CHAPTER VII

TRAFFIC ASSIGNMENT

Traffic assignment may be defined as the process of allocating a given set of trip interchanges to a specific transportation system. The process may be used to estimate the traffic load on the various sections of a system for a future year or for the simulation of present conditions. For a reproduction of the existing traffic loads, the origin and destination survey or present-day synthesized trip interchanges are used for the traffic assignment. For the future year a forecast of area-to-area movements must be made.

Input to the traffic assignment process are: 1) a description of the transportation system, and 2) a trip volume matrix of the interzonal trip interchanges. The techniques outlined in this manual will provide estimates of the traffic volumes on each link of the system, by direction, with directional turning movements at intersections.[1]

A. HISTORY OF TRAFFIC ASSIGNMENT

Highway system planning might be dated from the introduction of the origin and destination survey. The O-D survey produces "trip tables" that measure the trips people make independently of the routes that they select. Historically, origin-destination trip movements have been illustrated by some form of "desire lines" showing the magnitude of the trips on the shortest airline distance between the terminal points of the trips. The problem facing the highway planner, then, is the routing of these trips over the existing and/or the proposed facilities. This routing problem was the impetus for the development of the traffic assignment techniques. A compendium of correspondence, published in 1950 by the Highway Research Board, summarized the practices of several States in assigning traffic to routes. Considerable difficulty was expressed in the evaluation of the driver's choice of route to complete his interzonal trip. Quantitative route choice decisions were based on traveltime, distance, and user cost as comparison parameters. Some States based their decision

---

[1] Also see Appendix B - Biblography for more traffic assignment information - in particular, "Traffic Assignment, August 1973, Urban Planning Division, Federal Highway Administration, Washington, D. C. 20590.

on the engineer's personal experience and judgment. At that time no empirical formula had been devised and the analytical approaches that were suggested were based only on theory.

Mr. Earl Campbell of the Highway Research Board proposed an 'S' curve, based on theoretical considerations, relating the percent usage of a particular facility to a traveltime ratio. Apparently, the primary concern at this time was with the diversion of traffic from an existing street network to a proposed freeway or expressway facility. The traveltime ratio was expressed as the traveltime via the expressway divided by the traveltime via the existing street system.

To evaluate these theories, studies were undertaken which attempted to relate the choice of route to time and distance factors. As a result, empirical studies of street and freeway usage were made in some half-dozen cities in the United States. Tabulations of basic data were obtained from the studies of diversion to the following expressways: 1) Shirley Highway in Arlington, 2) Gulf Freeway in Houston, 3) Willow Run Expressway in Detroit, 4) Alvarado and Cabrillo Freeways in San Diego, and 5) Central Expressway in Dallas. From this information, AASHO developed a standard traffic diversion curve as recommended policy for predicting usage of urban freeways. The curve was based on the traveltime ratio as the most important parameter. Other organizations and State highway departments developed diversion curves using such parameters as time and distance, speed and distance, time saved and lost, and distance saved and lost.

Studies using these methods dealt, in general, with a single freeway and parallel existing routes. As the capability to handle single facilities improved, the need for techniques of analysis for entire highway systems was realized. The manpower and time requirements to perform the tedious calculations seemed to prohibit such extensive approaches to urban highway planning.

At first, traffic assignment was done manually; the mechanical techniques, as we now know them, were not available. The automation of traffic assignment procedures began with the advent of the punch card tabulating equipment, and some very sophisticated techniques were developed. As electronic computers came into general use in the highway field, traffic assignment computer programs were also developed, but they were only modest improvements on earlier punched-card tabulating procedures. They were, for the most part, tabulating programs that summarized the data that the engineer prepared. The route selections for each interzonal movement were still made by the engineer based on his personal knowledge and judgment. Given the interzonal movements and the routing that was selected by the engineer, the computer merely aggregated to the final result.

Attempts to develop a complete traffic assignment program were always blocked by the route selection problem. Fortunately, others working in a field quite unrelated to highways had a similar problem. The telephone companies were faced with the problem of route selection for the direct dialing of long distance telephone calls.

The most significant development in the field of traffic assignment came in 1957 with the presentation of two research papers. One was by Mr. E. F. Moore, titled "The Shortest Path Through a Maze," presented at the International Symposium on the Theory of Switching at Harvard University. The other was by Mr. George B. Dantzig, titled "The Shortest Route Problem" in Operations Research 5:270-3, 1957.

About this time, Dr. J. Douglas Carroll, Jr., was searching for a solution to the problem of traffic assignment for the Chicago Area Transportation Study. The services of the Armour Research Foundation were retained and Mr. J. G. Haynes and Mr. F. C. Bock were assigned to perform the research. This investigation resulted in an electronic computer program developed for an intermediate-size computer. It had been designed to find the minimum time (or distance) paths through networks. The program was something of a laboratory novelty as it used a large portion of the computer storage and, as a result, could accommodate only a very small network. It was, however, quite valuable as a basis for further development.

Concurrently with the work of the Chicago staff, engineers in Washington, D.C., were also searching for a solution to their assignment problems. A joint project was undertaken involving the Bureau of Public Roads, the Washington Regional Highway Planning Committee, and the General Electric Computer Department of Phoenix, Arizona. This project produced a battery of high-speed computer programs that would assign the nondirectional interzonal traffic movements, including a provision for specifying time penalties for turns. In addition, it incorporated the option of using a diversion or an all-or-nothing assignment.

Independently, Dr. Albert Mayer and his staff of the Detroit Area Transportation Study began the development with a slightly different approach. The California State Division of Highways, having developed their assignment techniques before the Moore Algorithm, then applied their unique diversion curve to the minimum path techniques in their version of the assignment program.

The Washington system was further refined by the Minnesota Department of Highways, the Bureau of Public Roads, and the General Electric Computer Department to provide greater flexibility by permitting traffic assignments by direction of travel. In 1960, General Electric, in cooperation with the District of Columbia Highway Department, added a refinement that prohibited selected turns in the calculation of the minimum time paths. Another modification, developed first by the staff of the Chicago study, and later by the Traffic Research Corporation and the Bureau of Public Roads, was the addition of techniques to calibrate an assignment by capacity restraint.

The initial BPR traffic assignment battery was written for the IBM 704 Computer. These programs were later modified for processing on the IBM 7090/7094 systems (early 1960's). This chapter describes the traffic assignment process as it relates to the programs developed for the IBM S 360 series of computers.

B. PURPOSES OF TRAFFIC ASSIGNMENT

The purposes of traffic assignment may be listed as follows:

1. To determine the deficiencies in the existing system.

2. To assist in the development of a future transportation system through an evaluation of the effects of improvements and additions to the existing system.

3. To provide systematic and reproducible tests for alternate system proposals.

4. To develop construction priorities by assigning the trips forecasted for intermediate years to their corresponding systems.

5. To provide the highway designer with the design-hour traffic volumes.

6. To provide necessary input and feedback to other planning tools.

C. THE GENERAL PROCESS OF TRAFFIC ASSIGNMENT

1. Traffic Assignment in the Transportation Planning Process.

As conceived today, a transportation planning study should be a cooperative, comprehensive, and continuing process. The principal objective of this transportation planning process is to determine the future form of the transportation network and the volume of vehicles or persons using any portion of this network.

There are four phases in any planning process: (1) organizing for the study; (2) collecting and analyzing the data; (3) forecasting, formulating, testing, and evaluating the plan or plans; and (4) plan implementation. The first technical phase of the transportation planning process is the inventory of the existing conditions. Analysis of the data collected in these inventories provides the source information upon which the estimates of the future growth of the area are based. After estimates of the future travel have been made, the trips are then assigned to an assumed transportation network. The results are evaluated with reference to the desired level of service plus the social and economic consequences of the assumed system. Inevitably some revision will be necessary. The information obtained during this assignment is then used to modify the system, and another future travel assignment is made to the adjusted transportation network. This process is repeated until satisfactory results have been achieved.

The traffic assignment techniques developed for use on a high-speed computer provide engineers and planners the necessary tools for testing alternate networks for adequacy in serving estimated travel demand. The efficiency of a network depends primarily on its location and its ability to satisfy this demand. Various possibilities, therefore, must be evaluated.

It should be understood that traffic assignment does not take the place of planning. It merely enables the planner to uncover the areas of greatest needs, and to test the consequences of various possible plans.

Analysis of the assignment results, while not considered part of the process by some, is extremely important. Traffic assignment analysis should be designed and carried out with the following applications in mind: (1) establishing the validity of the assignment results; (2) systematically producing workable data for evaluation (including economic evaluations, further general planning, design volumes); (3) permitting evaluations of internal system performance (identifying good and weak points in the system, delineating deficiencies, etc.); (4) establishing comparative evaluations with other parameters to aid in the planning and design toward an "optimum" system; and (5) permitting the evaluation and interpretation of results.

2. A General Description of the Procedure

The traffic assignment procedure is based essentially on the selection by an electronic computer of a minimum impedance-path between zones. To accomplish this task, a description of the network is coded, key punched, and stored in the memory of the computer. After selecting the minimum impedance-path between zones, the computer proceeds to assign the trips to these routes. Traffic volumes are thus accumulated for each route section.

For coding purposes, the route sections are considered to be the one-way part of a route lying between two intersections. They are referred to as "links." Intersections are points at which two or more route sections meet, allowing the possibility of a change in the travel direction. The intersections are referred to as "nodes." The centers of activity where trips are generated are also represented by nodes which are called "centroids." There is one centroid for each traffic assignment zone and each external station in the study area. There may be only four links connected to a node.

Each node in the system is identified by a unique number. The lowest node numbers are reserved for centroid nodes. The numbers may be as large as 16,000. In addition to the node number at the end of each link, information concerning the travel speed and distance on the link is necessary. The capacity and existing volume on the link should also be coded. There is provision for many other types of data. Suggested items are: functional classification, administrative jurisdiction, facility type, surface type, route number, land use, parking and condition. Of course, other items may be included, but none are mandatory. The more items recorded the wider the range of analysis of results that can be made.

After the coding is complete, the data are key-punched into standard tabulating cards and later used as input to the computer. These cards are subjected to detailed manual or machine contingency checks. Such checks guarantee that the network is continuous; i.e., that there are no missing links; that there are no dead ends; that each node has the correct number of links associated with it; that there are no duplicate numbers used for coding; that information coded for each link falls within certain specified ranges; and that there are no invalid data items in the cards. These checks try to insure that the computer processing will not fail because of coding inconsistencies, inaccuracies, or the incompleteness of a network.

These coded link data cards are then read by a computer program called BUILDHR (or NETWORK), which performs many edit checks along with many of the consistency network checks mentioned above. The program then writes a sorted file of link and intersection description records, which is called the historical record. The historical record shall be referred to as the HRO when it is being written out by a program, or HRI when it is being read by a program. It may be examined for detail by use of the program PRINTHR, or, alternatively, FORMAT. The historical record is the basic work file of the assignment programs.

The next step, the selection of the minimum impedance routes, is the key to the assignment procedure. The minimum impedance route is the shortest route from one node (usually a centroid) to another. All the routes from one centroid to all others are referred to as a "tree" or a "vine." The term "path" or "route" may be used in general discussion to eliminate confusion as to whether the path is a tree or a vine. A tree records the routings in such a manner that there is only one entrance link to a node. A vine records the routings in such a manner that all four links connected to a node may be traversed if necessary to ensure the minimum path. A vine is more accurate than a tree, but requires two to three times as much computer time to determine. If many intersections have prohibited turning movements, or large turning penalties associated with them, vines should be used. Otherwise, trees are recommended.

Whereas the tree is calculated to each node, the vine calculates to each of the legs of a node. This is a rather significant difference as shown in Figure VII-1. Suppose the minimum path between centroid A and centroid B is desired and the left turn on link 107-104 is prohibited. Suppose further that the minimum path to node 104 is via node 107 rather than via node 106. Under the tree option, the back node from node 104 is node 107, and since the left turn at node 104 is prohibited, the only available path from A to B is via nodes 107, 104, 103, 102, 101, and 105.

Under the vine option, the program will calculate the traveltime to the beginning of leg 3 at node 104 as coming from node 106. Therefore, under the vine option, the minimum path from A to B is via nodes 106, 104, and 105 - a much more realistic path.

The paths may be selected on traveltime (the most common criterion), or any associated link impedance such as distance or cost. The program BUILDVN reads the historical record and computes the minimum paths. The paths are written on a magnetic tape or disk file called PATHSO. When the file is read by subsequent programs, it is referred to as PATHSI. The paths may be examined for logical accuracy by use of the program PRINTVN.

Next, a program called LOADVN reads the PATHSI file and the TRIPSI (zone-to-zone trip matrix) file, and routes the zone-to-zone trips along their minimum path. As it does, it accumulates the link usage and the turning movements at each node. The program repeats this process for all selected zone-to-zone movements. When all routings are completed, the program reads in the HRI (historical record) file and merges the link volumes and turning movements with it, and writes out a new, more detailed HRO file. The program PRINTLD may

Portion of Transportation Network

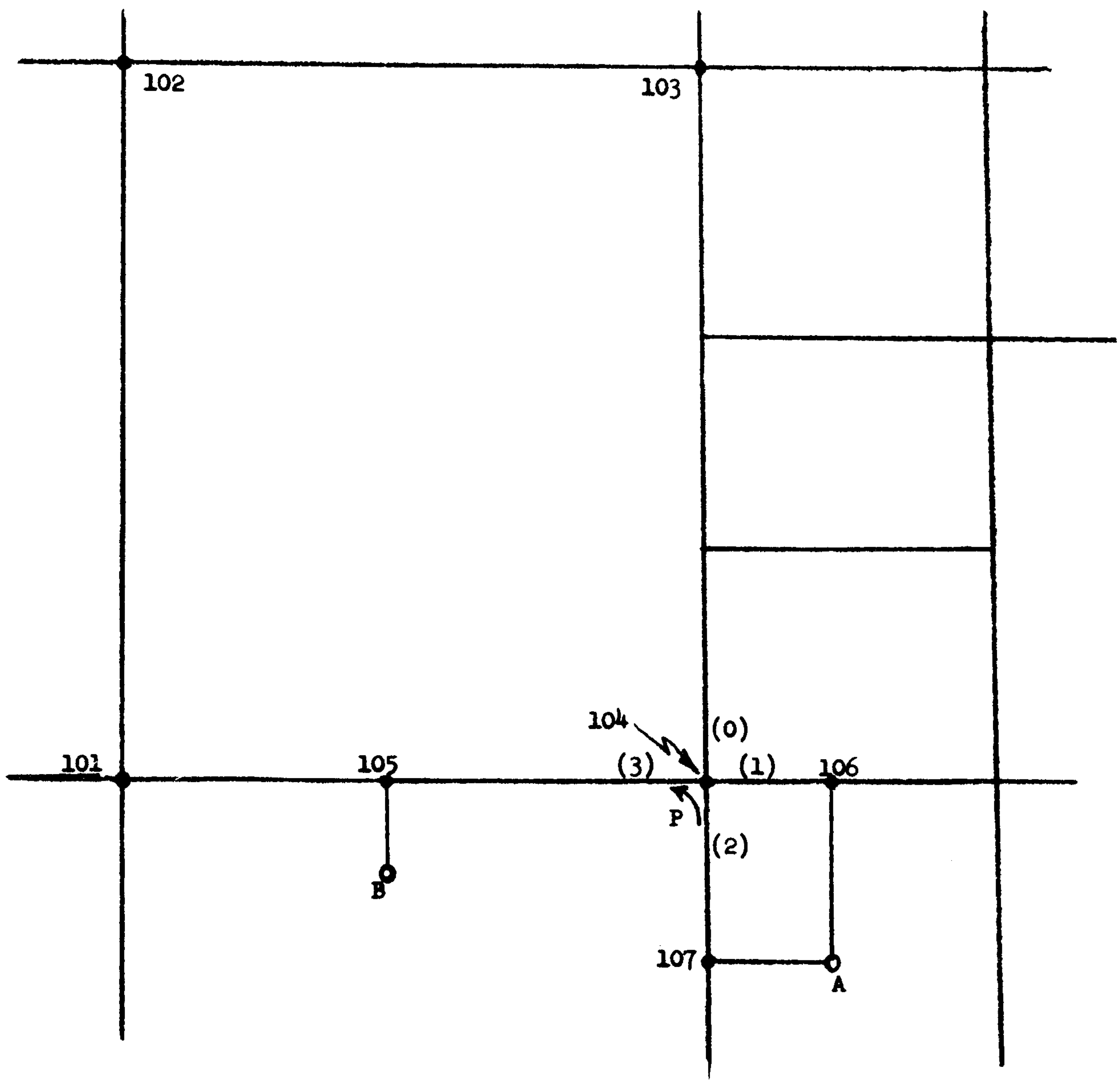


Figure VII -1

be used to read this HRO file (only now it will be referred to as the HRI file), and prepares readable printed summaries of the link loads and turning movements. Program FORMAT is a more complex, but a more useful program for examining the historical record in detail.

Some of the loads on the individual links may approach or exceed the capacity of the transportation facilities, thus affecting the traveltime or other criteria that were used to determine the minimum paths. In this situation, the computer program sequence may be interrupted by the analyst, and new minimum paths computed using a set of adjusted traveltimes. The automatic method for making these adjustments to the original network is called capacity restraint.

If the capacity restraint process is to be performed through the use of a computer program (the more logical approach), the program CAPRES is invoked. It reads the HRI file that contains the link speeds, travel impedance, volume and capacity for each link (where capacity is available) and adjusts the traveltime according to a predetermined volume-capacity relationship. The CAPRES program adjusts link traveltime in accordance with the level of congestion as reflected by the relation between assigned volume and link capacity. Thus, the speed necessary to travel the route section may be lowered much in the same way as increasing congestion causes speeds to be lowered in real situations. The use of capacity restraint to modify assigned traffic provides a more realistic distribution of traffic in the system.

The program CAPRES writes a new HRO file which can be read by the BUILDVN program, and the entire process is repeated until satisfactory overall loadings are achieved.

3. The Alternatives in Traffic Assignment

In simple terms, then, traffic assignment is the process of determining the amount of usage on segments of a highway network. The process is accomplished by first determining the most reasonable route, or path, through the network to be used while traveling from one point on the network to another. Once the path has been determined, the number of trips that desire to travel from the origin point to the destination point are routed along the path and the highway segment usage is accumulated. The process is completed for all points in the network where trips originate or terminate. In effect, traffic assignment, then, is a simulation of link volumes in a highway network.

The analyst who wishes to use traffic assignment techniques for traditional networks has several considerations before beginning the detailed work associated with the process:

(a) - All-or-nothing or Diversional Routing (not available in PLANPAC/BACKPAC package)

(b) - Directional or Non-directional Assignment (not available in PLANPAC/BACKPAC package)

(c) - Capacity Restraint

(d) - Peak Hour or Daily Traffic

Each of these items will be discussed in detail in the following paragraphs.

The term "traditional" is used simply because this type of network has been used for many years. Its counterpart is the "spiderweb" network. A traditional network is employed when greater detail is desired.

a. All-or-nothing or diversional routing--As discussed earlier, problems in determining the proper path between two points in the network will be quite prevalent when two or more higher-level-type facilities are competitive through major portions of the network. The most direct approach is simply to choose the facility that will result in the minimum delay or impedance between the points of decision. All the traffic between the considered points of origin and destination will then be routed along that path. This procedure is easier to use and is known as the "all-or-nothing assignment" technique. The alternative method is to allow several routings between the considered points of origin and destination. Then, the traffic is allocated by some criteria so that different portions will use the alternative routes. This method is known as "diversion assignment." Capacity restraint essentially provides for diversion to many routes based upon an averaging process between successive assignments.

The all-or-nothing technique is the more widely used since it is easier, less expensive, more comprehensible, and less prone to errors than diversion assignment. At the time of this manual preparation, the FHWA battery of transportation programs for use on the IBM System 360 does not include a diversion technique. The all-or-nothing techniques are offered in such a manner that the user can select the spatial parameter for selecting the optimum route. Variables such as time (the most commonly used), distance, cost, etc., or a combination of these may be selected at the user's discretion.

b. Directional or non directional assignment--Directional assignment allows the user to examine the segments of highway on a "directional" basis; i.e., the planner can analyze the usage in a north-to-south direction separately from the usage in the south-to-north direction. This means, of course, that he must prepare the network with more detail than if he is interested only in the total (non directional) usage on the segment of highway. The non directional usage can obviously be obtained through the use of directional assignments by simply adding the directional volumes for both directions of the link.

Non directional assignment involves more than this simple concept, however; one-way links are not utilized, which precludes the detailed use of ramps for freeways. The route from origin to destination will be same as the route from the destination to the origin. This will not necessarily be true in directional assignments. The directions of trips have no meaning in non directional assignments as the trips from origin to destination will result in the same link loads as if they were in the opposite direction. Turning movements through intersections have somewhat different meanings. Assignment of production-attraction, directional, or triangular trip tables will result in the same link loads. Directional trip tables should be used only for directional assignments. Since there is insignificant cost and time difference in the preparation of a directional network, it is the recommended procedure. The computer programs in the package are aligned to directional analysis.

c. Capacity restraint--Capacity restraint is the method whereby the link volumes resulting from a traffic assignment are compared to the vehicular capacity of the link, and travel times on the link are adjusted in a predescribed manner to reflect more realistic operating characteristics. This comparison is done on a directional basis. (No non-directional capability in PLANPAC/BACKPAC.) The ratio of assigned volume to capacity is referred to as the "volume-capacity ratio," or simply as "V/C." If only a relatively few segments in the highway network are overloaded, and most traffic appears to be operating near legal speeds, then capacity restraint techniques need not be considered.

Traffic can be assigned realistically to a highway network by considering the practical capacity of each link (or as many links as possible) in the network. The capacity of the links comprising the existing highway network can be computed, and an estimate of the future highway capacities can be made. However, it is difficult to estimate the speed at which future traffic will travel without knowing the volume which will be carried on a particular link. A speed (or traveltime) must be given for each link on the system, since this is the parameter which determines the minimum path to be selected by the tree-vine building program.

Capacity restraint, as the FHWA computer programs function, is applied in an iterative manner. As the user prepares the highway network for computer simulation, one of the additional parameters that must be provided is the capacity for as many segments of highway as possible. The paths for origin-destination movements are calculated and traffic assigned to them. The resultant "loaded network" is then examined automatically on a link-by-link basis to determine the V/C ratio. The adjusted link speed and/or its associated travel impedance is computed by use of the following equation:

$$T = To \left[1 + 0.15 \, (V/C)^4\right]$$

where T = balance travel time (at which traffic (V) can travel on the subject link)

To= free-flow travel time; observed traveltime (at practical capacity) times 0.87

Figure VII-2 graphically illustrates this relationship.

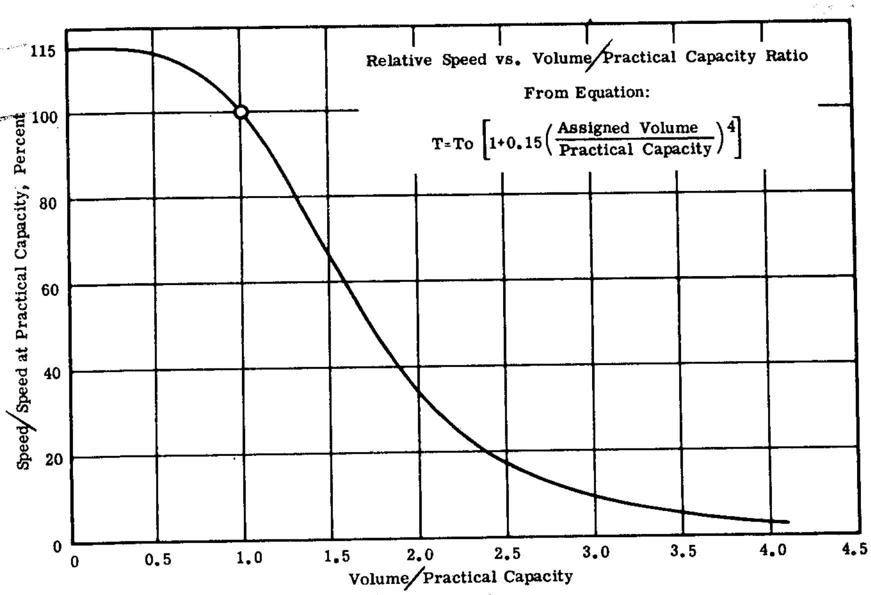


Figure VII-2 - - - Capacity restraint relationship

Direct use of the balance travel impedance for a successive traffic assignment tends to result in an extreme oscillation in the link volumes. To offset this, a different link travel impedance is obtained by combining the balance travel impedance (T) with a base travel impedance. The assignment traveltime is normally used as the base time. The combination is usually weighted so that the new impedance is one-fourth the difference between the base time and the balance time, or, expressed mathematically:

$$Ta = 0.75T_{base} + 0.25T$$

where Ta = assignment link travel impedance for use in next assignment.

The user may find that he wishes to change this weighting factor. The computer program CAPRES allows this.

An example of capacity restraint for a given highway link may clarify the process. Assume a link one mile long has a practical capacity of 32,000 vehicles per day, and a speed at that capacity of 60 mph. The traveltime at zero volume (To) is computed to be 0.87 minutes. The first assignment produces a volume on the link of 40,000 vpd, or a V/C of 1.25. Applying the above equation $T = To\,[1 + 0.15\,(V/C)^4]$: the balance travel time (T) is computed to be $T = 0.87\,[1 + 0.15\,(1.25)^4] = 1.19$ minutes, or a speed of 50.4 mph, which would allow for a capacity of 40,000 vpd. The assignment traveltime or speed would be computed as:

$$0.75\,(1.00) + 0.25\,(1.19) = 1.05 \text{ minutes,}$$
or 57.3 mph.

The next traffic assignment would then use a travel impedance of 1.05 minutes for the link when determining the minimum path routes. The subsequent assignment then would be adjusted in the above manner, and the process repeated. This process may be continued for as many iterations as desired, but experience has shown that after four iterations the accuracy of the assignments does not improve appreciably. Current practice based upon considerable experience suggests the averaging of the capacity restrained assignments rather than the use of any single assignment results. To obtain average loadings use VOLAVG, HRMOD, or WTLOAD.

To conform with the state-of-the-art procedures when CAPRES was designed, the program was designed to input an ADT triptable and a network with ADT count and hourly capacities. The usual operation factors down the link-loads (by the peak-hour factors input on link data cards) from ADT to peak-hour before calculating V/C ratios. This results in peak-hour loading conditions on all links, disregarding the fact that the critical congestion condition for various links typically occurs in 2 different time periods. A preferable method would be to use a peak-hour triptable (see section d) and appropriately utilizing the "INTERVAL" option to adjust for this. This is a less convenient procedure to implement.

Of interest to the prospective user is the way in which the "unloaded traveltime," To, is introduced into the process. This is accomplished by means of the link-data card and the BUILDHR program. For present networks, the specific directional link parameters required are hourly (practical) capacity, daily traffic count, peak-hour ratio (peak-hour count divided by daily count), and observed speed or traveltime.

Program BUILDHR transfers those parameters plus the generated "unloaded traveltime" to the historical record dataset. The unloaded traveltime (defined as the expected time required to traverse the link when only one vehicle is on it, i.e., during an uncongested situation) is calculated from the parameters listed above and is the basis of all capacity restraint calculations. It is assumed that this is typical of the highest speed which can occur on a specific link.

To calculate unloaded traveltime, it is assumed that the "BPR Speed-Volume Curve" (see Figure VII-2) represents the variation of speed on a link under varying degrees of congestion and also that the link parameters (observed speed, count, capacity) all occurred during the same period. Thus, the specific speed-volume curve for the subject link is defined by the point (V/C, speed), and the unloaded traveltime is calculated by solving the curve equation:

$T_o = T/ 1.0+0.15(V/C)^4$ where T_o is unloaded traveltime, T is the observed traveltime, V is the daily count, and C is the capacity (factored to daily level). A problem arises when the count or capacity on a link is not supplied. The solution chosen was to merely set unloaded traveltime equal to the observed traveltime in those cases. Of course, if the capacity is not supplied, no restraint is performed. If the count is missing, in effect, the assumption is that the count was zero at the time of observation. In the latter case, if this result does not suit the user, he should arrange to calculate and punch an "unloaded speed" rather than observed speed. This might be approximated by use of the 95th - percentile speed," or by "design speed" if a more precise procedure is not available.

Having satisfied himself that the present network is acceptable, the user will want to add to that network to represent the future situation. Other future network considerations are the appropriate capacity and peak-hour ratio to choose for specific facilities. Usually, these values will be similar to selected existing facilities.

d. Peak hour or daily traffic--Peak-period traffic assignments are used primarily to determine design volumes and in producing better estimates of speed related performance measures such as vehicle operating cost and air pollution emissions. They usually consist of three separate assignments using three different trip volume files. An abbreviated analysis would include only one peak-period movement, but it is suggested that the assigned volumes be investigated for both morning and evening peak periods, in addition to the off-peak period. A more stable trip volume file for each peak period usually results if a 2-hour peak period is isolated and a proportion of this 2-hour peak later factored to represent the design-hour traffic. Both 2-hour and 1-hour peak assignments have been made.*

To assign the forecasted peak-hour movement, the percentage of the total trips occurring during the peak periods by purpose of trip is analyzed for the survey data. These factors may then be applied for each trip purpose to the forecasted information and a trip file produced which represents the peak-period traffic movement.

For a Fratar analysis, separate growth factors may be applied for the three existing trip files and the forecasted peak-period trip movements obtained directly.

A disadvantage of using peak-hour traffic assignments is the greater cost. Part of this cost is due to the additional data collection involved. For example, traveltimes may be determined for three periods and capacity may vary by time of day (due to different parking conditions, use of reversible lanes, different signal cycling, turning movements, and percentage of trucks, as well as the important difference in ability and incentive of drivers in motion at different periods of the day). However, these factors are also those that make peak-hour assignments desirable.

Peak-hour traffic assignments are also more expensive in computer running time. Forecasting is more time-consuming, and the path building and loading must be accomplished for each time of day.

Despite the higher cost, peak-hour traffic assignment is a useful procedure and employs a time period short enough to yield realistic volumes for comparison with capacities. Experience has shown, however, that a peak-period traffic assignment may yield some unrealistic results. There should be justification for those results which vary excessively from the normal factors and splits. Some loadings have resulted in directional splits of 80-20, and these certainly must be substantiated by a thorough examination of the movements in question.

* See Chapter XII, Section H for a discussion of converting ADT to Peak-Hour volumes.

D. NUMBER AND TYPES OF ASSIGNMENTS

Now that the uses of traffic assignment and the several different types of assignments have been discussed, the application of the assignment technique to a transportation study will be described.

There are three basic categories of assignments which are often made in transportation studies. These are:

1. existing trips to the existing network;
2. future trips to the existing plus committed network; and
3. future trips to the existing plus committed plus proposed network.

The amount of detail used and the number of assignments made in each category for any city is dependent upon size, the ultimate goals of the study, and the financial resources available.

1. Existing Trips to the Existing Network

An assignment of the total number of present trips, computed by expanding the origin-destination survey data to the total universe or by applying of a mathematical model, to the present transportation network is usually made first. This assignment should be made only after a proper screen-line check has been made on the expanded trip data. The purpose of this assignment is to check the adequacy of the assignment procedure by testing its ability to mechanically reproduce the existing travel patterns within the study area.

This initial assignment is usually made by loading traffic on the minimum time paths computed between zones by the computer. An analysis of this assignment may reveal that many links have been assigned volumes which greatly exceed or are considerably less than the actual counted volumes on these links. Thus, the impedances must be adjusted to produce new minimum paths. These adjustments may be performed either manually or mechanically and repeated until existing travel patterns are simulated more closely and the network is calibrated. Note that the planner should also check the fineness or coarseness of his network, since a decision to delete (if too fine) or add (if too coarse) links would result in a changed assignment without adjusting the speeds.

2. Future Trips to the Existing Plus Committed Network

The future trips may be assigned to the existing plus committed network to determine the deficiencies in the existing system and to provide the framework for developing improvements and additions to this system. Again, this assignment should consist of an assignment to the computed minimum time paths and an adjustment by the use of the capacity restraint technique. If it was shown during the network calibration phase that an unrestrained assignment demonstrates a reasonable picture of true desires, it should be used.

3. Future Trips to the Future System

In determining the structure of the future transportation system, the mutual effect of land use and the transportation system must be analyzed carefully. In the optimum situation, several alternate land use plans and their accompanying transportation systems might be investigated. For each land use plan, alternate transportation systems can be designed and loaded with future trips. Again, if capacity restraint was used to calibrate the base year system, the same procedure should be used to obtain the most accurate results for the future system. Finally, the best land use and transportation plan can be determined which is consistent with the needs and desires of the community.

The determination of construction priorities for the chosen plan can be made by partial network assignments, using capacity restraint. This analysis will allow a comparison of the benefits to be obtained from following a certain construction priority.

Assignments may also be made by 5-year increments to allow for future adjustments in the forecasting and assignment procedure to more nearly fit actual travel patterns. This technique will allow the evaluation of procedures within a relatively short period instead of waiting 20 years for the forecast year to arrive.

E. MAJOR DECISIONS

In addition to deciding which computer programs to use, the following questions must be resolved before attempting any traffic assignment.

1. How will future trips and their distribution be estimated?
2. What will be the forecast year or years?
3. How many alternate networks should be tested and how many land use plans should be evaluated?
4. What is the availability of computer equipment?
5. Should the trip information be linked?
6. Should traffic zones or districts be used?
7. How should the external station movements be treated in the assignment?

F. SELECTING AND CODING THE ASSIGNMENT NETWORK

1. Obtaining and Recording Physical Data

a. Review of inventories and summaries--An inventory of the existing street and highway network is one of the first studies to be undertaken in the comprehensive planning process. The results of this inventory provide the information for defining the street and highway system to the computer. The information that is required for each link used in the traffic assignment highway system includes the link speed or traveltime, the link distance, the existing traffic volume, and the practical capacity. Each item will be discussed individually in the following paragraphs.

b. Map preparation--Two base maps are required to define the existing street and highway system. A map showing the traffic survey zones and their numbers must be available to locate the zone centroids. Appropriately scaled street and highway maps must also be available. It is desirable, but not necessary, that the zone maps and the street and highway maps be of the same scale. The zone map for a sample network is shown as Figure VII-3. The network map is shown as Figure VII-5.

The scale (or scales) of the street and highway maps will, of course, vary with the size of the study area. The Washington Metropolitan Area Transportation Study used maps of three different scales. The 1" = 2000' map of the area was used for the outlying area of Maryland and Virginia, the 1" = 1000' scale for the 10-mile square of the District of Columbia, and a 1" = 400' map for the downtown area. As a rule, a scale should be chosen so that very few major links on the traffic assignment network are less than one inch long.

As in Washington, several maps may be used for defining the street and highway network. In this case, match lines between the maps are mandatory. The physical size of the map is usually limited to the size of the reproducing equipment. A map larger than 4' x 5', however, may prove to be too cumbersome for efficient use. It may be advisable to obtain reproducible copies of these base maps by using a medium such as Cronar film. These are the master tracings from which the prints are made that are later used as worksheets during the analysis of assignments.

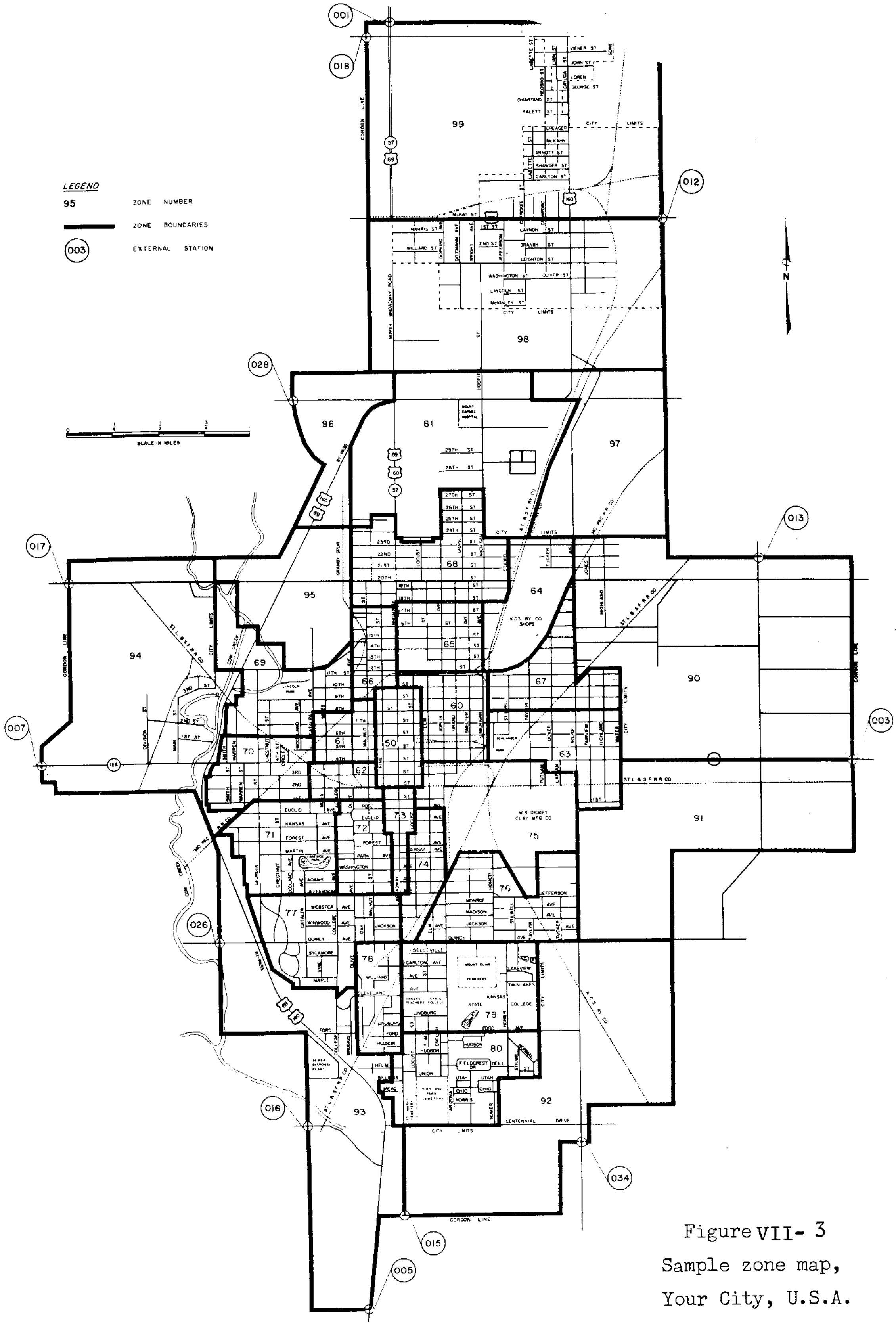


Figure VII- 3
Sample zone map,
Your City, U.S.A.

c. Speed and traveltime data--One of the major inputs to the traffic assignment process is a value for speed or traveltime on each link in the traffic network. These values are used in the computation of the minimum time path routings between traffic zones, which are eventually loaded with vehicular movements between these zones.

Speed or traveltime runs are usually made during both the peak and off-peak hours in urban areas. If peak-period traffic assignments are to be made, the corresponding peak speed or time should be recorded and used. For ADT traffic assignments, peak and off-peak speeds or times may be combined to represent average daily values. One method currently being used assumes that approximately two-thirds of the daily traffic occurs in the off-peak hours, and the value of

$$\text{ADT Traveltime} = \frac{2\ (\text{ off-peak traveltime }) + 1\ (\text{peak traveltime})}{3}$$

It is not economically desirable to obtain the speed or traveltime on every link in the network. Typical values of speed or time obtained for classes of links may be used on links having similar uses and characteristics. However, caution must be used when resorting to this procedure, since the accuracy of the assignment process is dependent upon these values. Methods for measuring these parameters can be obtained in other documents. The reader is also referred to Chapter XII, Section I, for a description of a license matching technique for gathering traveltime data.

d. Traffic count data--The directional traffic volume on as many streets and highways as possible, except the local streets, should be obtained during the survey. Although this information is not considered an integral part of the network description, it does permit the evaluation of the results of an initial traffic assignment. The capacity restraint program adjusts volumes by changing link traveltimes on the system. It also compares the measured with the assigned volumes for each link having this information coded as described on an earlier page. Link counts are also utilized (in program BUILDHR) to determine the curve relating speed to congestion.

e. Street capacity data--Data concerning the practical capacity of each link in the street and highway network are mandatory if the capacity restraint option is to be utilized. The inventory of the physical characteristics of the network should record such information as curb-to-curb width, parking regulations, and the type of control devices, including the signal timings. Programs for calculating street capacity are described in CHAPTER XI.

f. Selection of speed and traveltime data for future traffic network--The selection of speed or traveltime for each link in the traffic network should be made with care, since these values are used to build the minimum time path routes which will eventually be loaded with vehicular trips. As explained previously, speed or traveltime runs are often made to find the existing values on the present network. Judgment must be used to determine the values of speed or time on the future network.

The speeds to use on different categories of facilities may be determined on the basis of the desired highway or street capacity standards. The desired capacity on a particular facility is dependent upon the "level of service" to be rendered by that facility. For a more detailed discussion of the "level of service" concept, refer to the 1965 edition of the Highway Capacity Manual. Based on a desired level of service and the corresponding highway or street capacity, the speed on a certain type of proposed facility may be determined. Speeds may be obtained for freeways, expressways, arterials, collectors, and locals that are located in the CBD, intermediate, suburban, and rural areas. Figure VII- 4 illustrates the arrangement for a table of speeds by facility type and location within the urban area. This table would include speeds expected under the conditions shown. The table is for illustrative purposes and might vary by area.

Figure VII-4--Sample table of average running speeds to be used on future traffic network. Speeds, in MPH, are based on design capacity at level of service "C"[2]

Facility classification	Location			
	CBD	Intermediate	Suburban	Rural
Freeways	40	40	50	55
Expressways	30	30	35	40
Arterials	20	25	30	35
Collectors	15	20	25	35
Locals	10	15	20	25

The speeds recorded in Figure VII-4 have been determined for one particular level of service. There are six levels of service which have been defined by the Committee on Highway Capacity, Highway Research Board. A definition of these levels of service can be found in the 1965 edition of the Highway Capacity Manual. Each city or study must determine its own desired level-of-service standards, and develop a table of speeds based on the capacities corresponding to that level of service. (Note the discussion in section d concerning the way in which speeds, counts and capacities are related in CAPRES and how they are input via program BUILDHR.)

The traffic volume data should be recorded on the base maps along with the practical capacity of each link. With these data, the process of describing the network to the computer may begin.

---

[2]Level of Service "C" is defined as the middle range of stable flow, but speeds and maneuverability are more closely controlled by the higher volumes expected in this range. Most of the drivers are restricted in their freedom to select their own speed, change lanes, or pass. A relatively satisfactory operating speed is still obtained, with service volumes perhaps suitable for urban design capacity.

2. Preparation of Computer-Required Network Data

After all the physical data mentioned above are accumulated in a logical manner, the next step is to place it in a format suitable for input to the computer programs. It is suggested that the various items be prepared in the following order:

a - Define the basic transportation network
b - Locate and number the centroids
c - Connect the centroids to the arterial street system
d - Locate and define the nodes
e - Prepare a node-numbering table
f - Assign the node numbers
g - Code the turn penalties and prohibitors (use of leg codes)
h - Define the link parameters
i - Special treatment for external stations
j - Identifying and storing the maps and tabulations.

a. Define the network--Judgment is the major criterion for the selection of a network for traffic assignment purposes. The necessary information required for selecting the network is the street classification map, plus traffic volumes, street capacities, and a general knowledge of the area. All streets that carry a substantial volume of traffic should be included. Naturally, a substantial volume means something different in each city. In a large city, it may mean 5,000 vehicles per day. In smaller cities, the number might be 1,000. As a general rule, all expressways and all arterials should be included, as well as a portion of the collector streets. The local streets are not included, but are simulated by connections between zone centroids and arterials. For State or regional networks, the interstate, primary, and portions of the secondary systems should be defined.

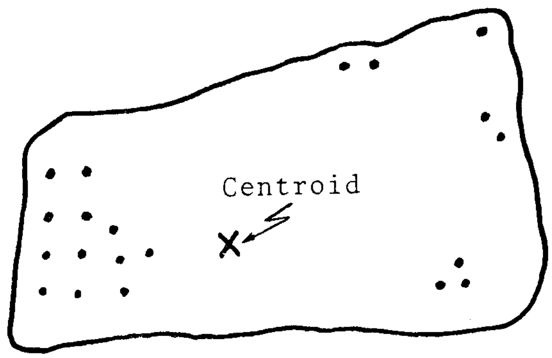
The assignment procedure does not assign intrazonal trips since all trips are loaded to and from a single point, that point being the zone centroid. Therefore, if all streets are included in the system, the assigned volume would tend to be lower than the actual volume counts. On the other hand, if too few streets are included in a network, they would tend to be overloaded.

In any size city, a general rule is to include all streets that are protected by a signal or a stop sign. Again, judgment is the major criterion as to which facility is to be included in a network. On the average, there is about one two-way link for every 100 persons in the study area. When the inclusion of a facility is questionable, it is better to include it than to reject it.

Each facility that is selected for use in the network is traced from the base map on the overlay that contains the centroid locations. There should be no dead-end links in the system. Refer to the sample network (Figure VII-5) and the base map (Figure VII-6). Note that the zone outlines are formed, as a general rule, by parts of the network.

b. Locate and number the centroids-- The establishment of traffic zones should consider the requirements of the traffic assignment procedure as well as the requirements for data collection. In addition, planning areas, census tracts, and the requirements with regard to traffic forecasting areas should also be recognized.

In traffic assignment, all trips are assumed to be loaded on the highway network from a single point established for each zone. The point of loading for each zone, defined as a centroid or loading point, should be located at the center of activity for the zone. For a completely residential zone, the center of activity would be the center of gravity of the zone's population. For example, consider the typical zone shown below.



Assuming each spot represents 100 persons, the center of population--the centroid--would be established approximately as shown.

For mixed land-use zones, such as residential and commercial, the location of the centroid is determined to a large extent by judgment based on expected trip ends. There is one centroid for each survey zone and external station. They are numbered in a consecutive, unbroken sequence beginning with number 1.

A transparent overlay is then placed on the street and highway maps and the centroids, with their corresponding numbers, are transferred to this overlay.

c. Connect the centroids--Each loading point or centroid must be connected to the arterial street system. Because of computer program restrictions, a centroid can have no more than four connections to the system. As these are hypothetical links that represent the local street system, they are drawn as dashed lines from the centroid to the arterial street. Centroids are not normally located directly on a link of the system. If they should fall on a link, they must be relocated adjacent to it and connected by a link of zero traveltime and distance.

It is recommended that a centroid be given as many connections as possible, consistent with reality (with a maximum of 4 allowed). This tends to smooth the traffic on the adjacent links. If only one connection is given to the centroid, the point at which it connects to the arterial street system will show abrupt changes in traffic volume at that point. This should be avoided where possible. For those centroids that represent only a few trips, it may be sufficient to connect them with only one or two links. This, again, is a judgment decision. When in doubt, the maximum number of local link connectors should be used. It is easier to delete a link that is not needed than to add a new link at a later time.

The centroid connections are illustrated in Figure VII-5.

d. Locate and define the nodes--Now, a circle or small dot is placed at each intersection in the system. These will be the nodes. A node is also inserted wherever a link crosses the match line between maps or jurisdictions, even though there is no actual highway intersection. One of the limitations imposed by the computer program is that there may be no more than four links connected to a node. When intersections of more than four links are encountered,

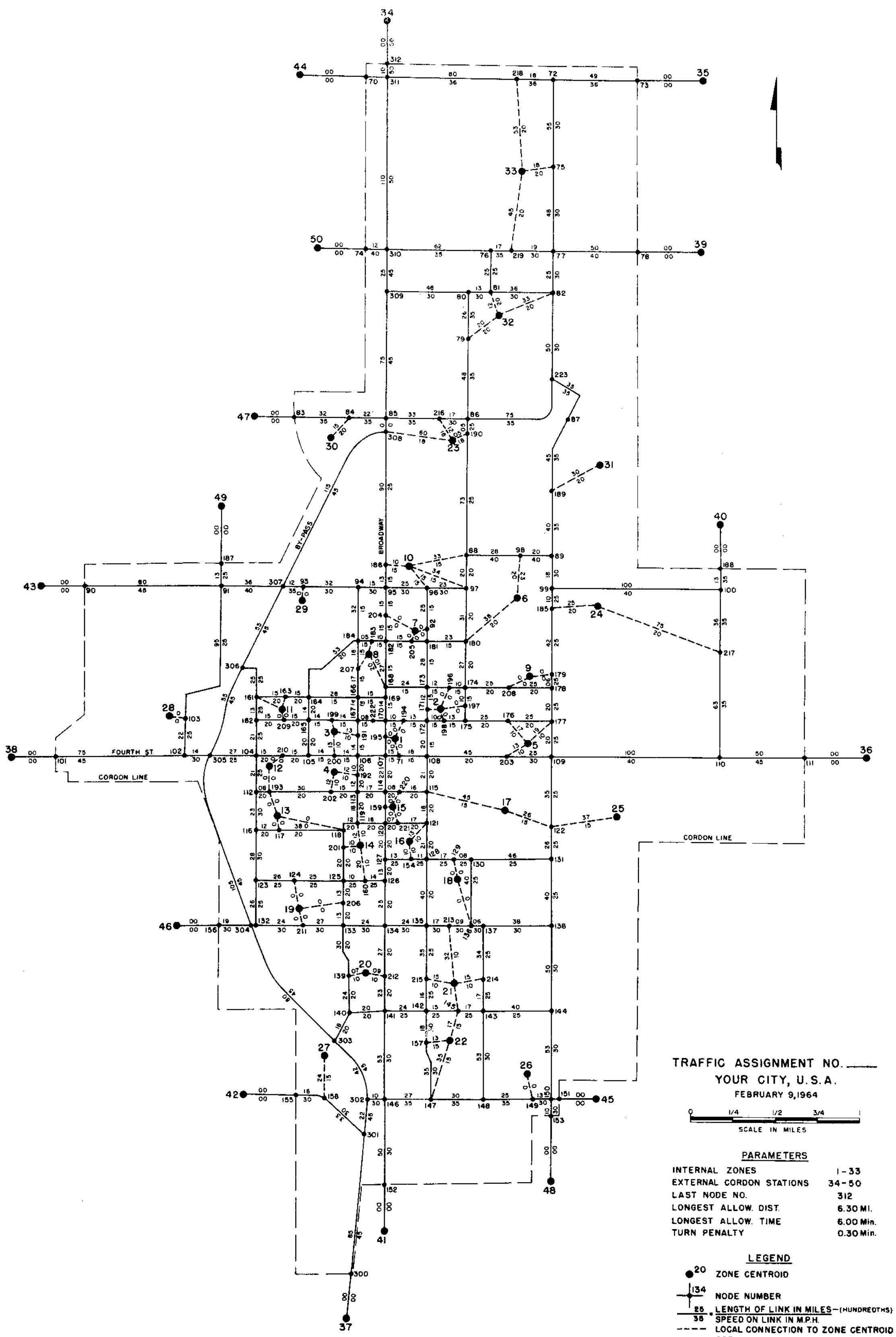


Figure VII-5 .--Sample network map, Your City, U.S.A.

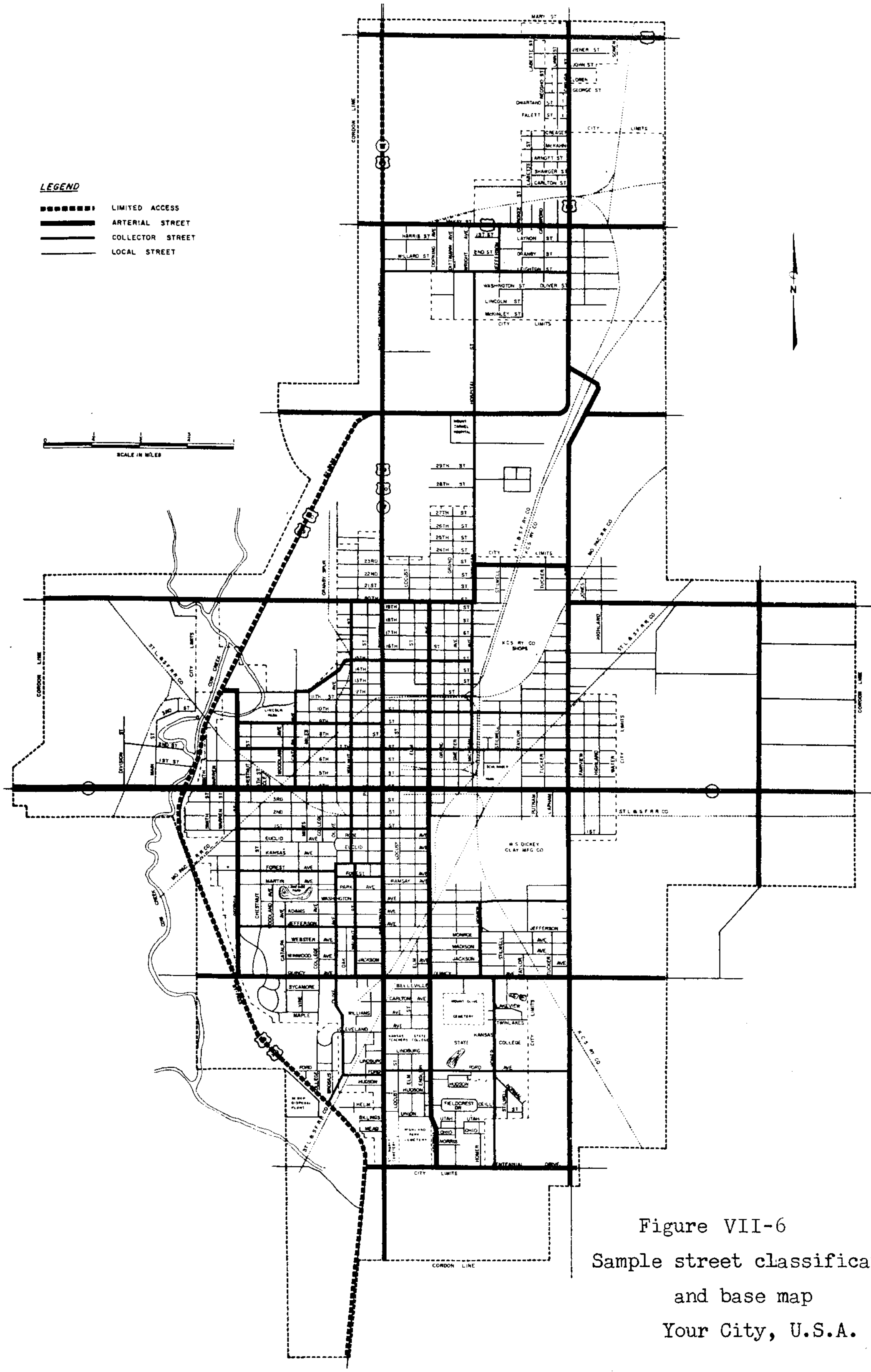
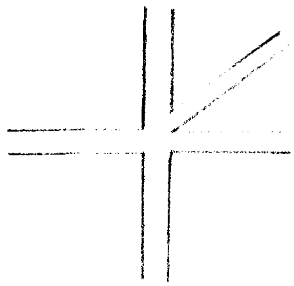


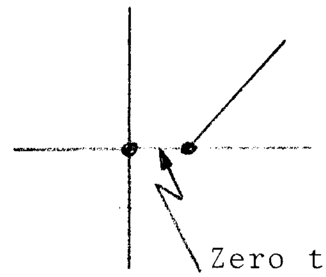
Figure VII-6
Sample street classification
and base map
Your City, U.S.A.

it is necessary to add extra nodes at the intersection in such a way that none of them has more than four connecting links. The following example shows how this may be done:

DESIGN



SIMULATION



The distance of a link must be such that it will not yield a travel time in excess of 32767 units (usually meaning 327.67 minutes). A more reasonable limit of 999 units should probably be kept as a maximum.

At this point, all one-way streets should be marked with arrows in the direction of travel and, if space is available, some of the major geographical landmarks should be identified such as bridges, major streets, etc.

If the system that is being coded contains some high-type facilities, such as freeways, their interchanges may be coded directionally. In directional coding, turning movements and weaving movements may be specified as links in the system. Thus, the longer distance and traveltime inherent in the loops of a cloverleaf interchange may be simulated in a network by directional coding. Some examples of directional coding are illustrated in Figure VII-7.

e. Prepare a node-numbering table--As stated earlier, the centroid numbering must begin at 1 and form a monotonic string until all centroids are numbered. It is suggested that other node numbers begin after a reasonable gap in numbers has been left for centroid expansion. A gap of approximately 20 percent of the number of centroids is a suggested guide. For example, if there are 300 centroids in the system, noncentroid nodes should not begin at less than 360. This will allow for later zonal refinement, if necessary. In areas where large growth is expected, and

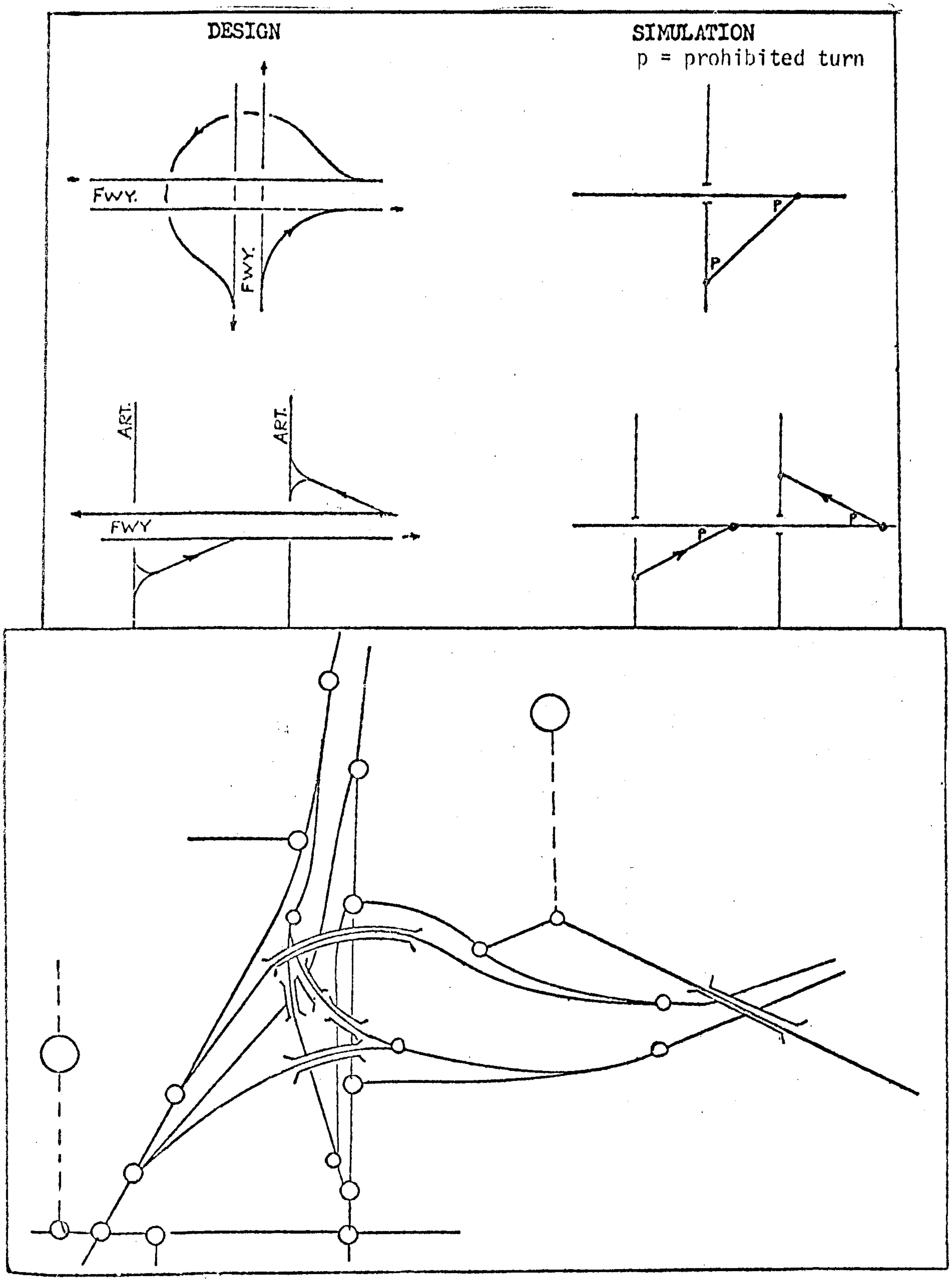


Figure VII-7 --Examples of directional coding.

revisions in zonal structure are anticipated, the gap should possibly be larger than this. The number of zones has been known to double in some studies. If sufficient gaps are maintained, future networks will involve only additions to the existing network, eliminating the need for a complete renumbering scheme. As opposed to past computer programs, the numbering logic need not be associated with a type of facility other than the centroid connector limitations.

A list of numbers to be used should be prepared. As a number is used, a notation is placed beside it. Notes indicating the map number on which the node was used can be very helpful. This list always provides the next node number(s) that are available for use. It also helps prevent the duplication of node numbers, which is not allowed.

f. Assign the node numbers--Many advantages accrue from adopting a systematic method of assigning node numbers. In general, it has been found best to proceed along the main radial highways, from the center of the urban area outward, and to complete the numbering in the sector between two radials before proceeding to the next. Then the nodes in the same numerical range are grouped together. This facilitates the process of plotting the trip volumes and other tabulated data during the analysis of the computer run.

The node numbers may be written either beside the dots representing the nodes or, if preferred, they may replace the dots. Legible writing is critical, as this is the master tracing that will be used throughout the traffic assignment. After completing the numbering, the maps should be reviewed to be sure that every node has been assigned a number.

g. Assign turn penalties and prohibitors (use of leg codes)--As each node is numbered each link connecting to it may be assigned a unique number, 0 to 3. This number shall be called the leg number, and should be printed on the map adjacent to the node number along the link that it refers to. The number should be placed within parentheses to avoid confusion with other posted link values. A placement system should be consistent; i.e., always place the leg code on the top of horizontal links, and to the right of vertical links, or perhaps always on the counter clock wise side of the link. Leg numbers are not an essential item, but must be included at nodes (intersections) where turning movements are to be penalized (delayed) or prohibited in the process of determining the minimum paths. It is not recommended that turning penalties be applied at selected sections of the study area and omitted at the surrounding areas, since this may cause the routings to completely (and unrealistically) by-pass the area. At nodes where leg numbers are included, be sure to include numbers for all connecting links.

During the routing process, as the path traverses a node, a penalty is levied depending upon certain parameters. The parameters are evaluated by determining which "in" leg was used, and which "out" leg was used when exiting from the node. If a penalty code is associated with that combination of leg movements, the penalty assigned to the code is added to the accumulation of elapsed impedances along the route. The penalty codes may range from 0 to 5, with zero having no associated penalty and 5 meaning the movement is prohibited and can not take place. The user can specify the penalty values for codes 1 to 4.

Generally, certain rules for selecting turn codes should be followed: a code should be used for normal-type left turns, one for normal-type right turns, and the remaining two codes for other turn penalties.

If there is room on the work map,the penalty code desired for a given turn can be printed directly. If there is not room, then a method should be devised so that a recording of all turn codes can be kept. Once the link data are all recorded on punch cards, the formatting programs, PRINTHR or FORMAT, will provide a listing of which codes were assigned. The maps in the figures in this chapter do not illustrate leg codes or turn codes due to amount of detail in small reproductions.

Leg numbers may be coded in the same sequence as the connecting node numbers. This is strictly for ease of reading reported outputs of some of the programs: sometimes the summaries are by leg code sort, and other times by connecting node sort. Another approach commonly used is to number the leg codes in a clockwise order from 12 o'clock. For program efficiencies, certain little tricks can be employed in the numbering scheme, but the insignificant savings (perhaps a maximum of 5%) of computer time in a few selected programs do not warrant considerable man-power to worry about it. Successive numbering beginning at leg 0 eliminates confusion when coding the link data cards.

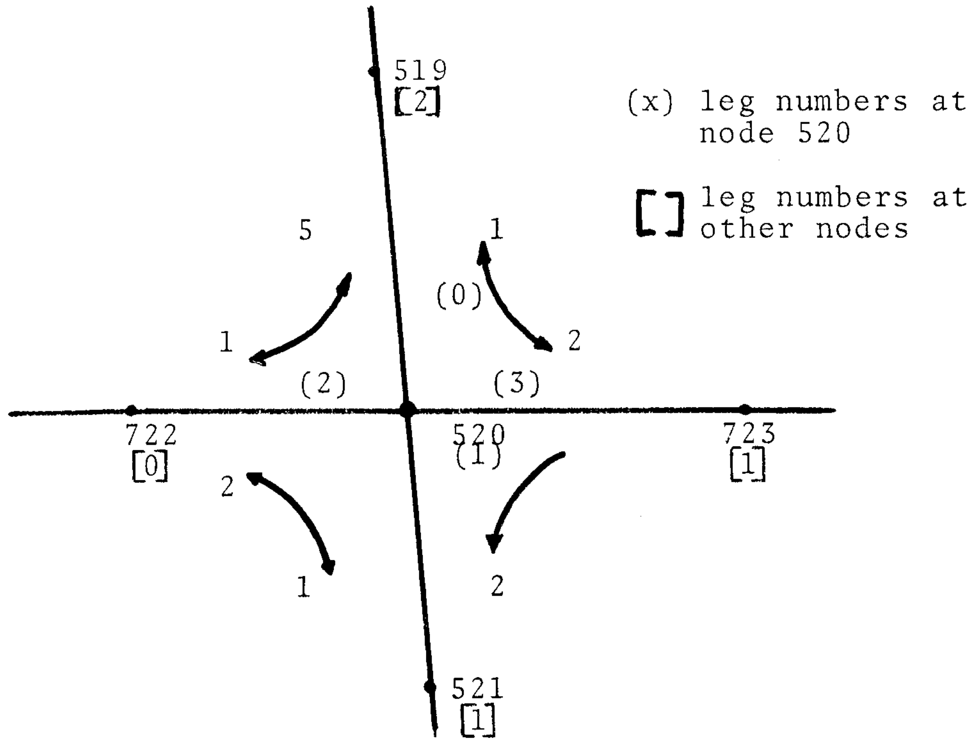


Figure VII-8 -- Sample leg codes and turn penalties

In Figure VII-8 the movement from 722-520-519 [520(2)-520(0)] is prohibited with a turn code of 5. All other left turns are assigned a turn code of 2, and all right turns except 521-520-723 [520(1)-520(3)] are assigned a turn code of 1. All thru movements and the [520(1)-520(3)] movement have no assigned codes, or zero turn penalties.

h. Define the link parameters--At this point, the overlays of the network showing the links, nodes, centroids, street names, signs, etc., are complete. All further work is done on transparent (reproducible) prints or opaque prints (such as Ozalid) of these maps.

On a print, each link must be defined by its two main parameters--the link distance and speed or traveltime. Measuring tapes are prepared from strips of tracing paper (about 8" x 1") and marked off in hundredths of a mile. A separate tape is made for each map scale. The title of the map with which it is to be used is clearly marked on the measuring tapes. As each link is measured, the distance is written along the link; e.g., 57. No decimal point is used; thus 57 means 0.57 miles.

The length of each link should be limited to a maximum of 99.99 miles. Any links that exceed the maximum distance must be divided into two or more smaller links by the insertion of additional "dummy" nodes.

For each link, either speed or traveltime is written under the link; e.g., 525. No decimal point is used; thus, 525 means 5.25 minutes or 52.5 m.p.h. The following example shows how distance and speed or traveltime are coded on the network map.

57

525

If peak-hour systems are to be coded in addition to the average daily traffic system, the appropriate speeds or traveltimes will also be written adjacent to the link.

i. Special treatment for external stations--Some analysts prefer to code the external stations as centroids lying right on the cordon line connected directly to the major facility crossing the cordon. This places the station in a location competitive with internal zones. and can cause some difficulties in trip distribution models and assignments.

Other analysts prefer to treat the external stations very elaborately by increasing the size of the study area. They remove the external station and extend the network through to the outlying zones, each of which contains a centroid or loading node. This, of course, requires special handling in the building of trip tables and in the preparation of the network. It does permit a "diversion" of the trips approaching the external station, as it gives them a choice of alternate routes to enter the study area.

j. Identifying and storing the maps and tabulations --Each traffic assignment is given an identification number. Some analysts have used the following two-digit system: The first digit refers to the year that the network represents, and the second digit represents the individual assignment or revision thereof. For instance, the number "1-5" would represent the existing system, revision of assignment number 5; the number "3-7" might represent a 1985 network, trial number 7. All maps and tabulations pertaining to the individual assignment are given this number.

All of the tracings and prints for a particular system or assignment are kept together in a roll in pigeon-hole files or any other suitable filing device. Copies of the following tabulations (usually the top copy) are bound in hard covers and preserved for reference:

(1) A tabulation of the link data cards used in building the network.

(2) The printed historical record as built by the computer.

(3) The tabulation of volumes as assigned by the computer.

(4) If printed, a tabulation of zone-to-zone trips as used by the computer.

(5) Tabulations of selected trees, and other information.

3. Coding the Link Data

Figure VII-9 is a format diagram of the link data card. The notes beneath the column designations describe the specifications for the fields:

Columns	Contents
1	Unused (perhaps identification)
2-6	A-node number
7	A-node leg number (0-3)
8-12	B-node number
13	B-node leg number (0-3)
14-17	Distance (XX.XX)
18	T or S for time or speed (A-B)
19-21	Time or speed (A-B) (X.XX/XX.X)
22-24	Turn penalty codes at node B
25-28	Hourly capacity (A-B)
29-31	Conversion factor (VPH/ADT), (A-B)
32-36	Directional count (A-B)
37-38	Street width (A-B)
39	Parking (A-B)
40	Unused (A-B)
41	T or S for time or speed (B-A)
42-44	Time or speed (B-A) (X.XX/XX.X)
45-47	Turn penalty codes at node A
48-51	Hourly capacity (B-A)
52-54	Conversion factor (VPH/ADT), (B-A)
55-59	Directional count (B-A)
60-61	Street width (B-A)
62	Parking (B-A)
63	Unused (B-A)
64	Administrative classification
65	Functional classification
66	Type facility
67	Surface type
68	Type area
69-70	Predominant land use
71-74	Link location
75-78	Route number
79	Condition
80	Unused

NOTES: Columns 2-6, 8-12, 14-17, 19-21, 25-38, 42-44, and 48-61 must be right-justified numeric characters with leading blanks permissible. Columns 7, 13, 22-24, and 45-47 may be numeric or blank. Column 18 must be "T" or "S"; 41 must contain "T", "S", "X", or "blank" (for one-way links); columns 40, 63, and 80 are undesignated but may be used. Other columns may contain any EBCDIC characters. If an "X" is coded in column 41, the A-B values for count, capacity, and street width are halved, and together with the other items (with the exception of turn penalty codes) in columns 18-40 are moved to columns 41-63 of the card.

Figure VII-9 -- Link Data Card Format

An inspection of the link data card shows that the data are of three types.

1. Intersection data

   a. Node and leg numbers
   b. Turn penalty codes

2. Directional link data

   a. Columns 18-21, 25-40, 41-44, 48-63

3. Nondirectional link data

   a. Distance
   b. Columns 1, 64-80

If it is found that, because of differing alinements or for other reasons, the distance (B-A) should be different from the distance (A-B), this can be accomplished by using two one-way link data cards. However, if the items in columns 1 or 64-80 need to be different by direction, it will be necessary to be more elaborate in coding with the critical streets represented by parallel links of differing node numbers in the same way that freeways are often coded.

The capabilities that must be considered while coding link data are two: (1) the provision to permit turn penalties and/or turn prohibitors, and (2) the ability to summarize traffic assignment outputs by many classifications (such as functional class, surface type, etc.). Program ANALHR provides for analysis and ta tabulation using these classifications.

If a user does not intend to do anything further than make an all-or-nothing loading, he could code the following mimimum number of items: A-node, B-node, distance, and speed. On the other hand, he might elect to code all of the items if he intends to make a comprehensive analysis of traffic. Further, if the user intends to use the UTPS package, program UROAD in particular, UTPS coding procedure must be investigated.[3/]

Program SUMLINK may be used to read the link data cards and produce summaries such as road-miles, count-miles, capacity hours and road surface area broken down by one-way and two-way links.

The "BUILDHR" program will carry along all of the data from the link data cards, even if the items (other than the minimum) are all blank; thus the Historical Record file

---

3/ See the "HR" program writeup on the "UTPS" tape, UMTA, UTP-10, Washington, D. C. 20590.

will be of the same size regardless of the number of items coded. In other words, the user should not forego coding certain items to save running time unless he is sure he will not find these items of value at any time during his analyses.

a. Turn penalty/prohibitor considerations--There are several items involved in the use of turn penalties or turn prohibitors. There are six graduations of turn penalties ranging from no penalty (code of zero or blank) to complete prohibition* (code of 5). The values to be represented by the other four codes (1-4) are not needed until run time; however, they should be decided upon at the beginning so that the coding will be on a uniform basis, particularly if the coding process is carried out by more than one person.

The philosophy of coding turns may be either to code like turns in a like manner (i.e., all left turns with a common code) or to estimate the delay time for each turn and to code accordingly (all turns which involve a like delay get the same code). The latter process will be more accurate but will take longer to accomplish.

In regard to thoroughness of coding, it is feasible to code turn penalty/prohibitors only at a few problem intersections (assuming, in effect, that all other turns involve no delay). However, the decision to move in this direction should not be made without considering the consequences. For example, coding turn penalties only in the central business district area may cause the assignment process to divert trips around the central business district. This may seem desirable, but, of course, should not be permitted if this is not what is really going to happen on the ground.

Having decided which intersections to code and the codes to apply to each movement, this information is furnished to the programs by following these rules:

1. Turn penalties/prohibitors are coded on the link from which the movement enters an intersection.

2. Turn penalties/prohibitors are indicated by specific codes which are related by means of leg numbers: therefore all leg numbers should be

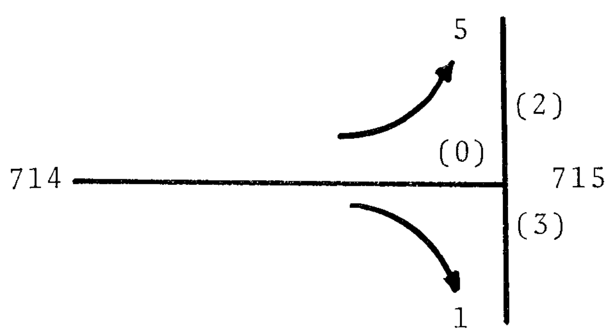
----

*It is not necessary to employ turn prohibitors to prevent traversing one-way links in both directions.

coded on intersections requiring turn penalties/prohibitors. The "BUILDHR" program assigns leg numbers where they are not coded, and it may not assign them in the order expected.

3. Turn penalties/prohibitors may be coded in either one-way link cards or in two-way link cards. In the first case, columns 22-24 are employed; in the second case, columns 22-24 and 45-47. Columns 22-24 are for the three potential turning movements leaving the link at the B-node end, columns 45-47 for the A-node end.

To choose the column in which to code a turn penalty, follow this rule: place the code for the lowest leg number (not counting the leg number of this link) in the first column; the second column is for the next highest leg; and the third column for the highest. Thus, for turn codes for a link with leg number zero, the progression is movements to leg numbers 1, 2, and 3; for a link with leg number 1, the columns are for movements to leg numbers 0, 2, 3; for leg 2: 0, 1, 3; and for leg 3: 0, 1, and 2. This order of use is mandatory--for example, when coding turns from leg zero for an intersection having no leg 1--but only legs 2 and 3, the first column would be left blank and penalty codes entered for movements to leg numbers 2 and 3.



For example, to enter the turn penalty and prohibitor shown above for the intersection represented by node 715, the turn penalties would be coded either in a one-way link card (714-715.0) in columns 22-24 or in a two-way link card (columns 22-24 if A-node is 714 or columns 45-47 if A-node is 715). The appropriate three columns would be coded as follows: "blank," 5, 1, for leg numbers 1 (nonexistent), 2, and 3, respectively.

b. "Classification" coding considerations--The major use of classifications such as Functional Class, Administrative Class, type of parking, etc., is to permit summaries by these classes. For example, total vehicle miles could be printed by functional class by street width.

The critical points to be considered are:

1. The classification should be fine enough that the needed information can be broken out, but

2. not so detailed that many of the summary values need be manually summed,

3. remember that all uncoded items will appear to the program as classification of "blank" (or zero for numeric-only fields such as street width),

4. that like items must be coded alike; e.g., First Street should not be coded both as "FRST" and "1ST" as they will appear completely different to the computer, and a summary would list them separately.

Certainly, the detail employed in these items will depend on the expense in time or dollars involved in getting and interpreting necessary data. This cost should be balanced against the benefit resulting from having this information in the file.

In transferring network data from the various possible sources to the link data card, the usual process is to first put it on a map of suitable scale. The minimum data to be put on the map will vary with the user but should include node numbers, distances, speeds, and, where required, leg numbers and turn codes. Centroids, local links, and one-way links should be so indicated. Such items as count, capacity, route or street name, and parking type may be considered desirable as well.

It is expected that with the higher number of coded items, the map scale may have to be increased. It may be desirable to denote functional class by some means such as dashed lines, and it may be well to show coordinate grids.

G. EDITING AND CALIBRATING THE NETWORK

1. Initial Edits of the Link Data

When all link data cards are coded, key-punched and key verified, they are ready to be input to the computer. There will most likely be initial coding errors in the network, so listings of the link data cards in both A-node and B-node sorts are advisable. If off-line sorting and listing capabilities are available, they should be utilized to aid in the process. If they are not available, a series of simple programs available in PLANPAC/BACKPAC package can easily be used along with the first BUILDHR run. The series includes:

1. BPRCOPY to place the cards onto a tape or disk,
2. SORT to sort the cards (now on tape or disk) on B node,
3. BPRDUMP to list the sorted file,
4. SORT again but this time on A-node/B-node, and
5. BPRDUMP to list that sorted file.

If the link data deck is relatively large, the final output of the A-node/B-node sort should be saved on tape or disk.

The link data cards on tape or disk can be input directly to the BUILDHR program (see LNKCDI option) and also can be updated by use of the PRKUPDT program if the records are in sort. Some users prefer changing the initial link card deck each time to retain a complete, updated network in card form.

The control card inputs to the BUILDHR program set certain parameters about the network. These parameters are normally kept in effect for the duration of analysis on that particular network. The program documentation states all the options available, so only a few of the more important ones will be discussed here. The user should definitely specify LASTZN (number of zone centroids) and LASTND (highest node number). The turn penalty information TPCD1-TPCD4 and TPEN1-TPEN4 and TSTAST are highly recommended for inclusion. Probably the next most important parameters are the speed checks for links within specified classifications. The other items have a great usefulness but are not necessary for most network editing.

The BUILDHR [4] program will pring messages about any link data cards with errors if error weights are included. When it is finished,it will have written a data set called HRO (historical record) which contains label records that explain what is on the data set, intersection detail records that contain information about each node in the network and link detail records that contain information about each link in the network. The HRO data set is written in the binary mode and therefore cannot be read directly by the analyst. The PRINTHR program will prepare a printed report detailing the link information. The report lists by A-node sort, the leg numbers, the turn penalty codes associated with the A-node, the link distance, speed, count, capacity, and the data from columns 37-40 and 60-80 of the link data cards.

If there are network errors, the output of the formatted historical record is then examined, along with the link card listing and output of the BUILDHR program. The sources of errors are determined to be either in the original network map, on the link data card, or both. When the map is correct, revisions are made to the link data deck. The revisions may be manually completed by altering or modifying the actual link data card deck, or by following the methods outlined in the following section.

2. Correcting Network Errors-Updating the Historical Record

The program UPDTHR [4] will update the historical record data-set by allowing the user to specify link additions, deletions, or changes. There are considerable advantages to using UPDTHR to update the historical record as opposed to manually correcting the link data.

1. There are fewer data cards to handle, eliminating a potential source of error.

2. Updating may be faster than having to go through BUILDHR again.

3. The program setup (JCL) is easier and less intermediate work space is needed.

The UPDTHR can also be used in place of BUILDHR to build the original historical record from link data cards.

4/ Program "NETWORK" in the PLANPAC/BACKPAC package performs the functions of BUILDHR, UPDTHR, GESERT, and PRINTHR. It is recommended that program be used in place of the ones being described here.

However, it is not capable of building all size networks; so BUILDHR is referred to as the universal building program. If the network being considered fits within the limitations of UPDTHR build option (see program writeup for details), then it should be used in place of BUILDHR; it is less expensive to operate.

If the UPDTHR program is used to update the historical record, the user should, when all errors are corrected, use the program UNBLDHR to convert the historical record back to link data cards. This is done so that he will always be able to recreate the network in case of loss or damage to the historical record data set. It also provides a "hard copy" of base data used in the transportation study.

An alternative to updating the historical record to make revisions is to update the original link data deck and proceed through the building phases again. The program PRKUPDT can be used to update (in link data card format) the data set that was used as LNKCDI to the BUILDHR program (recall that it is in sort by Anode-Bnode, or possibly by Anode and leg). In PRKUPDT several parameters are important:

```
PAR,INPUT=CARDS
SORTKEY,A,B
DEFINE,A=2-6,B=8-12
```

The user can then change items on specific links, delete links or even add new ones. The only strict requirement is that the input link data file (called TRPCDI) and the update cards be in the same sequenced order on A-B.

3. Checking for Network Logic Errors--Building and Tracing Paths and Plotting

When all directly noticeable errors are corrected, the network must then be checked for logic errors. The types of errors that must be checked for are:

1. Miscoded data items such as speed and distance
2. Wrong assignments of turn codes or prohibitors
3. Missing links
4. One-way links coded as two-way, and vice-versa
5. Tunnel links (those links that connect to the wrong nodes)

a. Building and tracing selected paths--The above errors can be located in several different ways. One method is to have the program BUILDVN compute selected routes throughout the network, and program PRINTVN format the zone-to-zone paths. By hand-tracing the paths printed by PRINTVN on the network map, most of the above errors will be quite obvious. The paths to be computed should be selected from varied centroid locations in the network. As a usual practice, 6 to 10 origin point centroids are selected. All trees are not built because the computer time can become quite large. It is advisable to build at least one tree from a CBD centroid, and several from scattered points around the peripheral area.

The PRINTVN program reads the PATHSI data set containing the paths created by BUILDVN (PATHSO) and prints the nodes in the order that they were traversed in arriving at the destination. Actually, the trace is printed in reverse order. The first number printed for a trace is the destination centroid for that particular O-D movement. The number to the right of that node is the node number for the node that was traversed prior to the node on the left. A series of node numbers follows until the node number at the origin point is printed. The analyst, in using the printed output, will normally use a red pencil and trace along the network map the route as designated by the string of numbers. He then examines the path in its entirety for logic, at which time network errors will be obvious.

It is not imperative to trace the paths to all centroids on the network; selected destinations will give a fairly good coverage. A destructive trace option is available in the PRINTVN program that eliminates a considerable amount of output. When the option (DSTRAGN) is used a given printed destination trace may not terminate at the origin point. When this occurs, the user simply scans the traces prior to the current one until he finds one that contains the node number that is the same as the one where the current trace terminated. The trace may be continued from that point. If that path had already been traced on the map, there is no further need to continue the tracing. It is recommended that the destructive trace option be used, but set it at a reasonable number, say 5-10, so that considerable frustration is not involved in trying to find the remainder of the trace.

The program TREETIME may be used to print nondestructive traces for selected origins. In addition to the tree traces, this program lists the cumulative time from the origin to each node of the trace. TREETIME reads a PATHSI (tree option only) data set and a corresponding historical record and prints nondestructive traces.

b. Plotting networks and paths--An alternate and less manpower-consuming method of checking for many network errors can be accomplished by using programs that prepare input tapes for automatic digital plotters. Initially, more work is involved in the preparation of node coordinates and in obtaining computer systems support to be able to combine the correct program decks that actually write the tapes for the local plotter. At the current time, the plotting series of programs are geared to a CALCOMP off-line plotter; with slight programming work, other plotters can conceivably be employed. Section F of CHAPTER XII describes the plotting programs in greater detail.

c. Network routing errors--The plotting (manually or mechanically) of selected paths may reveal that, in some instances, the true minimum time path has not been determined. This condition is usually caused by the addition of turn penalties and turn prohibitors to the network. This does not mean that turn penalties and prohibitors always force the computer to build a tree this way. However, the computed minimum time paths should be examined for illogical routings, and the turn penalties and prohibitors adjusted (added or removed) when necessary. The use of vines in the path-building phase will eliminate this type of error.

Illogical routings involving high-speed or low-speed links may be discovered. If the minimum time path criterion is used alone and a particular freeway is coded with a speed of 50 to 60 m.p.h., it may attract circuitous routings that are unlikely in reality. Thus, the freeway speed should be reduced to, say, 40 to 50 m.p.h.

Conversely, traveltime runs may indicate speeds of 10 m.p.h. or less in the central business district. If this speed is coded on CBD links, the computed minimim time path routings may unrealistically avoid the CBD. In this case, the very-low-speed links may have to be coded at a somewhat higher value to obtain realistic routes.

It should be noted that route selection is based on elapsed time; i.e., minutes per mile. This may be illustrated in the following manner:

Speed (m.p.h.)	Minutes/mile
60	1.0
40	1.5
30	2.0
24	2.5
20	3.0
15	4.0
12	5.0
10	6.0
9	7.0
8	8.0

Note that a difference of 1 minute/mile results in a change in speed of 30 m.p.h. at the upper range of the table, and only 1 to 2 m.p.h. at the lower range.

If there are no noticeable network errors, the network is ready to be tested to determine its ability to simulate existing conditions. If there are errors, a return to network editing as outlined in Sections 1 and 2 above is necessary.

4. Loading the Network, and Capacity Restraint

a. Loading the network--The next step in calibrating or checking the network is to assign the current trip table to the links in the network. Program LOADVN reads in the trip tables (TRIPSI) and the paths (PATHSI). The paths from origin to destination are examined to determine which links are used; the trips from O to D are accumulated on those links. During the process, the turning movements of vehicles at nodes are accumulated, if desired. The user may specify the origin zones to be considered, the destination zones to be considered and the trips to be considered. In checking the network at this phase, all vehicle trips between all zone pairs should be loaded.

When the program is finished with the assignment, it reads in the historical record (HRI) and merges the new link volumes and turning movements with it and writes out an expanded historical record (HRO). It also prints a summary of vehicle-miles and vehicle-hours.

b. Formatting the link volumes and turning movements--A companion program PRINTLD is used to put the link volumes and turns in a readable format. The program FORMAT is extremely useful in obtaining economic factors about the link loads. It will also print the link volumes. FORMAT is somewhat complex to use, but its flexibility warrants the time required to determine the proper setup criteria. Once the type of setup is satisfactory, the same control deck should be kept intact for further use.

c. Plotting an analysis of loaded networks--If this is the initial loading of a network, the output is generally a "free" or "desire" type assignment. There has been no adjustment to the network other than the correction of coding errors, and the trees have been built strictly on the basis of the traveltime as prescribed by the coder of the network. No attempt has been made to account for other parameters that may affect the route choice decisions between two points, such as congestion, pedestrian interference, pavement condition, etc. Because of this, the assigned volumes may be considerably in excess of the ground counts or the capacity of the links. Of course, some links may also be considerably underloaded.

The loading is analyzed by transferring the assigned volumes from the output of program FORMAT to a print of the network maps. This is a rather time-consuming procedure and, in practice, only the assigned volumes on the major facilities are investigated initially. If the assignment has been of existing traffic to the existing network, the assigned volumes may be compared with the ground counts. If not, the assigned volumes are compared to the capacities of the facilities.

Of course, if mechanical plotting of the network has been provided for, considerable time can be saved by using the plotting programs to post the volumes. Color-band widths can be used to aid in visual comparisons of overloaded or underloaded links or facilities.

If any large discrepancies show up at this time, the analyst must try to decide where the base of the problem lies. It could be improper trip tables, unrealistic travel speeds, or still some network errors. These problems should be remedied before continuing.

For a more complete discussion of the plot programs available, see Chapter XII, Section F, Graphical Display.

d. Restraining assignments--Capacity restraint is utilized in this phase of the work to change link speeds in response to loaded volumes, which should provide realistic assignments. The aim of the speed changes is to put load and speed in "balance" on each link. After this is accomplished,the network can be further reviewed to determine its adequacy for assignment purposes. When the network finally is considered acceptable for present-year assignments, it is recommended that the restrained speeds obtained should not be used for future trip assignments. Rather, the original link data speeds and/or desired speeds on new routes should be used.

An assignment restraint may be done by either of two methods: manually or automatically by capacity restraint. The manual process of restraining assignments will be discussed first, and then the automatic capacity restraint as performed by the computer will be illustrated.

The manual restraint of a traffic assignment is simply a process of deciding what link adjustments are necessary, coding and keypunching the necessary update cards, and revising the network description. The process of revising the network is continued until the traffic assignment is satisfactory. It is evident that this manual-restraining procedure may be very time-consuming and costly. If capacities are available for the links in the system, it is advisable to avoid these manual adjustments and allow the computer to make these adjustments automatically.

The capacity restraint procedure for adjusting a traffic assignment is a completely automated method of adjusting the network parameters. The theory of capacity restraint analysis is described in detail in Section C.3.C of this chapter. Details concerning the output summaries of the CAPRES program are contained in the program writeup.

5. Analytical and Utility Programs

Various programs have been developed that allow for analysis of traffic assignment operations. CHAPTER XII describes several of these programs. It is advantageous to use these programs and become quite familiar with them; they can many times (with a little imagination)be used for more purposes than their originally intended use.

6. Summary of Traffic Assignment Computer Programs

ANALHR - This program accepts as input any output of the assignment program. The program automatically stores the standard portion of each historical record (the first 17 words) into a preset area of the program. In addition it permits acquiring any loads or other information from the remainder of the input record and stores the information in the program area.

The program has the option of doing any or all of the following options:

GNWV	Generate new variables from the input variables. For example: Multiply the volume by the count to obtain vehicle miles, divide the volume by the capacity to get V/C ratio.
PRNT	Print any of the input or generated variables.
BM2R	Prepare a BCD output of any or all input or generated variables that among other purposes may be used as input to regression analysis.
REWR	Rewrite the historical record with generated variables added to the record.
CLAS	Classify the data into a three-dimentional matrix and print the resulting accumulations.

Each of the options listed above has a control feature. For example, if you wish to divide the volume by the capacity, you must first check that the capacity is not zero (or unreported). The control permits comparing the capacity field with a constant (or with another field) and based on whether the comparison results in less than, equal to, or greater than, do one of the following: skip the operation; handle the operation; or check the next control field.

BUILDHR - Build Traditional Historical Record. This program reads link data cards, edits them, and, unless errors are too numerous, prepares a historical record containing (1) descriptive print records, (2) a parameter record, and (3) one historical record for each node in the network described.

BUILDVN - Build Minimum-Impedance Paths. This program reads the HRI (Historical record data set) created by BUILDHR (or as modified by other programs) and prepares designated outputs (PATHSO = trees or vines; IMPEDO = skimmed trees).

CAPRES - Apply Capacity Restraint. This program reads in link capacities and loadings from a traditional historical record and then adjusts link traveltimes according to a predetermined relationship of volume to capacity on the links. The objective is to achieve a balanced and realistic traffic assignment.

FORMAT - Variable formats of historical record. This program formats traditional or spiderweb historical records. By use of appropriate control cards, the program can be instructed to (1) print detailed information on a link-by-link basis or (2) accumulate selected values from the network. The latter includes totals, means, and standard error measurements.

LNKCOST - Compute Link Travel Cost. This program reads speed-cost curve data cards, edits them in relation to other control information, and, unless errors are present, updates a historical record by the addition of link cost words for each curve present or for those curves which fall within that link's classification, depending on which option is being used.

LOADVN - Load trips on network links. This program reads the PATHSI dataset created by BUILDVN and loads specified trips from a TRIPSI (trip table) dataset. An HRI dataset is read and updated by either link loads or turning movements and output in an HRO dataset.

PRINTHR - Rigid Format of Historical Record. This program prepares a printout of selected data from the traditional network historical record file. Although the program can format a variety of data, the program FORMAT is preferred for flexible formatting.

PRINTLD - Format historical record link volumes (rigid format). This program prepares a printout of data from a loaded traditional record. Among the data which can be printed are counts, capacities, and turning movements (each optional) and link loads.

PRINTVN - Format zone-to-zone paths. This program formats for printing and traces to selected destination zones from selected origin zones. Traces may be nondestructive or iteratively destructive.

ALLINONE - In an effort to reduce the complexity of setting up job control language (JCL) and program control cards, the "ALLINONE" program was developed. This program acts as a "driver" for a series of selected "subject" programs: BUILDHR, PRINTHR, BUILDVN, PRINTVN, FMTSKIM, LOADVN, PRINTLD, CAPRES and STOCH. It has the ability to build a network, build and print minimum paths and skimmed trees, load and print the network and perform capacity restraint. Any or all of these functions can be executed in various combinations. For example, several iterations of capacity restraint can be accomplished in one execution.

Since the ALLINONE program actually executes established programs that have been internally linked together, there is no saving in execution time, but turnaround may be improved for a string of programs by avoidance of JCL and setup errors. Through the use of a cataloged procedure and the simpler program control cards, there is some saving in setup time as well. Printouts will look the same as if the programs were executed individually except for added ALLINONE messages. A maximum of 40 individual program steps can be executed in one execution of ALLINONE (obviously the user must carefully consider his choice of reports for a run of that size).

ALLINONE is directed by means of a few control cards to select the desired programs, prepare (internally) the required subject-program control cards, manage the data files and execute, in the proper sequence, the indicated programs. The user may add his own subject-program control cards to change default options. Some understanding of the various subject programs involved is necessary to make best use of the system. Any obvious errors detected in the control-card preprocessing phase cause the job to be aborted before the subject programs themselves are entered.

Since the ALLINONE program uses techniques requiring that appreciable modifications be made to the subject programs, expansion of the list of subject programs would require a significant programming effort and no such extension is currently planned.

SUMLINK - Reads link data cards in the standard 360 format and prepares summaries such as road-miles, count-miles, capacity hours, and road surface area, broken down by one-way and two-way links.

TREETIME - Prints nondestructive traces for selected origins and the cumulative time from the origin for each node of the trace. This program will not read vines (only trees).

UNBLDHR - Extract link data records from historical record. This is a general-purpose program capable of converting the Traditional Historical Record Dataset data to standard S 360 link card format. In addition, or alternately, it will punch x - y coordinates files.

NETWORK--An improved version of UPDTHR incorporating functions of PRINTHR and GESERT. (Also mentioned in section 2.)

SPEED--Copies a historical record, inserting link speeds which are based on degree of congestion, link classification, and user-supplied curves.

VMTSUM--Summarizes from a historical record tables of vehicle-miles of travel, street miles in 2 classification-field dimensions.

STOCH--performs a stochastic multipath traffic assignment, combining the functions of BUILDVN, LOADVN and PRINTLD. The trips from one zone to another are assigned several paths depending on the travel times and upon a user-supplied parameter, THETA.

UPDTHR--Update Historical Record. This program is a dual-purpose program for either building or updating Traditional Historical Record Files. When used in update mode it will add/delete/change links and data in existing Historical Record Files. In the build mode it may advantageously be used as an alternative to the BUILDHR program under certain circumstances.

VEHMILE--Obtain vehicle miles of travel. This is a general-purpose program capable of reading single or merged trip tables on one TRIPSI dataset and up to eight IMPEDI datasets, and preparing single or merged vehicle-mile trip tables on one TRIPSO dataset. Optionally, the user may request printout of total vehicle miles, total trip and average trip length by zone for each table produced.

VOLAVG--Will calculate the weighted average times, speeds, turning movements, and directional volumes from a historical record.

BLDSPTR	Build Spiderweb network*
COMPARE	Compare Network Assignments**
FMTSPLD	Format Spiderweb Link Loads*
FMTSPTR	Format Spiderweb Trees*
FMTSPWB	Format Spiderweb Network*
GEALPHA	Annotate Nodes for Plotting*
GECBWP	Plot Colored Link Band Widths*
GEPLOT	Plot Selected Network Areas*
GEPREP	Prepare Network on Paths for Plotting*
GESERT	Insert Node Coordinates in Historical Record*
LDSPWB	Load Spiderweb Network*
REVSPWB	Revise Spiderweb Network*
SELINK or LINKUSE	Determine trips using selected links*
TRPTAB	Obtain vehicle miles of travel (see VEHMILE on preceeding page). In addition, zone-zone VMT for selected origin zones and/or tables can be printed*&**

* See CHAPTER XII

** See CHAPTER V

7. Analysis and Presentation of Results

When the traffic assignment computer operations have been completed and the assigned volumes transferred to network maps, it is good practice to prepare a short writeup about the traffic assignment. This discussion, which would accompany each traffic assignment, should contain the number of the traffic assignment and additional explanatory information about the trips and the network.

The notes about the trips that were loaded to the network should record the following:

1. Are they existing or forecasted trips?
2. For which year?
3. Total daily or peak-period movements.
4. The type of trips--total vehicles, work trips only, transit trips, etc.,
5. For which land use plan?
6. Other identifications.

Concerning the network, the following information should be included:

1. Is it an existing or forecasted network?
2. Representing which year?
3. How was the loading performed--all-or-nothing, restrained, etc.,?
4. A total daily or peak-hour system
5. Any specific links that were tested
6. "System" numbers--It has been found useful to distinguish different transportation networks used in the assignment process by successive "system" numbers, even though the differences between networks may be small. The system number can then be used to identify link data cards, computer output, network maps, and traffic volume maps. The differences between systems should be clearly identified.
7. Other details.

It may also be advisable to include some of the results of a preliminary analysis of the network or, at least, indicate if the assignment was considered successful. Any computer program malfunction should also be noted in this brief writeup. If the facilities are available and the system is not excessively large, the assignment map could be photographed, reduced, and a print inserted with the text.

The necessity for maintaining accurate and detailed records concerning the traffic assignments will become obvious after several systems have been run.

The results of a traffic assignment may be illustrated in many ways. It may only be necessary to record the assigned volumes adjacent to the street segment on a copy of the assignment map. Some analysts prefer to illustrate the assigned volumes by flow bands on the street segments. The width of the flow band represents the assigned traffic volume.

Perhaps a more useful illustration would be to compare the assigned traffic volume to the capacity of the segment and record the percent usage of the capacity. To avoid a misrepresentation, however, either the capacity or the assigned volume must also be shown.

The title block for all illustrations should contain at least the system number, date, scale, and the network parameters.