# A Mechanical Method for Assigning Traffic To Expressways

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This paper describes the coding techniques and machine procedures worked out to facilitate a rapid assignment o expressways in the Detroit area. Using this assignment method 23,50ᒥ zone-to-zone movements were assigned to a network of expressways anc' -nnecting arterials totaling 375 miles in slightly less than three weeks.

Features of this assignment procedure are that alternate distances can be rapidly and accurately estimated by a machine technique. Second, is a method of treating expressway trips in parts and matching parts together to form trips thus eliminating the necessity of reviewing and coding each zone-to-zone transfer individually. Finally, the adaptability of this procedure to high speed computing and summarizing techniques makes possible a tremendous conservation of time and manpower.

## PART I: INTRODUCTION

● TRAFFIC assignment serves several useful purposes. One of the most important of these is in testing new route proposals for their ability to serve the traffic needs of an area. Traffic assignment can provide a very reasonable estimate of the demand for usage of new route proposals. It can point out locations where impossible overloads might develop or where traffic loads are not sufficient to justify expressway or freeway type construction.

Ideally a plan should be based on the traffic pattern developed from origin and destination information. After the plan is carefully worked out then it should be subjected to test by traffic assignment. This test might indicate that some rearrangement of routes is necessary or that new routes should be added or perhaps others dropped from the plan. Based on the test the plan should be revised and then tested again by assignment. This process should be continued within the limits of time until a suitable plan is devised. The best plan from a traffic service standpoint would be the one which served the most trips with more vehicle miles travelled on the routes of the plan (thus relieving existing streets) and had the most even or balanced distribution of traffic loads throughout the system.

This system of testing and revision is highly desirable but it had not been possible in the past due to the time required to complete an assignment. Measurements of distance and time via a proposed and alternate route for each zone-to-zone movement and calculation of ratios and allocation of traffic have been done manually. In addition to the time involved assignment has been subject to considerable human error. In the last decade the summary and tabulation has been mechanized to a certain extent, by the use of electronic tabulation and data processing equipment. Even so, the traffic assignment was still time consuming, tedious and subject to human error which was almost impossible to prevent or detect. In one city even with the aid of electronic data processing equipment the assignment took over a year to complete. The analysis and assignment took so long that the basic traffic pattern was considered outdated due to the rapid suburban growth and increase in vehicle registration.

The Staff of the Detroit Study was faced with the problem of assigning 23,500 transfers between zones (actually over 47,000 zone-to-zone transfers) to over 230 miles of proposed new routes. The time allotted for this job in the work program was six weeks. A manual assignment with an individual inspection of each zone-to-zone movement was out of the question.

To solve the assignment problem a highly mechanized procedure was developed which systematized the coding operation and eliminated many repetitive computations. This procedure made a complete assignment possible within three weeks with a small amount of manual work required. This included all necessary coding, keypunching,

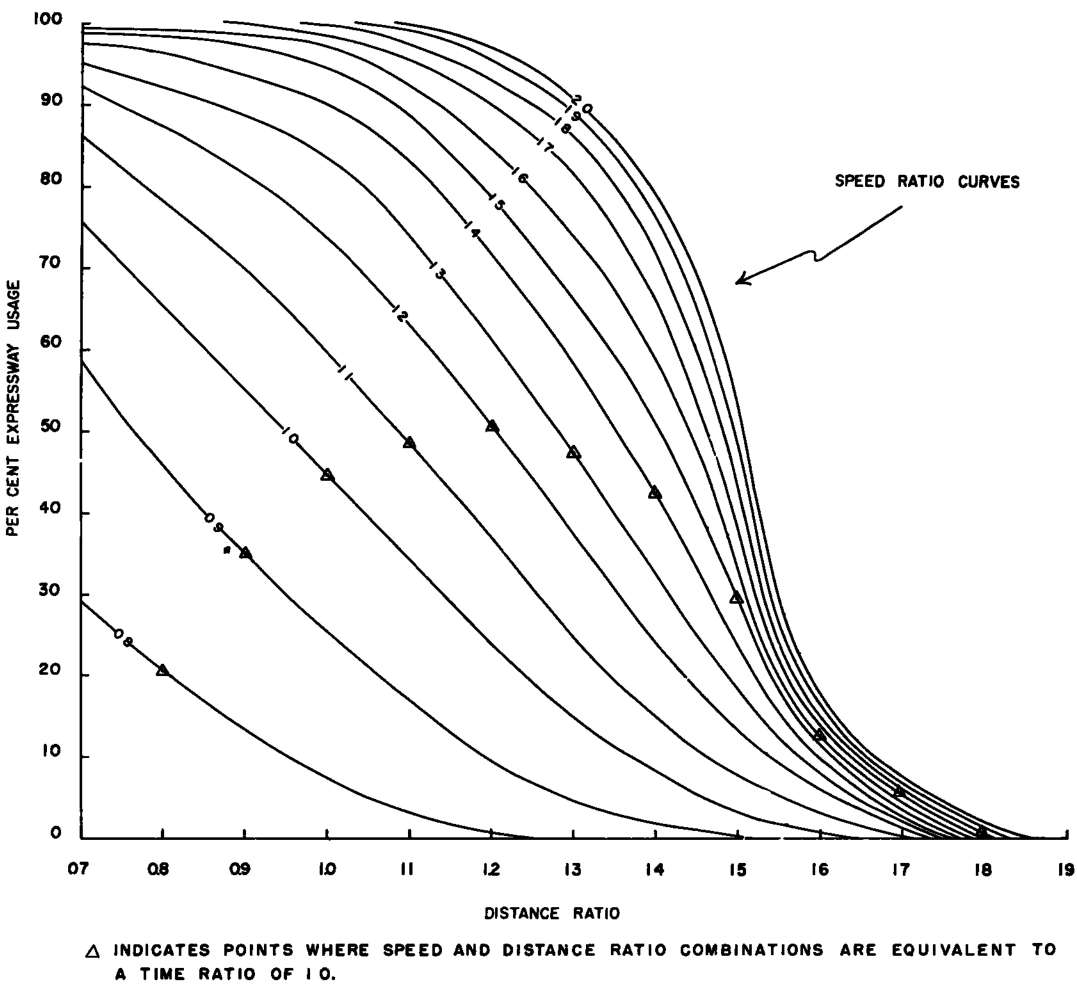



Figure 1. Expressway usage as related to speed and distance ratios.

data processing and tabulation of assigned volumes. The tabulation listed the volumes of all turning movements through every interchange and also the volumes approaching and leaving each leg of all interchanges. The assignment was done for 1953 traffic data as well as 1980 traffic data. While this procedure is highly mechanized it still permits the exercise of engineering judgement in selecting and coding travel routes for all transfers.

The purpose of this report is to present the method of assignment as worked out by the Detroit Staff. The report is organized as follows: Part II presents the basis for the assignment and describes the mechanical procedure in great detail; Part III presents the results and analysis of the assignment including a discussion of assignment versus flow, and suggestions for further research.

## PART II: ASSIGNMENT PROCEDURES

### Basis for Assignment

The assignment to expressways in Detroit was based on combinations of comparative distance and speed for an expressway and an alternate route. A family of distance and speed-ratio curves previously developed and made the subject of a paper presented at the Highway Research Board in January 1955 (See Bulletin 119, Highway Research Board, Washington, D.C.) was used to allocate trips to expressways. These curves are shown on Figure 1. To utilize these curves, distance and speed-ratios had to be calculated for the alternate and express routes. It was shown in the report referenced above that with an assumption of the ratio of speed on expressways to speed for city street travel the ratio of average speeds could be calculated using only distance measures. The formula for obtaining the overall speed-ratio when a 2:1 ratio of expressway speed to city street speed is assumed is as follows:

$$\text{Speed Ratio} = \frac{\text{Total expressway trip distance}}{\text{One-half of the distance on the expressway + distance between expressway and zone centers.}}$$

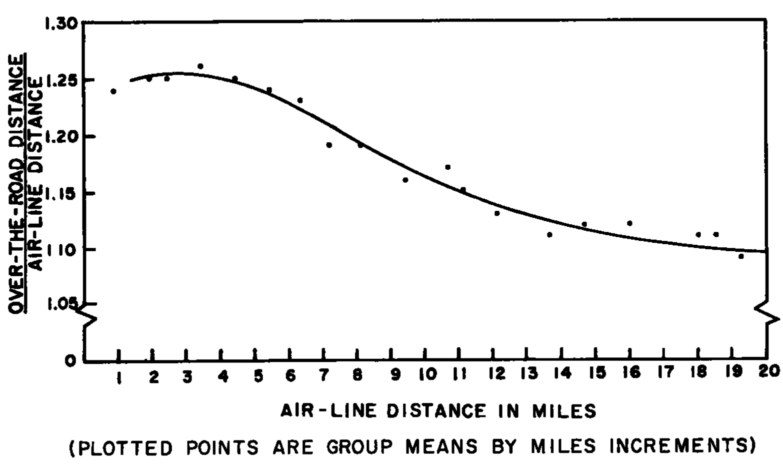
Therefore, both the speed and distance ratios can be calculated using only distance measurements and an assumption of the ratio of speed on expressways to speed on city streets. This assumption of the ratio of speed on expressways to speed on city streets for some future date is just as logical as the assumption of actual speeds and measurement of travel time for individual streets in the future. In addition to being logical this technique eliminated the need for making speed runs over many streets for use in determining travel times.

This method of determining speed and distance-ratios made the basic measurements easier but there was still the problem of comparing two routes for each of the many individual transfers between zones. In Detroit there were 264 analysis zones including 10 external station groups with possibilities of each having interchange with all others. There actually were slightly over 23,500 individual two-way transfers between zones out of the 34,800 possible.

## The Approach to the Problem

The approach to the problem of developing a procedure for making a rapid assignment of traffic was one of breaking the problem into its simplest parts and trying to find an answer to each problem in turn. For example, the assignment problem can be broken into three basic parts as follows:

1. Measuring and recording distance for the most convenient (shortest) route of travel via city streets for a traffic volume transfer between two zones.




Source: The Relationship Between Over-The-Road and Geometric Measures of Trip Distance for the Detroit Area. (Detroit Metropolitan Area Traffic Study. 1955).

Figure 2. Comparison of distance factor and airline distance.

2. Measuring and recording distances for the same transfer via a route utilizing expressways. This second step was divided into two parts. First, distances were recorded between zone centers and expressway ramps and second, distances and turning

movements were coded for the expressway route. The distance travelled on the expressway and the distance getting to and from expressways were tabulated separately so speed ratios could be determined.

3. Comparing the route measurements obtained in step 1 and 2 above and the calculation of speed and distance-ratios and from these ratios determining the allocation of trips to expressways. The procedure used in working out each of these problems is detailed below.

Measurement of Alternate Route Distance

This problem was approached with the idea that there is a predictable relationship between "straight line" or "airline" distance between two points and the actual "over-the-road" distance. If the street system were a pure grid then the "over-the-road" distance would be the same or very near the same as the "right-angle" distance. However, streets in the Detroit area were not laid out in a simple grid pattern, and there were many diagonal and radial streets. Therefore, to determine the relationship between "airline" and "over-the-road" distance a random sample of over 200 individual zone-to-zone movements was selected for testing. The "airline" distance was calculated between each pair of zones, and the distance via the best arterial route was measured. From a comparison of "airline" versus "over-the-road" distance the curve shown in Figure 2 was constructed and a mathematical relationship was determined.[1] The relationship had a 0.993 correlation ratio. For the sample used, a very accurate approximation of city street distance was obtained from converting "airline" distance by a factor dependent on the trip length. Therefore, if the "airline" distance between two zones is known, a close approximation of average alternate city street distance can be determined by using this curve.

The question then is how can the "airline" distance be calculated for the various pairs of zones exchanging trips. This problem was solved by overlaying and keying a half-mile grid pattern to the Study Area. Then the coordinates of the geographic center of each zone were determined. "Airline" distance between two zones was calculated by an electronic calculator (IBM604). This distance was simply the hypotenuse of right triangle. Given the coordinates of the zone centers it was a simple calculation for the 604. In the same operation the 604 applied an appropriate factor as determined from Figure 2 to the "airline" distance to approximate the "over-the-road" distance. These distances were punched into the zone to zone transfer cards. (Card 089—see appendix for card layout). This measurement technique made possible a tremendous time saving in calculating city street distance. The 604 does calculations at the rate of 6,000 an hour; so all the distances were determined in less than five hours after the cards were prepared and instructions wired into the 604. The whole process of coding, punching and tabulation takes one person about two days. This again is to compute alternate route distance for all 23,500 transfers.

The second problem was one of tracing and recording a route using expressways for a movement between two zones. The Detroit solution to this problem is described below.

Tracing the Expressway Routing

The expressway routing was an entirely different problem from the alternate routing and its solution was not as simple. Since turning movements and expressway mileage were required for the expressway route it appeared that some manual coding would be necessary. Therefore, efforts were directed toward de. sing a simple and systematic method of manually coding routes so that a minimum amount would be sufficient. Many zonal pairs have similar routings for a portion of the trip between them. For example, in Figure 3 the route from Zone A to the expressway ramp might be the same when Zone C, D or X is the destination zone. Likewise, the routing over the expressway network might be the same for many pairs of zones. In Figure 2 the route from B to C, D, or X is the same over the expressways as the route from A to these zones. Thus

[1] For complete discussion see "The Relationship Between Over-The-Road and Geometric Measures of Trip Distance for the Detroit Area," 8pp. mimeo., September, 1955.

much of the routing for these six transfers in the example is duplicated. It is possible that a routing between an expressway ramp and a particular zone center could have been used 263 times since there are 263 other zones with which this zone could exchange trips. If sections of routes could be coded once and then used over and over again whenever they appear as part of an expressway trip, the coding would then be much simpler. The foregoing hypothesis provided the basis of the expressway route tracing procedure developed by the staff.

There are three things which should be pointed out for an understanding of the coding system. First, all zone-to-zone transfers used in the assignment are two-way, all-vehicle totals, representing interchange between zones. Second, even though the transfers are two-way totals all traffic was considered to move from west to east. Therefore, for a particular zone-to-zone movement the zone having the smallest X coordinate for its geographic center was always considered as the origin zone. Third, existing individual zone-to-zone transfers were not considered in this coding method. Whole expressway trips from origin to destination were never coded as such. Instead these trips were coded in parts and by a system of master carding and machine matching fashioned together to make a complete trip via the expressway network.

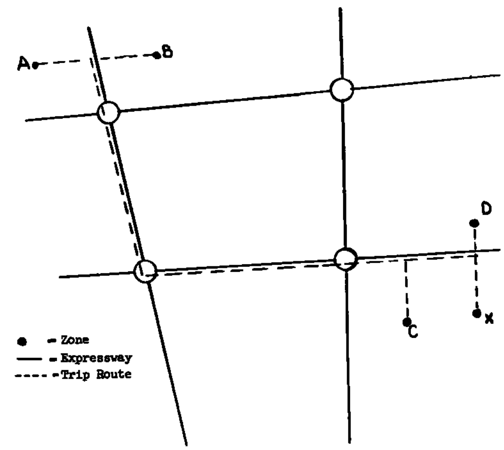



Figure 3. Illustration showing how various zone to zone transfers can have the same trip routing.

The first part involved coding a route and measuring distance between zone centers and the first or last interchange used in getting to or from the zone. The second step was to determine routings between all possible combinations of first and last interchanges. Routings obtained from these two steps are then combined as various zones match together as origins and destinations of trips and the expressway trip is determined.

To illustrate, consider a particular zone and see how the expressway trip would be coded. If this zone is an origin then the destination must be east of it. For a transfer between this zone and zones in a particular sector east of it there will be a particular expressway ramp which would provide the best routing via expressways. These trips, all moving in the same direction will pass through the same first interchange of the expressway network and approach it on the same leg. If this zone is a destination zone the best exit-ramp and the last interchange the trips could pass through could be determined for a group of transfers between it and origins in a specified direction. This routing is done for all zones as origins and again for all zones as destinations and punched into IBM master cards. The second coding operation is to code routing between each interchange and every other interchange so that routings are known between all possible combinations of one interchange used as a first and another used as a last interchange. As part of this coding operation turning movements are recorded for each interchange which lies on the expressway route between the first and last interchange.

To illustrate how the expressway routing is obtained consider a transfer between Zones A and B. Routing from Zone A to the expressway and to the first interchange is given on the master card coded in step one above for A as an origin zone. Likewise the routing from the last interchange to Zone B will be shown on the master card coded for B as a destination in step one. The route on the expressways between the first and last interchanges is determined from the coding in the second step which gives the routing between all interchanges. Controlling on first and last interchange the routing card from step two is matched with the cards from step one to form a complete routing by expressway.

Determining Turns in First and Last Interchanges. Thus far the coding and matching of cards results in obtaining all the information needed for the expressway route except the turns in the first and last interchanges. It should be obvious that these turns cannot be recorded in the original coding of the routings between zones and interchanges, because it is not known which zones will match up to make trips. For a particular zone all transfers will approach the first interchange or leave the last in the same direction, but some may turn right, left, or go straight through depending on what the destination zone is and where the last interchange is. To get around this problem a system of interchange leg codes (called approach and leave codes) and turning movement codes were devised. These codes are different from the usual codings in that the turns can be obtained by adding the approach or leave codes. For example, in Figure 4 a vehicle approaching on leg 1 and leaving on leg 3 must make a 4 turn $(1+3=4)$. In the same manner any turning movement can be obtained by adding appropriate approach and leave codes. Incidentally, the number 2 was left out of the leg numbering because it would result in two number 5 turning movements (i.e., $1+4$ and $2+3$.)

How then does this help in solving the problem of turns in the first and last interchange? In coding the route from origin to first interchange the approach leg number is coded, and in coding the route between last interchange and destination zone the leaving leg of the last interchange is coded. Then in routing trips between first and last interchanges the leaving leg of the first interchange and approach leg of the last interchange are coded. By adding the approach and leaving codes for the first and last interchange, the appropriate turns are obtained.

Use of Travel Direction Code. There is still one other basic step which must be explained. It is true that for zones lying in a particular known direction from an origin or destination one particular route to an expressway ramp and interchange can be picked. Consider again an origin zone. All destinations must be east of it. However, there is a sector of almost 180° from just east of north to just east of south within which these destination zones can fall. It is not likely therefore that there would be only one best route between a zone and an expressway for all trips leaving that zone. To narrow the range of choice of expressway ramps for any zone, all trips were classified into one of eight direction groups depending upon their slope. Although not always necessary this allowed eight choices of route between a zone and the expressway. In coding it was found that for some zones one route served all eight travel directions. Thus, the number of routes and ramp choices needed varied from one to eight with few zones requiring all eight.

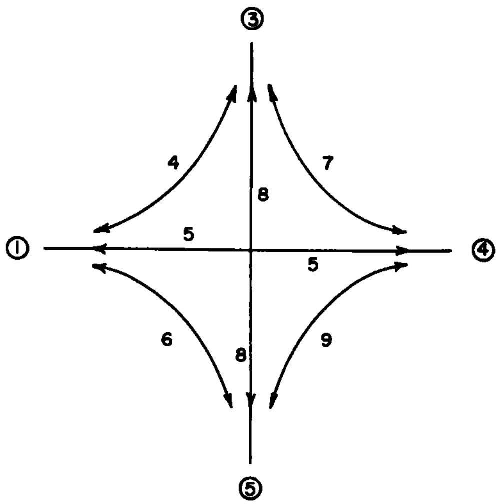


Figure 4.

To summarize, route coding was done abstractly in parts and matched together as various combinations of origins and destinations occurred, to form a complete trip. Routing for all zones between zone center and first expressway interchange is coded for eight possible directions of leaving when the zone is an origin. Each zone is coded in the same manner for possibilities as a destination. Routing between each expressway interchange and every one having a higher number is also coded. All codings are transferred to punched cards and trips are constructed by machine matching of master cards to produce expressway routings for all zone-to-zone combinations. The coding operation for the 264 analysis zones in the Detroit area took about a week and a half, with six people coding. This included a complete recoding as a check. The success of this kind of assignment depends a great deal on the accuracy of coding, since one master card may be used many times and any errors are duplicated each time it is used.

This paper so far has discussed in general the technique of coding and card matching used in assignment. A detailed explanation of the procedure is presented next so that it will be thoroughly understood.

Map Preparation and Expressway Numbering. A necessary first step before the coding can be started is the preparation of maps and coding instruments. Several map

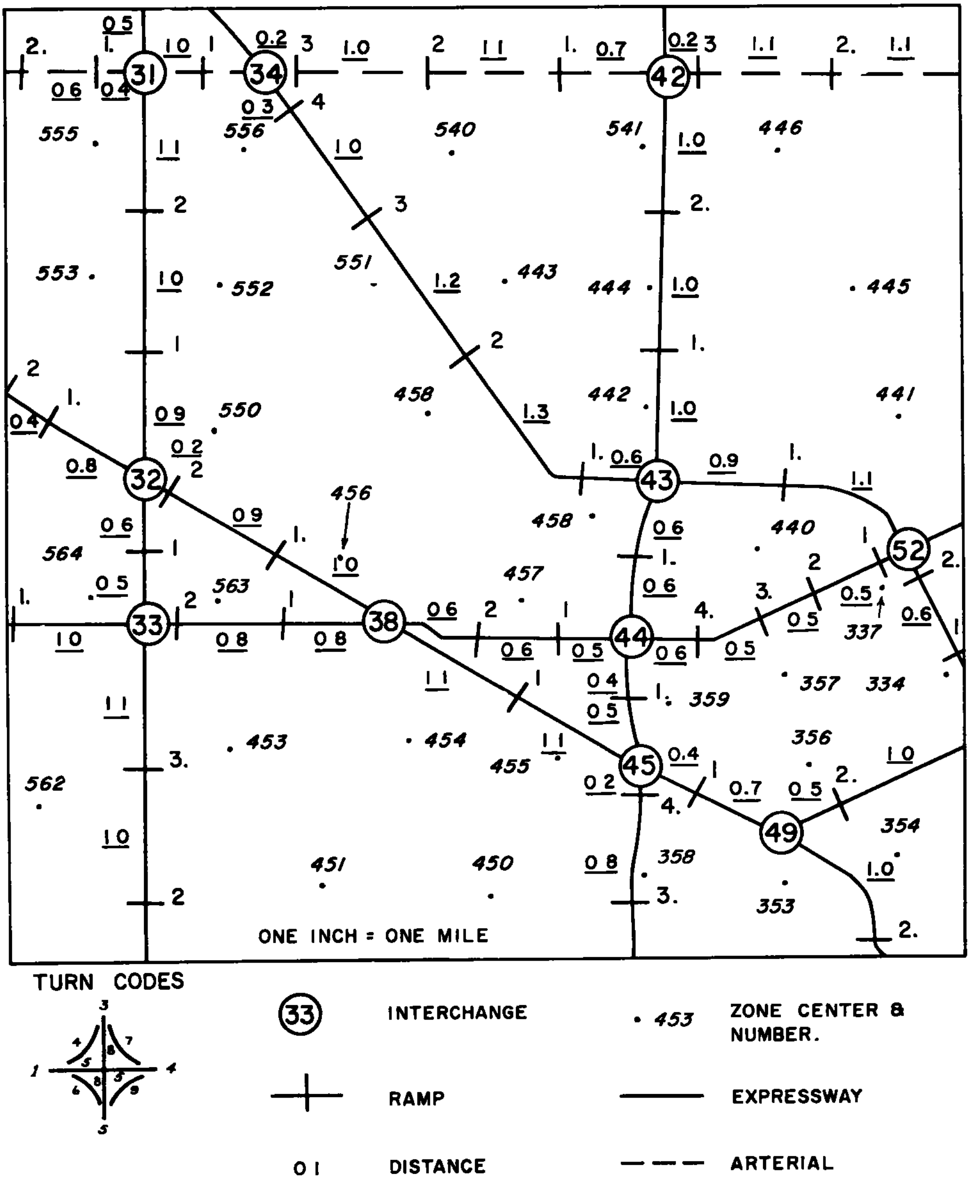



Figure 5. Section of expressway assignment coding map.

preparations are required before one can begin coding. First the proposed expressway network must be plotted and all ramps, interchanges and expressway sections located and designated in a systematic manner for easy reference. Since the street system is not essential to this coding operation, the expressway network can be plotted on a blank overlay, keyed to the street map. When the network has been plotted and interchanges numbered, copies of the map should be reproduced for use in coding the routing between the first and last interchanges. All that is needed for this is the interchange number and the distance between the interchanges. Detail required for coding the routing between expressways and zone centers, can then be plotted on the original tracing. For this map, ramps must be located and numbered and all geographic zone centers plotted and numbered. It would be desirable to show all zone boundaries on this map also. Distances between all ramps and between ramps and interchanges must also be measured and posted. Distances were measured and checked with a map meter.

Figure 5 is an inset from the coding map which was used for assignment in Detroit. The map scale is 1 inch equals 1 mile. This map is identical to the map the Detroit coders used except for two details. First, the zone boundaries were shown on the coders map in light colored pencil. Second, to insure that all coders recorded correct approach and leaving codes for interchanges, the leg numbers of all interchanges were designated with a colored pencil.

The expressway interchanges were numbered from north to south and west to east in sequential number as nearly as possible. Sections between interchanges were designated by the numbers of the interchanges it lay between, always listing the low interchange number first. For example, the section between interchanges 33 and 38 on Figure 5 is designated 3338. Ramps are identified by the section number plus the number of the ramp on the section. On section 3338 there are two ramps designated 33381 an 33382.

One other feature of the map should be explained. The system as shown includes expressways and connecting high type arterials. Expressways are designated by a solid line and the arterials by a dashed line. These connecting arterials were conceived as not quite as good as expressways in terms of service and capacity, but much better than ordinary surface arterials. By traffic engineering techniques and some construction these areterials could be improved to afford much better service than other arterials. To account for the differential service provided, a 10 percent additional increment was added to the arterial distance measures. This added distance increased the distance ratio thus decreasing assignment to arterials as compared to expressways.

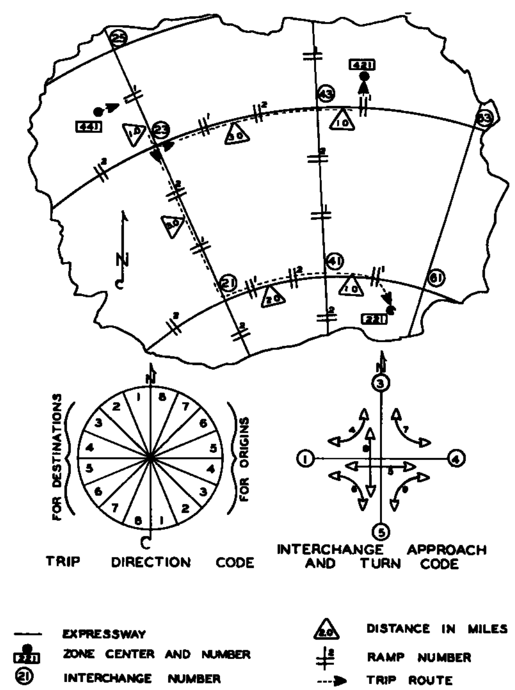



Figure 6. Illustration used to demonstrate trip routing via an expressway.

In addition to the map preparation, it is necessary to prepare a template showing the eight trip direction sectors for origins and destinations. (See Figure 6 and refer to trip direction code). This template is used as a guide by the person coding the routing between zones and expressways. The center of the template is placed over the zone center and the coder can then determine which zones have the possibility of exchanging trips with the zone being coded for any direction of travel. The coder can then select the best route to get to or from the expressway in serving trips between the zone being coded and all other zones falling in the direction sector, for eight direction possibilities.

These preliminary steps are followed by the preparation of Tables 1 and 2.

Preparation of Coding Table 1. The items recorded in the assignment Table 1 are shown below in heading form.

TABLE 1

| Zone No. | Zone is O or D | Direction Code | Ramp of Entrance or Exit | Number of First or Last Interchange | Approach or Leaving Code | Airline Distance Zone to Ramp | Dist. Ramp to Interchange |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |

Items are recorded in this table for every zone as an origin and destination possibility and for eight travel directions. This amounts to coding routes between zones and expressways sixteen times for every zone. However, about 70 percent of the coding is duplicated, since routing is often the same for 2 or more travel directions at a particular zone. Coding for origins is done separately and independent of coding for zones as destinations. It is best to have one person code all origin possibilities and another code all destination possibilities. After coding is completed and checked the data should be punched into IBM cards (card 087) and kept as two separate decks, one of origins, the other of destinations.

The first column in Table 1 is zone number. This, of course, is the number of the zone for which the routing is being coded. Zones are taken in rotation by numerical order. A list of zones ranked numerically is a handy check list to insure all zones are coded. In the second column (1) or (2) is entered to indicate that the zone is being considered as an origin (1) or a destination (2). The third column is used to show the travel direction being coded, of the eight possible. It is this step in coding where the template described earlier, is used. The ramp of entrance if the zone is an origin, or ramp of exit if the zone is being considered as a destination is recorded in column four. Column five is used to show the number of the first interchange for origin zones or the last interchange for destination zones. The number of the leg used in approaching the first interchange or in leaving the last interchange is entered in column six. Next the airline distance from the zone to the indicated ramp is entered. This distance in most cases will not be the distance from zone center to ramp, but will be an estimated average distance to the ramp from any place in the zone. Zone boundaries are necessary to obtain an accurate judgment of this distance, and that is why the boundaries are shown on the coding map. The last entry in this table is the distance between the indicated ramp and interchange. This distance is read from the map since distance was previously posted for the expressway system.

The "airline" distance between the zone and ramp (now in card 087) is multiplied by a constant 1.25 factor to convert it to equivalent arterial mileage. This calculation is made by the IBM 604. In addition the 604 adds a constant 0.1 mile to each zone to ramp distance to account for travel on the ramps in getting from surface streets to expressways. This final street distance is punched into the 087 cards.

This completes the coding required to fill in Table 1. The other coding operation is the designation of routing between the first and last interchanges. This routing is recorded in Table 2.

Preparation of Coding Table 2. Table 2 was set up to record the expressway routing and turning movements between the first and last interchanges. The layout of Table 2 is shown below.

TABLE 2

ROUTING OF EXPRESSWAY TRIPS BETWEEN INTERCHANGES

| First Interchange | Leaving Code | Last Interchange | Approach Code | INTERCHANGE TURNING MOVEMENTS — Interchange Numbers 1 2 3 4 5 6 7 … 30 31 32 33 | Distance Between Interchanges |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

Since the first and last interchanges are dependent upon the origin and destination of a trip, any combination of one first interchange with another last interchange may be involved. Therefore, it was necessary to code the route between each interchange and all others. This requires a total of n (n-1) codes where n is the number of interchanges in the system. The actual coding can be cut in half by coding each interchange to all interchanges with higher numbers. The route between any interchange and all other interchanges with lower numbers is obtained by reversing the first and last interchange numbers and approach and leaving codes and duplicating these cards. The routes and turns between interchange 32 and 51 is the same as the route and turns between 51 and 32.

In filling out this table the coder started with the lowest numbered interchange as the first, and coded routes between it and every interchange with a higher number in

TABLE 3

| Zone No. | Zone is O or D | Direction Code | Ramp of Entrance or Exit | Number of First or Last Interchange | Approach or Leave | Airline Distance Zone to Ramp | Dist. Ramp to Interchange |
|---|---|---|---|---|---|---|---|
| 441 | 1 | 5 | 23,251 | 23 | 3 | 0.4 | 1.0 |
| 441 | 1 | 3 | 23,251 | 23 | 3 | 0 4 | 1.0 |
| 421 | 2 | 5 | 43,631 | 43 | 4 | 0.4 | 1.0 |
| 221 | 2 | 3 | 41,611 | 41 | 4 | 0.4 | 1.0 |

numerical order. Then the interchange with the second highest number was taken as the first interchange and routes between it and every higher numbered interchange coded. This procedure was followed until all interchanges had been considered as a first interchange and routes designated between them and every interchange with a higher number.

The completion of Table 2 was the most difficult of the coding jobs. Nevertheless, three people were able to complete the coding and completely check every code twice in about 7 days. Only two coding errors were uncovered by the second check, and when they were corrected the coding was letter perfect.

Column one in Table 2 is used to record the number of the first interchange. The leg which would be used in leaving the first interchange was coded in column two. Column three was used for recording the number of the last interchange and column four for recording the leg number which would be used in approaching the last interchange. The next group of columns under the heading "Interchange Turning Movements" were used to indicate the movement through any interchange which might be on the expressway route between the first and last interchanges. This is done by entering the appropriate movement number in the column having the same number as the interchange. The last column in the table is used to record the distance on expressways between interchanges.

The basis for determining routing within the expressway system was that all trips were routed over the shortest distance between interchanges. When two routes had the same distance the one having fewer turns was selected.

When all the possible routings have been coded and recorded in Table 2 and completely checked, the information is transferred to IBM cards (No. 088).

With completion of basic coding, one can match any origin zone with any destination, and trace a trip via the expressway, at the same time recording the necessary distances and turns. This procedure is best illustrated with an example.

## Examples of Procedure for Tracing an Expressway Trip

Figure 6 represents part of a hypothetical expressway system. Zone 441 in this illustration is an origin and zones 421 and 221 are destinations. A trip from 441 to 421 would fall in travel direction 5 of the eight possible, whereas a trip from 441 to 221 would be in the 3 direction. These zones would have been coded and routings determined for origin and destination possibilities in eight travel directions. For this illustration only the routings for the 5 and 3 travel directions for the respective transfers are needed. Having the zone to zone movements indicated above, the problem is to match the first, middle and last parts of the route together to form a complete trip via expressways. The coding for the three zones as it would have been done in Table 1 is shown in Table 3.

The first and last parts of the expressway trip can be determined from the Table 1 entries. The middle part of the trip must be obtained from Table 2. For this example Table 2 would have been coded as shown in Table 4.

For the transfers between 441 and 421 the following procedure is used in determining the expressway routing. The first entry from Table 1 shown above is matched with the third entry in Table 1. This gives the entrance ramp as 23251 and the exit ramp as 43631. The first interchange the vehicle would pass through would be 23 and the last

TABLE 4

| First Interchange | Direction Leaving | Last Interchange | Direction Approach | TURNS THROUGH INTERCHANGE 21 | 23 | 41 | 42 | Distance Between Interchange |
|---|---|---|---|---|---|---|---|---|
| 23 | 4 | 43 | 1 | - | - | - | - | 3.0 |
| 23 | 5 | 41 | 1 | 7 | - | - | - | 5.0 |

would be 43. By comparing entries from Tables 1 and 2 one can see that the vehicles approach 23 from direction 3 and leave in direction 4. Adding the approach and leave codes results in a 7 turn through interchange 23. This would be a turn from the north leg to the east leg which is correct. The vehicles then approach interchange 43 from the 1 direction and leave in the 4 direction. The approach and leaving result in a 5 movement which is a straight through movement from west to east and is the correct movement for this transfer.

For the trip between 441 and 221 the second and fourth entries from Table 1 are matched with the second entry in Table 2. Results of this matching show the first ramp as 23251 and the last as 41611. The first interchange is 23 and the last is 41 and the vehicle passes through 21 with a 7 movement in making the trip. By adding the interchange approach and leaving codes an 8 movement is obtained for interchange 23 and a 5 movement for interchange 41 which are the correct turns.

Distances for both transfers, via expressways, can be obtained by adding the distance from origin zone to entrance ramp, entrance ramp to first interchange, first interchange to last interchange, last interchange to exit ramp and exit ramp to destination zone. The "airline" distance between zones and ramps must be increased by a factor of 1.25 to convert it to arterial mileage and in addition a tenth of a mile added for each ramp.

Now that the procedure for routing and measuring expressway and city street trips has been described, the remaining basic problem is to compare the two routes and allocate a percent of trips to expressways. The solution to this problem is described next.

## Method for Comparison of Routes and Allocation of Trips

As stated at the beginning of this chapter, the allocation of trips to expressways was based on combinations of distance and speed ratios. Therefore, these ratios had to be calculated for each group of zone-to-zone trips. The easiest way to make this calculation, utilizing electronic equipment, was to summarize the pertinent route information for the expressway and alternate route onto one punched card. Card number 089 is the card which is used to summarize the route information and to calculate the speed and distance ratios and percent and number of vehicles assigned to expressways. The layout of this card may be seen in the appendix.

The first three columns of card 089 contain the card number. Columns 4 through 19 contain the number of the origin and destination zone and the number of trips between them for 1953 and 1980. Columns 4 through 19 are obtained from the cards used in making the C and D trip transfer tables. The alternate distance columns 20, 21, and 22 are calculated as described earlier in this paper. The "airline" distance and direction code (column 23) were available from a deck of zone-to-zone cards used in making "Trip Desire Charts."[2]

Columns 24 through 36 are obtained by matching the origin columns and trip direction columns on card 089 with the origin and direction code for the 087 origin deck of cards, and transfer-punching the information from card 087 onto card 089.

Columns 37 through 49 are obtained in the same manner by matching the destination and direction codes for the two cards and again transfer-punching the 087 information into the 089 card.

Columns 50 through 54 are obtained as a result of matching the 088 card with the 089 card and transferring information. The control for this matching operation is the first and last interchange number, which appears in both sets of cards. From the 088 cards the distance between the first and last interchange is transferred into columns 50, 51 and 52. The first and last turns recorded in columns 53 and 54 are obtained by adding approach and leave codes for the first and last interchange. The 604 does this automatically after reading one code from one card and the other code from the second card.

At this point all the basic information necessary for calculating speed and distance

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[2] See paper, "Construction of Trip Desire Charts", Detroit Metropolitan Area Traffic Study, June 28, 1955.

ratios has been transferred to the 089 card. Information for the remaining columns on Card 089 is obtained by manipulating data already punched in the card. The next item, distance on the expressway, was obtained by adding distance ramp to interchange (cols. 32, 33, 34), distance interchange to ramp (45, 46, 47), and distance interchange to interchange (50, 51, 52). The total expressway trip is calculated by adding the entry in columns 35, 36 and 48 and 49 which are the distances between zones and ramps, to the distance on the expressway. Distance-ratio is obtained by dividing the total expressway trip distance (cols. 58, 59, 60) by the distance on the alternate (cols. 20, 21, 22). Speed-ratio is determined by dividing the total expressway trip distance by half the distance on the expressway plus the zone-to-ramp distances.

A deck of master cards showing the percent assigned for the various combinations of distance and speed ratios was made up for use in determining the percent assigned for card 089. These cards were match-merged with the 089 cards and the percent assigned, punched into the 089 cards. The 1953 and 1980 vehicles assigned were determined by multiplying the 1953 total transfer (col. 10-14) and the 1980 transfer (col. 15-19) by the percent assigned. This whole procedure except for the initial coding can be done by high speed electronic calculators and tabulators.

After the number of vehicles assigned is calculated and punched into the cards the interchange turns and section volumes can be summarized and plotted on maps. Details of the summarizing procedure can be seen from the step by step machine procedure in the appendix.

## Chapter Summary

In this paper the coding techniques and machine procedures worked out by the Detroit Staff to facilitate a rapid machine assignment were presented. The reasoning and approach to the problems were shown and the coding technique and machine procedures were explained in great detail.

Several features contribute to the speed and workability of this system. First, is that alternate distances can be rapidly and accurately estimated by a machine technique. Second, is that the concept of treating an expressway trip in parts and matching parts together to form trips eliminates the necessity of reviewing each zone to zone transfer and makes coding vastly simpler. Finally, the adaptability of this procedure to high speed computing and summarizing makes possible a tremendous conservation of time.

One hundred zone-to-zone transfers were pulled at random to check the expressway routing, resulting from the coding and matching technique. The 100 transfers were coded for the best expressway route and compared to the routing which resulted from this assignment procedure. Less than five percent of the routings were different. Even for the ones which differed, the percent assigned was only slightly different. Therefore, it appears that this procedure is not only fast but accurate as well.

Using this assignment method 23,500 zone to zone transfers were assigned to a network of expressways and connecting arterials in the Detroit Metropolitan Area totaling 370 miles in slightly less than three weeks.

# PART III: RESULTS AND ANALYSIS OF ASSIGNMENT

## Need for Two-Variable Assignment Curves

After the assignment in Detroit was completed, it was possible to summarize the distance and speed-ratios which occurred. Figure 7 illustrates the range of speed and distance-ratios which were obtained. The unshaded areas are ones where speed and distance-ratios did not occur. Values of speed and distance-ratios were obtained throughout the shaded area. This pretty clearly shows the range of possible distance and speed-ratio combinations and demonstrated the need for a two-variable solution to the assignment problem.

Table 5 gives a comparison of the assignment using the speed and distance-ratio-curves to the assignment using curves developed for the Shirley Highway.[3] This com-

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[3] Trueblood, Darel L., "Effect of Travel Time and Distance on Freeway Usage". Bulletin 61, Highway Research Board, Washington, D.C.

parison was made possible by converting all the various combinations of distance and speed-ratio to equivalent time-ratios. Equivalent time-ratio is determined by dividing distance-ratio by speed-ratio. Trips were then summarized by equivalent time-ratios showing total assigned and total trips for 1953 and 1980. Knowing the total trips for each time-ratio it was possible to apply assignment percentages based on the Shirley time-ratio curve, and thus determine the amount of trips which would have been assigned by the Shirley time-ratio curve.

From Table 5 it can be seen that the total trips assigned by the distance-speed-ratio curves was 1,534,914. The Shirley curve assigned 96,774 more to make a total

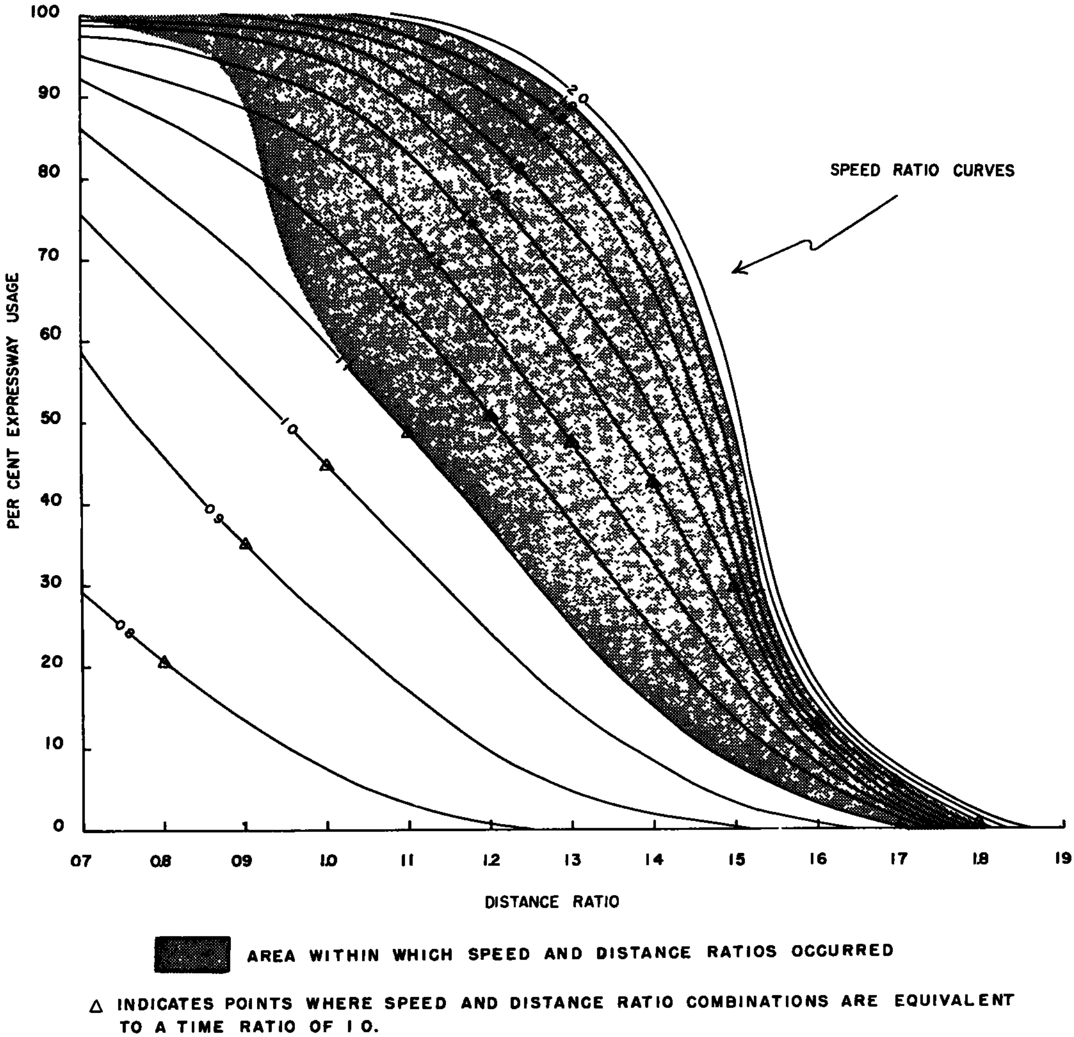



Figure 7. Expressway usage as related to speed and distance ratios.

of 1,631,688 trips. The difference in total assignment is not critical. However, the difference in the number assigned for certain individual time-ratios is critical. Assignment by the two curves was very close for time-ratios up through 0.8. However, for time-ratios higher than 0.9 the Shirley curve assigned much higher percentage-wise. At a time-ratio of 0.9 the Shirley curve assigned 13.9 percent higher; for time ratios of 1.0 it assigned 40.5 percent more and at 1.1 it assigned 98 percent more. From ratios of 1.2 and above the assignment was more than doubled by using the single-variable time-ratio curve. It is true that more than half of the transfers had time-ratios less than 0.9. However, there is still a substantial difference in the number assigned for time ratios of 1.0 and 1.1.

The apparent reason for this differential in assignment is that equivalent time-ratios of 1.0, 1.1, etc. are the result of combinations of high distance and speed-ratios as well as low ones. A low assignment would be expected for these combinations involving high distance-ratios. The Shirley time-ratio curve or any time-ratio curve cannot take these variations into account since it can only assign one value for every time-ratio and this value represents a mean based on the characteristics of trips found in the Shirley Study. The Shirley trips involved slower speeds and smaller distance disadvantages for time-ratios of 1.0 and higher; therefore, its proportinate use should be higher.

The expressway network designed for the Detroit Area afforded a definite time advantage for the average trip assigned. The mean time-ratio was 0.76. Most of the

TABLE 5

COMPARISON OF ASSIGNMENT BY SPEED AND DISTANCE-RATIO CURVES TO ASSIGNMENT BY SHIRLEY TIME-RATIO CURVE

| Time Ratio | 1953 Total Trips | Number Assigned by Speed-Distance | Number Assigned by Shirley Curve | Difference | Percent of Difference |
|---|---|---|---|---|---|
| 0.4 | 159 | 157 | 159 | + 2 | 1.3 |
| 0.5 | 51,912 | 51,377 | 50,874 | - 503 | 1.0 |
| 0.6 | 422,047 | 409,297 | 400,945 | - 8,352 | 2.0 |
| 0.7 | 443,671 | 402,715 | 385,994 | - 16,721 | 4.2 |
| 0.8 | 455,059 | 350,114 | 350,395 | + 281 | 0.8 |
| 0.9 | 316,352 | 172,130 | 196,138 | + 24,008 | 13.9 |
| 1.0 | 283,651 | 96,933 | 136,152 | + 39,219 | 40.5 |
| 1.1 | 185,042 | 30,841 | 61,064 | + 30,223 | 98.0 |
| 1.2 | 143,156 | 14,762 | 30,063 | + 15,301 | 103.7 |
| 1.3 | 112,487 | 5,120 | 13,498 | + 8,378 | 163.6 |
| 1.4 | 47,235 | 1,334 | 3,779 | + 2,445 | 183.3 |
| 1.5 | 62,451 | 134 | 2,498 | + 2,364 | 1,764.2 |
| 1.6 | 5,544 | 0 | 111 | + 111 | - - |
| 1.7 | 1,842 | 0 | 18 | + 18 | - - |
| TOTAL | | 1,534,914 | 1,631,688 | 96,774 | |

trips fell in the range where they had high assignment by both the speed-distance-ratio curves and the time-ratio curve. The fact that most of the trips fell in this range was due to the high speed-ratios obtained. The high speed-ratios were due to the layout of the expressway network, which made it possible for a large portion of the average trip via expressways to be on the expressway itself. The assumption of a 2:1 ratio between expressway and city street speeds was also a factor.

Assignment to an expressway network, having more trips in the high distance-high speed-ratio ranges, would be quite a bit higher using the time-ratio curve as opposed to the distance-speed-ratio curves. These kinds of speed and distance-ratios would be possible in a network which, due to its high speed potential, caused trips to divert from greater distances, thus causing high distance and speed-ratios. Since it is almost impossible to determine the kind and range of trips which will occur in a given expressway network, it seems logical to use a series of curves which are flexible and can take a greater range of activities into account. Such are the distance-speed-ratio curves.

## Assignment vs. Flow

Traffic assignment does not always provide the planner with an accurate description of flows on expressways. Actual flows are dependent upon capacity. It is possible that volumes could be assigned to an expressway which could not possibly be handled, due to capacity limitations. Therefore, assignment and flow are not necessarily synonomous.

Even though flows are not always accurately predicted, traffic assignment provides the planner with the kind of information he is seeking. For example, a good approximation of expressway demand, if each trip could be made on most convenient route, is obtained. The demand based on any criteria can be estimated with reasonable accuracy. In general the traffic assignment provides the planner with a tool which can be used to test the effectiveness of a plan from the standpoint of traffic service. For example an assignment of very high loads might indicate a defect in the plan which could be better corrected by adding another expressway or a shift in location rather than the addition of more lanes. An assignment of small volume raises a doubt as to the necessity of providing the amount of capacity in the plan.

Traffic assignment was a very useful tool in arriving at a final expressway plan for the Detroit Area. One plan was devised and tested by assignment. The assigned traffic resulted in some impossible over-loads and a general uneven distribution of the traffic load. Based on the assignment a new plan was devised and tested. The second plan proved much better than the first. The assigned loads were more evenly distributed and 200,000 more trips (9.2 percent more) were carried. The total vehicle mileage travelled by all trips in the area was almost identical for both plans. Therefore, based on the information gained from the traffic assignment a plan was devised which carried more trips, distributed the load more evenly and kept the total vehicle miles the same and with only a slight addition in the expressway mileage of the system. Based on the second assignment a few minor changes were made and a final plan was laid out. The process of assignment, plan revision, reassignment and final revision required about four months.

## Suggestions for Additional Research and Development

Some additional work is necessary to determine whether or not the speed and distance-ratio curves have universal application. Exploration might reveal other variables which could serve as a better predictor of expressway use. Refinement of the assignment procedure through improved coding and machine techniques would be desirable.

A real contribution could be made with the development of basic flow theories, so that traffic flow could be simulated. A field barely touched awaits the researcher in traffic simulation with high speed computors. A traffic simulation model would be very useful in estimating flows on arterial streets, under different and changing conditions. It seems entirely possible that a model could be developed whereby flows could be estimated on an expressway and street system at the same time. By changing the locations or capacities of proposed facilities the whole traffic load would be automatically and instantaneously rearranged. With this kind of a model and a given set of traffic requirements the effects of alternate kinds of solutions can be determined and weighed. Solutions to problems of this order have already been worked out for hydraulic systems and electrical networks. Some experimentation and research along these lines might prove profitable in developing a flow theory for urban traffic volumes.

It is true that this kind of approach to urban traffic is for the future but how long in the future depends upon the curiosity and ingenuity of the researcher.

## ACKNOWLEDGMENTS

The author wishes to express his appreciation to the Policy Committee of the Detroit Metropolitan Area Traffic Study for permitting him to prepare this paper. He also wishes to thank the many persons who helped and advised him in its preparation, particularly J. Douglas Carroll, Jr., Director of the Study, Darel Trueblood of the Bureau of Public Roads, and M. Earl Campbell of the Highway Research Board. The assistance of Robert Vanderford, Tabulation Supervisor for the Study in working out the details of the assignment procedure is also gratefully acknowledged.

# Appendix

## *Step by Step Machine Procedures*

Robert E. Vanderford

From previous procedures there should be available a set of cards with the interzonal traffic at present volumes and expected volumes at some future date - in this case, 1953 and 1980. The street distance from zone center to zone center must be punched in the cards along with the code for direction travel. Following is a step by step outline of the machine procedure:

1. Sort the inter-zone cards (089) to direction within zone of origin and selective merge behind zone to ramp master cards (087).
2. Intersperse gang punch ramp number, first interchange, approach code, distance ramp to interchange, and distance zone to ramp.
3. Sort the inter-zone cards (089) to direction within zone of destination and selective merge behind ramp to zone master cards (087).
4. Intersperse gang punch ramp number, last interchange, leave code, distance-interchange to ramp, and distance ramp to zone.
5. Run inter-zone cards (089) through collator pulling all cards where section (first four digits of ramp) of origin equals section of destination. Run equal section cards through again pulling equal ramps. Discard equal ramps as non-expressway trips. Hold equal section cards for step No. 13.
6. Sort the inter-zone (089) cards to last interchange within first interchange and selective merge behind interchange to interchange master cards (088). The unmatched are set aside.
7. Intersperse gang punch distance interchange to interchange into inter-zone cards (089) using the 604 Electronic Calculator. On the same pass, add first interchange leave code from the master card (088) to first interchange approach code from the inter-zone card (089). Punch as first interchange turn code into the inter-zone cards. Add last interchange approach code from the master card (088) to last interchange leave code from the inter-zone card (089). Punch as last interchange turn code into the inter-zone cards (089).
8. Check unmatched from Step No. 6 to make sure that first and last interchanges are the same. Put through 604 and add first interchange approach to last interchange leave. Punch as first interchange turn. As the trip passes through only one interchange, distance-interchange to interchange, the last interchange turn are left blank.
9. Because the expressway system is quite complex there are trips that double back at the first or last interchange, as a result to the coding and matching procedure. One example of these is shown in Figure A.

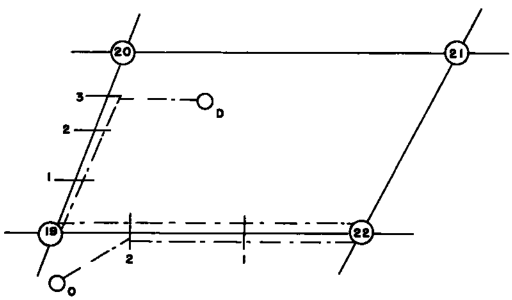



Figure A.

In coding O as an origin for the travel direction of a trip between O and D, ramp 19223 would be selected and 22 would be coded as the first interchange. The coding for D as a destination in this travel direction would show ramp 19203 as the last ramp and 19 the last interchange. Matching with an interchange routing card would result in the section between ramp 19223 and interchange 22 being duplicated in the trip. These double-back trips can easily be detected because the approach and leave codes for interchange 22 are the same, or to say it another way, the turn in interchange 22 is double the approach or leave code. Therefore, sort all inter-zone cards, except equal-section, on first turn. The two's and ten's are obviously doubled back. The five's, seven's and nine's cannot be doubled. Since there is no approach code two, there will not be any doubled back trips in the four's.

There are other kinds of doubled back trips but they are all detected by sorting on the turns and checking to see if the turn is twice the approach or leaving code.

10. All doubled back at origin trips should be reproduced using the opposite first interchange and approach from the one punched in the card. First turn code and distance interchange to interchange must be dropped and repunched as in step No. 6, using the new first and last interchange.

11. All inter-zone cards must be put through steps 9 and 10 again for last interchange turn and leave code and doubled at destination trips corrected. Less than 2 percent of the trips will have portions doubled back.

12. After all doubled back trips have been corrected, all inter-zone cards except equal section trips are put through the 604. Distance ramp to interchange, distance interchange to interchange, and distance interchange to ramp are totaled and punched as distance on expressway. On the same pass distance zone to ramp, and distance ramp to zone are added to distance on expressway and punched as total expressway trip.

13. Sort the equal section cards from step No. 5 the last interchange within first interchange. Selective merge behind interchange to interchange master cards. Set unmatched aside.

14. Put merged cards from above through 604. Add distance ramp to interchange to distance-interchange to ramp from the equal section card. Subtract distance-interchange to interchange and change sign to plus if answer is negative. Punch as expressway distance. Add distance-zone to ramp and distance-ramp to zone to expressway distance and punch as total expressway trip.

15. Put unmatched from step No. 13 through 604. Subtract distance-ramp to interchange from distance-interchange to ramp. Change sign to plus if negative and punch as expressway distance. Add distance-zone to ramp and distance-ramp to zone to expressway distance and punch as total expressway trip.

16. Put all inter-zone cards from steps 12, 14 and 15 through 604. Divide total expressway trip by distance on alternate route. Carry result to two decimal positions and punch as distance-ratio. Divide total expressway trip by one half the expressway distance plus the zone to ramp and ramp to zone distances. Carry result to one decimal position. Punch as speed-ratio.

17. Sort above cards to speed-ratio within distance-ratio and merge behind percent assignment master cards.

18. Make a 604 pass intersperse gang punching percent assignment and extending 1953 and 1980 traffic volumes in each card by percent assignment. Punch as 1953 and 1980 vehicles assigned.

19. Summarize interchange turns and section and ramp volumes. Sort first turn within first interchange. Blanks in first turn are held for ramp summary.

20. Cut a summary card for each turn at each interchange with 1953 and 1980 volumes assigned.

21. Sort inter-zone cards from above to last turn within last interchange. Blanks in last turn are set aside for ramp summary.

22. Cut a summary card for each turn at each interchange with 1953 and 1980 volumes assigned.

23. Sort inter-zone cards from above to last interchange within first interchange.

24. Cut a summary card for each pair of interchanges. Set inter-zone cards aside for ramp summary.

25. Sort interchange to interchange master cards to last interchange within first interchange. Match against interchange pair summary cards from step No. 24.

26. Reproduce 1953 and 1980 assigned volumes from interchange pair summary cards into matching interchange to interchange master cards.

27. Sort interchange to interchange master cards on the column reserved for turns through the lowest numbered interchange, in this case, column 20. Cut a summary card for each turn code showing interchange number, turn code, 1953 and 1980 vehicles. Use 604 or 402-519.

28. Sort on next interchange, column 21. Cut summary cards as above.

29. Continue above until last column in interchange to interchange card has been sorted and summarized.

30. Combine summary cards from above with summary cards from steps 20 and 22. Sort to turn code within interchange number.

31. Run a tabulation showing interchange number, turn code, and total vehicles assigned 1953 and 1980. Post figures to map of expressway system.

32. Sort all inter-zone cards to interchange approach code within ramp of origin.

33. Cut a summary card for each approach code at each ramp. Show 1953 and 1980 assigned vehicles.

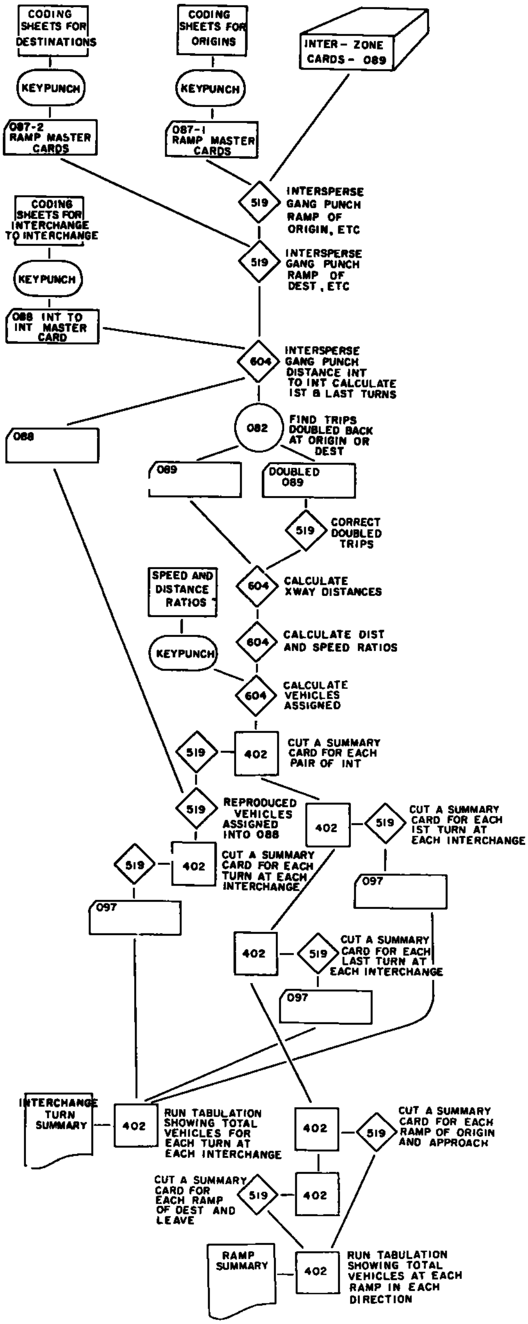
34. Sort all inter-zone cards from above to interchange leave code within ramp of destination.

35. Cut summary cards as in step 33.

36. Combine summary cards from steps 33 and 35. Sort the approach-leave code within ramp number.

37. Run a tabulation showing ramp number, approach-leave code, 1953 and 1980 vehicles assigned. Post figures to map of expressway system.

# *Flow Diagram for Machine Traffic Assignment*




EXPRESSWAY ASSIGNMENT FLOW DIAGRAM

# Card Layouts