit trips per capita increases consistently with increasing concentration and decreasing car ownership, whereas the number of total person-trips in

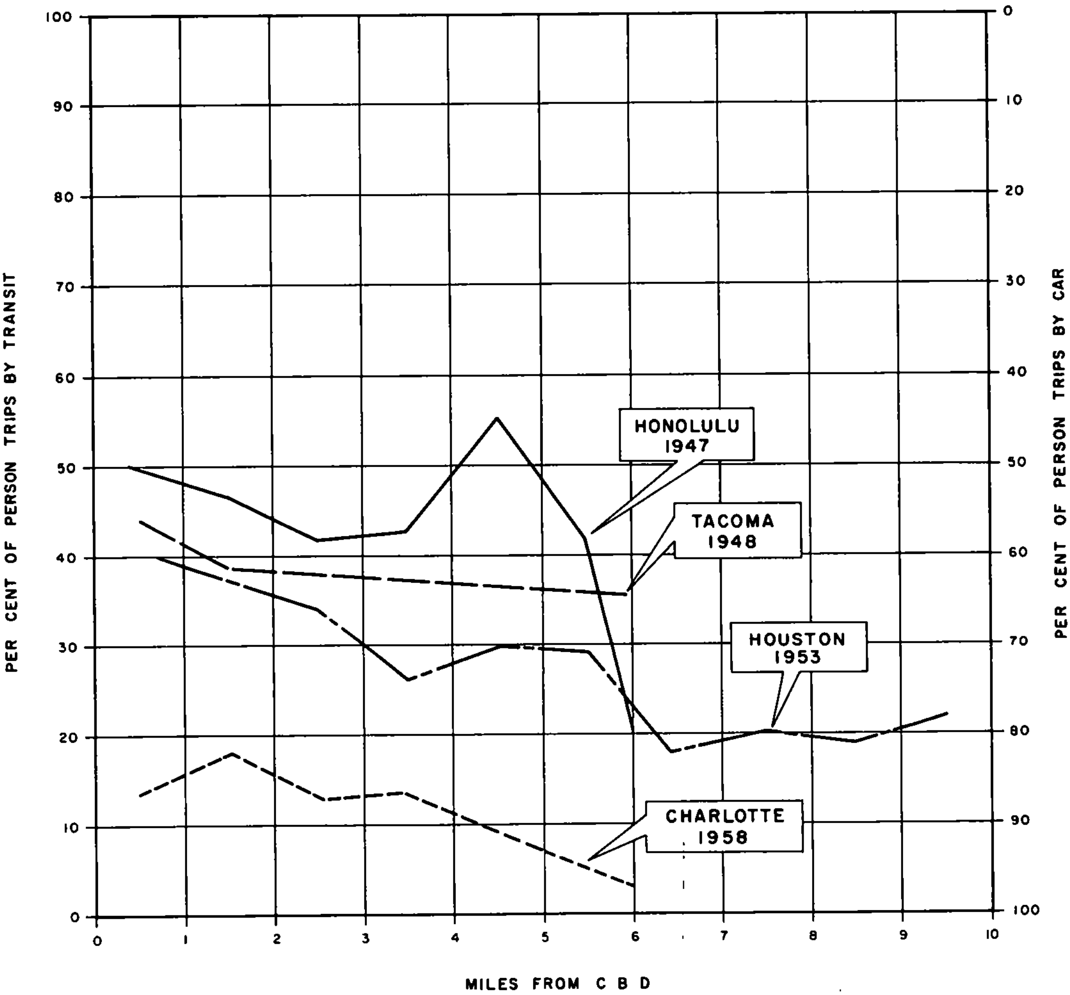


Figure 10. Travel modes of central business district trips in relation to distance from central business district.

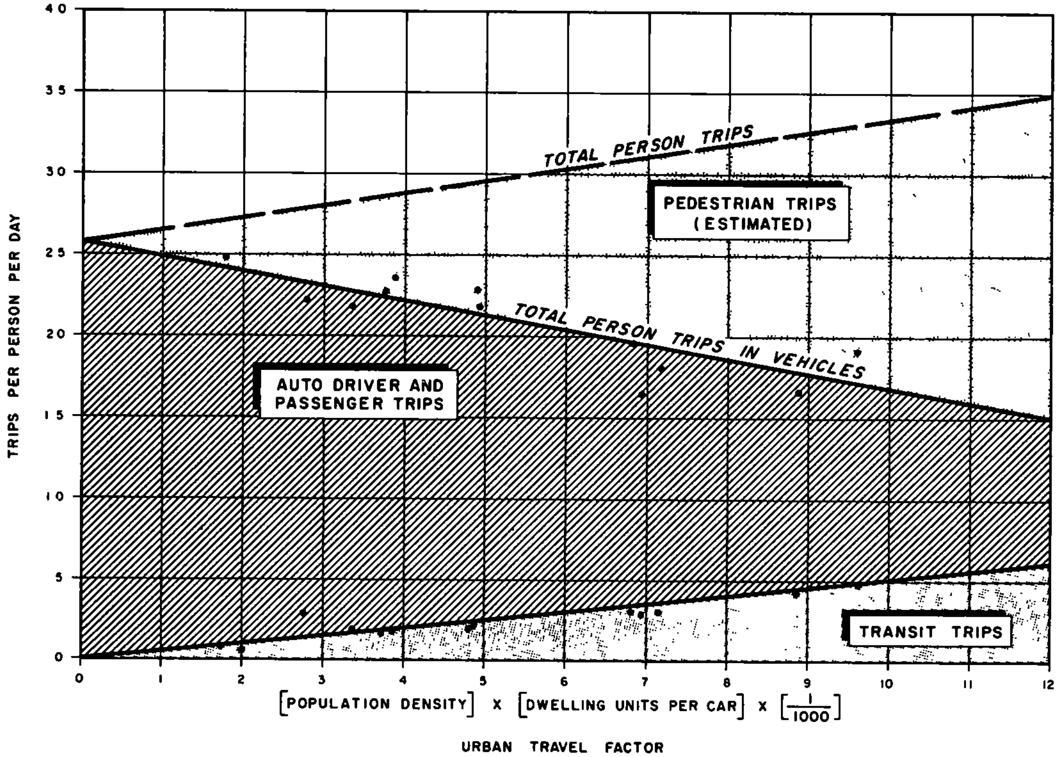


Figure 11. Summary of urban trip generation.

vehicles decrease; both trends appear linear. A city with a travel mode factor of 10 would generate 0.5 transit trips and 1.2 auto trips per person—a total of 1.7 person-trips in vehicles per day. Similarly, a city with a factor of 5 would generate 0.3 transit trips and 1.9 auto trips per person per day—a total of 2.2 person-trips in vehicles per day. Pedestrian trips increase rapidly as the travel mode factor increases. This is because the number of destinations within walking distance increases in very dense areas.

Inasmuch as car ownership will tend to become more uniform in urban areas, population density may emerge as a basic variable affecting over-all trip generation in urban areas. Population density, in turn, generally depends on central city densities because most suburban areas are developing at about the same density. As density increases, there is an increase in total person-trips, a decrease in person-trips in vehicles, and an increase in transit trips.

Compactness within an urban area could, therefore, be construed as a means of minimizing urban travel. This, however, is not the trend. As the desire for single family dwelling units continues to outpace the recentralization of cities, as car ownership and incomes rise, the trends will probably continue in the other direction. Improved mobility brought about by decreased travel times may also foster some dispersion.

Thus, because of changing urbanization patterns and socio-economic standards, transit assumes a new, often complementary, role. It will remain especially valuable in serving radial home-to-work CBD travel, and in maintaining compactness and concentration within the central business district; its future importance to downtown will be largely contingent on its past importance.

FREEWAY TRAVEL

Trip generation characteristics provide insight into the nature of urban vehicular travel. In combination with trip length characteristics, it is possible to determine the per capita vehicle-miles of travel within an urban area. The aggregate future use of highways in an urban area can then be related to the capacities afforded by various classes of highways.

Trip Length Calculations

Zone-to-zone movements tabulated in origin-destination studies provide a basis for

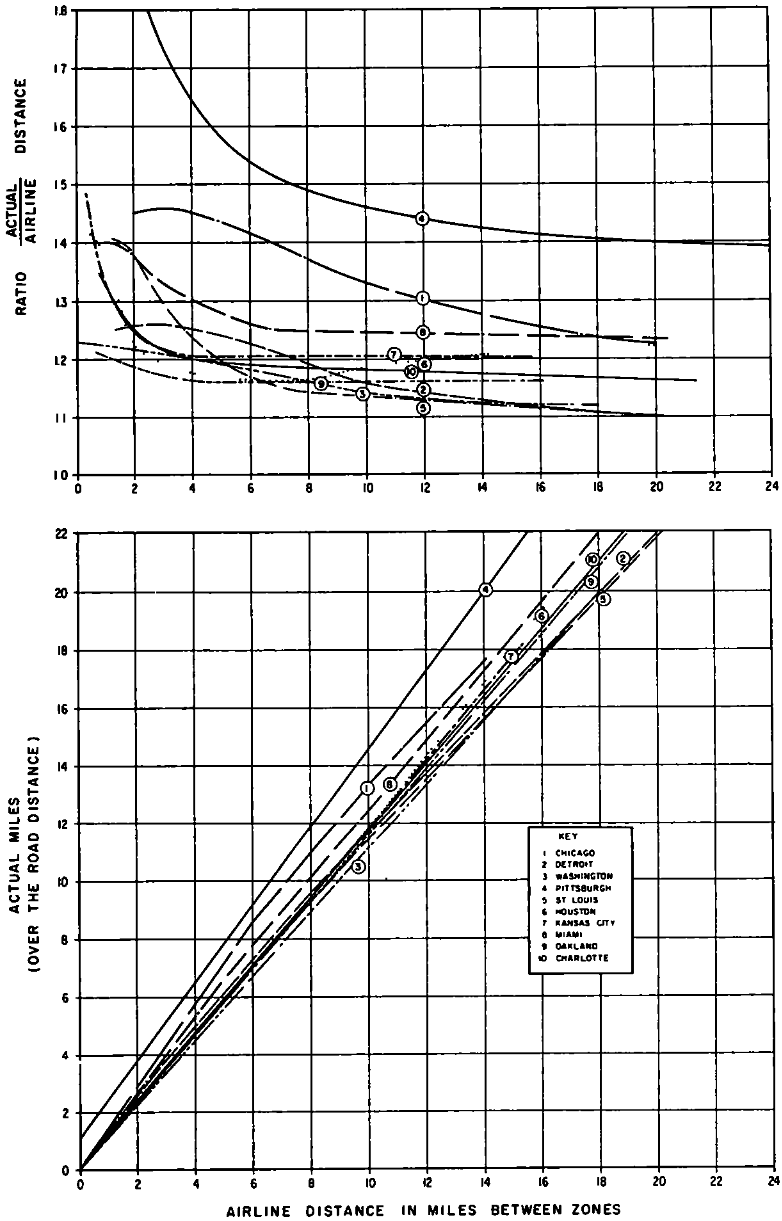


Figure 12. Trip length comparisons.

determining "airline" trip lengths. These "airline" distances should then be adjusted to represent actual "over-the-road" travel.

Actual and airline distances were calculated from random samples of interzonal movements for a series of urban areas. These comparisons (Fig. 12) show how the relationship between airline and actual distance depends on the configuration of the street system. In cities such as Detroit, Washington, and St. Louis, with radial-concentric patterns, actual distances are about 1.15 times the airline distance. Grid-iron street patterns, such as found in Chicago, require about 25 percent longer travel over the streets; in cities where street patterns are restricted by topography, as Pittsburgh, over-the-road distances are nearly 40 percent greater.

These trip-length relationships, by analogy, provide a basis for anticipating the ratios between airline and actual distance in any urban area. (Many of the recent computer programs being used in current origin-destination studies evaluate vehicle-miles of travel directly from basic information.)

Magnitudes of Urban Highway Travel

From analyses of origin-destination data in various cities, estimates were developed of total daily vehicle travel. Expressed on a per capita basis, present daily vehicular travel (i.e., driver trips) approximates 7 mi per urban resident. (The range is from 5 to 9 mi.) By 1980, assuming a continuing trend for greater vehicle use and continued urban dispersion, average daily vehicle-miles may range from 9 to 14 mi per capita (averaging about 10). By relating these unit values to estimates of future urban population, future urban freeway and arterial use has been derived for 1972, 1975, and 1980 (16).

TABLE 11

GENERALIZED ROADWAY REQUIREMENTS, PER 10,000 POPULATION

Population of Urban Area[1]	Anticipated Percent of Total Travel on Freeway System[1]	Route-Miles of Freeway Required[2]	Route-Miles of Arterial Required[2]
10,000	20	0.4	4.8
75,000	30	0.6	4.2
500,000	40	0.8	3.6
1,000,000	50	1.0	3.0
5,000,000	60	1.2	2.4

[1]Source: (16).
[2]Calculated, assuming distribution of roadway facilities consistent with required capacities (or uniform demand per sq mi).

Earlier studies have found apparent justification nationally for approximately 10,000 route-mi of urban freeway for 1960; 13,600 for 1972; 14,500 for 1975; and approximately 16,000 urban route-mi for 1980. By way of comparison about 3,000 urban freeway-mi are currently in operation.

Although urban Interstate highways as presently defined comprise some 5,000 mi of the system, about 6,700 mi currently lie within areas essentially urban in character. The expansion of urbanization will increase the average diameter of cities thereby encompassing additional rural Interstate mileage on the radial routes that serve each community. By 1972, about 8,400 route-mi of the presently defined Interstate system will probably be urban; by 1975, about 8,850 mi; and by 1980, approximately 9,600 mi. Thus, about 62 percent of the apparently needed route-miles urban freeways will likely be supplied if the Interstate system is completed by 1972.

TABLE 12

PRESENT AND ANTICIPATED CAPACITIES, KEY SCREENLINES, ST. LOUIS, MO.[1]

Screenline	Possible Capacity		Percent Increase
	Present	Anticipated	
Lindbergh Boulevard			
Surface streets	21,000	33,250	58
Expressways	3,600	16,200	350
Total	24,600	49,450	101
City Limits			
Surface streets	35,540	42,250	19
Expressways	0	34,200	0
Total	35,540	76,450	115
Kings Highway			
Surface streets	30,130	40,280	34
Expressways	3,600	36,000	900
Total	33,730	76,280	127
Grand Boulevard			
Surface streets	29,100	31,250	7
Expressways	3,600	30,600	750
Total	32,700	61,850	89
Natural Bridge			
Surface streets	17,900	19,550	9
Semi-expressways[3]	-	8,000	-
Subtotal	17,900	27,550	54
Expressways	-	28,800	-
Total	17,900	56,350	202
Delmar			
Surface streets	29,260	31,450	7
Semi-expressways[3]	-	8,000	-
Subtotal	29,260	39,450	35
Expressways	-	28,800	-
Total	29,260	68,250	133
Choutea-Manchester			
Present	25,480	32,420	27
Semi-expressway[3]	-	5,400	-
Subtotal	25,480	37,820	48
Expressways	5,400	28,800	433
Total	30,880	66,620	116
Chippewa-Watson			
Present	15,030	20,300	35
Semi-expressways[3]	-	-	-
Subtotal	15,030	20,300	35
Expressways	-	12,600	-
Total	15,030	32,900	119

[1] Source: (11).
[2] With improvements.
[3] Lindberg Boulevard, city limits expressway.

Analyses were made of the travel assigned to projected freeway systems in various cities as they relate to total urban travel. The proportion of trips and vehicle-miles of travel assignable to an adequate freeway system was found to increase as cities get larger: in cities under 100,000 people, freeways may carry up to one-quarter of all automobile travel; in urban areas of over 1,000,000 people, one-half or more of all such travel could be served by an adequate freeway system.

In most communities of less than 100,000 population, potential freeway volumes could generally be accommodated on high-type arterials. This is not the case in larger cities where demands closely match freeway capacities. As urban areas exceed 2,000,000, volumes potential to certain heavier traveled routes were found to exceed capacities provided under present concepts of freeway planning. These overloads result from the increased accumulation and concentration of travel desires within large areas, and from the convergence of freeway routes.

A comparison of projected urban freeway systems with the population of the areas they serve indicates that about 1 mi of urban freeway will be generally required per 10,000 residents. This tentative criterion should be modified when applied to the high-density central cities of the largest and oldest metropolitan areas, such as New York, Chicago, Philadelphia, and Boston, where public transportation, particularly rapid transit, provides effective service and where a sufficient network of freeways might be comparatively uneconomical to develop. Just as it is difficult to extend their transit potentials to all other urban areas categorically, it is equally inappropriate to apply nationwide freeway criteria without certain modifications.

Verification of Criteria

Development of equilibrium between the aggregate vehicle-miles of travel in an urban area performed on freeways, arterials, and other streets, and the capacity provided by each facility provides an alternate method of calculating the required route- and lane-miles. These relationships can be formulated as

$$V = K_1 \frac{M_f C_f}{P} = K_1 \frac{V_f}{P}$$

$$V = K_2 \frac{M_a C_a}{1-p} = K_2 \frac{V_a}{1-p}$$

$$V = V_f + V_a$$

in which

V = total vehicle-miles of travel performed;
V_a = total vehicle-miles of arterial travel performed;
V_f = total vehicle-miles of freeway travel performed;
C_f = freeway capacity (vehicle-miles per mile);
C_a = arterial capacity = $\frac{C_f}{3}$;
P = percent of total travel on freeways;
M_f = miles of freeway required;
M_a = miles of arterials and collectors required, and
K_1, K_2 = factors that compensate for the unequal distribution of demand throughout the urban area; if capacity were distributed precisely in accord with demand, these values would be unity. In these equations, the travel along local residential streets (usually about 5 percent of the total vehicle miles) has not been considered.

Based on these relationships, the required roadway facilities per 10,000 residents have been computed. These calculations summarized in Table 11 have assumed the following:

1. Daily travel equivalent to 12 vehicle-miles per urban resident.
2. A freeway capacity of 60,000 vehicles per day, and an arterial capacity of 20,000 vehicles per day.
3. Varying proportions of freeway travel—the proportions increasing as cities get larger.

The calculations have assumed that the route-miles of expressways and arterial facilities will be distributed in strict accordance with demand. Although such a precise, or optimum allocation of facilities is difficult to attain in practice, adjustments in lane-miles may compensate, to a large extent, for the nonuniform loading; for example, multilane freeways could have daily capacities as great as 120,000 to 150,000 vehicles per day, per mile of route. Similarly, the average daily travel (expressed in vehicle miles per capita) approximates 7 mi per capita per day, and is expected to increase to 10 mi per capita per day by 1980 (16), and is somewhat below the 12 mi per capita used above. Thus, Table 11 reflects factors of conservatism that tend to compensate for the variabilities in the distributions of roadway supply and demand.

The roadway requirements for cities of various size are given in Table 11, and tend to substantiate the 1 mi of freeway per 10,000 residents criterion; for example, an urban area with 1,000,000 population would require approximately 1 mi of freeway and 3 mi of arterial per 10,000 residents; about 50 percent of all its travel would be on freeways.

Freeway requirements will also depend on population density. The average spacing for eight-lane freeways should approximate 4 mi for a population density of 10,000 persons per mi. Assuming travel of 6 mi per capita per day on freeways, and an average freeway capacity of 120,000 cars per day on eight-lane freeways, the formula is

$$G = \frac{2C_f}{dpv}$$

in which

G = average grid spacing in miles;
C_f = average daily freeway capacity;
d = population density, persons per square mile;
p = percent of total travel on freeways; and
v = total daily travel expressed as vehicle-miles per capita.

For an over-all gross density of 20,000 persons per sq mi, the average freeway grid spacing should be about 2 mi—virtually the minimum spacing commensurate with adequate geometric design. For a density of 20,000 persons per sq mi, arterials would have to be spaced at intervals of ⅓ mi.

From these calculations it appears that an over-all central city density of about 20,000 persons per sq mi is the maximum concentration of people that can be accommodated by freeways and arterials, based on the preceding spacing criteria. (Such densities, however, are not common nor are they being attained in most areas of new urban growth.)

TABLE 13

SUMMARY OF CAPACITY GAINS, ST. LOUIS METROPOLITAN AREA[1]

Facility	Present	Anticipated	Percent Increase
Surface	203,440	250,750	23
Semi-expressway	-	21,400	-
Subtotal	203,440	272,150	33
Expressway	16,200	216,000	1,235
Total	219,640	488,150	122

[1]Source: (1).

Freeway Services

The present patterns of regional development accentuate the need for new transportation facilities. Freeways will increase the accessibility and attractiveness of the central business district; they will permit through traffic to bypass the downtown area; they will reduce travel times, operating costs, and accidents. Although the effective capacity of an urban transportation system can be increased in many ways, the greatest increases are presently taking place through the development of freeway systems.

St. Louis, Mo., is a lucid example of the service afforded by freeways. The aggregate one-direction peak-hour "possible" capacity in 1957 across eight "screenlines" totaled about 203,000 vehicles per hr on arterials and 16,200 vehicles per hr on freeways. Tables 12 and 13 show that maximum improvements to arterial streets would increase the total existing capacity about 47,000 vehicles per hr, 21 percent; and development of a semi-expressway would increase this capacity about 21,000 vehicles per hr, 10 percent. The completion of the freeway system would increase the existing capacity an additional 200,000 vehicles per hr, 91 percent. Thus, of a total 122 percent increase over existing peak-hour capacity, freeways would provide about three-fourths of the gain. Improvements to arterials would be relatively economical to achieve and could be accomplished while freeways are still under construction. They would, however, accommodate only a fraction of the anticipated traffic increases.

SYSTEMS APPROACH

The vast impact of transportation facilities on community growth and development requires a total "systems" approach involving all modes of transportation and all interested organizations and governmental agencies.

In the past, too many transportation plans, studies, and improvements were developed in relative isolation, concentrating almost entirely on one specific mode, and often overlooking the basic intereffects of "feedback" between transportation and land use.

Models and Synthesis

Analyses of numerous comprehensive origin-destination studies have revealed various statistical relationships between travel and population and economic indexes. Precise mathematical formulas have been developed to define the effect of income, density, car ownership, and other variables on travel mode and rates of trip generation.

Economics dictates that trip lengths be determined largely by trip purpose; persons are willing to travel much farther to work, for example, than to shop or school. The travel pattern of a particular zone is determined by the relative location of various competing opportunities (places of work, recreational facilities, shopping centers, schools, etc.) throughout the community, and the availability and quality of the transportation facilities affording access to each using travel time as a measure of the latter, the forces attracting travel can be precisely measured. The average family in a large urban area, for example, can be expected to make six or seven trips daily, while higher income families have been observed to make as many as 10 or 12 trips. Trip generation is also sensitive to population density, with families in dense urban core areas showing much less mobility than those in auto-oriented suburban areas.

TABLE 14

COMPARISON OF CHATTANOOGA SCREENLINE CROSSINGS, 1960[1]

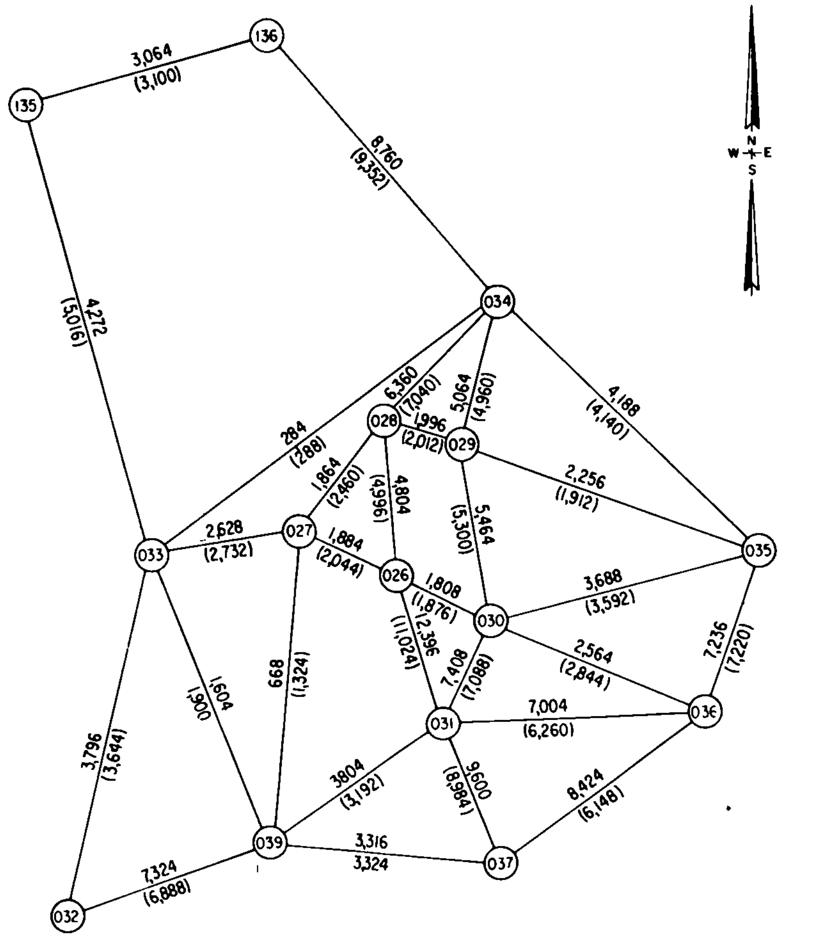
Total Trips					Work Trips				
Link	Bridge	Synthetic Data	O-D Data	Percent	Link	Bridge	Synthetic Data	O-D Data	Percent
256-547	Olgiati	12,416	12,836	96 7	256-547	Olgiati	6,736	6,964	96 7
257-243	John Ross	17,208	17,356	99.1	243-257	John Ross	8,244	7,624	108.1
440-494	Thrasher	6,400	7,700	83.1	440-494	Thrasher	2,132	2,116	100.8
Total		36,024	37,892	95.1	Total		17,112	16,704	102.4

[1]Source: (17).

"Models of system performance" permit analytical evaluation of alternative transportation networks through the use of statistical and probabilistic techniques. Such factors as travel speeds, capacity restraints, travel costs, and land impacts may be analyzed for different modes in various combinations and benefits of each alternative system compared.

Illustration of Synthesis

Models must, of course, be tested against real situations before they can be considered adequate. Such tests, involving re-creation of current travel patterns through the application of models to current land-use data were conducted during 1960 in Chattanooga, Tenn., in conjunction with the Tennessee State Highway Department and the U.S. Bureau of Public Roads as prototypes for similar syntheses (17). These studies assumed that the models would be applicable in making future travel projections if they could



NOTE
ZERO VOLUMES NOT SHOWN

LEGEND

245 ACTUAL VOLUMES
(174) SYNTHETIC VOLUMES

Figure 13. 1960 actual and synthetic traffic volumes, central business district, Chattanooga, Tenn.

re-create current travel patterns accurately. Accordingly, synthesized 1960 travel patterns were compared with actual movements recorded in the 1960 origin-destination study.

The model involved two basic areas of work: (a) estimation of the number of trips, by mode of travel with origins and destinations in each zone of the study area, and (b) distribution of trip ends between all possible zone pairs. The study was primarily designed to test the trip distribution model and was based on an analysis of the 384,500 internal passenger car trips (70 percent of the total vehicular trips) within the study area.

To test the reliability of the model, comparisons were made between synthetic trip estimates and actual origin-destination data. Comparative assignments to a "spider web" network connecting all adjacent downtown zone centroids is shown in Figure 13.

TABLE 15

COMPARISON OF TRIP LENGTHS, CHATTANOOGA, 1960[1]

	Auto Driver Trips		Percent of Total		Cumulative Percent	
Trip Length (min)	O-D Data	Synthetic Data	O-D Data	Synthetic Data	O-D Data	Synthetic Data
0	41,640	43,292	14.88	15.14	14.88	15.14
1	1,040	2,184	0.37	0.76	15.25	15.90
2	8,536	13,224	3.05	4.62	18.30	20.52
3	13,904	18,896	4.97	6.61	23.27	27.13
4	21,512	19,348	7.69	6.76	30.95	33.89
5	21,416	20,408	7.65	7.14	38.60	41.03
6	17,848	17,776	6.38	6.22	44.98	47.25
7	17,136	17,212	6.12	6.02	51.10	53.27
8	16,132	16,904	5.76	5.91	56.87	59.18
9	12,947	13,212	4.63	4.62	61.49	63.80
10	13,136	12,876	4.69	4.50	66.19	68.30
11	12,104	11,448	4.32	4.00	70.48	72.30
12	10,392	10,480	3.71	3.66	74.22	75.96
13	9,144	9,928	3.27	3.47	77.49	79.43
14	9,468	9,236	3.38	3.23	80.87	82.66
15	8,148	7,720	2.91	2.70	83.78	85.36
16	7,404	6,308	2.65	2.20	86.43	87.56
17	7,240	5,580	2.59	1.95	89.02	89.51
18	5,000	4,052	1.79	1.42	90.80	90.93
19	6,832	4,076	2.44	1.43	93.24	92.36
20	3,508	3,624	1.25	1.27	94.50	93.63
21	3,700	3,248	1.32	1.14	95.82	94.77
22	2,756	2,348	0.98	0.82	96.80	95.59
23	2,108	2,092	0.75	0.73	97.56	96.32
24	1,676	1,672	0.60	0.58	98.15	96.90
25	1,400	1,636	0.50	0.57	98.66	97.47
26	956	1,584	0.34	0.55	99.00	98.02
27	776	1,168	0.28	0.41	99.28	98.43
28	548	1,140	0.20	0.40	99.47	98.83
29	420	772	0.15	0.27	99.62	99.10
30+	1,060	2,572	0.38	0.90	100.00	100.00
Total	279,887	286,016	100.00	100.00		

[1]Source: (17).

Approximately three-quarters of all synthesized trip linkages within the central area were within 15 percent of the actual values. Comparable accuracy was found for other trip linkages within the study area.

A comparison of actual and synthetic volumes crossing the Tennessee River screenline are compared in Table 14. The assigned screenline crossings totaled 36,000 and comprised about 95 percent of the observed ground count. Synthesized work trips across the Tennessee River screenline accounted for about 102 percent of the actual work trip crossings.

A more detailed comparison of trip lengths, in terms of travel time is given in Table 15. Intrazonal trips (indicated as 0 min in length) amounted to about 15 percent of the total trips in both actual and synthetic data. The average trip length in terms of minutes of offpeak driving was calculated as 8.54 min from the survey data and 8.32 min from the synthetic data—a difference of less than 3 percent.

These and other syntheses currently under way appear to provide a rational approach to the planning and design of urban transportation systems. Although much work remains to be done, tools are emerging to aid the predictive process.

TOWARDS ACHIEVING BALANCE

Population projections in North America foresee no slackening in growth rates throughout the remainder of this century. Cities will proliferate and change in shape and structure commensurate with changes in economy, technology, and the desires of their populace. During the past 20 or 30 years there has been a tendency for central city densities to decrease in population, employment, and other types of land use; although the distractions of an economic recession in the 1930's and a great war in the 1940's tended to obscure this trend. The "normal" decade of the 1950's seems to confirm it and give it perspective. These changes have taken place despite enormous urban growth and have been accompanied by pronounced changes in the form of urban transport. Private per-capita car ownership throughout large urban areas has increased several times in the last 30 years; public transportation has declined sharply.

These trends seem likely to continue. Although patterns of land use and choice of travel mode may be guided to some extent—in some cases encouraged and in other cases restrained—it is not likely that the trends can be completely reversed short of a drastic change in the basic environment, such as could be brought about by a war or strong government edict. Although a city can adapt over a period of years to any transportation form, once it has adapted, it can no longer fully re-create its earlier condition. Though it is easy to anticipate various technological advances, it is difficult to evaluate fully their impacts on urban structure and economy.

American cities are served today by two forms of personal transportation strikingly different in their characteristics and adaptability to the evolving city form—the private automobile and the public transit vehicle. Their relative merits are in large measure complementary. The private vehicle best serves movements that are dispersed in space and time (e.g., suburbia); successful public transportation is contingent on the concentration of travel (e.g., close-in, densely populated CBD-oriented parts of the central city). Achieving balance between the modes, therefore, depends on achieving balance between the spatial concentration and dispersion of activity within the urban region. Thus, transportation and land-use elements should be conceived and planned as an integral system, attaining complementary relationships that re-enforce each other.

Modal Interrelationships

Several tentative and generalized indicators emerge from the preceding analyses, showing how the various forms of transport serve the evolving urban complex and how balance may be attained in accommodating the traveling public. Some of the findings, particularly relevant to freeways and rapid transit are summarized as follows:

1. Size of Urban Area. —Rapid transit systems have generally been successful where urban areas exceed 2,000,000 people; however, some rapid transit may also be desirable in certain areas between 1,000,000 and 2,000,000 population. Under present

concepts of freeway planning, when urban areas exceed 2,000,000, volumes along heavier-traveled routes may exceed capacities provided by eight-lane freeways (16).

2. Density.—Rapid transit systems appear generally to require densities of 14,000 to 20,000 persons per sq mi throughout substantial corridors within central cities. Where densities exceed 20,000 persons per sq mi, extremely close spacing of freeway and arterials is required. Within this range of densities, construction costs of transit facilities appear to be substantially less than those for freeways.

Much work remains to be done in determining the relative construction costs of rapid transit as compared with freeways under varying intensities of development. Preliminary analyses seem to indicate that for gross population densities of less than 15,000 to 20,000 per sq mi, construction of freeways is less expensive than that for rapid transit and the subway construction ($16,000,000 to $20,000,000 per mi) becomes less expensive only when gross population densities exceed 25,000 to 30,000 per sq mi. Rapid transit busways would generally be less costly than freeways, except for needed downtown distributor and terminal facilities which would substantially increase their costs.

Rapid transit could probably be developed in central cities with densities ranging from 10,000 to 15,000 per sq mi. (At present, central city densities of 15,000 or more per sq mi are usually found only in cities of over 1,000,000 population.)

3. Urban Travel Factor.—Wherever travel mode factors exceed 7.0 (i.e., urbanized area densities of 7,000 per sq mi, and 1 household per car), rapid transit systems have been found to function effectively. In this regard, bus rapid transit could probably be developed in areas with factors of 5 to 9 and rail rapid transit could probably be developed in areas with factors of 8.

4. Central Area Concentration.—Systems of rapid transit have been found to function, and hence appear desirable, where the number of destinations per sq mi of CBD exceeds 300,000 persons.

A detailed analysis of the central business district is beyond the scope of this paper. It is nonetheless fully recognized that downtown, centrally located in the urban complex, is the focus of the highest densities of urban travel. For downtown to remain as the hub of the urban region, attractive accessibility must be provided; freeway, parking and transit facilities will all usually be required.

Parking facilities, both within the central area and at key transit stops, will become increasingly important and are an essential part of a balanced transportation system. In some cases free downtown parking (and transit) may be necessary to place the central area on a competitive basis with outlying commercial centers; in other situations pricing mechanisms may be designed to encourage short-term parking within key central areas.

The information set forth in this paper suggests how professionals may objectively approach problems of transportation planning. There is, of course, a constant need for additional research, verification, and analysis. The analyses set forth have merely begun to explore the numerous applications of data already collected.

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