Effects of Alternate Loading Sequences on Results From Chicago Trip Distribution and Assignment Model

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Use of alternate loading sequences has little effect on areawide totals for travel estimates (as applied to Pittsburgh Area Transportation Survey data). However, when smaller units—zones, districts, rings, sectors, links, or specific movements—are considered, the differences can be large and can exert a definite influence on design and economic analyses.

•THE BASIC concepts of traffic assignment—the allocation of vehicle trips to routes in a transportation network—evolved in the early and middle 1940's. The early work in assignment consisted primarily of estimating the diversion of traffic from existing roads to new, improved, high-speed arterials or freeways. Travel time savings and distance savings were the primary bases for the estimates.

Later attempts at estimating traffic diversion used the travel time (or speed) ratio and travel distance ratio, and better results were obtained. In 1955 the Detroit Metropolitan Area Traffic Study developed a method of estimating diversion using both the speed and distance ratios, and this was used in assigning traffic to a network of freeways and arterials. However, only two routes could be considered for each interzonal movement: the most direct arterial and the most advantageous freeway route. Although this method was workable and produced meaningful and useful results, a more efficient method of assigning traffic to an urban network was needed.

In 1957 the breakthrough in network assignment occurred. Edward F. Moore presented a paper entitled "The Shortest Path Through a Maze" to the International Symposium on the Theory of Switching at Harvard University. At about the same time a paper by Dantzig was published. Of these, the paper by Moore is more widely used in transportation planning.

Also in 1957, the staff of the Chicago Area Transportation Study (CATS) was looking for a computer program to assign traffic to a large urban road network and contracted with the Armour Research Foundation (now the Illinois Institute of Technology Research Institute) for its development. Mertz (4) reports the progress thus:

> This investigation resulted in an electronic computer program for an intermediate size computer for finding the minimum time (or distance) paths through a network. The program is something of a laboratory novelty in that it is limited to 18 nodes (intersections) and is quite extravagant of memory storage. It provided the beginning, however, for further development.
>
> Mr. Morton Schneider and others on Dr. Carroll's staff further refined the method through many evolutions on an intermediate size computer to the point where they were able to accommodate enough nodes to encompass a small section

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> of the Chicago metropolitan area. These efforts were still in the research and development category. Dr. Carroll decided that the method was feasible but far greater computer storage capacity and computing speed was needed to do the job for the highway system for the whole Chicago area.
>
> At this point, a computer programming development was undertaken by the Chicago staff for the largest and fastest electronic computer then available in the country. . . . This resulted in an operational program to assign traffic to the existing arterial streets as well as the proposed freeways and expressways for the entire Chicago metropolitan area.

In 1958 CATS used an IBM 704 for the first traffic assignment to a metropolitan road network. Morton Schneider developed a trip distribution model known as the intervening opportunities model or the opportunity model. This was combined with the traffic assignment program and together they are known as the Chicago trip distribution and assignment model or, commonly, the Chicago (CATS) model. With some modifications, this model is used by the Pittsburgh Area Transportation Study (PATS).

The CATS assignment program utilizes an unusual capacity restraint feature. Capacity restraint is based on the premise that as the volume on a link increases, the time required to traverse that link increases. The CATS program applies the restraint after the trips from each zone have been assigned. In this way, travel times on links change throughout the assignment process, tending to prevent one roadway from being overloaded while a nearby parallel route is almost unused; in reality, this is how traffic behaves.

There are other capacity restraints in use today, but all of them use an iterative approach. After all trips have been (distributed and[1]) assigned, the restraint feature is applied and link travel times are changed according to the volumes on the links. Trips are then (redistributed and) reassigned, and the process is repeated until some criterion of change reaches an arbitrarily selected acceptable level.

With the CATS approach to capacity restraint, the order in which trips from the zones are loaded onto the network can have two important effects on the assignment process:

1. It can change minimum time path from A to B. If trips from a zone are assigned near the start of a loading sequence, the minimum time paths to other zones probably will not vary much from the initial (free) minimum paths; if trips from the same zone were loaded late in the loading sequence, the minimum paths could vary greatly from the initial ones.
2. This change in minimum time path can result in different zone-to-zone movements as calculated by the opportunity model. One of the factors influencing the magnitude of zone-to-zone movements is the ranking of destination zones by travel time from each origin zone. A separate ranking is made before trips from each origin zone are distributed. If the changes in interzonal travel times can change this ranking, they can also alter the calculated zone-to-zone movements.

Although the transportation studies currently using the Chicago model know that the assignment loading sequence can have these effects, they have never evaluated the changes which occur. It is generally agreed that the adverse effects can be minimized by the use of a random or selected loading sequence which does not load zones from any concentrated area consecutively; spatially concentrated loading can result in distortion of the natural trip distribution and assignment patterns.

The purpose of this study is to determine a measure of the magnitude of the effects of alternate loading sequeces on:

1. The total vehicle-miles of travel (VMT) in the network;
2. The volumes assigned to links in the network; and

[1] The Chicago model, and most other models, can use either predetermined trip interchanges or internally calculated interchanges.

3. The magnitude of the zone-to-zone interchanges as calculated by the intervening opportunities model.

ROAD NETWORK

The network used in this study is the PATS 410 network (Fig. 1). It consists of the basic 1958 network plus 99 miles of new freeways for which the Pennsylvania Department of Highways believes it has the finances to build by 1980 in the internal study area. It is not the network recommended by PATS in its final report; network 410 was used here primarily for convenience and, in addition, because it is the basic network used by PATS to provide the Pennsylvania Department of Highways with freeway design volumes.

TRIP INPUTS

The basic trip inputs were the forecast 1980 trip ends for each zone, i.e., 226 internal zones, 46 adjacent area zones, and 8 points-of-entry. These trips were stratified as long residential, long nonresidential, and short, as required by the format of the intervening opportunities model.

DISTRIBUTION MODEL

All interzonal trip transfers were calculated by the intervening opportunities model, using the formula:

$$V_{ij} = \sum_{L} V_i \left[e^{-LV} - e^{-L(V + V_j)} \right] \qquad (1)$$

where

V_{ij} = number of trips from zone i to zone j;
V_i = number of trip origins in zone i;
V = number of satisfactory trip destinations lying closer (on the basis of travel time) to zone i than does zone j;
V_j = number of satisfactory trip destinations in zone j;
L = probability of a trip of a certain type stopping at a random destination;
e^{-LV} = probability of getting to zone j and of not finding an acceptable destination closer than zone j;
$e^{-L(V + V_j)}$ = probability of going beyond zone j and of not finding an acceptable destination even after considering zone j; and
$e^{-LV} - e^{-L(V + V_j)}$ = probability of stopping in zone j.

A separate calculation is made for the short, long residential, and the long nonresidential trips from each zone of origin.

There is one major difference between the CATS and PATS versions of the model: CATS uses one short L and one long L value for the entire study area; PATS uses separate long and short L values for each zone.

ASSIGNMENT PROCESS AND CAPACITY RESTRAINT

The trips are assigned to the roadway network in the following manner:

1. The network is provided as an input to the computer, complete with initial link travel times and 24-hour capacities.
2. The numbers of short, long residential, and long nonresidential trip ends in each zone are also inputs.

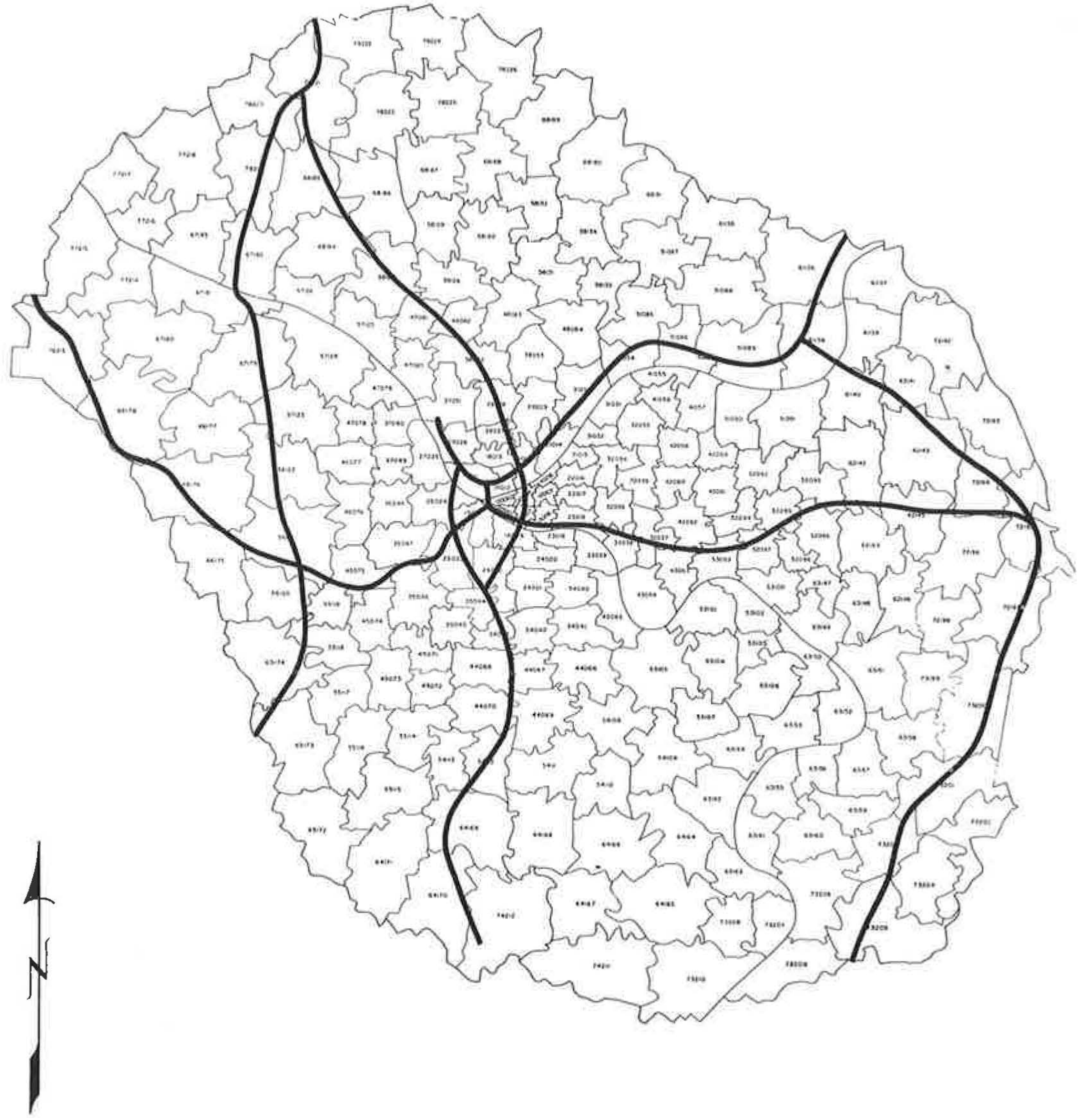

Figure 1. PATS 410 network.

3. The computer seeks out the minimum time paths from the zone loaded first to all other zones and ranks these zones by travel time from the origin. The interchanges from this origin zone to all other zones are then calculated.

4. The calculated trip interchanges are then assigned to their respective proper minimum time paths according to the all-or-nothing method.

5. After all trips from the first zone have been assigned to the network, new link travel times are calculated to reflect the increased volume. The accumulated volume on each link is compared with the link's capacity, and the travel time is adjusted according to:

$$T_N = T_O \times 2^{V/C} \qquad (2)$$

where

T_N = new link travel time,
T_O = initial travel time (before any traffic assigned), and
V/C = volume-to-capacity ratio.

For computational purposes only, the V/C ratio has a limit of 2; thus, the maximum travel time on a link is four times its initial travel time ($T_N = T_O \times 2^2 = 4\,T_O$). Figure 2 shows this relationship. This curve was used because it was believed that a normal travel time vs volume/capacity curve would permit a majority of the trips to be assigned in an essentially unrestrained manner.

6. After steps 3 through 5 are completed for the first zone in the loading sequence, they are repeated for the second zone, the third zone, and so on until all trip interchanges have been calculated and assigned to the network.

LOADING SEQUENCE

This paper concerns itself with capacity restrained assignments only. In free (unrestrained) assignments the link travel times do not change from the initial values; hence, the loading sequence has no special significance or meaning.

Both CATS and PATS used "random" loading sequences with the Chicago model to eliminate bias and concentrated loading of trips. These were not random in a true mathematical sense. Rather, the sequences were handpicked or obtained on a sorter. It should be recognized that the use of a randomly generated loading sequence means only one thing: personal bias has been eliminated. There are almost 1.7×10^{565} possible loading sequences in the PATS area of 280 zones. Even considering only the 226 zones that send trips, there are still almost 1.8×10^{421} possible loading sequences.

For this study three loading sequences have been chosen for comparison. The first is the normal PATS sequence used in all official PATS assignments. It is developed from a reverse sort of the zone numbers. Zone 100 is loaded first, then 200, 010, 110, 210, . . . 179, 279, 089, 189, 099, 199. The scatter of this ordering is shown in Figure 3.

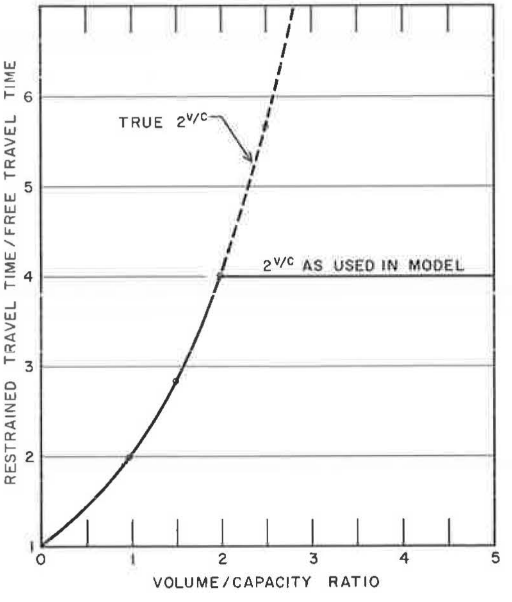

Figure 2. Travel time ratio vs volume/capacity.

As a comparison, this sequence was completely reversed. Zone 199 is loaded first, then 099, 189, 089, 279, . . . 210, 110, 010, 200, 100.

The third sequence tested was the numerical sequence. As the name implies, zone 001 is loaded first, then 002, 003, 004, 005, . . . 278, 279, 280. This sequence loads trips originating in the CBD first, and then spirally works its way outward to the edges of the study area.

Although only zones 1 through 226 send trips, all 280 zones were used in setting up the sequence. It must be remembered that all network, trip, and L inputs were held constant during all three assignments; only the loading sequence was changed.

VEHICLE-MILES OF TRAVEL

An important step in any transportation study is the calibration of the trip distribution and assignment models so that they reasonably simulate the total VMT (or some other parameter) in the study area. If there were any great differences in the total VMT between reasonable alternate loading sequences, it would be normal to question seriously the choice of loading sequence, and possibly even the validity of the model itself. Since, however, the variations in individual link travel would tend to be canceled out when aggregated, the total VMT would not be expected to vary much between loading sequences. Table 1, giving VMT data for the three loading sequences, confirms this.

The assignment of trips in the internal area by the reverse normal sequence produced 33,000 more VMT than did the normal sequence, a difference of only 0.20 percent. For the adjacent area the reverse sequence gave 31,000 fewer VMT than did the normal, a difference of -0.32 percent. Both of these are very close to the normal results, well within the accuracy of the data on which they are based. Summed for the

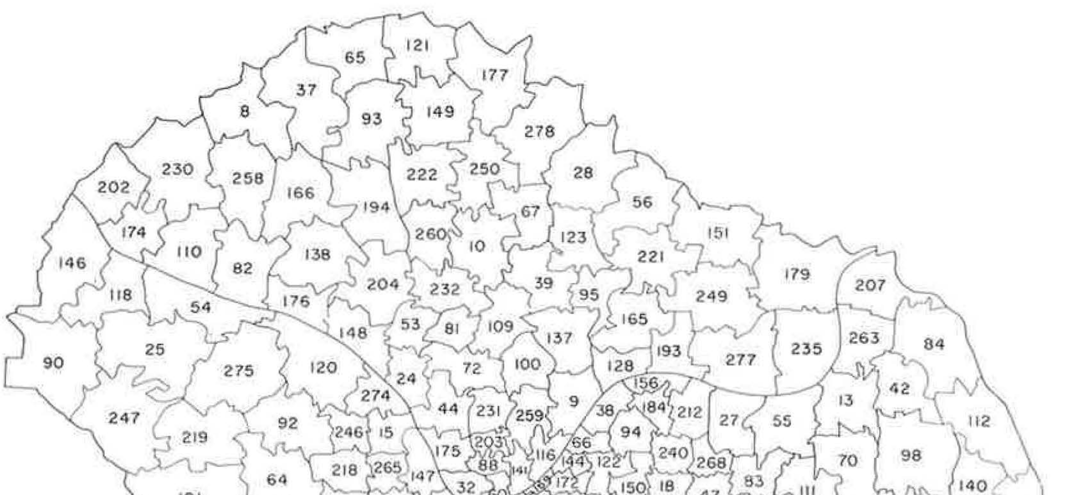

Figure 3. Loading sequence of internal zones—based on a 280-zone sequence (including adjacent area and points-of-entry).

TABLE 1

TOTAL VEHICLE-MILES OF TRAVEL: INTERNAL AND ADJACENT AREAS

Sequence	Internal VMT	Adjacent VMT	Total VMT
Normal	16,671,300	9,505,700	26,177,000
Reverse	16,704,300	9,474,700	26,179,000
Numerical	17,125,700	9,875,000	27,000,700

TABLE 2

VEHICLE-MILES OF TRAVEL BY RING: INTERNAL AND ADJACENT AREAS

Ring	VMT Normal	VMT Reverse	Diff. (%)	VMT Numerical	Diff. (%)
0	269,900	281,900	+4.4	262,700	-2.7
1	878,900	871,900	-0.8	797,900	-9.2
2	1,500,900	1,506,300	+0.4	1,389,400	-7.4
3	2,058,700	2,042,700	-0.8	1,957,800	-4.9
4	2,094,000	2,134,900	+2.0	2,049,600	-2.1
5	3,656,500	3,694,500	+1.0	3,813,000	+4.3
6	3,733,400	3,742,100	+0.2	4,061,100	+8.8
7	2,479,100	2,430,100	-2.0	2,794,300	+12.7
All internal[a]	16,671,300	16,704,300	+0.2	17,125,700	+2.7
8	4,891,400	4,837,900	-1.1	5,249,700	+7.3
9	4,614,400	4,636,800	+0.5	4,625,200	+0.2
All adjacent[a]	9,505,700	9,474,700	-0.3	9,875,000	+3.9
Total[a]	26,177,000	26,179,000	+0.008	27,000,700	+3.1

[a]Because of rounding, columns may not add to totals.

entire study area, the difference was only 2,000 VMT—0.008 percent—an unbelievably close correspondence.

The numerical sequence produced 454,400 more VMT than did the normal sequence in the internal area and 369,300 more VMT in the adjacent area. These represent differences of 2.7 and 3.9 percent, respectively. For the total study area the difference was 823,700 VMT, an increase of 3.1 percent. Although this is more variation than the reverse normal sequence produced, it is still within the accuracy of base data.

Table 2 shows the vehicle-miles of travel by ring obtained from each loading sequence for the internal and adjacent areas. Since all planning at PATS was done for the internal area, the differences observed in the adjacent area are not of prime importance. It suffices to say that for the adjacent area the reverse sequence produced 0.3 percent fewer VMT than did the normal sequence, whereas the numerical sequence gave 3.9 percent more VMT than did the normal sequence.

The comparisons for the internal rings (0 through 7) are interesting. Again the numerical sequence produced a greater overall difference in VMT than did the reverse normal sequence (2.7 percent vs 0.2 percent). The differences by ring when the reverse normal sequence was used showed no apparent pattern of increases and decreases. By contrast, the numerical sequence produced fewer VMT than did the normal sequence in rings 0 through 4 but more VMT in the other rings. The exact reason for this phenomenon is unknown; however, one possible explanation is worth considering. Trips from zones in ring 0 (the CBD) are sent first, zones in ring 1 (around the CBD) send their trips next, and so on, spirally outward, until all trips have been sent. When the trips from the innermost rings are assigned to the network, they result in increased travel times on the links of the network they use. Because of the mechanics of the model, all trips from a zone must be sent, but no zone must receive trips from all other zones. Therefore, the increased travel time on links in the inner rings made those zones less attractive as destinations and, in effect, diverted trips to other zones. The result is reduced VMT in the innermost rings. This is only an hypothesis, but it seems reasonable.

It is possible, also, to study the results by district, the area between two successive ring lines in a sector. Table 3 summarizes the effects of the alternate loading sequences on district vehicle-miles of travel. Figures 4 and 5 show the changes by district for the internal area only.

It is clear that there is an appreciable difference in the effects of the alternate loading sequences on the district vehicle-miles of travel. First, the use of the numerical sequence results in larger changes than does the reverse normal sequence. In the internal districts, the numerical sequence produced differences as large as 27.4 percent, almost twice as large as the maximum difference of 14.1 percent from the reverse normal sequence. The same is true for the adjacent area districts where the maximum differences are 14.9 percent for the numerical and 6.5 percent for the reverse normal sequence.

By comparing Figures 4 and 5, the effects of a numerical loading sequence are seen more clearly. Figure 4 shows that the districts with increased VMT from the reverse loading sequence were scattered over the study area in no apparent pattern. Figure 5 shows that the districts with increased VMT from the numerical loading sequence were concentrated around the outer portions of the study area. The reason for this has been discussed previously. There is no apparent reason for the area of decreased VMT on the western side of the study area.

Because of the amount of work and time involved in analyzing the vehicle-miles of travel by zone, a sample of 34 scattered internal zones (15 percent) was selected. These zones showed increases and decreases as large as 33 percent with both the reverse and the numerical loading sequences.

The most important conclusion from this part of the study is that the use of an alternate loading sequence has very little effect on the total vehicle-miles of travel in the study area. When smaller units of area—rings, sectors, districts, or zones—are considered, the effects of alternate loading sequences are much more pronounced. The smaller the area under consideration, the larger the difference in travel can be.

The next logical question is, "How do link volumes vary with loading sequence?"

TABLE 3

CHANGES IN VEHICLE-MILES OF TRAVEL BY DISTRICT

Area	Normal vs Reverse		Normal vs Numerical	
	Avg. Percent	Percent Range	Avg. Percent	Percent Range
Internal	+0.4	-14.1 to +10.5	-0.5	-27.4 to +19.8
Adjacent	-0.2	-4.4 to +6.5	+5.8	-5.5 to +14.9

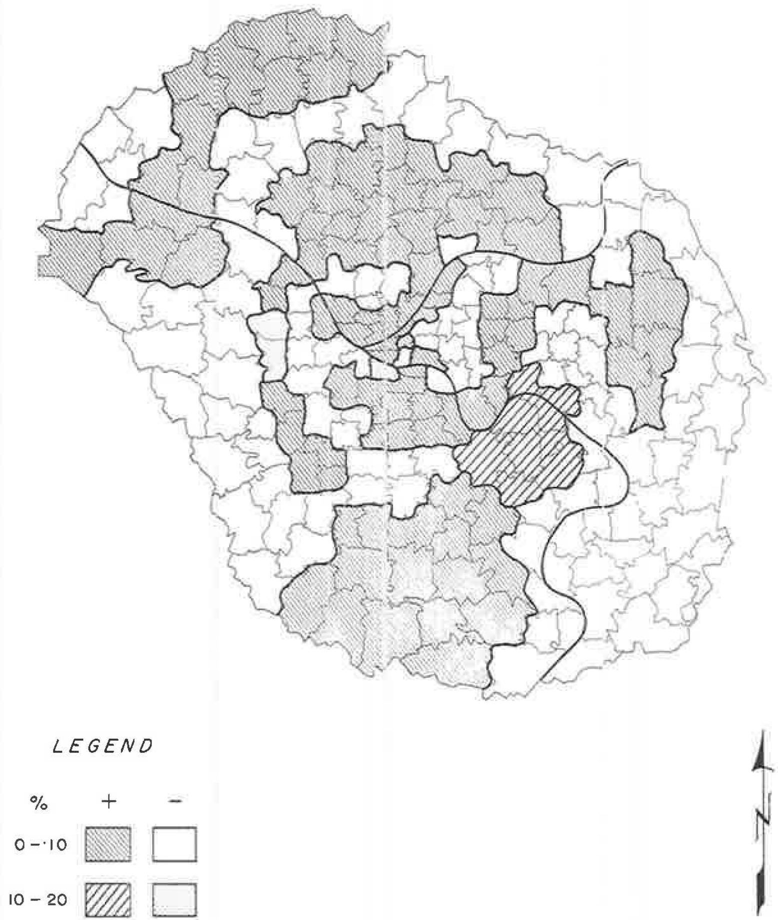

Figure 4. Vehicle-miles of travel by district: reverse vs normal sequence.

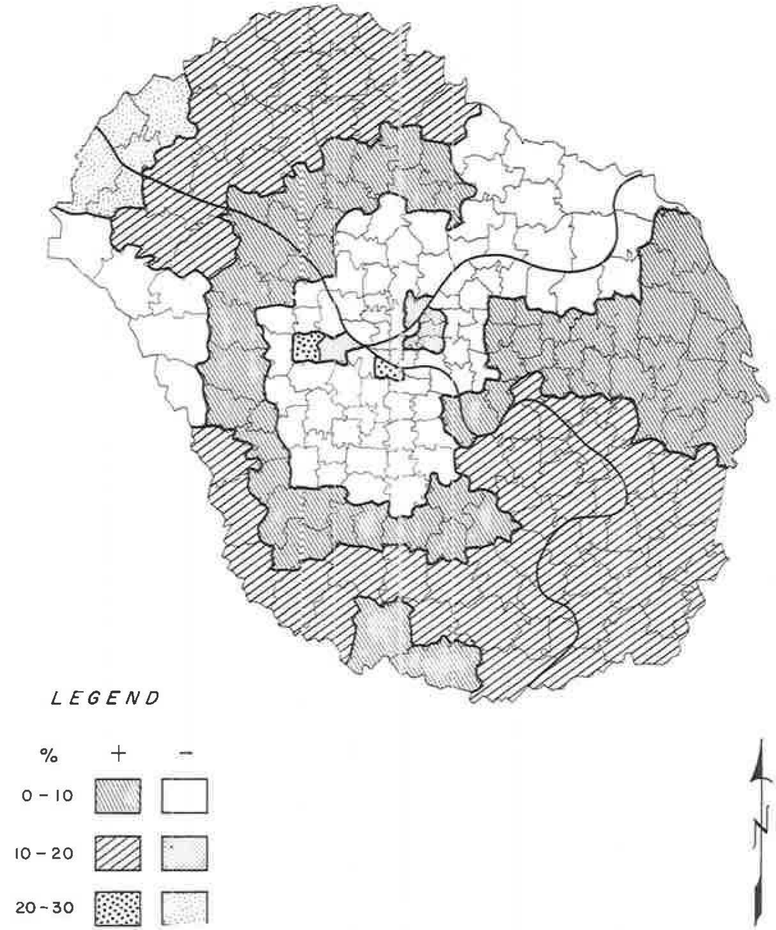

Figure 5. Vehicle-miles of travel by district: numerical vs normal sequence.

LINK VOLUMES

The 410 network used in this study has 3,041 links, including 2,136 arterials, 379 freeways, and 526 ramps. Table 4 shows the volume groupings used and the number of links in each volume class based on an assignment using the normal loading sequence. Because of the amount of time involved in the link-by-link analysis, only the results of the normal and reverse normal sequences have been compared.

In all studies of link volumes, comparisons are based on the normal sequence volumes. Thus, a difference of +10 percent means the alternate (reverse) sequence resulted in a 10 percent higher value than did the normal sequence.

It was believed that the root-mean-square (RMS) error of the link volumes would be a useful measure of the variations that occur. This is comparable with the standard deviation of a group of data around its mean (7). For each volume class the RMS error was found thus:

$$\text{RMS error} = \sqrt{\frac{\sum_{i=1}^{n}\left(V_{Ri} - V_{Ni}\right)^2}{n}} \tag{3}$$

where

V_{Ri} = link volume from reverse loading sequence,
V_{Ni} = link volume from normal loading sequence, and
n = number of links in a particular volume class.

All links were grouped by the normal sequence volume. Table 5 summarizes the calculations made. From this table, it is clear that the higher the volume assigned to a link, the less likely it is to fluctuate widely (on a percentage basis) when an alternate loading sequence is used. Figure 6 is a plot of the percent RMS error vs mean normal volume. The curve is handfitted to the data. The rapid decline in percent RMS error with increasing volume is very apparent. Links with volumes of less than 1,000 had an RMS error equal to 192 percent of the mean volume. As has been recognized by transportation planners, these low volumes are unreliable for many reasons, including the network configuration and loading node placement. These links seldom pose critical problems in planning work, but when such links are encountered, the planner must use his professional judgment and personal knowledge of the situation as guides.

TABLE 4

VOLUME GROUPINGS

Class	Normal Sequence Vol. (000)	No. Links
1[a]	0- 1	354
3	1- 3	305
4	3- 5	387
5	5-10	761
6	10-15	542
7	15-20	292
8	20-30	242
9	30-40	88
10	40-50	44
11	50-60	21
12	60-70	4
13	70-80	1

[a]Original classes 1 and 2 combined.

Three links showed variations in excess of 1,000 percent. One was 1,277 percent, one 1,148 percent, and one 1,060 percent. The assigned volumes from the normal loading sequence were 480, 384, and 664, respectively. In each case the link was near, but not connected to, a loading node. It is believed that the differences were due primarily to changes in the distribution of trips from the nearby loading nodes. But this emphasizes a definite problem in constructing networks: loading nodes must be placed in such a way as to minimize their effects on the volumes assigned to major links near them. Two of these three links were expressway ramps—such vast dif-

TABLE 5

LINK VOLUME DATA BY VOLUME CLASS: NORMAL VS REVERSE

Class	No. Links	Mean Normal Vol.[a]	Mean Reverse Vol.[b]	Diff. (%)	RMS Error	Percent RMS Error[c]
1	354	361	560	55.1	694	192.0
3	305	2,192	2,400	9.5	1,203	54.9
4	387	4,076	4,459	9.4	2,376	58.3
5	761	7,363	7,540	2.4	1,605	21.8
6	542	12,307	12,245	-0.5	2,424	19.7
7	292	17,270	17,063	-1.2	3,109	18.0
8	242	24,224	23,279	-3.9	3,755	15.5
9	88	33,748	33,377	-1.1	4,252	12.6
10	44	43,917	44,224	0.7	3,030	6.9
11	21	53,708	53,654	-0.1	2,041	3.8
12	4[d]	66,018	62,519	-5.3	—	—
13	1[d]	71,880	68,380	-4.9	—	—

[a]Mean volume of all links whose normal volume fell into a given class.
[b]Mean reverse sequence volume of all links whose normal volumes fell into a given class.
[c]Percent RMS error = RMS error/mean normal volume.
[d]Sample too small for statistical reliability.

ferences in volumes can be extremely important in the design of ramps and their terminals, and possibly in the design of the freeway itself.

The loading sequence underwent a most severe and drastic change when it was reversed. For this reason, the results of the link volume study are viewed most favorably.

From the foregoing link volume analyses, it can be concluded that in a restrained assignment using the Chicago model, the loading sequence exerts a definite influence on the volume assigned to each link in the network. Whether the volume on a particular link increases or decreases when the loading sequence changes is a function of loading sequence, location of the link with respect to other links, closeness to a loading node, etc. The change (plus or minus, and magnitude) cannot be predicted; generally speaking, the higher the assigned volume, the greater the faith that can be placed in it as a good estimate of that link's volume.

It is essential that the reader recognize that the network did not change during these assignment runs. If it had, more drastic changes in link volumes undoubtedly would have occurred. Because of the stability of freeway volumes during the changes in loading sequence, it is the author's belief that freeway volumes obtained from a restrained assignment can be used for design purposes under the following conditions:

1. No freeway, ramp, or major arterial link should connect directly to a loading node (zone centroid).

2. The arterial route system must be detailed enough to represent the major through routes and collector routes available to drivers in the area.

3. Perhaps most important, the volumes must be based on one freeway network (system). Major realignment of routes, or the addition or elimination of routes, can drastically influence the assigned volumes on all routes. Therefore, freeway volumes derived from an assignment using one network should never be used (except for comparison) with a different network.

4. All inputs to the model must have been carefully calculated and evaluated. If these are not reliable, why do an assignment?

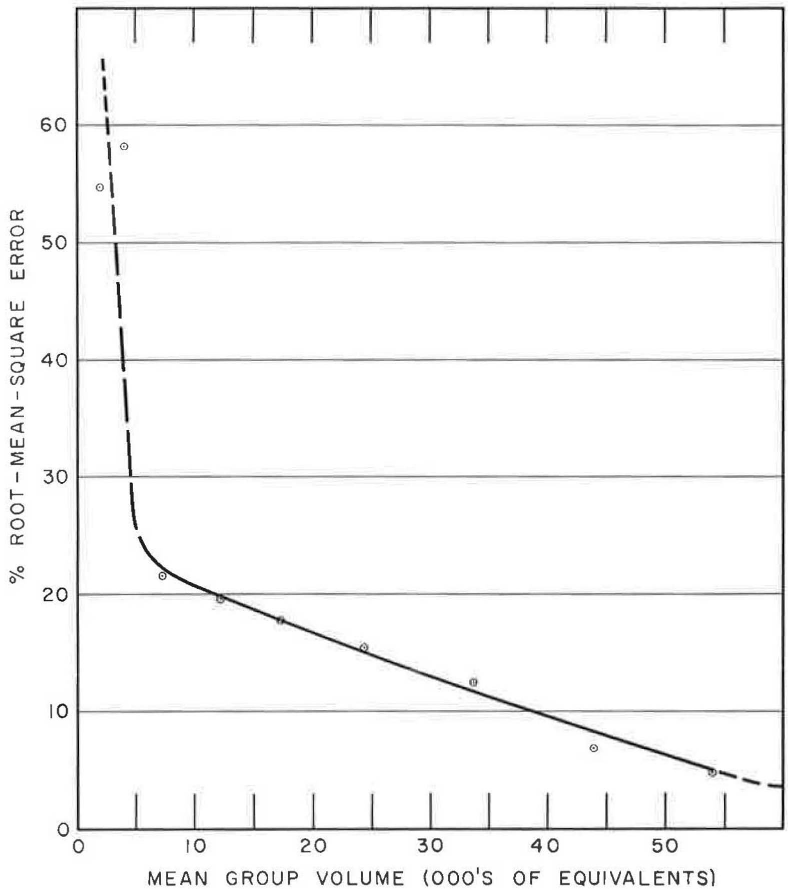

Figure 6. Percent RMS error vs mean group volume.

Some people argue that assignment volumes should not be used for design purposes. But what more reliable estimate of future freeway volumes is available?

SELECTED LINK STUDY

It was decided to investigate in detail the effects of alternate loading sequences on the volume assigned to one key link in the network. The link selected was the Fort Pitt Bridge, a double-decked major connection on the Penn-Lincoln Parkway between the Golden Triangle and the southern and southwestern suburbs. (The Penn-Lincoln Parkway is actually a freeway according to the AASHO definition.)

The link volumes used in this study were obtained from the regular assignment outputs. The detailed data on individual interzonal movements were provided by the selected link subroutine developed for PATS by Morton Schneider. This subroutine gives the origin zone, destination zone, path time, and volume of each interzonal movement whose minimum time path utilizes the selected link (in this case, the Fort Pitt Bridge).

Figures 7 and 8, respectively, show the northbound and southbound volumes on each approach, on the bridge itself, and on each exit. The changes between normal and reverse normal sequences and between normal and numerical sequences are given in Table 6.

When the volumes from the normal and reverse sequences were compared, only one link (H) showed an increased volume (16.4 percent); all other link volumes decreased

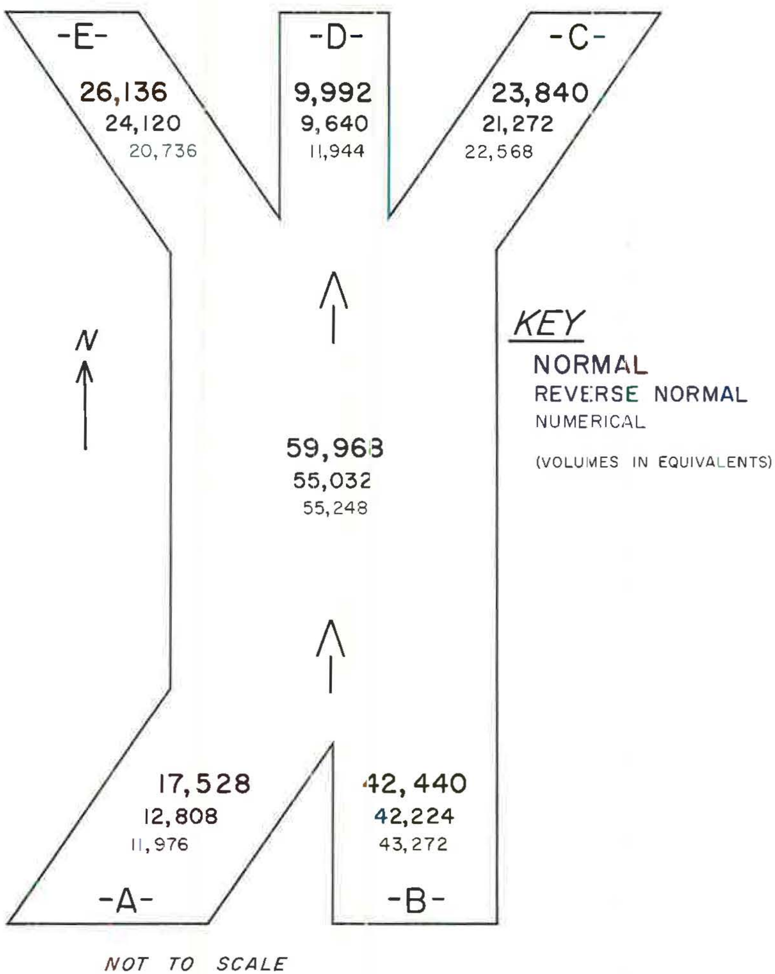

Figure 7. Fort Pitt Bridge: northbound volumes.

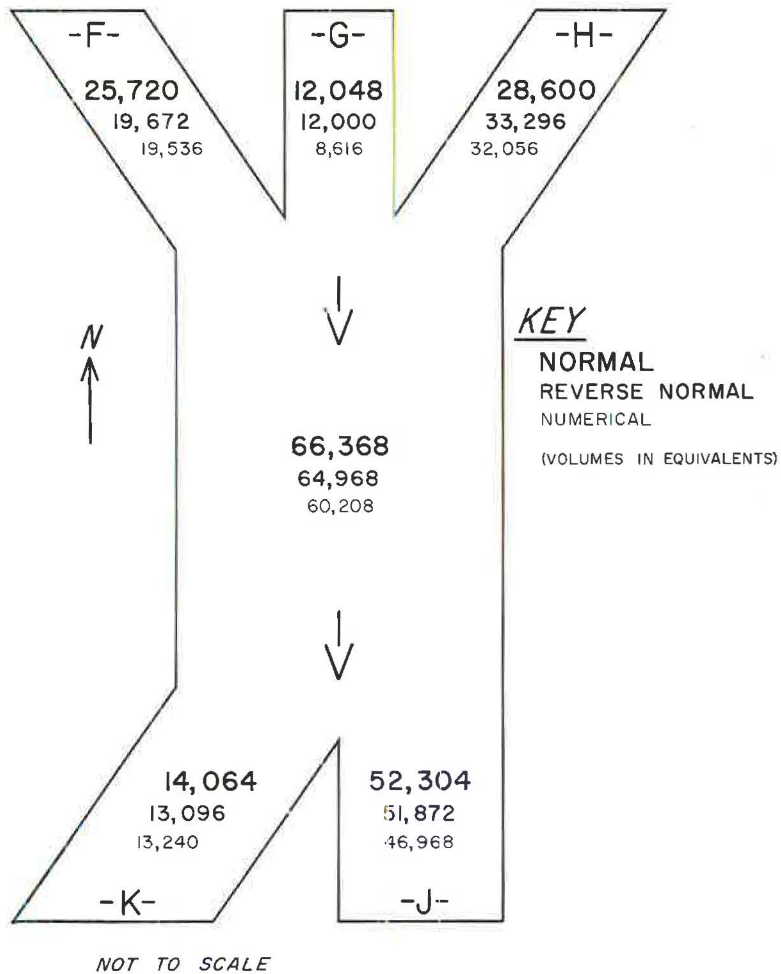

Figure 8. Fort Pitt Bridge: southbound volumes.

TABLE 6

FORT PITT BRIDGE VOLUMES: NORMAL VS REVERSE AND NORMAL VS NUMERICAL

Direction	Link	Normal	Reverse	Normal vs Reverse		Numerical	Normal vs Numerical	
				Change	Percent		Change	Percent
Northbound	A	17,528	12,808	-4,720	-26.8	11,976	-5,552	-31.7
	B	42,440	42,224	- 216	- 0.5	43,272	+ 832	+ 2.0
	FPB	59,968	55,032	-4,936	- 8.2	55,248	-4,720	- 7.9
	C	23,840	21,272	-2,568	-10.8	22,568	-1,272	- 5.3
	D	9,992	9,640	- 352	- 3.5	11,944	+1,952	+19.5
	E	26,136	24,120	-2,016	- 7.7	20,736	-5,400	-20.7
Southbound	F	25,720	19,672	-6,048	-23.5	19,536	-6,184	-24.0
	G	12,048	12,000	- 48	- 0.4	8,616	-3,432	-28.5
	H	28,600	33,296	+4,696	+16.4	32,056	+3,456	+12.1
	FPB	66,368	64,968	-1,400	- 2.1	60,208	-6,160	- 9.3
	J	52,304	51,872	- 432	- 0.8	46,968	-5,336	-10.2
	K	14,064	13,096	- 968	- 6.9	13,240	- 824	- 5.9

between 0.4 and 26.8 percent. When the numerical sequence volumes were compared, three links (B, D, and H) had increased volumes (2, 19.5, and 12.1 percent); all other links had losses between 5.9 and 31.7 percent.

Of primary concern here are the normal vs reverse normal volume changes. (The numerical data are given for comparison only.) The Fort Pitt Bridge (FPB) itself showed small percentage changes in volume. These are not considered to be of great importance and would have at most minor influence on design. However, a few of the ramps (A, F, and H) showed large volume changes that could influence the design of the facility. This is one more indication of the danger of relying too heavily on assigned volumes for design purposes without first investigating the details of the network.

As a special part of the selected link study, an analysis was made of individual zone-to-zone movements using the Fort Pitt Bridge. A full deck of cards of zone-to-zone movements using the Fort Pitt Bridge was obtained as an output from each selected link assignment. The cards from the normal and reverse sequences were matched to find the number and volume of interzonal movements using the bridge on both assignments, as well as the number and volume of those movements using it with only one loading sequence. The same was done for the normal and numerical sequences (Table 7).

Table 7 shows a summary of interzonal movements assigned to the bridge. A matched movement is one whose minimum time path uses the Fort Pitt Bridge with both loading sequences. An unmatched movement is one using the bridge on only one sequence. For example, in the southbound normal vs reverse data, there were 2,831 interzonal movements whose minimum paths used the bridge with both loading sequences, 1,250 others used it with the normal sequence only, and another 1,313 used the bridge with the reverse sequence only. It is interesting that an average of 68 percent of the southbound movements and 75 percent of the northbound movements matched. There is no apparent reason for the differences in percent, but the results show that, despite a drastic loading sequence change (complete reversal), 68 to 75 percent of the same movements use the bridge. This is very important since it shows the basic stability of movements assigned to a link in a freeway system.

Table 7 also summarizes the two components of volumes assigned to the Fort Pitt Bridge. The matched volume represents the sum of all interzonal transfers whose minimum paths used the Fort Pitt Bridge on both the normal and reverse sequences. The unmatched volume represents those trips whose minimum time paths used the bridge on one assignment only. Comparing the southbound normal vs reverse data, the volumes that matched (49,592 and 49,280) represent the volumes of the 2,831 matched interzonal movements (Table 7). The difference between the matched volumes represents the net effect of changes in the calculated volume of each of the 2,831 move-

TABLE 7

ZONE-TO-ZONE MOVEMENTS AND VOLUMES USING FORT PITT BRIDGE

Direction	Assignment		Matched[a]	Unmatched	Total	Percent Matched
			(a) Zone-to-Zone Movements			
Northbound	Normal	85	2,835	1,011	3,846	74
	Reverse	06	2,835	952	3,787	
	Normal	85	2,925	921	3,846	76
	Numerical	07	2,925	523	3,448	
Southbound	Normal	84	2,831	1,250	4,081	69
	Reverse	04	2,831	1,313	4,144	
	Normal	84	2,724	1,357	4,081	67
	Numerical	05	2,724	752	3,476	
			(b) Volumes (vehicle equivalents)			
Northbound	Normal	85	47,680	12,288	59,968	80
	Reverse	06	46,384	8,648	55,032	84
	Normal	85	49,400	10,568	59,968	82
	Numerical	07	45,600	9,648	55,248	83
Southbound	Normal	84	49,592	16,776	66,368	75
	Reverse	04	49,280	15,688	64,968	76
	Normal	84	48,728	17,640	66,368	73
	Numerical	05	46,544	13,664	60,208	77

[a]Those interzonal movements or trips using Fort Pitt Bridge on both assignments of pair.

ments. In addition, there were 16,776 trips using the Fort Pitt Bridge only when the normal sequence was used; another 15,688 used it with the reverse sequence only.

Approximately 75 percent of the southbound volume and 82 percent of the northbound volume matched. (These same percentages were found for the normal-numerical analysis.) It is especially important to recognize that although the total directional volume assigned to the Fort Pitt Bridge with each loading sequence is about the same, a sizable portion of this volume is peculiar to each loading sequence. This means that there are about 16,000 southbound trips and 10,000 northbound trips whose presence is solely a function of loading sequence. Their distribution between the approaches to and exits from the bridge is a key factor in weaving area design, but determining this distribution was beyond the scope of this study. The previous numbers—16,000 and 10,000—may be misleading. They do not represent weaves, but the portion of the total volume that is a function of loading sequence. The actual volume of the weaves is, in all probability, much smaller.

VARIABILITY OF INTERZONAL TRIP DISTRIBUTION

As the basis for trip distribution, the intervening opportunities model uses the ranking of trip ends by travel time at the time of distribution. It was believed, therefore, that the use of an alternate loading sequence in a restrained assignment would change the volume of individual zone-to-zone movements. By use of the selected link subroutine, the volume of each interzonal movement using the Fort Pitt Bridge was obtained as an output from each assignment. Those matching—appearing on both assignments of a pair—were then compared. It would have been desirable to compare all possible zone-to-zone movements in the study area, but the amount of time and work involved was too great.

Table 8 gives the distribution of differences (normal volume minus reverse or numerical volume) for the northbound and southbound movements. The most important finding is that 80 to 85 percent of all movements corresponded exactly, and 97 percent of all movements were within 8 trips of the value from the normal distribution. Approximately 1 percent had differences greater than 16 trips. (It should be remembered

TABLE 8

CUMULATIVE TRIP DIFFERENCE DISTRIBUTION

Diff. (+)	Normal-Reverse			Normal-Numerical		
	No. Z-Z[a]	Cum. No.	Cum. Percent	No. Z-Z[a]	Cum. No.	Cum. Percent
(a) Northbound						
0	2,215	2,215	78.1	2,413	2,413	82.5
8	531	2,746	96.9	431	2,844	97.2
16	52	2,798	98.7	44	2,888	98.7
24	11	2,809	99.1	16	2,904	99.3
32	10	2,819	99.4	4	2,908	99.4
40	3	2,822	99.5	6	2,914	99.6
48	4	2,826	99.7	4	2,918	99.8
56	4	2,830	99.8	—	—	—
64	1	2,831	99.9	1	2,919	99.8
72	—	—	—	—	—	—
80	—	—	—	3	2,922	99.9
88	1	2,832	99.9	—	—	—
112	1	2,833	99.9	—	—	—
144	—	—	—	1	2,923	99.9
192	1	2,834	99.9	1	2,924	99.9
264	1	2,835	100.0	—	—	—
312	—	—	—	1	2,925	100.0
(b) Southbound						
0	2,348	2,348	82.9	2,316	2,316	85.0
8	434	2,782	98.3	362	2,678	98.3
16	26	2,806	99.1	15	2,693	98.8
24	6	2,812	99.3	11	2,704	99.2
32	6	2,818	99.5	3	2,707	99.3
40	2	2,820	99.6	3	2,710	99.4
48	3	2,823	99.7	1	2,711	99.5
56	2	2,825	99.8	5	2,716	99.7
64	—	—	—	2	2,718	99.7
72	—	—	—	—	—	—
80	2	2,827	99.9	—	—	—
88	—	—	—	1	2,719	99.8
96	1	2,828	99.9	—	—	—
104	1	2,829	99.9	1	2,720	99.8
120	—	—	—	1	2,721	99.9
168	—	—	—	1	2,722	99.9
184	1	2,830	99.9	1	2,723	99.9
192	1	2,831	100.0	—	—	—
232	—	—	—	1	2,724	99.9
392	—	—	—	1	2,725	100.0

[a]Zone-to-zone movements.

that all interzonal transfers were rounded to the octal digit.) This is a much better correspondence than was expected and means that the majority of interzonal trip transfers using the bridge are affected very little by variations in loading sequences. A few movements showed differences of more than 56 trips, but these constitute less than 0.2 percent of the total movements.

This indicates that 99 percent of the interzonal movements using the Fort Pitt Bridge are only very slightly affected by the use of alternate loading sequences when the trip distribution is determined by the intervening opportunities model. It is believed that a similar ratio would be found if all possible interzonal transfers were compared.

TABLE 9

COMPARISON OF INTERZONAL MOVEMENTS

Normal Vol.	Reverse Range[a]		Numerical Range[a]	
0	0- 8	(1,742/1,929)	0- 24	(1,756/1,790)
8	0- 48	(1,750/2,008)	0- 48	(1,731/1,969)
16	0- 56	(525/694)	0- 24	(580/751)
24	8-120	(252/367)	8- 80	(299/412)
32	16- 64	(107/177)	0- 72	(134/203)
40	8- 96	(65/124)	24- 56	(89/143)
48	24- 64	(40/79)	16-136	(45/83)
56	40- 80	(24/48)	32- 96	(27/56)
64	16- 96	(8/32)	48- 80	(15/39)
72	48-120	(12/38)	8-256	(12/40)
80	16-160	(7/30)	24-104	(10/31)
88	56-112	(4/13)	48-112	(6/14)
96	72-176	(4/16)	32-128	(2/15)
104	88-128	(5/15)	24-128	(4/15
112	80-144	(3/9)	104-216	(2/9)
120	16-168	(0/11)	88-168	(3/11)
128	112-152	(0/9)	112-144	(2/10)
136	120-152	(1/5)	120-144	(1/5)
144	112-192	(1/11)	152-208	(1/6)
152	120-152	(3/7)	104-160	(3/6)
160	144-176	(3/8)	136-184	(1/8)
168	160-184	(1/3)	88-192	(0/3)
176	144-200	(3/7)	176-232	(2/6)
184	144-208	(1/6)	16-192	(2/6)
192	192-240	(1/4)	168-232	(0/4)
200	152-232	(0/4)	176-200	(1/3)
208	96-200	(0/2)	64-208	(1/2)
224	232	(0/1)	232	(0/1)
280	272	(0/1)	264	(0/1)
304	112-248	(0/3)	72-336	(0/3)
320	264	(0/1)	280	(0/1)
328	240	(0/1)	248	(0/1)
392	128	(0/1)	80	(0/1)
464	272	(0/1)	344	(0/1)
480	480	(1/1)	88	(0/1)

[a] (X/Y):
X = number of matching interzonal movements with a reverse (or numerical) volume equal to normal volume, and
Y = total number of matching interzonal movements with normal volume shown.

The volume of each zone-to-zone movement was studied using the Fort Pitt Bridge as compared with its volume from the normal loading sequence. The results of the analysis are given in Table 9. These data are based on a volume grouping of the matched zone-to-zone movements obtained with the normal loading sequence. For example, with a normal volume of 24, when the reverse sequence was used, the movements ranged between 8 and 120 equivalents. Similarly, the corresponding movements ranged between 8 and 80 equivalents when the numerical sequence was used.

The data show that the smaller a given interzonal movement is, the more likely it is that the volume of the movement will not be changed by the use of an alternate loading sequence. Whether or not this would hold true for even larger movements is a matter of speculation, but there is some indication that the trend would continue. The sample of movements greater than about 56 is too small to make a more positive statement.

In summary, the selected link study has shown that although a link's volume may remain almost unchanged when alternate loading sequences are used, the movements comprising that volume may not be the same ones. This is especially important where complex weaving maneuvers are encountered, as in multiple-approach and multiple-exit bridges and closely spaced interchanges.

CONCLUSIONS

What does all of this say about the effects of alternate loading sequences when used with the Chicago trip distribution and assignment model?

A brief review of the study is in order. Three assignments were run using different loading sequences: normal, reverse normal, and numerical. All other factors were held constant: trip inputs, the network, and the long and short L's. All results were compared with those from the normal loading sequence. Several conclusions may be drawn from these results.

1. The use of a reasonable alternate loading sequence has a very small effect on the total number of VMT in the study area. As expected, the reverse normal sequence gave a closer estimate (to the value from the normal sequence) than did the numerical sequence, but both were close to the base (normal) value.
2. When the amounts of travel as determined by alternate loading sequences for smaller units of area—rings, zones, sectors, or districts—are compared, the effects of alternate loading sequences are more pronounced; the smaller the unit of area, the greater the difference can be. Again, the reverse loading sequence gave results that corresponded more closely to those from the normal sequence than did the numerical sequence.
3. The volumes on individual links are subject to fluctuations when alternate loading sequences are used. The higher the volume assigned to a link, however, the less likely it is to change greatly when other loading sequences are used.
4. Because of the large fluctuations that can occur in link volumes when the loading sequence is changed, extreme care must be taken when using the assignment data for work with arterials. Perhaps corridor analysis should be used. However, freeway volumes are only slightly influenced by changes in loading sequences, and they can be used for design much more reliably. It should be remembered, though, that the volume on a freeway link is a function of the freeway network. That volume should be used only in conjunction with the whole network. Using a freeway link volume with a different network can lead to gross errors.
5. Although the volume of a given interzonal movement may vary from one loading sequence to another, it is estimated that in only 1 percent of the cases will this variation be more than 16 trips.

In setting up a network, there are two important points to be remembered. First, never connect a loading node directly to a ramp or freeway link; in fact, loading nodes should be offset from the arterial system by "local links." Second, when there is any doubt about the inclusion of a link in the network, put it in.

In summary, the use of alternate loading sequences has little effect on areawide totals for travel estimates. However, when smaller units—zones, districts, rings, sectors, links, or specific movements—are considered, the differences can be large and can influence both design and economic analyses.

SOME FURTHER THOUGHTS

Throughout this report the phrase "ideal loading sequence" has been avoided, and for good reason. What is an ideal loading sequence? Is it a mathematically random loading sequence? Probably not. Is it one that loads long trips first and short trips last? Or the reverse? Does it load CBD trips first? Does it produce the closest estimate of VMT, or the closest estimate of volumes on existing freeway links? Or does it load in increments?

For areawide totals, the use of reasonable alternate loading sequences has little effect on the results. But link volumes are susceptible to the influence of loading sequences. Should full confidence be placed in the assigned volume from one sequence? Would a better estimate of the future link volume be an average link volume, derived from two or more assignments using different loading sequences?

These are only a few of the questions that should be answered in future studies of the effects of loading sequences on assignment results.

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