Review and Evaluation of Electronic Computer Traffic Assignment Programs

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● THE automation of traffic assignment procedures began, of course, with punched card tabulating equipment for which some very sophisticated techniques were developed (1).

As electronic computers began coming into use in the highway field, developments in the areas of structural design, roadway design, surveying, hydraulics and related fields progressed rapidly. Traffic assignment programs were also developed but they were modest improvements on earlier punched card tabulating procedures. They were limited to an analysis of segments of isolated freeway routes. They were for the most part tabulating programs that summarized the data that the engineer prepared. The interzonal movements had to be routed through the highway system visually by using a map and such elements as distance, time, etc., had to be coded and punched for each movement. The computers merely aggregated the parts for a final result. In one such program, the engineer furnished the routings in terms of map inches at various speeds along with a map scale factor. The program converted from map scale to miles and time, determined the percent diversion to the freeway route by consulting a stored table that represented a time-ratio diversion curve. It then accumulated the diverted volumes on the various elements of the freeway that were also stored as a table. At the conclusion, the accumulated volumes were summarized in various ways and punched into cards for further processing. Such developments were significant steps forward in relieving the engineer of burdensome work and in speeding up the assignment process but much manual labor and judgment was still required. The selection of the routings still had to be done by hand. This could rarely be delegated to clerical help so the horsepower of the analysis staff was severely limited.

The American Association of State Highway Officials' Policy Manual states that the travel time ratio is the travel time via the freeway divided by the travel time for the quickest alternate routing. This statement clearly indicates that the criterion for route selection shall be minimum time. Usually the development of a computer program to solve any particular problem can proceed in an orderly fashion once the criterion for solution of the problem has been clearly stated. The route selection problem languished, however. Fortunately, others working in a field quite unrelated to highways had the same problem. The telephone people were faced with the problem of route selection for direct-dialing long distance telephone calls. It is not obvious how the circuit is selected without human intervention for a call from Washington to St. Louis, for example, when one considers that the most direct circuit may be busy. The number of possible circuit routings to St. Louis is practically unlimited if the imagination is given free rein.

The breakthrough came in 1957 with the presentation of two papers. One was by Edward 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 George B. Dantzig, titled "The Shortest Route Problem," in Operation Research 5:270-3. About this time, J. Douglas Carroll, Jr., was searching for a solution to the problem to help in the assignment of the Chicago Area Transportation Study. The services of the Armour Research Foundation were retained and J.G. Haynes and F. C. Bock were assigned to work on the problem (2).

This investigation resulted in an electronic computer program for an intermediate size computer for finding the minimum time (or distance) paths through a network.

The program is something of a laboratory novelty in that it is limited to 18 nodes (intersections) and is quite extravagant of memory storage. It provided the beginning, however, for further development.

Morton Schneider and others on Carroll's staff further refined the method through many evolutions on an intermediate size computer to the point where they were able to accommodate enough nodes to encompass a small section of the Chicago Metropolitan Area. These efforts were still in the research and development category. Carroll decided that the method was feasible but far greater computer storage capacity and computing speed was needed to do the job for the highway system for the whole Chicago area.

At this point, a computer programming development was undertaken by the Chicago staff for the largest and fastest electronic computer then available in the country. The writer had the good fortune to be associated with the project in a minor consulting capacity. This resulted in an operational program to assign traffic to the existing arterial streets as well as the proposed freeways and expressways for the entire Chicago Metropolitan Area.

About this time, Albert Mayer and his staff of the Detroit Area Transportation Study took up the development along slightly different and independent lines, but using what has come to be universally known as "The Moore Minimum Path Algorithm". Their development was also successful but for a smaller but equally speedy machine.

The Washington Regional Highway Planning Committee, whom the writer now represents, was also searching for a solution for their assignment problems. A joint development project was undertaken involving G.E. Brokke of the Division of Highway Planning, Office of Research, Bureau of Public Roads; William F. Boardman, Acting Technical Director, of the Washington Regional Highway Planning Committee, The General Electric Computation Laboratory, Phoenix, Arizona; and the writer, who was then representing the Division of Development, Office of Operations, Bureau of Public Roads. Paul Jennings of the General Electric Company deserves much credit for his unflagging efforts in bringing the computer programming to a successful conclusion. Many assignments have been made for the Washington area with this system.

The Washington system was further developed by the Minnesota Highway Department, the Bureau of Public Roads, and the General Electric Company to provide greater flexibility.

Many developments have followed in quick succession with many technical ramifications and for different types of computers. Interest in the electronic computer approach to traffic assignment is now widespread.

The Division of Development, Electronics Branch of the Bureau of Public Roads has prepared a non-machine language computer program manual for traffic assignment patterned after the Washington and Minnesota developments. Its purpose is to aid those who wish to develop their own programs. The principles of the Moore Algorithm are clearly set forth.

Very little has been published, however, concerning the technical details of the assignment programs now in existence that use the Moore Minimum Path Algorithm. This led the Origin and Destination Surveys Committee of the Highway Research Board to initiate the preparation of this report. To aid in the gathering of the necessary information, a questionnaire was sent to each of the known developers for their consideration. All graciously replied. Each of the developments are briefly discussed.

DEFINITION OF TERMS

The following terms have become quite standard among developers and users of traffic assignment programs that use the Moore Minimum Path Algorithm:

Node—A node is defined as a point of intersection in the highway network.

Link—A link is the one-way portion of the highway network connecting two nodes.

Centroid or Loading Point—A node in the network that is considered to be the point of origin or destination of trips for a geographical area or zone. Often centroids are connected to the highway network by hypothetical links that do not represent segments of real highway facilities. In other developments, the centroids are considered to be at intersections of the highway network.

Tree—A tree is the aggregate of all the minimum path routings from a node to all other nodes in the network. Usually the interest is in the trees from centroids to all other nodes in the system.

Routing or Trace—A routing is a part of a tree. It is the minimum path through the network from one node to another.

Tree Building—The use of the Moore Algorithm for computing minimum paths is generally referred to as tree building.

Network Description—The network description is the highway network under consideration described in tabular form as nodes, directional links, link impedances, link distances, turn restrictions, etc.

Loading the Network—The process of assigning the interzonal volumes to the network as dictated by the routings determined by tree building has come to be known as loading the network.

Directional Loading—Each one-way link in the network description is loaded with the volumes assigned to it from a so-called square table of directional interzonal movements.

Non-Directional Loading—This is the result when a so-called triangular table of non-directional (sometimes called two-way) interzonal movements is assigned to a network. To prepare such a table, the trips between a pair of zones are added together without regard to direction. For this kind of interzonal movement table, the volumes are usually listed only once, normally from the low-numbered zone to the higher. For example, the trips from zone 1 to zone 50 and those from zone 50 to zone 2 are added together and are listed as being from 1 to 50, there being no movement listed from 50 to 1. When assigning this form of table, the volumes are generally accummulated on only the links whose direction is from low-numbered nodes to high, regardless of the direction indicated in the tree trace. For example, if a trace indicated that a routing passed through a link defined as being from node 500 to 499, the interzonal volume would be accumulated on its complement; that is, links 499 to 500. This system dictates that there can be no one-way streets. At the conclusion of loading, only one-half of the network description has been loaded.

Link Volumes—The total interzonal volumes assigned to a link in the network. These are sometimes referred to as leg volumes. The physical analogy is the traffic volumes occurring at mid-block between intersections.

Non-Directional Turning Movements—The turning movements at the intersections are considered to be two-way. The straight-through movements are also considered to be turning movements in the context that they are part of the movements within the intersection. In this case then there are six possible turning movements within a four-way intersection where all the connecting streets are two-way.

Directional Turning Movements—As explained, there can be a maximum of twelve directional turning movements in a four-way intersection.

Capacity Restraint—Some developments have incorporated what has come to be known as capacity-restraint or capacity feedback. This is a process whereby assigned volumes are related to the capacity of the highway facilities in such a manner that overloaded routes become less attractive as minimum path candidates. This requires that the link impedances in the network description be automatically changed by the program as links become overloaded. This feature is regarded by some as a form of diversion assignment.

Link Impedance—Some impedance value must be assigned to each link in the network description for the minimum path algorithm to select minimum routes. This impedance may be some average value for travel time. It may be distance if minimum distance routes are desired or it may be a combination of the two. It is generally agreed, however, that travel time alone will not give balanced assignments inasmuch as there are many other factors besides travel time that influence the motorist in route selection. Travel time is probably the strongest single factor, however, and thus furnishes a good point of beginning for defining link impedances.

Diversion Assignment—This term is usually reserved for time ratio diversion in the sense that it is defined in the AASHO policy manual on urban design. Some use a combination of time and distance as the criterion for diversion to proposed facilities.

Diversion requires that there be at least two routes through the network found for each interzonal movement and the volume split according to some diversion criterion.

All-Or-Nothing Assignment—This is the term applied to the process of assigning 100 percent of an interzonal movement to the minimum path with no diversion.

Land-Use Feedback—This is a term coming into more frequent use. It is generally recognized that the assignment process cannot be regarded as a separate element of highway planning that is insulated from other variables. When the location of a proposed system of highways has been fixed by virtue of assignment and other considerations, it is recognized that the building of the proposed system will in itself alter land-use patterns which in turn affect the forecasts of interzonal movements. This definition implies then that the whole highway planning process is a continuing iterative system.

CHICAGO AREA TRANSPORTATION STUDY

The Chicago system is programmed for an IBM computer containing 32,000 words of memory storage. The system will accommodate a maximum of 700 centroids (zones) and 4,095 nodes. The total number of directional network links cannot exceed 14,000. Any particular node may have any number of links connected to it.

The program is for directional assignment (a square table of interzonal volumes) by the so-called all-or-nothing method. Turning movements are not computed at a single node representing a street intersection. Turning movements are obtained where desired by describing each turning movement as a link in the network. This procedure requires that more than one node be used to describe each intersection for which turning movements are required.

There are two major options that may be invoked when using this program as follows:

1. The program will forecast the interzonal volumes as an integral part of the assignment process, if desired, by the Chicago method or sometimes called the opportunity model (see HRB Bull. 253). If this option is invoked, the minimum path trees are used in the dual role of forecasting and assignment to the network. If the option is not invoked, the program will accept tables of interzonal movements as input.
2. Capacity restraint is also an optional feature. It functions in the following way: After a tree has been built from one centroid to all other nodes, the forecasted interzonal volumes with an origin at that centroid are accumulated on the links of the network as indicated by the routes in the tree. The accumulated volumes on each link in the network are then compared with the capacity of that link. The impedance of the link is automatically adjusted according to a volume-capacity criterion. After this has been done for the whole network, the next tree is built and the process repeated until all interzonal volumes have been assigned. When the option is not invoked, the link impedances remain constant throughout the process.

Machine running time for one assignment is about 5 hours for a system of 650 centroids, 4,000 nodes and 13,000 links. This is with interzonal volumes being generated internally but without the capacity restraint option functioning. Capacity restraint increases the running time between 5 and 20 percent depending on the system.

The staff requirements are reported as two draftsmen, four coders to prepare the network description and later to post the results, three punched card machine operators, an economist, two traffic engineers and the programmer.

At present the program is not documented in such form that it is ready for distribution to other prospective users. Schneider reports that it could not be run without his help.

From the beginning, a machine installation located in another city has been used. Scheduling, travel, shipment of materials, and communication are considered to be nuisances but not real impediments to the orderly prosecution of the work.

WASHINGTON, D.C., AND MINNESOTA SYSTEM

The Washington and Minnesota developments are discussed together because the Minnesota development is an extension of the Washington system.

There is a total of eighteen programs in the development package. All the programs are stored on a magnetic library tape in such a fashion that any of the programs can be easily called from the library and put into action to do the specific job indicated at any particular phase of the assignment process. The system was programmed by the General Electric Co. to function on any size IBM 704 without any program modification. The size of machine required is dictated only by the size of the network under study. The maximum size, however, is 4,000 nodes, any number of which may be centroids, which requires a 32,000-word 704. There can be a maximum of four links exiting from or entering a particular node. More than one node must be used to describe more complex intersections.

The system will accommodate the following options:

1. Non-directional assignment:

   (a) By the all-or-nothing method.
   (b) By the time-ratio diversion.
2. Directional assignment:

   (a) By the all-or-nothing method.
   (b) By the time-ratio method.
3. Forecasting by the Fratar method either directionally or non-directionally.

All turning movements are obtained at all intersections that the user designates. The system does not incorporate any capacity restraint at this time.

Unique features of the system are:

1. The program library concept.

2. There is a program to update the network description. This program has the ability to add, delete, or change links in the network in such a manner that alternate systems can be analyzed by only changing the affected parts.

3. Any tree or trees may be built separately and also any centroid may be loaded separately.

4. Selected links in the network can be separately loaded. This feature is generally used after an assignment has been completed in situations where particular problems exist. For example, suppose that the assignment shows that a particular section is congested The links in the congested area can be designated as selected links. The output is:

   (a) An assignment to the entire network but only of the volumes that passed through the selected links.
   (b) The origin, the destination, the link of entry, the link of exit and the volume of every movement that passed through each selected link.

There are many other uses such as investigation of interchange spacing, weaving movements, etc.

5. A complete analysis of vehicle hours and vehicle-miles is computed by highway systems and political jurisdictions within the network area.

6. After basic network descriptions and interzonal volume tables are established, card handling is limited to network changes.

Machine running time varies with the options selected but a typical assignment run for a system of 500 centroids and 3,500 nodes is three to five hours. Running time reduces about inversely as the square of the number of nodes.

Washington's staff requirements are one draftsman, three clerks for coding the network and posting results, and two engineers. Minnesota reports essentially the same staff requirements.

The programs are not yet available for general distribution but will be in the not too distant future.

DETROIT AREA TRAFFIC SURVEY

DATS has two traffic assignment programs. Inasmuch as they are quite different, they will be discussed separately.

Expressway Assignment

The expressway assignment program is for the IBM 650 computer with two tape units and an external Ramac disc storage unit. As the title implies, the program assigns only to the expressway system. The maximum capacity is 400 zones (centroids), 75 expressway interchanges and 425 ramps.

The assignment method is non-directional, utilizing minimum distance paths and time ratio diversion. Turning movements are computed at all ramps.

Machine running time for a system of 15 expressway interchanges and 4,300 interzonal movements is about 7 hours. For 30 interchanges and 20,000 interzonal movements, the time is 20 hours.

The staff requirements are one professional and 4 non-professional people to prepare the input and analyze the results.

At present the program is not available for use by others but will be documented shortly.

Arterial Assignment

The arterial assignment program is for the IBM 704. The system has a maximum capacity of 999 nodes, any number of which may be centroids.

The method of assignment divides interzonal volumes over alternate minimum time paths. Non-directional interzonal volumes are assigned. No turning movements are computed.

Machine running time is approximately 4½ hours for a single assignment to the maximum size network. Forecasting is not an integral part of the system.

A unique feature of the program is that after a "Desire Assignment" the volumes are distributed over alternate paths by subsequent assignments with the aim of bringing assigned volumes to within 20 percent of capacity on originally over-assigned links. The alternate paths are computed through networks with link values adjusted according to capacity restraints.

The staff requirements are one professional and four non-professional people in addition to computing center personnel for data preparation and analysis of results.

This program is considered to be still in the development stage. Documentation will begin in 1961.

SERVICE BUREAU CORPORATION

The Service Bureau Corporation assignment programs were written to fulfill the needs of a traffic study for the City of Boston. They were developed for the IBM 704 with 8,000 words of memory storage. The maximum number of nodes is 1,350 of which a maximum of 300 may be used for centroids. Each node may have a maximum of seven outbound links and any number of inbound links. A gravity model forecasting phase is part of the package. It use is optional, however. Directional interzonal movements may be supplied as input. If the gravity model option is invoked, the time function of the gravity model is derived from the minimum path trees.

No turning movements are computed at a single node. Turning movements may be obtained where desired by describing the movements with pseudo nodes and links. The all-or-nothing method (no diversion) is used.

Machine running time for a network consisting of 1,300 nodes, of which 250 are centroids, is slightly over six hours including generation of the interzonal movements by the gravity model. Without the gravity model, the time is reduced by about 20 minutes.

No information concerning the staff requirements for analysis and coding was reported because the Service Bureau supplied only the programming and data processing services. The data coding and analysis was done by outside consultants.

These programs offer three unique features.

1. The gravity model has provision for optionally generating movements for a period that actual ground count traffic volumes are available. The program statistically compares the two sets of data. On the basis of the analysis, changes may be made in the gravity model parameters.

2. This is the only reported development for which the nodes are identified by map coordinates rather than by arbitrarily assigned numbers.

3. The programming was done using the FORTRAN system of automatic programming which allows for rapid program development. Programs written in FORTRAN are usually slower running than the same program written in the conventional manner. They have the advantage however of easy translation to other IBM computers.

The programs are not available for general distribution but inquiries concerning them will be welcomed by the Service Bureau Corporation.

TRAFFIC RESEARCH CORPORATION

The assignment program is presently operational for the IBM 650 equipped with magnetic tape units. The system, as now functioning, will accommodate 100 centroids (zones) and 1, 800 nodes for directional assignment. Machine running time for a system of 100 centroids and 250 nodes is 50 to 60 hours.

The development thus far has been considered as a pilot model prior to being programmed for an IBM 7070. It is therefore not available for use by others.

The system has many unique features so it is discussed in some detail.

Trip Generation

Interzonal trips are generated by mode of travel, purpose and time of day using a gravity model developed from basic O-D data.

Route Generation

A highway system composed of nodes and links is first described. Each link is assigned a distance, legal speed limit, number of lanes, turning restrictions, capacity and travel time. The minimum time path principle is then used to find the shortest routes between all pairs of zones or loading centroids.

Trip Assignment

The interzonal trips are first assigned to the minimum paths based on the legal speed limit. The capacity-volume relationship is then evaluated and the route travel times revised accordingly. The system is then "fed back" to the route generation phase and new routes generated. The old routes are kept on record however. The trips are now assigned between the new routes and the old routes in inverse proportion to their travel times. This process is continued until the system stabilizes. As many as four routes are kept on record for any O-D pair. If and when a fifth route is found that is shorter than the longest on record, it replaces the longest.

Gravity Model Feedback

Once the route generation and assignment loop stabilizes, the system may be fed back to the trip generation phase to regenerate and redistribute trips according to the new travel times found due to capacity restraints.

The whole process continues until road user time is optimized within the capacity of a transportation plan. The system can still further be fed back to the land-use plan to take into account changes in land use due to the transportation plan selected. Provision is also made for balancing of auto and transit use due to capacity restraints. The parking function can also be taken into account.

Although still in the development stage, this system is the most comprehensive of all those reported.

CONNECTICUT STATE HIGHWAY DEPARTMENT

The Connecticut assignment programs are written for the Remington Rand File Computer—Model 1, which is classified as an intermediate speed machine, but has large storage capacity. The development was initiated originally for an analysis of a transportation plan for the City of Hartford, but has now been extended to six other cities within the state.

A maximum network size of 10,000 nodes of which 165 may be centroids is reported. It is interesting to note that this is more than twice the maximum number of nodes reported for any other development.

The program is for either directional or non-directional assignment by the all-or-nothing method and has been used primarily with a gravity model program that uses the minimum path trees for the time function in generating the interzonal movements but the system will accept movements from any other forecasting method as input.

Turning movements are calculated at selected intersections or all intersections as desired. Distributions of time and distance versus assigned volumes may be obtained for the whole system or for selected routes within the system. An additional feature provides for obtaining the origin and destination of all movements passing through selected links or all links.

For a system of 120 centroids, 1,400 nodes and 2,500 links, the machine running time is 39 hours, data preparation and analysis is reported as about 180 man-hours.

The programs are not presently available for distribution but are in the process of documentation.

CALIFORNIA DIVISION OF HIGHWAYS

The California assignment program is developed for the IBM 650 computer but will shortly be revised for an IBM 704 with 8,000 words of memory storage. The present development will accommodate a maximum of 699 nodes and 1,000 links. Any node may be either a loading centroid or a street intersection or both. Turning movements are available for all intersections.

Most assignment programs have been developed around the Moore Minimum Path Algorithm. California however developed their assignment program prior to the minimum path development. So-called "by-hand" routings were supplied as input. Now routes are calculated by the minimum path principle and supplied to the original assignment program as input. For small highway system analyses, hand routings are still used.

The system uses the California freeway diversion formula which incorporates both time and distance as the criterion for diversion to the freeway routes. As many as 4 different routes between a pair of centroids may be compared:

1. The existing street system route.
2. The basic route (this is interpreted as being the modification of the existing route caused by the superimposing of a proposed freeway system).
3. The best time freeway route.
4. The second best time freeway route.

The diversion formula assigns 50 percent of the interzonal movement to the freeway portion and 50 percent to the basic route if the two are equal in time and distance. If there is both a best and second best freeway route, the freeway portion is further split between them by a ratio of their time and distance. The percentage assigned to the freeway route is further reduced if the percent assigned is less than 50 percent of the total movement and the difference in distance between the freeway and basic routes is less than two miles. For economic comparisons, 100 percent of the interzonal movements may be assigned to the existing routes. The program accommodates non-directional (so-called two-way) movements only.

Forecasting is not an integral part of the assignment program. California uses a gravity model, the Fratar method or a multiple regression method (which is their own development) for forecasting.

For a network of 699 nodes of which 210 are centroids, the machine running time for a complete analysis is 125 hours. It is estimated that the machine time varies directly as the square of the network size.

The map work and analysis is done by the district offices so staff requirements and time estimates were not reported. The programs are available for distribution through HEEP, an organization of highway users of IBM equipment.

MISSOURI STATE HIGHWAY COMMISSION

The Missouri assignment program is developed for the IBM 650 computer and will accommodate a highway network composed of 791 nodes and 200 centroids. For networks requiring a greater capacity, a technique has been developed such that the network may be divided into two parts. The minimum path trees are developed separately for the two parts and then combined (3).

Another unique feature is what is called a "speed flatterner curve" that optionally distributes tree paths to parallel streets in a grid network. This has the effect of spreading the assigned volumes over all the parallel streets within a corridor movement. The system is non-directional and uses the all-or-nothing method or a time ratio diversion curve. The mimimum path principle of route calculation is used. Forecasting is not an intergral part of the system.

The output is punched cards in the form of minimum path trees or "loaded trees" which may be combined by punched card equipment to accumulate the total link volumes or turning movements.

Machine running time for a system of 1,300 nodes and 270 centroids, which requires the trees to be computed in two parts, requires about 120 hours for the all-or-nothing method. For time ratio diversion, the time is doubled.

The staff requirements are one engineer and two technicians to prepare the input and analyze the results.

The programs are documented in such form that others may use them. Copies may be obtained by writing to the Missouri State Highway Department.

BRITISH ROAD RESEARCH LABORATORY

England is also making excellent progress in the traffic assignment field. Their development is for the Ferranti Pegasus Computer. The system will accommodate a maximum of 44 centroids and 255 links for completely directional assignment by the all-or-nothing minimum time or cost paths. All turning movements are computed.

The English development is unique in two respects in that each link in the system is considered as a centroid or loading point and that travel may be stratified by cost of travel.

Machine running time is one hour for a system of 100 links, each of which is considered as a traffic origin.

The program is available but of course would have to be reprogrammed for use on computers in this country.

DISCUSSION

Program Availability

Only two of the respondents to the questionnaire stated without any qualification that their programs were available for general distribution. This is not because any of them wish to maintain any proprietary rights in their developments. It would be most difficult, therefore, for any prospective user to acquire and use any of these programs without a great deal of consultation with the developer. The reasons for this situation are many and not generally understood. To discuss the problem, there must be a clear definition of what constitutes a computer program in its finished form. Such a program consists of three major parts, as follows:

1. A carefully written user's manual which describes the programs in detail from the engineer's point of view including such items as data preparation, staffing requirements, suggested sequence of program utilization, interpretation and analysis of results, common pitfalls, experience of prior users, etc., so that the prospective user may decide whether the program is applicable to his particular needs, and, if it is, to proceed to use it without undue study and delay.
2. A programmer's manual which describes the programs from a programmer's point of view. Such a manual includes general and detail flow charts, copiously annotated program listings accompanied by symbolic program cards. The test of the completeness of the programmer's manual is that any competent programmer exper-

ienced with the machine in question should be able to very quickly understand in detail any part of any of the programs so that he could modify them for special needs without a great deal of study. Without adequate documentation, it often takes longer to understand someone else's program than it took to write it originally.

3. A machine operator's manual should contain all that an experienced machine operator needs to know to successfully operate the programs and to deal with unusual operational problems without a programmer being present. The operator's manual is accompanied by the actual machine language program cards.

Programs documented in this fashion would be almost ready for distribution, but not quite. There must be facilities for reproduction and program maintenance. Program maintenance is something that hasn't received much publicity in the highway field but we will hear more about it as computers become more commonly used. No program is perfect. Most of them are not completely de-bugged. It is not unusual for "latent bugs" to be discovered in a program even after it has been in heavy use for months and even years. Programs are constantly being improved and modified. Large computer installations have a staff devoted exclusively to program maintenance. For programs to be successfully distributed, then, there must be adequate documentation and provision for the issuance of errata sheets and the latest changes and modifications. The programmers are not to blame for the lack of documentation. Most programs are developed under a great deal of pressure, usually with a deadline to be met. Usually, at the time of development, no thought is given to sharing the programs with others. When the programs do become operational, the sponsor usually assumes that because they are running, they are complete, and the programmer is assigned another job just as urgent as the first. Probably only the programmer is aware of the "patches" and modifications that had to be made to get the programs to run. Six months later even he has trouble in remembering what was done. Program development is an expensive business. The Washington and Minnesota developments came to more than $50,000 before they became completely operational. Minor troubles still are being discovered. The writer believes that these developments must be shared, but it would be unfair to burden the original developer with the job of distribution, reproduction and follow-up. The Highway Engineering Exchange of Programs (HEEP), an organization of highway users of IBM computers, is doing a good job in this field, but only one assignment program is reported as having been submitted to them. Perhaps there is a need for a central exchange of programs used only in the highway planning field without regard to the manufacturer of the machine. No central distributing agency can function, however, unless the programs are documented according to clearly set forth rules. It is the responsibility of the sponsor of the development to state clearly to the programmer that documentation will be required and to give him the time to do it after the development is operational.

Large Versus Small or Intermediate Machines

The larger the machine, the less it costs to operate for a particular assignment job. This assumes of course that the user is being charged for the machine only for the actual running time. Two of the respondents reported about 125 hours of intermediate size machine time for an assignment to a system of about 250 zones and about 800 nodes (these are average figures). Forty dollars an hour is a fair charge for the machine involved. This is neither the lowest nor the highest figure for the machine. At this rate, the cost is about $5000 for machine time for an assignment. The large high-speed machines will handle much larger networks with a machine running time of about 3 to 5 hours for a complete assignment at a cost of about $1,000 to $2,000. Here again, these are median figures. Even with no adjustment for network size, the cost is less than one-half. This is not to imply that the users of intermediate size machines should abandon their developments in favor of the larger machines. There are many advantages to being able to work locally. But to those who are considering entering this field, the following facts are pertinent. There is already pressure for assignment systems to accommodate larger networks than the largest now available. The so-called second generation of faster all-transistor machines is now here. When assignment systems become available for them, the machine costs will probably be cut to one-half of the best now operating. Even larger and faster machines are just over the horizon. Programming for the larger machines is considered by many to be less difficult than for the smaller machines. It is most unlikely that any state highway department or planning group will be able to afford installations of the large machines in the foreseeable future.

Usually then, if the larger machines are to be used, travel, shipment of equipment and data, scheduling and communication problems will be involved. Those who now operate that way report that the problems are nuisances but not real obstacles to the prosecution of their work.

The writer also believes that the highway planning staff should include people trained in computer programming and to a limited extent, machine operation.

Program Use

There is general agreement among the users of assignment programs that many assignments are necessary before a balanced system for any urban area can be achieved. The Washington Regional Planning Committee has completed their twenty-third system analysis. Short-range assignments have been made, as well as long-range, to answer questions concerning stage construction. In one case, a complete assignment was made to answer questions about one particular ramp. New assignments reflecting changes in land use are needed. The mass transit problem must be solved. The writer knows of no group who has been willing to settle for a single assignment once they have placed themselves in a position to do them quickly and inexpensively with electronic computers. The trend is now toward continuing studies in urban areas. The highway planner must be active over a broad range from land-use planning on the one hand to geometric design on the other. No one assignment can answer all the questions simply because there is no single solution to a transportation problem.

Capacity Restraint

All of the respondents to the questionnaire agree in principle that some sort of capacity restraint is necessary to achieve balanced assignments. Two of the respondents, Chicago and Toronto, have capacity restraint built into their assignment programs now. Others are actively working on the problem. Chicago has made several assignments to very large networks using this feature and very favorable results are reported.

There is a reluctance, however, on the part of many to rely on a completely automatic procedure to bring assigned volumes into agreement with highway capacity. Also there is not agreement as to the procedure to be used. The Chicago system varies link impedances as a network is loaded.

The Toronto method loads the whole network before any adjustment of impedance takes place. New routes are then calculated but the old are kept on record and the volumes split according to the travel time on the new and the old. This process is continued until the system stabilizes with as many as four alternate routes sharing a particular interzonal volume according to the travel time on each.

Others believe that trip time length should be a factor such that long trips would be assigned first and impedance adjustments made, then the next shorter trips and so on, so that the shorter trips will be forced to seek existing street routes if the desired freeway routes are functioning at capacity. Others argue that the intermediate length trips should have the first opportunity to use the freeways because the longest trips are more likely to have equal time freeway choices and so can be easily diverted to an alternate freeway route.

To say the least, capacity restraint is a controversial subject. Those who are pioneering in this field are to be commended. Proven techniques are bound to emerge from their efforts.

Land-Use Feedback

It is obvious that a transportation plan, if developed, will affect land-use patterns which will, in turn, affect the transportation system. Excellent developments in this area are under way and more can be expected.

It is interesting to note that since comprehensive assignments to entire highway networks have become a reality, the emphasis is returning to the area of traffic forecasting.

Network Size

The maximum size of networks that can be accommodated varies from a few hundred nodes to several thousand. The question arises as to what node and link capacity is required for cities or transportation plans of various sizes. This also, is a controversial subject. There is general agreement that the minor streets that can be classified as local service need not be defined in the network. All agree that the proposed freeways should be included. The arterial streets lying between the two extremes are the facilities that some say should be included sparingly if at all. Others maintain that a very comprehensive arterial system is required.

Network size depends on the size of the city and the needs of the particular study. If the problem is limited to a general system location study, inter-district movements may be assigned to a rather grossly defined system to obtain meaningful results. If locations are fixed within narrow limits and information is required concerning interchange spacing and number of lanes, interzonal movements should be assigned to a system that includes a fairly comprehensive arterial network. If information is required as to ramp configuration, ramp capacity and modifications to the existing street system to insure that the proposed system will function adequately requires a well-defined arterial system as well as relatively small assignment zones.

Assignments for various years for the purposes of establishing a schedule of priorities for stage construction of an established plan also require detailed definition of the network to avoid distortions. The Washington Regional Highway Planning Committee has been able to serve all needs in the area (forecast population 3,000,000) comfortably with a 4,000-node system.

REFERENCES

1. "Traffic Assignment by Mechanical Methods." HRB Bull. 130 (1956).
2. "Investigation of Methods for the Assignment of Trip Demand to a Road Network—Phase 1: Algorithm for Finding the Shortest Paths Between Pairs of Points in a Network." (June 1957).
3. "Data Processing Breakthrough Scored by Missouri Highway Department." American Highways, p. 7 (July 1960).