A Comparative Description of a Capacity-Restrained Traffic Assignment

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• THIS PAPER specifically presents a step-by-step case history of a "capacity-restrained traffic assignment" and compares it to three other kinds of assignment that are in use today. It has also the more general purpose of starting to move the capacity-restraint method out of the research institutes and into the State highway departments and local planning offices where it will do the most good. Traffic assignment in general is the technique used to determine in advance how well a proposed highway system will work. Its components are (a) a table giving traffic volumes between traffic analysis zones in some future year, (b) a highway network proposed for the same year, and (c) a program for routing all the interzonal trips through the network and totaling the volume "assigned" to each link. Testing alternate proposed systems in this way, it is possible to produce one that will function without undue traffic congestion.

Doing away with traffic congestion requires a number of steps in addition to traffic assignment, including steps in the planning and design areas, as well as all those in the areas of finance, construction, maintenance, and operation. However, without reliable traffic assignments it is not possible to pursue any transportation plan with confidence that it will succeed.

Before the introduction of traffic assignment, highway planning tended to proceed on the basis of estimates of percentage increases in the loads to be carried by individual existing roads. This approach has been made rather obsolete by changes such as the growing recognition of individual highways as parts of highly interdependent systems, and by the large-scale additions of new facilities to existing systems—particularly freeways. The start of highway-system planning, at least within urban areas, might be dated from the introduction of the origin and destination (O-D) survey. This kind of research produces "trip tables" which indicate the interzonal trips people make independent of the routes they select. Once there is a trip table, there can be traffic assignment.

A typical situation today might include a town which has had an O-D survey and has projected its trip table to 1980. On the basis of the projection it is concluded that two or more freeways will be needed, and a total highway system is proposed for construction by 1980. At this point at least three important questions can be raised: (a) Does the proposed network provide sufficient highway capacity where it is needed, so as to minimize congestion? (b) Does it provide no more than the minimum amount of necessary highway capacity to be paid for from the public purse? (c) How is the network to be designed in terms of lanes and turning movements? These are questions that can be answered by traffic assignments.

This hypothetical town can consider four different types of assignment. It can trace a path through the network by hand for each interzonal connection, and assign the appropriate volumes to each link for each path. This "hand-trace assignment" could take a great deal of time, however, and if an electronic computer is available, its use is likely to be considered.

The major planning problem is posed by new facilities—especially freeways--and for some years when computers were new to this field, their contribution was limited to assigning parts of interzonal volumes to freeways alone. The computer "freeway assignment" was a giant stride forward, especially in large cities where hand tracing was almost prohibitively time consuming, but it left unanswered the important questions

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about the adjustment of the other parts of the network to the new facilities.

Only in recent years has it become possible to program a computer to trace paths through an entire major street system. The products of the simplest of such programs are called "desire assignments" because every interzonal volume is assigned to the best path that could be desired, regardless of the capacities of the streets. Such an assignment was made in Detroit for 1958, and it was found that more than 300,000 vehicles desired to use some individual links of the freeway network. This was an interesting statistic, but not very useful for planning purposes because it was not considered practical to try to provide that much capacity in a single facility.

The development of "capacity-restrained assignment" is a very recent achievement but its advantages are so obvious that future assignments may be expected to be of this type just as quickly as computers with their programs, and the necessary know-how, can become available to highway planners. Once capacity-restrained assignment is in general use, that hypothetical town is not likely to choose hand-trace, freeway, or desire assignments. Instead, there is likely to be general agreement on the following six capacity-restrained assignment steps as constituting good highway system planning from the assignment point of view (1). For the most part these steps are applicable and desirable regardless of the particular assignment technique adopted.

First, present-day volumes are assigned to the present-day street network, and the results compared to traffic counts. This serves to validate the trip table and the O-D survey sample from which it is derived.

Second, at least two alternative future land-use plans are developed, perhaps one assuming a continuation of present trends and the other assuming some reasonable planned improvements. Each land use plan will produce a different future trip table, and both of them are assigned to the present major-street network to provide a starting point for the planning of future networks.

Third, the future-trip table based on the first land use plan is assigned to several alternative proposed future networks until a good one can be demonstrated.

Fourth, alternative networks are tested with the trip table based on the second land use plan until a final proposed network can be selected.

Fifth, morning and afternoon peak-hour volumes are assigned to the selected network as an aid to its geometric design.

Finally, five-year step forecasts between the present year and the future planning year are assigned as an aid to the determination of priorities for construction. Also, five years pass fairly quickly and these five-year interval assignments allow a periodic checking of forecasts against the actual situation.

These six steps call for 15 or 20 traffic assignments, which means considerable work and cost. The time and money for such research and planning are not a large part of the total costs of well-planned highway construction, however, and are actually small when compared to the high costs of poorly-planned construction with its possible waste and continuing traffic congestion. This report is intended to illustrate how useful a capacity-restrained assignment can be to good highway planning, as well as to demonstrate how it works.

ASSIGNMENT BACKGROUND

The Program

The essence of capacity-restraint assignment is a program for an electronic computer. Computers have proved themselves capable of performing extremely intricate tasks with great speed and accuracy, and it is some times overlooked that they can do absolutely nothing except what they are instructed to do. A set of computer instructions is a "program," and the development of a program for the performance of something as intricate as traffic assignment is a long, difficult, and costly job.

The one whose workings are described in this paper was developed by the Detroit Area Traffic Study and the Computing Center at Wayne State University. The original objective was to program a high-speed computer to assign traffic to the major streets of Detroit, but two interim objectives have developed. One is to prepare the IBM 650 to assign traffic to a 240-intersection network, which is probably large enough to handle

TABLE 1

TYPICAL SPEEDS AND CAPACITIES[a] ON FOUR-LANE HIGHWAYS

Area	Speed (mph)			Capacity (thousands)		
	Arterial		Freeway	Arterial		Freeway
	Standard	Major		Standard	Major	
CBD	10	20	45	22	27	78
City	15	25	50	16	19	56
Suburbs	20	30	55	12	15	42

[a]24-hr average weekday; practical, not ultimate.

all Michigan cities except Detroit. The other is to specify every step of the capacity-restrained assignment procedure in an operating manual that will allow the Michigan State Highway Department to perform such assignments on a routine basis.

At its present stage of development, this method includes the following steps. First, every link in the network to be tested is classified as to its type, the area in which it is located, and its pavement width. A distinction is made between three types: freeways, major arterials (such as divided highways), and standard arterials; and three areas: the central business district (CBD), the rest of the city, and the suburbs.

Next, a capacity can be given every link by looking it up in a table on the basis of its type, area, width, and kind of intersecting streets (2). A typical speed can be given each link on the basis of its type and area. Table 1 gives typical speeds and typical capacities for four-lane streets. These generalized measures should be replaced by more exact measures when they are available.

Then, the length of each link is measured by the computer on the basis of a coordinate-coding of each intersection. From its length and speed, the computer determines a travel time for each link, and this time is the "value" (V) of each link which the computer uses to determine paths through the network. With this information and a trip table, the actual assignment can begin.

The assignment proceeds in a series of "passes" over the network. On each pass the computer determines the shortest time path between every pair of intersections which has been identified as the origin and destination of a trip. On the first pass, travel times are determined on the basis of typical speeds and all volumes are assigned to their quickest paths, thus providing a "desire assignment." At the end of the first pass, the computer determines the ratio (R) between assigned volume and capacity for every link, and this quantity is used to compute a new travel time on each link according to the conditions of congestion pictured by the desire assignment. Where R is high, speed is reduced below typical speeds and travel time is increased; where R is low, speed is increased above typical speeds and travel time is reduced.

The formula according to which these increases and decreases are determined is the keystone of the capacity-restrained program.

$$V_i = e^{(R_i - 1)} V_o \tag{1}$$

in which

V_i = travel time on a link for a given pass;
e = 2.71828;
R_i = ratio of averaged assigned volumes (from all preceding passes) to capacity; and
V_o = original (typical) travel time on link.

The formula was derived both by mathematical logic and by trial-and-error experimentation (3).

For the second pass these travel times reflecting congestion on original best paths are used in the computation of a second set of paths between every pair of origin-destination intersections. Each interzonal volume is then divided evenly between the two paths that have been traced for that trip, and the averaged volumes are used to compute new values of R and another set of travel times. For the third pass the same procedure is followed, and such passes can be repeated, dividing interzonal volumes over more and more paths, until capacity-adjusted speeds, on the average, come to approximate typical speeds. The two measures of speed will converge as assigned volumes converge on capacities. This particular type of "convergence" will happen quickly when the network provides sufficient capacity exactly in the places where it is needed, and will never happen completely if the network does not contain sufficient capacity for the volumes assigned to it.

This approach was tested by using it to assign a 1950 trip table to the 1950 arterial streets of Flint, Mich., and comparing the assigned volumes to traffic counts (4). It also has been the approach followed in the assignment to a proposed 1980 network for Flint.

Volumes and Network

The network proposed in Flint for 1980 was selected not because it was suspected of being poor and in need of testing, but because it was known to be the well-planned product of lengthy research by the City of Flint, by the city-planning firm of Ladislas Segoe and Associates, and by the State Highway Department. Douglas Carroll helped conduct one of the early O-D surveys in Flint in 1950, and further research in 1960 had forecasted its trip table to 1980 (5). Being able to rely on network and volumes was a great help in this continued experimentation with the assignment program: it was expected to be a "good" network, as defined later.

A part of the network shown in Figure 1 is the major street system of Flint in 1950. When a "desire assignment" of 1980 traffic volumes was made to this network, about two-thirds of its links were loaded beyond their capacity. Because these overloaded links tended to be the high-capacity ones, it is obvious that no amount of capacity restraint and the tracing of alternate paths could bring about "convergence" with capacity for these volumes on this network. In fact, the volumes were so far beyond the capacity of the system that one-third of the links were loaded to more than twice their capacity, and one out of every ten links was assigned a volume more than five times its capacity.

Figure 1 also shows the additional facilities proposed for 1980 Flint, and Figure 2 shows the types of facilities proposed. The major addition is a system of three freeways: an east-west one running just south of the CBD, a north-south one along the western edge of the metropolitan area, and a branch of the north-south one passing through the city just to the east of the CBD and rejoining the other at the northwestern edge (top of map). The freeways along two sides of the CBD carry only "through" traffic, as all turning movements to and from the CBD are carried by service drives connecting with the freeways only at the outer corners of the downtown section.

Flint is astride a major north-south route through Michigan, and traditionally its two major arterials have been Dort Highway which runs north-to-south on the eastern edge of the city, and Saginaw Avenue which is shown in Figure 2 as branching off from Dort on the south to run through the CBD, and rejoining Dort on the north. Other major arterials reach into the four quarters of the area, except to the far northwest, and are joined together by a grid of standard arterial streets.

The detailed design of this network is not complete, but tentative widths were obtained for every part of it. All the freeways sections were treated as if they were of four-lane width, and many of the existing arterials streets were treated as if they had been considerably widened from their width as of today. This, then is the network expected to be a "good" one, and in general it was not disappointing. Of course, to a large extent, its satisfactory nature was a function of the way in which "good" was defined.

Figure 1. 1950 and 1980 networks.

Figure 2. 1980 network by type.

A "Good" Network

A good highway system is one that provides sufficient capacity where it is needed to avoid undue congestion, without providing unneeded capacity. The idea of "sufficient capacity" has a relatively clear meaning, but the idea of capacity "where it is needed" is a little harder to define in practice. In American cities it is common for major corridors of vehicular movement to contain more vehicles than can be carried on a single facility, so that it is unavoidable that some vehicles will travel on paths through street systems that are different from the paths composed of the most direct facilities between their origins and destinations. On the other hand, it seems unlikely that more than two or three parallel facilities would be required for any such corridor in order to avoid forcing any trip to take an extremely indirect path. One exception to this is that the unusually long trip through a modern city should use a freeway, so long as the cost of the possible indirectness of the freeway path is offset by a savings in travel time.

These general considerations about what constitutes a good highway system can be stated in the form of a four-part operational definition of "good" in terms of the characteristics of a capacity-restrained traffic assignment. A good highway system allows the following:

1. "Convergence" of assigned volumes and capacity in three or four assignment passes, because two or three paths as alternatives to the "best" path should handle practically all trip volumes.
2. Total vehicle-miles of driving through the system which are not greatly in excess of the mileage required for all trips to take their "best" paths, otherwise capacity has not been provided where it is needed.
3. Total vehicle-hours of driving through the system which are not greatly in excess of the hours required for all trips to take their "best" paths at typical speeds, which is the same as saying that congestion-adjusted speeds should converge to be approximately the same as typical speeds in three or four assignment passes.
4. Freeways should tend to carry the longer rather than the shorter trips, because the costs of freeways are only justified by the benefits of removing "through" traffic from standard arterial streets.

The indefinite quality of phrases like "not greatly in excess of" is not the handicap it appears to be. The usual purpose of traffic assignment is to compare alternate networks, although that is not the case for the Flint assignment discussed here. When alternate networks are tested, "excess" vehicle-miles or vehicle-hours can be simply defined as the additional miles or hours required to travel through one network as compared to another. Each of these general principles can be illustrated in terms of the actual workings of the Flint assignment.

THE ASSIGNMENT

Convergence

Figure 3 shows the assigned volume on each link of the Flint 1980 network, expressed as a percentage of the capacity of that link. This is a picture of the situation at the conclusion of the first pass or "desire" assignment. At this point, all volumes have been assigned to the path between their particular origin and destination which can be traveled in the shortest amount of time at typical speeds. This kind of path is said to be the "best" path. The lightest links on this map were included in no best paths and therefore have zero volumes.

In connection with the next darker class of links, it should be noted that no traffic assignment assigns to a network every vehicular trip reported during an O-D survey. Those trips having both their origin and destination within a single traffic analysis zone cannot be assigned. Such intrazonal trips have to be considered "local traffic" and be kept off the arterial street system. This is not entirely realistic because local trips can make up a large proportion of the traffic on major streets in the CBD, and perhaps 20 percent of the traffic on other arterial streets in the city. The next darker links in

Figure 3. Volumes as percent of capacity, first pass.

ASSIGNED VOLUMES AS PERCENTAGES OF CAPACITY

0% 1-74% 75-124% 125-199% 200% or More

Figure 4. Volumes as percent of capacity, second pass.

Figure 3 have been assigned a volume at least 25 percent below capacity, and therefore a volume likely to move without congestion even when local traffic is taken into consideration.

The next class of links have been assigned a volume within 25 percent of their estimated capacity, and those in the class after that are definitely congested, having been assigned a volume between 125 and 199 percent of capacity. Links in black are heavily congested, having been assigned more than twice their capacity.

On this first pass, every link but one in the 25-link freeway system is loaded to capacity, and almost one-half the freeway links are congested, two of them heavily. Of the other heavily congested links in the system, about three-quarters are funneling traffic onto or off the freeways. A fact to be especially noted, however, and one that illustrates clearly the danger in using desire-assigned volumes for design purposes, is that the majority of these congested links are adjacent and parallel to underassigned links. This means that, were this network in actual operation, its links would not carry volumes like those assigned on this first pass. Furthermore, it might operate much more effectively than the number of congested links suggest because many vehicles could avoid congestion by taking paths along the underassigned adjacent and parallel links, which probably would be only slightly less direct than their "best" paths.

If the first pass is called a "desire assignment," then the second pass might be called a "rush-hour assignment" in that its paths have been traced through a network in which popular links have had their speeds slowed to the minimum. It can be considered the "rush-hour pass" only in the limited sense that, for the average trip, the path traced at this point is likely to be the one that deviates the farthest from the "best" path, and this is analogous to the real situation in which drivers are most likely during rush hours to seek the suggested alternatives to their own choices of best paths.

During the second pass, volumes are divided evenly between the two paths that have been traced for each trip. The averaged volumes on each link are expressed as percentages of capacity, with results in Flint that are shown in Figure 4. Here the distribution of heavily congested links is considerably different from that at the conclusion of the first pass. Only two links originally assigned more than twice their capacity are still in that class after the second pass. These two links are parts of standard arterial streets in the suburbs carrying traffic to and from freeway ramps; they were assigned more than four times their capacity on the first pass. Therefore, they are left with at least a double load from their averaged assigned volumes even if they were zero-volume links on the second pass. In addition, 21 links which were not heavily congested after the first pass are heavily congested after the second, although they have been assigned only one-half the volume of any particular trip.

On the whole, there are more links assigned volumes near their capacity after the second pass than after the first, so that it can be said that convergence has begun. On the other hand, a few links that were congested after the first pass are underloaded after the second, and the opposite is also true. The third and subsequent passes are "balancing assignments," then, and convergence should proceed rapidly. Figure 5 shows the situation at the conclusion of the third pass. Now there are no zero-volume links, and the number of heavily congested links has been reduced by two-thirds.

It is after the third pass, however, that there is the first hint of a few trouble spots in the network, in the form of congested links that are not paralleled by underassigned links. After the fourth pass, a considerable amount of convergence has taken place (Fig. 6). A number of links continue to be congested, however, and four links are loaded to more than twice their capacity at this point. Again, they are links providing access to the freeways, specifically to the branch north-south freeway passing through the city.

At this point there was an inclination to consider the assignment complete, and to view the remaining degree of lack of convergence as an indication of points in the proposed network that were in need of change. However, a fifth pass was made to check this conclusion, with the results shown in Figure 7. There continue to be four heavily congested links, and they continue to be links providing access to the branch north-south freeway.

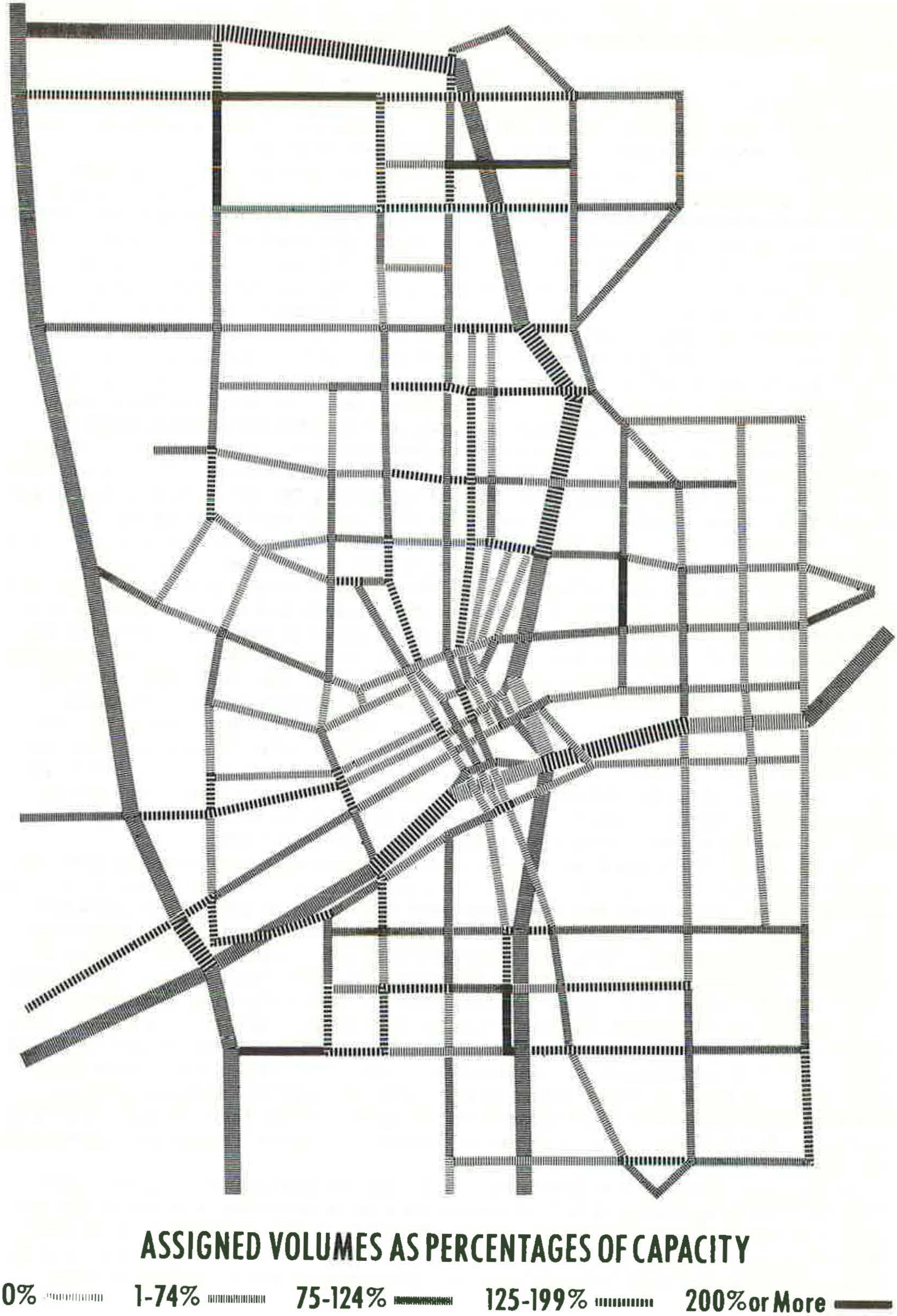

Figure 5. Volumes as percent of capacity, third pass.

Figure 6. Volumes as percent of capacity, fourth pass.

Figure 7. Volumes as percent of capacity, fifth pass.

TABLE 2

LINKS BY ASSIGNED VOLUME AS A PERCENTAGE OF CAPACITY AT BEGINNING OF CAPACITY RESTRAINT

Capacity (%)	First Pass	Second Pass					
		0%	1-24%	25-74%	75-124%	125-199%	200% +
0	21	2	3	2	3	3	8
1-24	66	0	11	27	13	11	4
25-74	85	0	1	42	29	8	5
75-124	60	0	0	36	16	6	2
125-199	44	0	0	8	26	8	2
200+	21	0	0	0	10	9	2
Total	297	2	15	115	97	45	23

One important question is whether the balancing process is continuing with different links being congested on different passes, or whether links that are congested on one pass continue to be congested on the next. This question is answered in Tables 2 and 3. Table 2 shows that a number of originially underassigned links are overassigned after the second pass. Also, 8 links originally overassigned were underassigned after the second pass. Table 3 shows that nearly all the links that were congested after the fourth pass had also been congested after the third.

Vehicle-Miles

At this point it could be concluded that, in terms of speed of convergence, this network needs certain revisions in street widths before its design is finalized, but that it is generally a good network. There are other criteria, however, and one of them is given in Table 4—vehicle-miles. This table shows that the 930,000 vehicles assigned to the network would travel a total of 3,928,000 vehicle-miles on their average weekday if all of them could travel over their "best" paths, for an average of 4.22 miles per vehicle trip.

The paths traced for the second pass are longer, however, requiring nearer 4,000,000 vehicle-miles of travel. When volumes are averaged over the first two sets of paths there are 31,000 additional miles of travel compared to the desire assignment. Paths

TABLE 3

LINKS BY ASSIGNED VOLUME AS A PERCENTAGE OF CAPACITY AT CONCLUSION OF CAPACITY RESTRAINT

Capacity (%)	Third Pass	Fourth Pass					
		0%	1-24%	25-74%	75-124%	125-199%	200%+
0	0	0	0	0	0	0	0
1-24	8	0	6	2	0	0	0
25-74	112	0	2	99	11	0	0
75-124	111	0	0	15	91	5	0
125-199	59	0	0	0	17	39	3
200+	7	0	0	0	0	6	1
Total	297	0	8	116	119	50	4

TABLE 4

VEHICLE-MILES

Type	Vehicle-Miles (thousands)				
	1st Pass	2nd Pass	3rd Pass	4th Pass	5th Pass
Total	3,928	3,959	3,997	3,988	3,975
Avg. trip-miles	4.22	4.26	4.30	4.29	4.27
Freeways	1,983	1,339	1,512	1,581	1,594
Hi-types	1,171	1,255	1,232	1,266	1,277
Lo-types	774	1,365	1,253	1,141	1,104
CBD	603	568	612	603	589
City	2,103	2,188	2,224	2,227	2,216
Suburbs	1,222	1,203	1,161	1,158	1,170

of the third pass are longer still, but there is some reduction on the fourth pass.

If the four passes are considered to be the complete assignment, then the effort to avoid congestion in this particular network requires some 60,000 additional vehicle-miles of travel on an average weekday, compared to the mileage required if all trips could travel their "best" paths. Whether this is excessive depends on whether the additional mileage could be less on an alternative network. Averaged over all the 930,000 vehicular trips, this appears to be a minimal increment.

Due to capacity restraint about 400,000 fewer miles are assigned to the freeways than would be the case if all vehicles took their "best" paths. About 460,000 more miles are required on other arterial streets: 100,000 on major arterials (divided highways, one-way streets, etc.), and 360,000 on standard arterials. In Flint, the additional miles are driven in the general city, rather than in the CBD or the suburbs.

In terms of vehicle-miles, then, this appears to be a generally "good" network at supplying capacity where it is needed. Its degree of goodness is measured by the difference between 4.22 vehicle-miles driven on the average interzonal trip over its "best" path, and 4.29 vehicle-miles for the average trip after the capacity-restraint adjustments.

TABLE 5

VEHICLE-HOURS AT TYPICAL SPEEDS

Type	Vehicle -Hours (thousands)				
	1st Pass	2nd Pass	3rd Pass	4th Pass	5th Pass
Total	135	166	161	156	154
Avg. trip-minutes	8.7	10.7	10.4	10.1	10.0
Freeways	39	26	30	31	31
Hi-types	48	52	51	52	53
Lo-types	47	88	80	73	70
CBD	21	27	27	26	25
City	79	101	97	94	93
Suburbs	35	38	37	36	36

TABLE 6

VEHICLE-HOURS AT CONGESTION-ADJUSTED SPEEDS

Type	Vehicle-Hours (thousands)				
	1st Pass	2nd Pass	3rd Pass	4th Pass	5th Pass
Total	388	311	186	164	155
Avg. trip-minutes	25.0	20.1	12.0	10.6	10.0
Freeways	71	24	29	32	32
Hi-types	56	51	46	47	48
Lo-types	261	236	111	85	75
CBD	19	34	24	20	19
City	145	175	103	93	88
Suburbs	224	102	59	51	48

Vehicle Hours and Speed

If all 930,000 vehicular trips are considered as being driven at typical speeds on every pass, regardless of congestion, the vehicular hours of driving time required on this network are as given in Table 5. On their "best" paths, vehicles would drive a total of 135,000 vehicle-hours on an average weekday, and the average trip would take a little less than 9 minutes. Capacity restraint adds about 21,000 vehicle-hours, however, and brings the average trip to about 10 minutes. This is not a realistic picture, of course, because congestion on "best" paths would reduce speeds below the typical.

Table 6 gives the influence of congestion on vehicle-hours. They are increased so much on the "desire" assignment that the average trip takes 25 minutes instead of 9. Nothing like this could occur in actuality, however, because all trips could not possibly be contained in their "best" paths. By the end of the fourth pass, a major degree of convergence has taken place, and the average trip in congestion-adjusted hours takes only about ½ minute longer than in unadjusted hours. The convergence is even greater at the conclusion of the experimental fifth pass but, as noted earlier, the fourth pass can be considered to end the assignment because the problems remaining at its conclusion are still there after the fifth pass.

This is particularly clear when speeds are considered, as in Table 7, where vehicle-miles have been divided by the two measures of vehicle-hours. At typical speeds, all these 930,000 vehicle-trips on an average weekday could be made at an average speed of 29 mph. The effect of congestion as measured by Eq. 1 is to reduce this average speed to 10 mph if all vehicles were to use their "best" paths.

On each successive pass, the congestion-adjusted speed comes closer to the typical speed for the same traffic distribution, and by the end of the fourth pass they are nearly the same. The convergence of average speeds for all trips is complete after the fifth pass, but after both the fourth and fifth pass it is clear that congestion is continuing on some standard arterial streets in the suburbs. Like the convergence of assigned volumes and capacity, then, this convergence of typical speeds and congestion-adjusted speeds suggests a generally good proposed network, but also indicates that certain types of streets in certain areas are in need of design revision.

Paths

The fourth criterion of a "good" network is that its freeways should tend to carry the longer trips. In the trip table assigned here, the 930,000 vehicle-trips are divided over 3,980 specific interzonal exchanges, and a path must be computed through the network for each of these 3,980 interzonal trips. Table 8 gives the number of such paths using the freeways, and the number not using them, by path length in miles. The gen-

TABLE 7

TYPICAL SPEEDS AND CONGESTION-ADJUSTED SPEEDS

Type	Speed (mph)									
	1st Pass		2nd Pass		3rd Pass		4th Pass		5th Pass	
	Typical	Adjusted	Typical	Adjusted	Typical	Adjusted	Typical	Adjusted	Typical	Adjusted
Total	29	10	24	13	25	21	26	24	26	26
Freeways	51	28	52	56	50	52	51	49	51	50
Hi-types	24	21	24	25	24	27	24	27	24	27
Lo-types	17	3	16	6	16	11	16	13	16	15
CBD	29	32	21	17	23	28	23	30	24	31
City	27	15	22	13	23	22	24	24	24	25
Suburbs	35	5	32	12	31	20	32	23	33	24

eral conclusion to be drawn is that the vast majority of short trips do not use the freeways, whereas the vast majority of long trips do.

There is another important point to be made about paths—the success of a traffic assignment in predicting actual traffic counts depends on two things: (a) the validity of the assigned trip table and (b) the realism of the selected paths. All other factors such as the character of the capacity-restraint formula, the accuracy of the estimates of capacity and speed, and the quality of classifications of street by type and area are of importance only as they lead to the computer simulation of actual driver behavior in the selection of paths.

A sample of paths was selected for examination from the tape record for the present assignment passes, although this operation is not a necessary part of capacity-restrained traffic assignment. The most typical situation which was found (Fig. 8) shows the paths traced on each pass between the external station at Saginaw and Dort on the south and the same two highways on the north. For its "best" path (from the desire assignment), the trip has been routed up Saginaw to the first street giving access to the branch north-south freeway, and thence to the freeway itself. It travels up the freeway to the northernmost ramp and then takes one link of Saginaw to its destination.

The so-called "rush-hour" path (second pass) avoids the congested freeway and

TABLE 8

LENGTH[a] OF FREEWAY AND NON-FREEWAY PATHS BY PASS

Miles	First Pass		Second Pass		Fourth Pass	
	Freeway	Non-Freeway	Freeway	Non-Freeway	Freeway	Non-Freeway
0-3	300	1,520	80	1,660	230	1,560
4-6	880	410	360	1,130	670	680
7-9	610	30	290	320	530	100
10+	230	0	100	40	200	10
Total	2,020	1,960	830	3,150	1,630	2,350

[a]Rounded to tens.

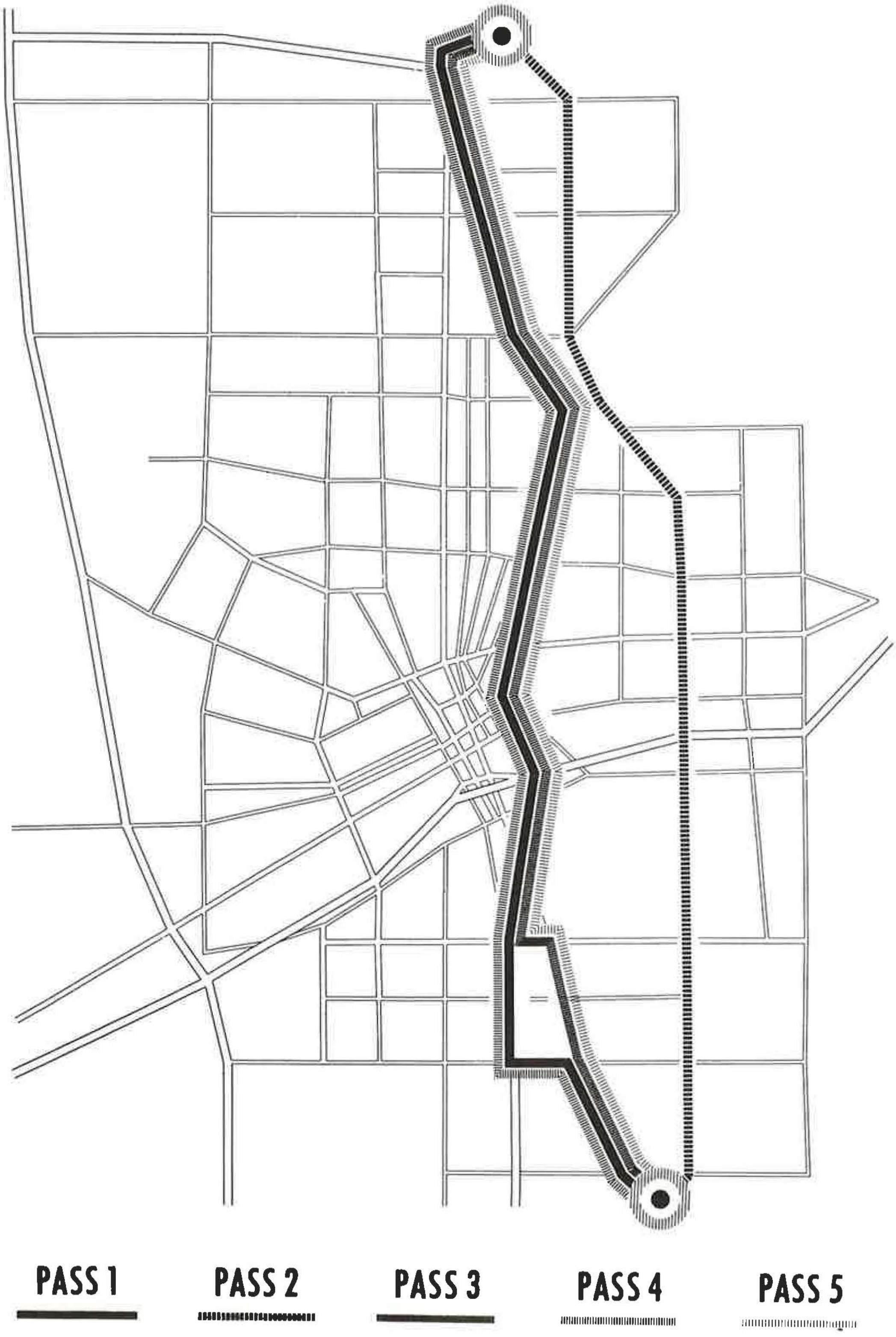

Figure 8. Set of paths A.

Figure 9. Set of paths B.

travels up Dort Highway all the way from origin to destination. When all volumes have been divided between their first two paths, congestion-adjusted speeds on the freeway are high enough again to bring the path back to it, with the exception of one link. This is shown by the third path, which indicates that the southernmost freeway link in the "best" path has remained congested enough, and the alternative is good enough, so that the path continues up Saginaw to the second street giving access to the freeway. From the point of entering the freeway, this third path is the same as the first path. The fourth pass is exactly like the first, and the fifth pass is exactly like the third.

Although this rapid convergence is typical of many parts of the network, another situation is shown in Figure 9. These paths connect two intersections in the northwest section where there is insufficient capacity in the network. No two of the five paths are exactly alike, and to some extent the situation is one of paths moving farther away from the congested north-south corridor through the center of the area. Of course, at the conclusion of the fifth pass, 20 percent of this trip's volume is on each one of these paths so that some of its drivers are assumed to prefer the freeway and some are assumed to prefer the more direct but slower routes over standard arterial streets.

Figure 10 shows another situation in the case of the paths connecting the intersections at the outer southeast and northwest corners of the network. Here the upper parts of three of the paths use the branch north-south freeway and two use the outer north-south freeway, whereas on later passes their southern parts avoid the congested central corridor by staying to the east until they can take the east-west freeway to its interchanges with the others.

As mentioned earlier, a more limited number of alternative paths than this is the usual situation. In fact, in the case of 3 of the 22 paths examined, exactly the same path was traced for all five passes. For example the trip between the southern and the northern terminals of the north-south freeway along the western edge of town do not leave that freeway on any pass.

The important point is that this proposed network has been tested by a capacity-restrained assignment method which has distributed volumes over paths reflecting familiar driver behavior. That is, they are distributed over reasonable and realistic paths. The consequences have been discussed in terms of convergence, mileage, speeds, and paths, with the conclusion that the network is generally a "good" one in terms of the locations of major facilities. All of these considerations refer to only one of the two uses of traffic assignment, however—the use for network testing. The other use is in connection with the design of individual facilities. The kind of information provided by a capacity-restrained assignment for this purpose can be illustrated by the link record.

Link Record

Table 9 gives the kind of information available for every link in the network before and after an assignment. Reading across are the fifteen crucial digits which constitute the complete description of the link that the computer must have before the assignment begins. These are the numbers of the two intersections the link connects, the type and the area of the link, its pavement width in feet, its practical 24-hr capacity in thousands of vehicles, and its length in miles.

Table 10 gives the link's travel time and assigned volume, pass by pass. At the far end of the first line is its original (or typical) speed for the desire assignment. This number varies with both type and area (Table 1). The length of the link divided by its speed gives the link's "value" (V) for path-tracing purposes, which is travel time expressed in thousandths of hours. Beside it is recorded the same travel time expressed in minutes, simply for ease of interpretation.

When the computer has the fifteen crucial digits plus V for every link the assignment can begin. Link record A is the link record for the curved segment of the branch north-south freeway which appeared as heavily congested in Figure 3 (after the first pass). On the line for Pass 1 of this record is the volume of 129,000 vehicles which was assigned to this link on a "desire" basis. This is followed by 2.30, which means that the assigned volume is 230 percent of the capacity of the link (that is, R = 2.30).

Figure 10. Set of paths C.

TABLE 9

LINK RECORDS

Link Record	Intersections		Type	Area	Width (ft)	Capacity (×1,000)	Length (mi)
A	150	152	1	2	48	56	2.09
B	177	178	3	2	44	14	0.55
C	38	125	3	2	44	16	0.55

At this point Eq. 1 is applied, and the "typical" travel time is increased by 2.7 raised to the R^{-1} power. In this case, the equation produces a V of 150, which means 9 minutes of travel time, which in turn means that the speed on the link is dropped to 14 mph for the second pass. This speed is only slightly below the typical speed of a standard major street in the city, but such streets tend to be underassigned on the first pass and to have higher than typical speeds for the second pass. In any case the speed of 14 mph was such that this freeway link was included in no path on the second pass and was assigned no volume. But one-half the volumes of the trips using this link on the first pass are still considered to be assigned to it, so its average assigned volume after the second pass is 64,000 vehicles, or 115 percent of its capacity.

This volume allows a speed of 44 mph on the link, according to Eq. 1, and this speed determines its travel time for the third pass. At that point the trips whose paths include this link have a total volume of 93,000 vehicles, but only one-third of this volume, along with one-third of previously assigned volumes, is considered to be actually

TABLE 10

ASSIGNED VOLUMES AND TRAVEL TIMES FOR LINK RECORDS

Link Record	Pass	Assigned Volume			Travel Time		
		Avg. (×1,000)	Per Pass (×1,000)	R	V (hr × 10^{-3})	Min	Speed (mph)
A	0	-	-	-	41	2.5	50
	1	-	129	2.30	150	9.0	14
	2	64	0	1.15	47	2.8	44
	3	74	93	1.32	55	3.3	38
	4	77	88	1.38	59	3.5	35
	5	70	39	1.24	52	3.1	40
B	0	-	-	-	37	2.2	15
	1	-	0	0	13	0.8	42
	2	33	66	2.36	144	8.6	4
	3	22	0	1.56	65	3.9	8
	4	17	0	1.18	44	2.6	13
	5	13	0	0.95	35	2.1	16
C	0	-	-	-	37	2.2	15
	1	-	2	15	15	0.9	37
	2	8	13	47	21	1.3	26
	3	14	26	85	31	1.9	18
	4	14	15	88	32	1.9	17
	5	14	14	88	32	1.9	17

Figure 11. Freeway design, hand trace.

assigned to the link. Its average assigned volume, then, is 74,000 vehicles after the third pass, or 132 percent of capacity.

After the fourth and final pass, the average assigned volume is 77,000 vehicles, or 138 percent of capacity, which is the capacity-restrained assigned volume. It allows a speed of 35 mph on the link, and would lead the planner to consider increasing the width of the link from four lanes to six. (Assignment of peak-hour or design-hour volumes could be relied on to lead to the same conclusion only to the extent that such hourly volumes are some fairly constant percentage of the 24-hr volumes used here.) The assigned volume after the experimental fifth pass is somewhat closer to the original capacity but still represents a degree of congestion and a necessity for redesign.

Link record B is a link record of a different kind. It represents a link of a standard major street in the city which is about four lanes wide and can carry an estimated 14,000 vehicles per day without congestion, at an average speed of 15 mph. On the first pass, it was assigned no volume at all and its speed was increased to 42 mph. In this case, the increased speed led to an overassignment on the second pass and speed dropped to a mere 4 mph. No volumes were assigned to it thereafter, and its final volume was close to capacity.

Link records A and B both represent extreme situations, whereas link record C is the record for a more typical link. It appeared in few paths on the first pass and its speed was more than doubled, then reduced again on subsequent passes. By the third pass, its assigned volume was close to capacity and did not change again, so that it appears that the link is designed about as it should be for 1980 traffic volumes.

This completes the description of the kind of information available from a capacity-restrained traffic assignment. Consideration has been given to (a) the four tests of the total system in terms of convergence, miles, speeds, and paths, and (b) the test of every individual link with the related data of assigned volume, width, and speed. The following section compares this with the kind of information available from other types of traffic assignment.

COMPARISON TO OTHER ASSIGNMENTS

Freeway System

In the process of planning a Flint network, the State Highway Department made a hand-trace assignment to the version tested here as well as to two earlier versions. In addition, a diversion-curve assignment was made on the computer to the freeway subsystem of the network. Therefore, with the desire assignment and the capacity-restrained assignment described in this report, a comparison can be made of the results of four different assignments to this particular freeway layout. All of the assignments obtained both link volumes and turning movements, so that a mass of information is available for analysis, but it is summarized here in the form of four maps (Figs. 11 through 14).

Figure 11 shows the kind of freeway system that would be constructed if the volumes assigned by the hand-trace method were to be treated as design volumes. The broken line indicates that the assigned volume could be handled without undue congestion by a two-lane freeway, and the narrowest solid line indicates that four lanes would be required. The solid line is widened by ⅛ in. for each additional needed pair of lanes and the widest line indicates that a ten-lane freeway is called for by the assigned volume to that particular link.

The Highway Department does not intend to use these particular hand-assigned volumes for design purposes; they were produced as a general test of the freeway-system layout. For example the Department would not design and construct the ten-lane freeway section shown, but instead would conclude that ". . . there must be revisions in the original system to provide capacity on other facilities in the immediate vicinity." This is a useful approach and one clearly preferable to less systematic and more subjective methods of traffic estimating.

On the other hand, at the conclusion of this particular hand-trace assignment there were other facilities in the immediate vicinity which were loaded with volumes significantly smaller than their capacities. This raises the possibility that the system might

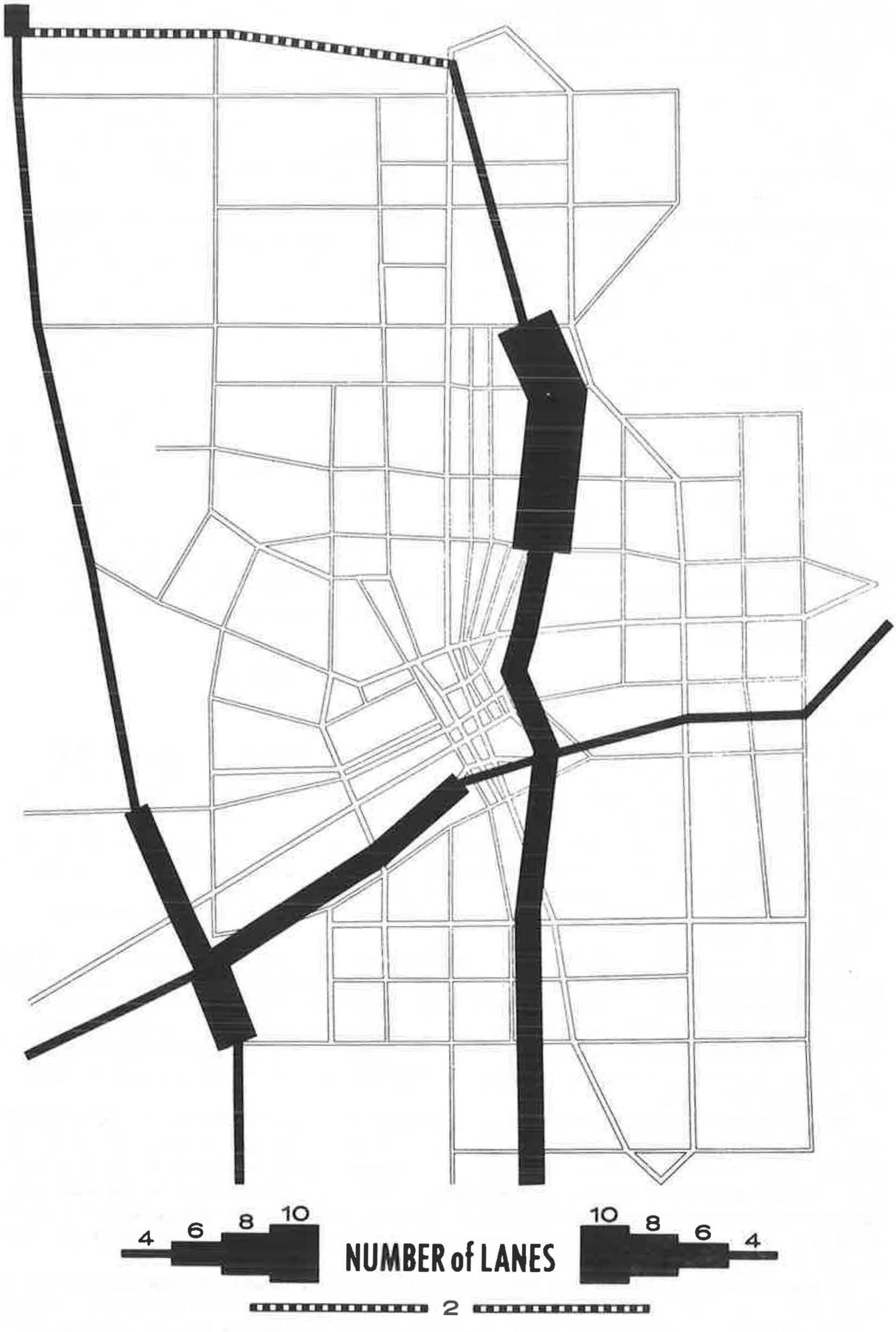

Figure 12. Freeway design, diversion curve.

Figure 13. Freeway design, "desire."

not appear to need added capacity if the assignment technique allowed individual interzonal volumes to be divided between alternate "best paths." Such a procedure is recommended by the probability that all drivers making the same interzonal trip are not likely to select the same route if there are very many choices to be made along the way.

When hand-trace volumes are compared to the results of other kinds of assignments, another kind of question can be raised. For example, the hand-trace assigned 23,000 more vehicles to the most heavily assigned link than any of the other methods (to be specific, a total of 152,000 vehicles compared to 129,000, 115,000 and 77,000 by the other methods). What factors did the hand tracers take into account to produce this volume? They could be correct, but the computer volumes always have one advantage: the factors taken into account to produce them can be precisely specified.

Figure 12 shows the results of a computer freeway "diversion curve" assignment, mapped in the same way as the results of the hand-trace. The two assignments produce a similar pattern of results, and the computer assignment has the advantage already mentioned. On the other hand, the computer assignment, too, can be questioned on the basis of the desirability of alternate paths. In addition, the freeway assignment has the major shortcoming of providing no assistance for the process of adapting an existing street system to a new freeway system, which is the reason the Highway Department had to do the hand tracing.

Figure 13 shows the same network as it was described at the conclusion of the first pass or desire assignment reported in this paper. Compared to Figure 12, it makes clear the effects of not dividing interzonal volumes by means of a diversion curve before assigning them (in that there are even more unrealistically high volumes), but again its general pattern is comparable to the results of the other two methods. This kind of desire assignment has been used for planning purposes in a number of cities, because it combines the advantage of objectivity offered by a computer assignment with the advantage of testing a total major street system as does the hand-trace assignment. However, the results of this assignment, too, can be questioned on the grounds that heavily overassigned and underassigned links make it unavoidable that some of its assigned volumes will vary from actual traffic flows, and this might not be the case if alternate paths could be determined by the assignment technique.

Figure 14 shows the results of the fourth pass of the capacity-restrained assignment mapped in the same way as the others. This is the only assignment discussed here that can meet the objection mentioned. It prescribes a system of seventeen freeway links of six lanes each and eight freeway links of four lanes each. It demonstrates an assigned volume on every link beyond the capacity of a smaller freeway (thus justifying construction), and within the prescribed capacity (thus realistically aiding in design).

It is confidently predicted that, if the network were revised to provide these freeway capacities and to provide additional capacity at the indicated points of access to the freeways, the revised network would pass the assignment test by "converging" quickly to typical speeds and capacities, requiring minimal additional vehicular miles and hours, and carrying longer trips on its freeways. In other words, it would prove to be a "good" network providing sufficient capacity where it is needed. More important, it is probable that the revised network would carry Flint traffic in 1980 without undue congestion, assuming the validity of the 1980 trip table and a typical distribution of local (intrazonal) traffic.

Comparative Time and Cost

It has been difficult to compare time and cost for the various assignments discussed here. The largest part of the capacity-restraint costs have been for experimental program development that will not need to be repeated. The Highway Department's record of expenditures for the hand trace includes only direct costs, and it is difficult to separate costs of the other assignments from various overhead charges. One reliable comparison is that the path-tracing part of the hand assignment took 44 man-days at the Highway Department and the path-tracing part of one comparable pass took 12 hr on the 650-RAMAC computer at Wayne State University.

This is by no means a reliable estimate of the ratio of total times and costs, however. A computer-hour is more expensive than a man-day, and a network for the

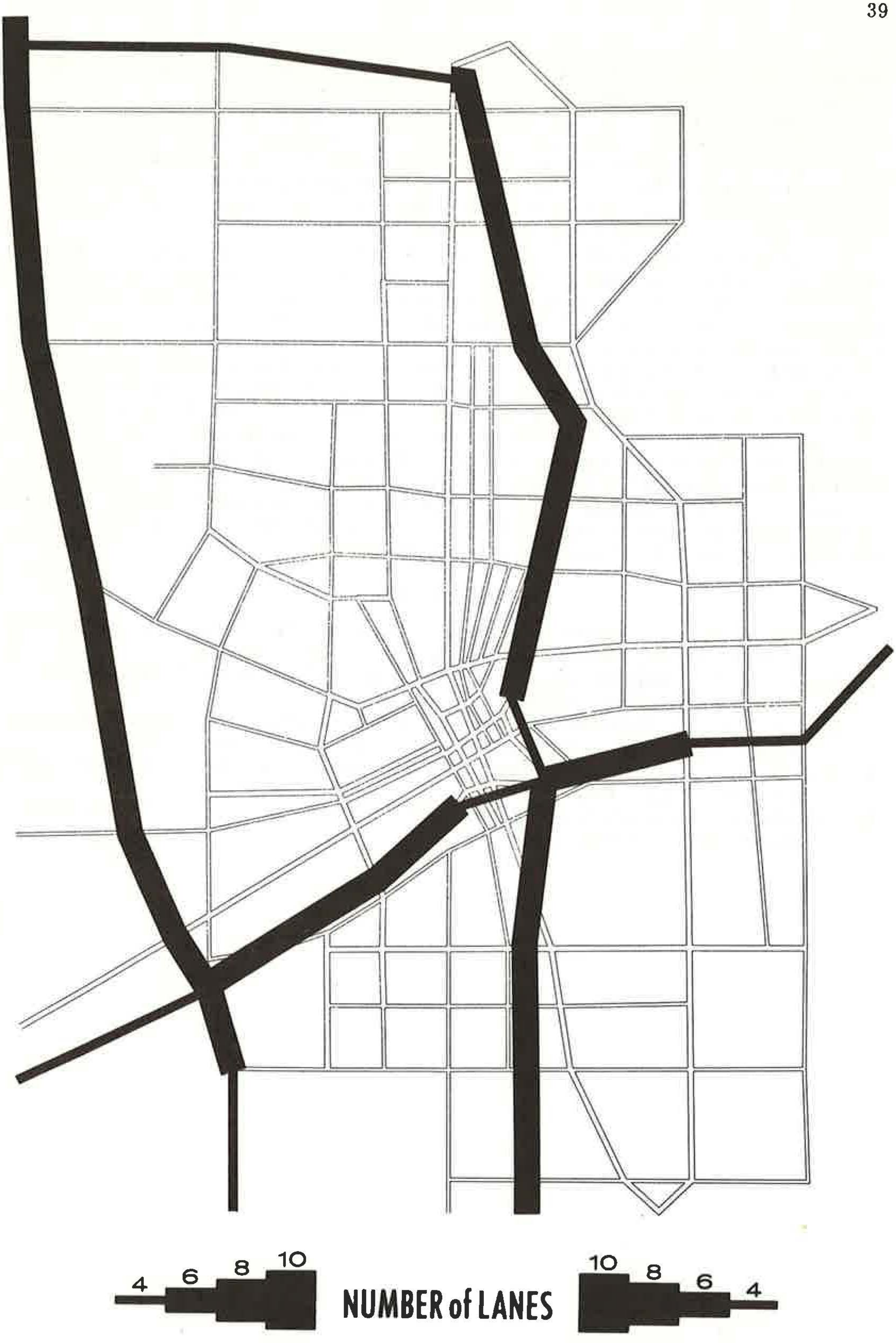

Figure 14. Freeway design, capacity restrained.

computer needs more preparation than a network for hand tracing. The Highway Department reports that it can complete a hand-trace assignment to a network like the present one in about one month at a total direct cost of about $2,000.

It seems likely that, with their own 650 computer, a capacity-restrained assignment would take them about the same amount of time from beginning to end, although much less time would be spent on path-tracing and much more time on network description and output analysis. The computer assignment probably would cost at least twice as much as the hand-trace, although the cost consequences of reducing it to a routine, mass-production operation are hard to estimate.

So long as relatively small computers are the only ones readily available to highway departments and local planning offices, the capacity-restrained assignment must justify itself on the grounds of its superior usefulness and reliability; it cannot be entirely competitive in terms of cost. This paper has tried to demonstrate, however, that they are nevertheless superior enough to justify a greater cost, and now that a 650 program can be made generally available it is to be hoped that they will be more widely used.

In the long run, the solution to the need for such assignments on a routine basis is the wider availability of high-speed computers. The U. S. Bureau of Public Roads is developing programs for the IBM 704 and 7090 which are comparable to the one described here but reduce assignment time to a matter of minutes and reduce costs to a few hundred dollars, and such computers are becoming more readily available around the country for traffic assignment on a routine basis. If this work continues, there is no doubt that it will soon be possible to provide more and better traffic assignments for highway planners than have been available in the past.

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