System Configurations in Urban Transportation Planning

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Urban transportation facilities should be planned, designed and operated as a unified system. Accordingly, some of their system configuration aspects are analyzed with emphasis on highway networks. Two approaches are utilized: (a) empirical analyses of existing and proposed systems; and (b) travel patterns simulated for a hypothetical community of nearly 3 million people with vehicular trips assigned to a series of alternate networks. Both studies clearly emphasize the importance of avoiding route convergence in areas of high trip density.

•URBAN transportation facilities should be planned, designed, and operated as a unified system. Despite the importance of transportation system considerations, prior emphasis has been largely placed on the many other aspects of urban transportation planning, such as land use-traffic generation quantification, and traffic distribution models.

The system concept, however, is usually the end result of the comprehensive transportation planning process (or, in more specific terms, the traffic engineer's operational analyses). Origin-destination (O-D) patterns, and urban trip linkages have little meaning to the road user, per se; his interest is in system efficiency, when and where he travels.

Accordingly, some general analyses on urban transportation system configuration are set forth. In developing systems (as in achieving transportation "balance") two basic criteria emerge. First, it is necessary to determine how much transportation can be provided within an urban area, by each of the various modes—this relates to desired levels of service and abilities to finance the recommended system. Second, it is necessary to determine the shape or configuration patterns of the recommended transportation system. The present study concentrates on this second aspect.

Most O-D studies have compared alternate systems to some extent. Generally, they have emphasized effects of shifting alignments and/or adding or subtracting links rather than altering configuration patterns.

The problem has been approached theoretically by Smeed in England (1). His studies indicate that average distances traveled by radial routings are 48 percent greater than ring routings, and 68 percent greater than direct routings where work places are uniformly distributed; when work places are proportional to distance, radial routings are 38 percent greater and ring routings 90 percent greater. Thus, high capacity radial routes continued to the center of town are likely to encourage people to travel by routes which pass through the central area.

This paper sets forth practical, observable characteristics of transportation systems and derives inferences based on planned systems; it also simulates loadings on hypothetical systems. It is an outgrowth of a study in process on urban transportation balance.

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"Systems," as used herein, refer to the total regional street or transit network. This contrasts sharply with the system configuration aspects of site plans for shopping centers, world's fairs, or civic centers, or with the analysis of a particular route or interchange.

HISTORICAL, OBSERVABLE, AND EMPIRICAL RELATIONSHIPS

The street systems of the world's cities date to antiquity—to the grids of Mohenjo-Daro (2800-2500 B.C.) and to the random patterns of Athens and Pompeii. Historically, many urban circulation systems developed radially from downtown. This is particularly true of many street patterns in the Old World. It is also true in older American cities where plank roads, horse-car lines and railroad routes helped shape urban transportation and land-use patterns. Even today, for example, there are comparatively few crosstown public transportation routes except in larger cities. In contrast, most Spanish-American cities adapted to the grid system, as did cities laid out as part of public land's surveys (2).

Existing Systems in Perspective

A general overview of existing urban transportation systems provides a logical point of departure. History, topography, and economic factors, as well as community attitudes and entrepreneurial foresight influenced patterns.

Most rapid-transit routes developed radially from downtown, although circumferential routes were developed extensively in Paris and Berlin. Within the United States, radial routes predominate, except for a single crosstown facility between Brooklyn and Queens and the Bloor Street line under construction in Toronto. The latter, however, may be construed largely as a radial facility, and may serve to shift the focus of downtown to the Bloor-Yonge intersection.

Generally, rapid transit lines were located under or over streets, and followed direct and optimum alignments. The notable exceptions, however, were the many lines developed over alleys or at-grade in Chicago, often involving right-angle turns and located several blocks from major business centers; their poor alignment adversely influences patronage, particularly short-haul and non-CBD trips.

Urban street systems vary far more widely in terms of capacity and configuration. Eastern cities—established long before the automobile—often have narrow (and even discontinuous) arterial street systems; in contrast newer cities have wide multilane arterials (for example, Newport, R. I., compared with Salt Lake City, Utah).

Urban street patterns combine radial circumferential and grid-iron configurations. Boston, Providence, Hartford, Nashville, and St. Louis, for example, have radial circumferential street patterns; the planned street systems of Buffalo, Washington, Detroit, and Indianapolis provide radial systems superimposed on grids; Manhattan, Chicago, Kansas City, Los Angeles, Philadelphia, San Francisco, Oklahoma City, Tulsa, Phoenix and Tucson have rectangular street grids (in some cases with a few radials superimposed). The majority of radial routes in all cities focus on downtown.

Each street pattern has its relative merits. Radial streets, for example, will reduce travel distances, particularly to downtown. They are usually well developed in central cities and suburbs, whereas circumferential routes are notably absent from suburban areas. Radials can, however, develop undue convergence, especially on approaches to downtown.

Diagonal streets superimposed on grid-iron systems create capacity and congestion problems where they intersect grid arterials. In Chicago, for example, the major diagonal routes usually require multiphase signal controls where they cross section-line streets. But the absence of diagonal routes (e.g., Tulsa) can create unduly heavy turning movements at conventional intersections, and also require multiphase signal operations.

Problem of Route Convergence

In most cities, major roadways generally converge on downtown and then traverse the central area. Thus daily, only one-third to one-half of all vehicular traffic entering downtown actually has its destination there (3, 4). A considerable proportion of this non-CBD traffic would be divertible to alternate facilities, such as inner or intermediate freeway loops.

Undue convergence of transportation facilities, generally results in operational problems, inadequate capacity and queueing. Examples of convergence include the Santa Ana and San Bernardino Freeways, junction on the east side of the four-level interchange in Los Angeles, the Route 128 and Southeast Expressways converging on the Fitzgerald Expressway, in Boston and the Meadowbrook-Long Island Expressway Junction in Nassau County. In Boston, five street-car routes converge on a two-track Boylston Street Subway, frequently resulting in peak-hour delays. Similarly, before the opening of the State Street subway in Chicago, four northside rapid transit routes converged on a two-track approach to the Loop, resulting in backups over two miles during the morning peak hours. Problems of convergence are also endemic in sections of the New York subway system; therefore, they are not limited to any particular mode of transportation.

The focusing of all streets on downtown should be carefully re-evaluated in light of current travel patterns, and anticipated growth trends. In most large cities, generally less than 10 percent of all motor vehicle trips have origins or destinations in the CBD (Table 1). Similarly, within the next 20 years, the greatest growths in travel can be expected between non-downtown locations (Table 2).

A fundamental question is, therefore, if the majority of all urban motor vehicle trips do not have origins or destinations downtown, why focus all freeway routes within the urban area on the CBD? Moreover, since convergence of routes develops difficult problems of balancing capacities, can a freeway system be developed that avoids undue route convergence, particularly in central areas?

System Configuration Alternatives

The optimum urban freeway configuration will obviously depend on urban area land use, topography, and street patterns. Freeway systems (Fig. 1) include four types of particular interest (also, see 3 and 6).

Single Route.—In all but the smallest urban areas, more than a single freeway will be required to (a) provide area-wide distribution and (b) to avoid overloads. The Hollywood Freeway, Long Island Expressway, and Fitzgerald Expressway illustrate single radial routes in large urban areas.

Radial Systems.—Radial systems of freeways conform to the radial patterns of urban travel. They reduce vehicle-miles of travel for downtown oriented trips, adapt to varying conditions of topog-

TABLE 1

PERCENT OF URBAN AREA AUTO DRIVER AND PASSENGER TRIPS MADE TO OR FROM THE CBD[a]

Urban Area	Year	Percent
Chicago	1956	3.5
Philadelphia	1960	3.4
Detroit	1953	6.5
Washington, D. C.	1955	25.3[b]
Pittsburgh	1958	7.9
Minneapolis-St. Paul	1958	9.4[c]
St. Louis	1957	6.4
Houston	1953	12.2
Kansas City	1957	8.7
Phoenix	1957	14.8
Nashville	1959	14.1
Tucson	1960	10.8

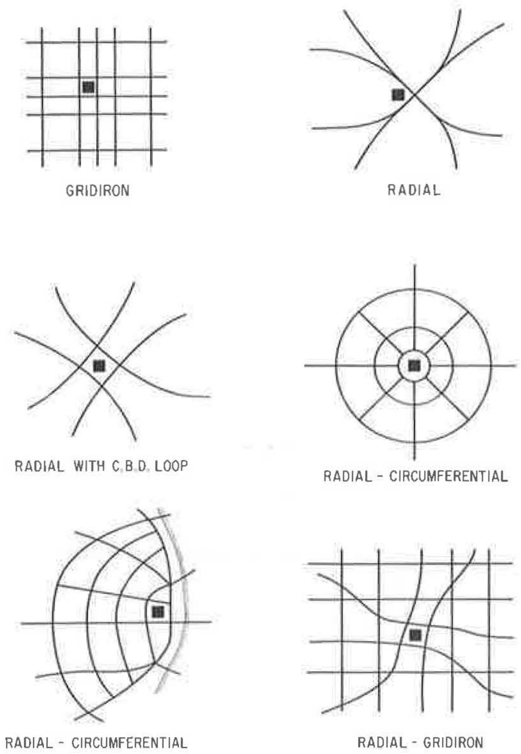
[a] Computed from O-D studies in each urban area.
[b] Zero sector.
[c] Minneapolis CBD.

TABLE 2

GROWTH INDICES[a] IN SELECTED URBAN AREAS
(Percent Increase to 1980)

City and Study Year	Population	Cars Owned	Vehicle Trips	Vehicle-Miles	CBD Person Trips	Non-CBD Person Trips
Chicago, 1956	51	94	79	120	10	80
Detroit, 1953	48	61	67	75	22	85
Washington, 1955	73	114	100	177	26	135
Pittsburgh, 1958	29	66	75	60	8	66

[a] Computed from O-D studies; also see ref. (5).



GRIDIRON RADIAL

RADIAL WITH C.B.D. LOOP RADIAL - CIRCUMFERENTIAL

RADIAL - CIRCUMFERENTIAL RADIAL - GRIDIRON

Figure 1. Typical urban freeway system configurations.

raphy, and encourage corridor expansion. Generally, they have variable spacing between routes, although their tributary populations may be the same. They may engender high concentrations along close-in portions of freeways, involve convergence of routes, funnel all freeway traffic into system focal points, and require varying amounts of surface street travel. Moreover, radial freeways alone do not serve the rapidly growing circumferential trip linkages.

Radial Circumferential Pattern.—Radial-circumferential patterns (or a variant, radial freeways interconnected by a downtown freeway loop) have been traditionally planned in many urban areas. Such systems vastly improve the accessibility and trading area of downtown, expecially in small- or medium-sized areas. They provide an even distribution of facilities with demands and afford direct access among all parts of the urban area.

The systems, however, focus routes on downtown, making travel through downtown the most direct route for many non-CBD linkages. They may, therefore, achieve high traffic concentrations on close-in freeway sections and also involve some route convergence with complex interchanges.

Grid-Iron Pattern.—Grid-iron freeway patterns are simple and regular in their design and spacing. They avoid undue route convergence and focus, and enable downtown loop freeways to serve primarily downtown. They tend to equalize growth opportunities for all parts of the region. They do not, however, necessarily adapt to areas with restricted topography.

Some Empirical Investigations

To investigate the effect of alternate configurations, the relation between maximum and average loadings on selected urban freeway systems was analyzed (Table 3 and Fig. 2). The ratio between anticipated maximum 1980 load-point volumes and average volumes approximates 2.4 for grid systems in large cities, 4.0 for radial-circumferential systems in large cities and 2.2 in medium-sized cities.

The relative use of downtown freeway loops by through and CBD traffic provides another measure of the "convergence aspects" of urban freeways. Anticipated 1980 use of freeways in Kansas City and Phoenix is compared in Table 4. Both cities would have a 1980 population of about 1,250,000. In Kansas City, with a radial circumferential system, approximately 51 percent of all freeway trips would enter the inner loop as compared with 38 in Pheonix. However, 68 percent of all inner loop freeway trips in Phoenix would have origins or destinations in the CBD as compared with only 38 in Kansas City. Thus, Kansas City's inner loop freeways would carry predominantly non-downtown trips.

Analyses of two partial freeway systems clearly denote the desirability of system continuity. In Los Angeles, completion of the south (Santa Monica Freeway) leg of the Inner Loop, delivered 40,000 additional vehicles daily into the freeway system—these vehicles negotiated a "U" type routing to avoid more direct arterial travel. Similarly,

TABLE 3

EFFECT OF SYSTEM CONFIGURATION ON MAXIMUM FREEWAY LOADINGS IN SELECTED URBAN AREAS[a]

System	City	Population 1980	Max. Load Point	Avg. Volume	Ratio
Grid	Chicago[b]	7,802,000	150,000	64,000	2.34
	Pittsburgh[b]	1,902,185	93,000	38,100	2.44
	Phoenix	1,250,000	92,000	39,600	2.35
Radial Grid	Detroit	4,400,000	240,000	70,000	3.43
Radial-Circumferential	Large:				
	Washington	2,720,700	287,000	60,800	4.72
	St. Louis	1,721,360	204,000	60,600	3.36
	Kansas City	1,340,220	208,000	56,100	3.70
	Medium-Sized:				
	Nashville	467,113	75,300	33,400	2.27
	Charlotte	409,735	53,000	29,800	1.78
	Chattanooga	344,528	55,700	22,500	2.48
	Lexington	220,000	43,000	18,000	2.38

[a] Computed from O-D studies in each urban area.
[b] Capacity restrained assignment.

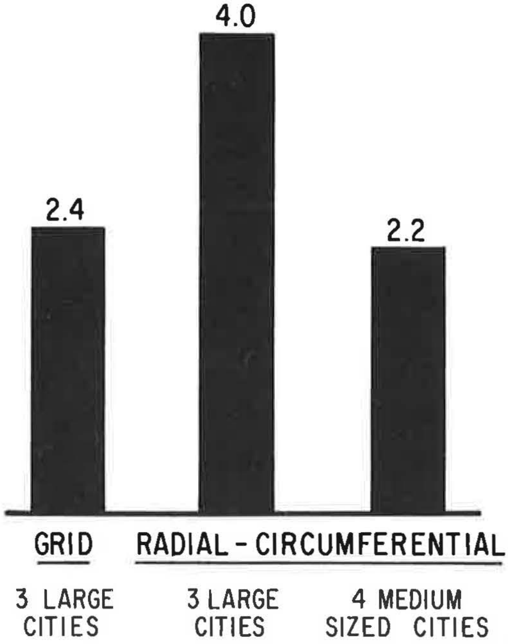


Figure 2. Ratio of maximum-load point to average route volume selected urban freeway systems.

TABLE 4

COMPARATIVE 1980 FREEWAY USE, KANSAS CITY AND PHOENIX URBAN AREAS

Item	Urban Area	
	Kansas City	Phoenix
1980 population	1,340,220	1,250,000
Type system	Radial-Circumf.	Grid
Total freeway trips in urban areas	936,000	682,000
Percent of total trips on inner loop	51.1	38.3
Percent of all freeway trips to or from CBD	19.3	26.2
Percent of all freeway trips on inner loop to or from CBD	37.9	68.4
Ratio 4:6	1.34	0.56

Source: Computed from anticipated traffic volume maps for each urban area.

in Pittsburgh, a partial freeway system was estimated to increase Golden Triangle cordon crossings about 63 percent over existing levels, while a complete system would result in only a 16 percent increase (7).

SIMULATION OF TRAVEL IN A HYPOTHETICAL CITY

The preceding analyses suggest that grid freeway systems appear to develop more equitable traffic loadings in large urban areas. However, because of variability among areas in structure, input assumptions, growth and travel projections, and traffic assignment procedures, special analyses were simulated for a hypothetical urban area. Population and land-use distribution, travel patterns, and assignment procedures were held constant while the system configuration was varied.

Basic Assumptions

A symmetrical urban area, containing nearly 2,920,000 people in 784 sq mi was assumed for purposes of analyses (Fig. 3 and Table 5). This population was distributed around a 4-mi central area in five rings of density—decreasing from 15,000 to

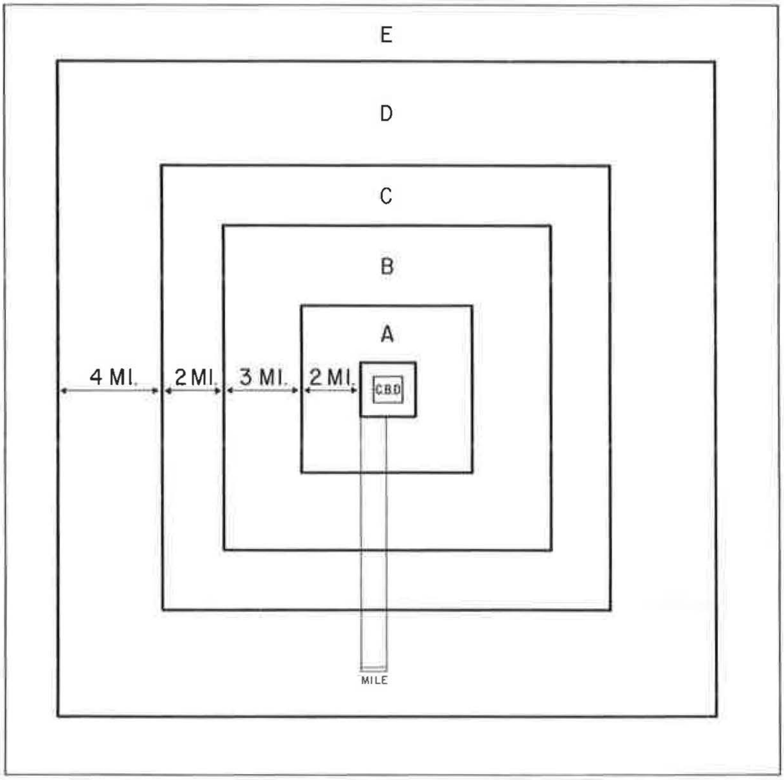


Figure 3. Study rings.

TABLE 5

POPULATION AND VEHICLE TRIPS SIMULATED FOR HYPOTHETICAL CITY

Ring	Zones	Area (sq mi)	Population Density	Population	Veh. Trip Rate per Capita	Veh. Trip Productions		Trip Attractions			
								Strong Centralization		Average Centralization	
						Total	Per Sq Mi	Total	Per Sq Mi	Total	Per Sq Mi
CBD	1-4	4	0	0	0	0	0	385,000	96,250	260,200	65,050
A	5-37	33	15,000	495,000	0.80	396,500	12,000	500,000	15,500	554,000	16,790
B	38-84	107	8,000	856,000	0.90	770,400	7,300	701,500	6,550	751,900	7,025
C	85-112	112	5,000	560,000	1.00	560,000	5,000	450,000	4,000	472,700	4,220
D	113-192	320	2,500	800,000	1.10	880,000	2,750	670,000	2,100	682,000	2,130
E	193-244	208	1,000	208,000	1.20	249,600	1,200	150,000	720	145,900	700
Total or Avg.		784	3,723	2,919,000	0.98	2,856,500	3,643	2,865,500	3,655	2,866,700	3,656

1,000 persons per sq mi. A total of 244 zones were developed, based on areas 1-mi square in the central rings and 4-mi square in the periphery.

Assumed rates of trip attraction and production, and trip densities are also given in Table 5. Approximately 2,866,000 assignable vehicle trips were assumed—almost one per capita. Trip production per square mile declined at a slightly slower rate than population density—from 12,000 in Ring B to 1,200 in Ring E. Two basic concentrations were assumed for the 4-sq mi downtown area and its environs—385,000 and 260,000 trip ends, respectively.

The trips were linked by means of a conventional gravity model:

$$T_{i-j} = \frac{P_i \; A_j \; F_{i-j} \; K_{i-j}}{\sum_{j=1}^{n} A_j \; F_{i-j} \; K_{i-j}} \qquad (1)$$

in which

P_i = productions in zone i;

A_j = attractions in zone j;

F_{i-j} = friction factor between zones i and j;

T_{i-j} = trips from zone i to zone j;

K_{i-j} = "kay" factor between zones i and j, assumed as 1.0; and

n = number of zones.

A sufficient number of iterations were run to converge the trips attracted to within 5 percent of the trip attraction in each ring. The friction factor curve was based on that developed for a large metropolitan area of comparable population. The resulting trip lengths averaged about 20 minutes. Eighty-five percent of all trips were 30 minutes or less and trips under 3 minutes accounted for only 10 percent of the total.

Thus, the trip estimates did not fully include intrazonal trips, which could substantially increase the number of trips without any substantial change in the total number of vehicle-miles. (To some extent, the long average trip length serves to compensate for exclusion of commercial vehicles and external trips.)

The gravity model was based on minimum time paths between zones on Freeway System 1. A 2-mi arterial street grid was assumed to cover areas outside of the intermediate loop freeway and a 1-mi grid was assumed within the loop. Local streets were spaced at intermediate distances. Speeds were assumed at 15 mph on local streets, 25 mph on arterials and 45 mph on freeways; these speeds are consistent with general practice. A 15-sec turn penalty was added at intersections to eliminate zigzag routings. Traffic was assigned on all-or-nothing allocation basis according to minimum travel time paths. The system configuration required access to and from zone centroids via arterial streets. Only arterials were connected directly to the freeway system.

The basic freeway systems considered are shown in Figure 4 and summarized in Table 6. They include attenuated asymmetrical and symmetrical grid patterns (Systems 1, 2, 2A), a radial grid network (System 3), and two radial-circumferential patterns (Systems 4 and 5). Traffic assignments were obtained mechanically for all systems except the symmetrical grid; this system was subsequently developed to equalize use of the full asymmetrical grid network.

The freeway systems average 0.7 miles per 10,000 residents (Table 6). All freeway patterns provided an increase in the frequency of routes as they approached the center of the city. In addition, all configurations avoided convergence of routes within the central area.

Results of Simulation

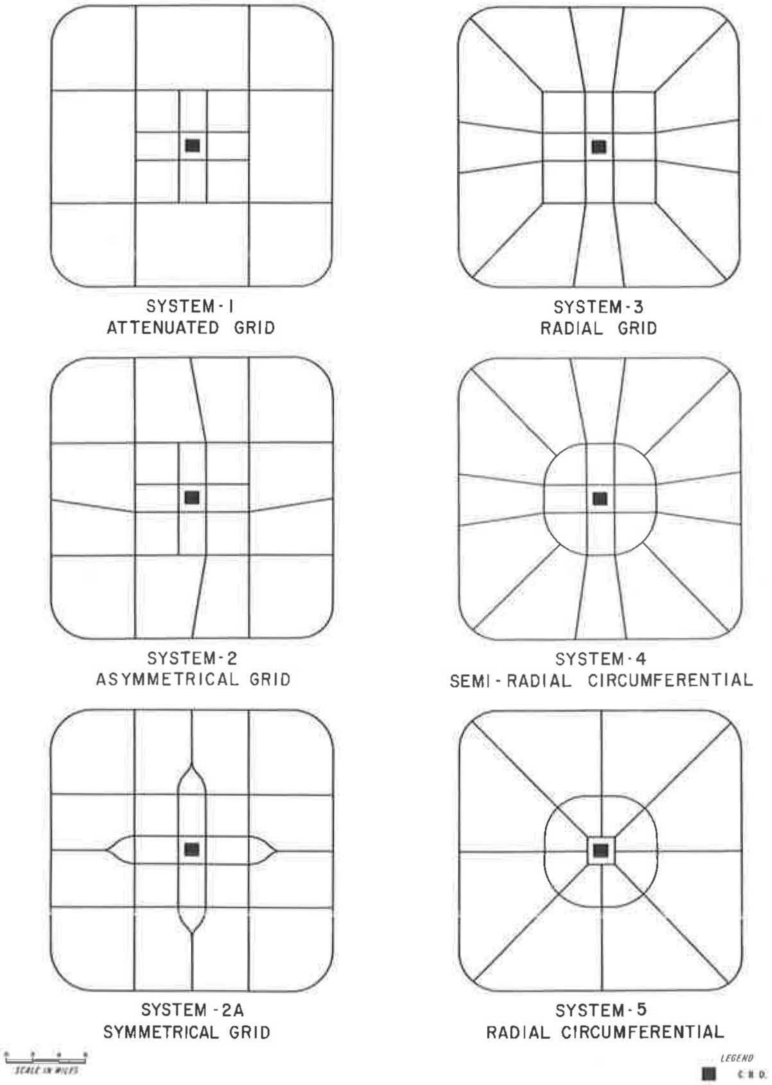
The results of the computer assignments are given in Tables 7, 8, and 9, and shown in Figure 5.

Because of rounding in the assignment process, approximately 2.6 million trips were actually assigned. For all systems, the assignable vehicle-miles of travel approximated 25 million—8.5 veh-mi per capita. (If additional intrazone and nonassignable travel were considered, these values would probably increase 15 to 20 percent.) Thus, these estimates are generally comparable to anticipated per capita travel in other urban areas. Average system speed approximated 28 mph.

There is little difference among the plans in total travel assigned. However, developing a high central-area concentration tends to have a very slight increase in overall travel. (For example, in System 1 from 24.91 to 25.13 million veh-mi.)

As given in Table 7, 52 to 56 percent of all travel would take place on the various freeway systems. This percentage range is comparable with estimated usage of freeways in large metropolitan areas.

Average daily volumes per mile of route ranged from about 63,000 to 70,000; the



SYSTEM-1
ATTENUATED GRID

SYSTEM-3
RADIAL GRID

SYSTEM-2
ASYMMETRICAL GRID

SYSTEM-4
SEMI-RADIAL CIRCUMFERENTIAL

SYSTEM-2A
SYMMETRICAL GRID

SYSTEM-5
RADIAL CIRCUMFERENTIAL

Figure 4. Freeway systems tested.

TABLE 6

SUMMARY OF SYSTEMS CONSIDERED

System	Type	Miles	Miles/ 10,000 Capita
1	Attenuated grid	187	0.64
2	Asymmetrical grid	211	0.72
2A*	Symmetrical grid	220	0.75
3	Radial grid	218	0.75
4	Semi-radial-circumf.	218	0.75
5	Full radial-circumf.	190	0.65

*This system developed after detailed analyses of others.

TABLE 7
PERFORMANCE CHARACTERISTICS OF FIVE HYPOTHETICAL FREEWAY SYSTEMS

Item	System 1		System 2		System 3		System 4		System 5	
	Concentrated CBD	Avg. CBD	Concentrated CBD	Avg. CBD	Concentrated CBD	Avg. CBD	Concentrated CBD	Avg. CBD	Concentrated CBD	Avg. CBD
Total vehicles assigned	2,600,000		2,600,000		2,600,000		2,600,000		2,600,000	
Trips to or from CBD	385,000	260,000	385,000	260,000	385,000	260,000	385,000	260,000	385,000	260,000
Percent to or from CBD	14.8	10.0	14.8	10.0	14.8	10.0	14.8	10.0	14.8	10.0
Total vehicle-miles (millions)	25.13	24.91	24.33	24.22	25.00	24.84	25.05	24.87	25.15	24.99
Vehicle-miles per capita	8.60	8.53	8.33	8.29	8.56	8.51	8.58	8.52	8.62	8.56
Vehicle-miles on freeway (millions)	13.43	13.23	13.21	13.19	13.92	13.71	13.88	13.66	13.25	13.03
Percent of total	53.4	53.1	54.3	54.4	55.7	55.2	55.4	54.9	52.7	52.1
Vehicle hours on system (millions)	0.88	0.87	0.85	0.85	0.86	0.86	0.87	0.86	0.87	0.87
Vehicle hours on freeway (millions)	0.29	0.29	0.31	0.30	0.31	0.30	0.29	0.29	0.29	0.29
Percent of total	33.3	33.0	34.0	34.2	35.7	35.2	35.4	35.0	33.5	33.0
Average trip length (min.)	20.30	20.08	19.61	19.61	19.85	19.85	20.08	19.85	20.30	20.30
Average trip speed (mph)	28.55	28.63	28.62	28.49	29.06	28.89	28.79	28.91	28.58	28.40
Average volume per mile on freeway	71,800	70,750	62,600	62,500	63,850	62,900	63,650	62,600	69,740	68,580

TABLE 8
COMPARATIVE TRAFFIC VOLUMES ON ALTERNATE FREEWAY SYSTEMS

Segment	Attenuated Grid (1)		Asymetrical Grid (2)		Symmetrical Grid (2A)[a]		Radial-Grid (3)		Semi-Radial-Circumf. (4)		Radial-Circumf. (5)	
	Conc. CBD	Avg. CBD	Conc. CBD	Avg. CBD	Conc. CBD	Avg. CBD	Conc. CBD	Avg. CBD	Conc. CBD	Avg. CBD	Conc. CBD	Avg. CBD
Inner loop:												
Length (mi)	8	8	8	8	8	8	8	8	8	8	6	6
Avg. vol	108,425	99,700	122,760	124,410	122,760	124,410	143,300	134,625	130,400	121,275	135,475	128,310
Max. vol	-[b]	-[b]	165,370	163,145	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]
Min. vol	-[b]	-[b]	80,145	80,670	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]	-[b]
Inner radials:												
Length	24	24	24	24	24	24	24	24	24	24	24	24
Avg. vol	93,200	85,400	109,505	106,990	109,505	106,990	127,630	119,790	115,500	100,900	99,675	90,950
Max. vol	105,850	96,650	168,760	166,130	124,440	120,210	142,400	133,625	125,970	116,325	151,700	135,950
Min. vol	83,400	76,139	53,575	48,395	101,670	98,075	117,700	110,890	98,300	90,650	72,600	67,350
Intermediate loop:												
Length (mi)	32	32	32	32	32	32	32	32	27	27	25	25
Avg. vol	139,200	141,350	107,615	107,610	107,615	107,610	107,450	109,780	115,400	115,000	99,350	100,450
Max. vol	156,700	159,644	125,922	122,070	125,922	122,070	120,960	131,850	136,950	138,700	106,750	110,650
Min. vol	130,600	133,000	99,430	98,880	98,880	99,430	92,750	84,875	85,810	92,575	90,650	95,500
Outer radials:												
Length (mi)	48	48	72	72	80	80	79	79	84	84	60	60
Avg. vol	78,400	82,400	71,720	69,555	71,720	69,555	54,750	56,740	61,091	60,640	84,950	83,370
Max. vol	115,110	117,950	139,210	140,771	88,000	85,000	95,450[c]	93,110[c]	104,500	104,000	149,550	147,950
Min. vol	53,550	53,550	31,710	30,645	31,710	30,645	5,790	5,980	6,400	7,825	7,000	7,000
Outer loop:												
Length (mi)	75	75	75	75	75	75	75	75	75	75	75	75
Avg. vol	23,650	25,600	28,550	29,970	28,550	29,970	27,440	27,990	24,830	25,700	29,600	30,050
Total miles	187	187	211	211	219	219	218	218	218	218	190	190

[a] Estimated from averaging loadings on long and short radials in systems.

[b] All inner loop volumes assumed equal because of loading symmetry.

[c] Coding bias develops short sections 115,965 and 116,075, respectively.

TABLE 9

RELATION OF MAXIMUM TO AVERAGE VOLUMES, FIVE HYPOTHETICAL FREEWAY SYSTEMS

System	Max. Load Point	Average Volume	Ratio
(a) Concentrated Central Area			
1	156,700 C	71,800	2.18
2	168,760 R	62,600	2.69
2A	124,440 R	62,600	1.99
3	143,300 L	63,850	2.24
4	136,950 C	63,650	2.15
5	151,700 R	69,740	2.18
(b) Average Central Area			
1	159,644 C	70,750	2.26
2	166,130 R	62,600	2.66
2A	124,410 L	62,500	1.99
3	134,625 L	62,900	2.14
4	138,700 C	62,600	2.22
5	147,950 R	68,580	2.16

Note: L = inner loop; R = radial; and C = intermediate circumferential.

higher volumes occur on Systems 1 and 5 which have the least mileage. These average loadings compare with those generally anticipated for urban areas of 3,000,000 population (3).

General Similarities.—From a review of the traffic flow patterns, certain similarities are apparent:

1. In all plans, there was an increase in loadings as routes approach the center. This is consistent with the increases in trip generation, trip attraction, and trip density, resulting from more intensive land use, and from the center's position as a focus for trip linkages.

2. The ratio of maximum load point to average volumes ranged from 2.0 to 2.7 (for symmetrical and asymmetrical grid systems, respectively). These ratios are less than those on most planned systems; this difference may be explainable in part by (a) the symmetry of the hypothetical region, and (b) the avoidance of route convergence.

3. Loadings were generally comparable to those anticipated for most urban areas of similar size. Maximum volumes, for example, ranged from 125,000 to 170,000 vehicles per day.

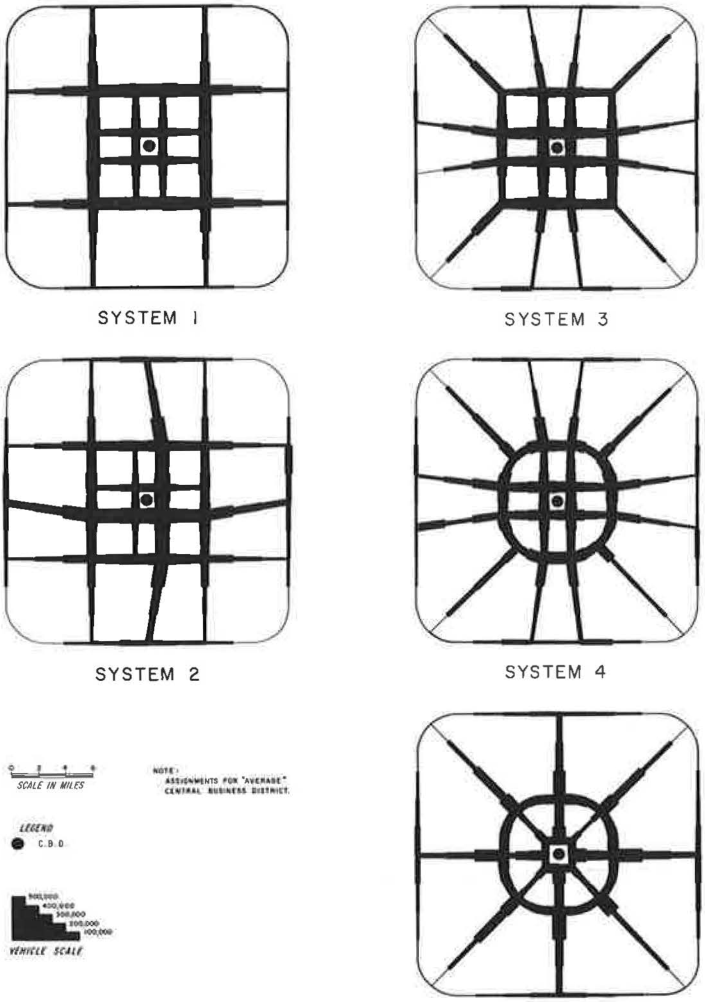
4. Various loadings appeared more sensitive to changes in system links than changes in the O-D pattern. Inclusion or deletion of links (viz., Systems 1, 2, and 2A) created more significant differences than changing the intensity of the downtown area 50 percent. This suggests (a) relative insensitivity in assignment procedures, and (b) some compensation for the increase in downtown trip ends, by a corresponding decrease in trip attractions of surrounding areas. Generally, a 50 percent increase in the core area trip intensity resulted in an approximate 10 percent increase in inner loop volumes. Volumes on outer sections, in turn, tend to increase by smaller percentages as downtown intensity is reduced.

5. Average volumes on the inner loop ranged from 100,000 to 150,000 vehicles per day. Volumes on the intermediate circumferential generally exceeded 100,000 vehicles per day. Volumes on the 75-mi outer circumferential generally averaged under 30,000 vehicles per day. Thus, the intermediate circumferential freeway is an essential link in large urban areas. The outer loop, in turn, is perhaps the least valuable in terms of traffic volumes served. Accordingly, freeway plans for large urban centers should give important consideration to incorporation of intermediate loop freeways.

6. There was a rapid build-up of traffic at locations where interchanges are spaced at 2 miles apart. The heaviest volumes occurred on continuous routes.

7. The maximum volumes (170,000 to 160,000 vehicles per day) slightly exceeded the flows that can be effectively carried on 8-lane urban freeways. (This suggests that some urban areas beyond this population range might need to augment freeways with other transportation services, even with optimum system configurations—assuming that arterials are loaded to capacity.)

Apparent Differences.—While the aggregate amount of traffic assigned in the various systems was approximately the same, the specific loading patterns reflected each system's particular geometry.



SYSTEM 1

SYSTEM 3

SYSTEM 2

SYSTEM 4

SYSTEM 5

Figure 5. Assigned daily traffic volumes.

1. The heaviest volumes (up to 170,000 vehicles per day) were found under the asymmetrical grid system (System 2) on the sections of route that traverse the entire area and are adjacent to the CBD. The two continuous routes served very much like single radial facilities; they clearly depict how radial freeways can attract heavy traffic volumes.
2. Elimination of the asymmetry (System 2A), however, appears to develop the most equitable loading pattern. Maximum volumes on the inner loop, intermediate circumferential, and key radials would generally be less than 125,000 vehicles per day.
3. The heaviest volumes on the intermediate loop (160,000 cars per day) occurred with the attentuated or truncated grid system (System 1). Conversely, System 1 develops the lightest volumes on the inner loop and inner radial freeways.
4. The complete radial circumferential system (System 5), tends to develop greater extremes in radial loadings, particularly with a concentrated central area generation.
5. Radial-circumferential facilities (Systems 3, 4, and 5) tend to increase inner loop volumes by about 10 percent over that of a symmetrical grid.

6. The differences in inner loop use do not, however, appear significant among the various systems. However, the complete radial-circumferential network (System 5) has the tightest loop in area. Thus, it is subject to eight freeway interchanges as compared with four on the other systems. This suggests more difficult geometry, and increased intra-stream conflicts.

Evaluation

The hypothetical study represents a pilot attempt at synthesizing urban travel patterns and freeway loadings. The conclusions derived, therefore, are merely suggestive, and are obviously subject to additional refinement and verification.

The study achieves realistic traffic volume patterns consistent in magnitude and spatial location to those found in urban areas of comparable size. It shows that loadings are more sensitive to adding, deleting, or "warping" links, than to downtown concentration, per se. It shows how system continuity, i.e., extending freeway routes throughout an urban area, tends to maximize their use. It demonstrates the importance of the intermediate freeway loop in large urban areas. Moreover, the importance of avoiding route convergence is clearly indicated.

The study suggests that a carefully designed grid system would achieve a more equitable loading system than a radial-circumferential system with fewer operating problems on the inner loop. But the distinction is not clear, particularly in light of the study limitations.

To develop a workable model, it was necessary to oversimplify study networks and trip-distribution patterns. Yet, despite these limitations, the study appears to represent a feasible prototype for subsequent analyses.

The traffic patterns obtained, for example, are generally similar to those set forth by Fisher and Boukidis (8). However, the differences between radial and grid systems are somewhat less pronounced. The study also tends to verify some of the system planning criteria set forth in recent transportation studies.

EMERGENT PRINCIPLES AND CONCLUSIONS

In analyzing and appraising freeway system configuration, it is often hard to rely on precise quantification alone. Just as in the analysis of simple traffic designs, one-way systems, intersection channelizations, and site plans, the total design should look natural and prove workable. Accordingly, various system planning principles emerge from the analyses set forth herein, in terms of both system operations and relation to the urban environment. These principles include:

1. System permanence—The relation of the system to the permanent elements of urban structure, and the avoidance of compromises in structure or configuration.
2. System adaptability—The ability to work under alternative loading patterns or land-use plans, since, in the final analysis, any future loadings represent a projection that may or may not be actually achieved.
3. Continuity of capacity—The minimization of differentials in capacity between various points along the system.
4. Equalization of lane densities—A changing of lanes only at locations where comparable changes in the overall traffic magnitudes are anticipated.
5. Regularity and clarity—Provision of a clearly discernible and easily recognizable pattern. The elimination of multiphase or offset intersections has its counterpart in freeway system configuration; offsets and stubs should be avoided.

One basic principle emerges from the various studies set forth herein: Urban freeway systems should be carefully designed to avoid route convergence in central areas. The analyses also suggest the desirability of grid, rather than radial, freeway systems in large urban areas. It is, of course, recognized that the freeway system should adapt to the urban street configuration, and to topographic and land-use controls.

One of the most significant conclusions emerges as a by-product of the study. The synthesis of the urban travel and freeway traffic volumes, although still in initial stages, appears feasible and desirable. This pilot study suggests that, given the population distribution for an urban area, its basic land form and geography and various system geometrics, future freeway traffic volumes might be developed with less dependence on precise trip allocation models.

REFERENCES

1. Smeed, R. J., "Route Development in Urban Areas: Part 1, The Effect of Some Kinds of Routing Systems on the Amount of Traffic in the Central Area of Towns." Jour. Inst. of Hwy. Engineers, Vol. 10, No. 1, p. 5-30 (Jan. 1963).
2. Stanislawski, D., "The Origin and Spread of the Grid Pattern Town." Geographic Review, Vol. XXVI, No. 1, p. 105-120 (1946).
3. "Future Highways and Urban Growth." Wilbur Smith and Associates (1961).
4. Schmidt, R. E., and Campbell, M. D., "Highway Traffic Estimation." Eno Foundation, Saugatuck, Conn.
5. "Urban Transportation Issues and Trends." Automobile Manufacturers Assoc., Detroit (June 1963).
6. "Chicago Area Transportation Study." Vol. 3 (1963).
7. Pittsburgh Area Transportation Study, Vol. 3.
8. Fisher, H. J., and Boukidis, N. A., "The Consequences of Obliquity in Arterial Systems." Traffic Quarterly (Jan. 1963).