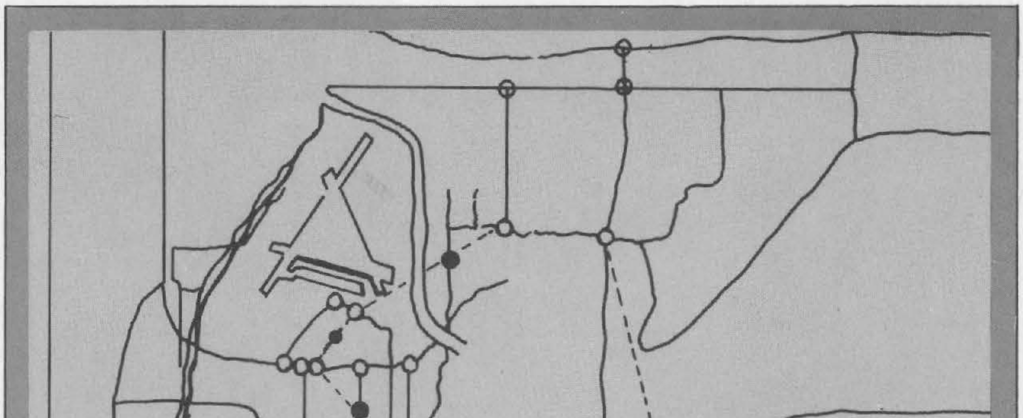
TRAFFIC ASSIGNMENT
August 1973

methods applications products



U.S. DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

TRAFFIC ASSIGNMENT
August 1973

methods **applications** **products**

Prepared by

Comsis Corporation
Wheaton, Maryland

For

Urban Planning Division
Office of Highway Planning

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration

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PREFACE

The major purposes of this guide are:

- to present in concise terms the techniques currently available for estimating loads on a transportation network, with reference to more detailed literature should the reader desire additional information.
- to discuss the operational decisions that must be made in applying any traffic assignment technique such as the selection of zones and network, selection of network impedance values, and the trip loading - adjustment process to be applied.
- to describe the numerous uses for the traffic assignment procedure in addition to the traditional network planning application.
- to present the evaluation of the products of the assignment process made by professional personnel and the uses to which they are put.

This guide is not intended to be a manual of procedures which can be followed to produce traffic assignments to a transportation network. Also, it does not recommend the use of any specific operational procedures or package of computer programs. The document is a presentation of the existing knowledge in traffic assignment methods, applications, and products of the assignment process.

This document should be useful to at least three groups of individuals: professional transportation planning personnel who are interested in evaluating currently used techniques and procedures; those starting their careers in transportation planning and who wish to arrive at some conclusion regarding techniques and procedures available for traffic assignment; and administrators in Federal, State, and local government as well as other government personnel who as part of their responsibility must be in a position to understand and evaluate traffic assignment results.

This document is the result of the work of the COMSIS Corporation, under contract to the Federal Highway Administration. The contractor's personnel worked in conjunction with personnel of the Urban Planning Division of the FHWA and a number of other professional personnel experienced in traffic assignment techniques and procedures. Information for the document was gathered from field visits to a number of State highway departments, urban transportation planning studies, and councils of governments and transportation consultants as well as from reports available from numerous sources. While space does not permit mention of all sources of information here, we have attempted to reflect the philosphy and views expressed by those professionals contacted in the field.

CONTENTS

CHAPTER I
BACKGROUND

DEFINITION AND GENERAL DESCRIPTION

Traffic assignment is a process used to aid in the development of loadings on a network of transportation facilities. The result of the assignment process is an estimate of user volumes on each segment of a transportation network as well as the turning movements at intersections of the network. Traffic assignment is used for the simulation of current traffic volumes on a transportation system and the forecast of probable future volumes using trip interchanges from an origin destination survey or as developed from modeling techniques. The user volumes may be the number of vehicles, the number of total persons, the number of transit riders, or any other user characteristic that can be described by an origin, destination, and some quantifiable trip interchange characteristic. The result of the process is the type of information gathered in field counts of traffic volumes or transit ridership.

uses of traffic assignment

There are many uses of traffic assignment techniques. These include:

- The development and testing of alternate transportation systems.
- The establishment of short range priority programs for transportation facility development.
- The detail study of traffic generators and their effects on the transportation system.
- Analysis of location for facilities and service within a transportation corridor.
- Development of design volumes
- Providing necessary input and feedback to other planning tools.

The application of the assignment process has included urban area networks, statewide systems, and national systems. The process has been used to assign vehicles to a highway network, passengers to transit networks, passengers to air carrier routes, and freight to rail lines. Some special applications include: the scheduling of a trucking system for solid waste pick-up and disposal; the placing of public facilities such as fire stations; obtaining "official" distances for rate bureaus; economic studies such as for filling station location and usage; and air pollution studies of exhaust emissions.

input & output

Input to the traffic assignment process, regardless of the type of network to be considered (transit, highway, rail, etc), includes:

- Network geometry - A description of the interconnections and segments of the network representing the transportation system under consideration. This may be viewed as a map containing the network to be studied.
- Network parameters - The assignment process (except for "direct" assignment methods) requires network segment values to allow selection of routes through the network under study. Only one value is required. Examples of the value would be travel time, distance, travel cost, or a combination of these. No other network parameter is required, but others are developed for

special analytical purposes as will be described.
- Interchange values - This value is the characteristic to be loaded onto the transportation network through the assignment process described by an origin, a destination, and an interchange value. Examples of the value would be vehicles, persons, or tons of cargo.

The output of the traffic assignment process basically consists of loads on each of the segments of the transportation network. These may be 24 hour vehicular highway traffic volumes, peak hour transit volumes, or yearly volumes of freight flow. In addition to the segment volumes, the assignment process produces turning movements at segment intersections, minimum routings through the transportation network, and the minimum summation of impedances between origins and destinations.

Assignment techniques (except "direct" assignment methods such as DTEM see page 55) rely on the determination of routes through a network of facilities based upon segment impedances such as time, distance, or cost of travel or a combination of these. Interchange values described by an origin and destination are then accumulated on the network segments comprising the path(s) calculated between the origin and destination. The accumulation of all origin-destination interchange values on the network segments is the load on the transportation network.

The traffic assignment process is but one procedure in the transportation planning process (see next section). However, the results (i.e., traffic flows on segments of a network) of the assignment process are usually viewed as the most critical, are most widely used, and are the type of results which are most understood by the administrator, the public and the planners. The intermediate results of the process, the interchange value summations (impedances), are used for other analytical procedures such as for modal split analysis, trip generation, and land use distribution. The final segment loads are widely used and generally receive more exposure, analysis, and evaluation than those from the other procedures.

TRAFFIC ASSIGNMENT IN THE TRANSPORTATION PLANNING PROCESS

Base Network Development, Model Formulation, and Plan Development

Traffic Assignment techniques play a large role in many phases of the transportation planning process. For purposes of discussion, the continuing urban transportation planning process will be singled out. The continuing elements of the process consist of the following five phases:

- Surveillance - maintenance of transportation related data on a current basis
- Continuing reappraisal - insuring maintenance of planning process and program on an up-to-date basis
- Service - supply data as needed to local, state, and federal agencies
- Procedural Development - improve techniques
- Annual report - describe progress of continuing process

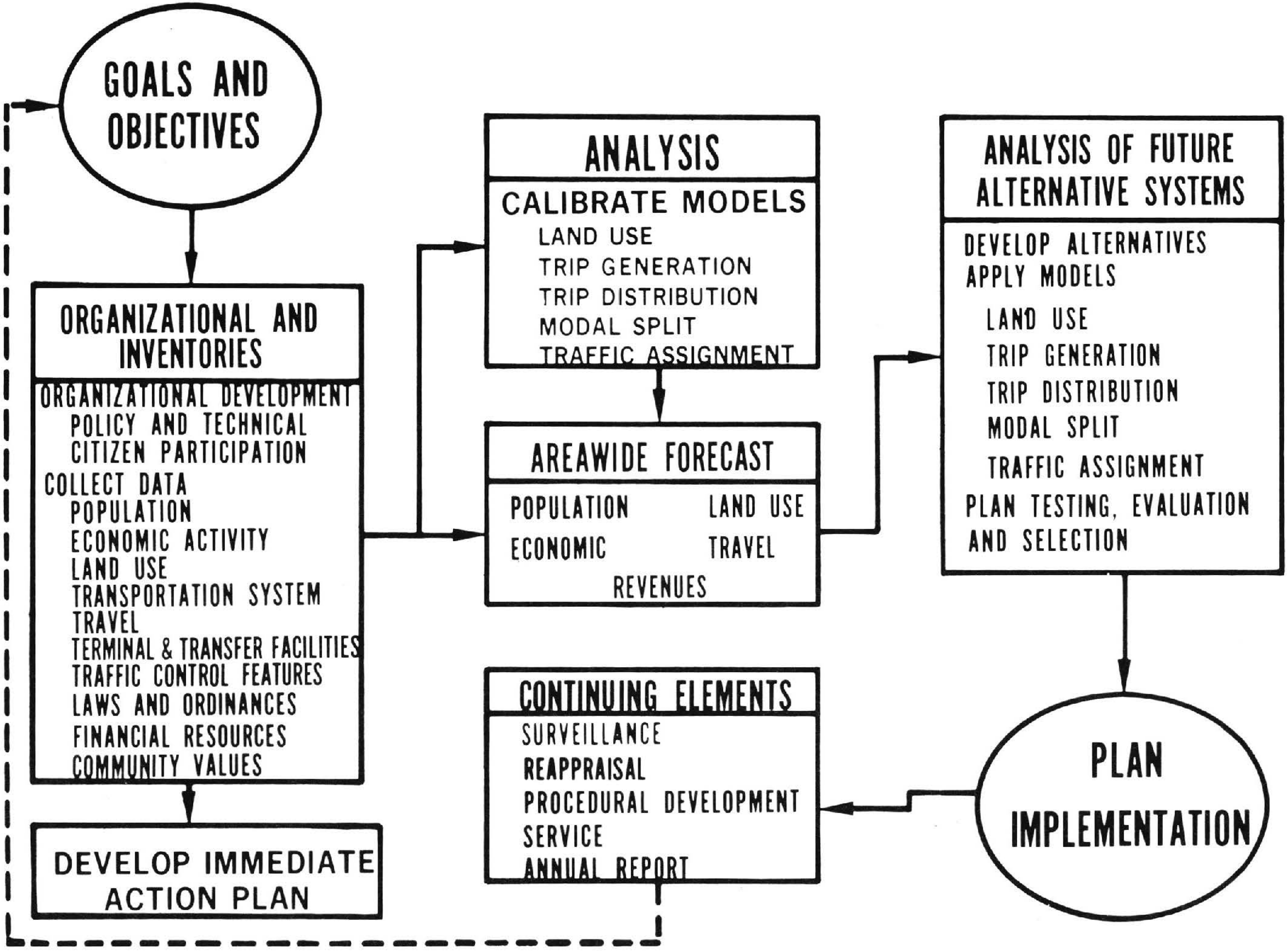


FIGURE I-1
THE CONTINUING URBAN TRANSPORTATION PLANNING PROCESS

As an initial phase in the continuing process, base networks must be developed and planning models formulated. The overall technical process is illustrated in Figure I-1 and includes the overall phases of (1) formulating goals and objectives; (2) organization for the process and collection of data (inventories); (3) analysis of current conditions including the calibration of models; (4) areawide forecasts of future conditions; (5) the analysis of future alternative systems; (6) the continuing elements of surveillance, reappraisal, procedural development, service, and annual report. Reference should be made to Figure I-1 in the following discussion.

basis for assignment networks

Transportation facility inventories provide the basis for traffic assignment networks. The network is a key item in the selection of geographic analysis units (zones) for planning purposes. As will be described later, there is a necessary and direct relationship between the size and shape of geographic analysis units and the transportation network selected for planning purposes. This relationship will vary in accordance with the uses to be made of the assignment techniques, such as, regionwide planning, corridor analysis, small area study, etc. The assignment technique is first utilized on the existing network at the time of the initial data collection. The results of the coded and factored origin and destination survey (i.e. trips) are assigned to the network for survey validation purposes. The assignment technique provides an inexpensive and efficient means for accumulating O-D trips across screenlines and portions of screenlines as well as through corridors for comparison with ground counts. In conjunction with the O-D data validation, the choice of zones and network are evaluated during this initial phase. Adjustments normally have to be made to the extent of network and the inter-connection between the network and the zoning system. Very seldom are changes made in the zones themselves due to the work involved.

zone to zone impedances

After the survey data is validated and the extent of the coded assignment system and zone system examined, the network is used to obtain zone-to-zone impedances for input to other planning tools. These impedance values are initially based upon travel time surveys. However, during the traffic assignment model calibration, adjustments are made to the initial values. The effects of these changes and decisions as to values to use for future assignments are extremely important. In trip distribution model calibration, the impedances provide a measure of the zonal separation which is a necessary input to most distribution models. The impedances on a zone to zone basis are also used for calibrating many modal split models. Here, values such as the impedance on the highway network divided by the impedance on the transit network or the difference in impedances is sometimes used. In other cases, accessibility measures are used which depend on zone to zone separation values for their calculation. These accessibility measures are also used by several land use distribution models currently in use (1). Although not used to any great extent, there is growing evidence that trip generation is related to some degree to the accessibility of households to their surrounding area (2).

As part of the calibration process for trip distribution and modal split, a comparison of model produced travel is generally made with travel based on the O-D survey. This comparison again utilizes the assignment process where the model trips are loaded on the base network and compared to the

O-D travel loaded on the base network. Comparisons are normally made by screenline, portions of screenlines, system type (functional class, i.e., arterials, collectors, etc.), and individual links.

After the calibration process is completed there are some basic types of assignments made which include:

- Existing trips to the existing network
- Future trips to the existing plus committed network
- Future trips to the existing plus committed plus proposed network(s)

These types of assignments are made to assist in formulating and evaluating alternate transportation systems for serving future demand.

Detailed Network Study

role in continuing planning

The continuing transportation planning process puts emphasis on the use of the traffic assignment technique for specific, detailed study and analysis as well as model formulation and development, and evaluation of alternate transportation systems. There is continuing refinement of future system plans through reappraisal of changes in an area and improvement of forecasting techniques. In addition, emphasis is placed upon the following types of functions in which traffic assignment plays a major role.

- priority planning through the assignment of travel for intermediate years to their corresponding systems
- detailing of route locations through established corridors and studying in more detail features such as alternate interchange location
- evaluating the effects of new and large generators such as airports, housing developments, and commercial complexes on the surrounding transportation system, and the provision of additional service where necessary
- development of design hour volumes and other factors necessary for the detailed design of facilities

HISTORICAL DEVELOPMENT OF THE ASSIGNMENT PROCESS

Individual Route Study

early applications

The traffic assignment process, as generally practiced, is highly dependent upon origin-destination trip information and can be dated to the collection of such data. Initial application of the traffic assignment idea was related to the testing of alternate locations for a single new transportation facility such as a toll facility, freeway, or other high type route. Origin-destination information collected at roadside locations on existing facilities was used as a base. This travel was usually factored to represent some future demand considering factors such as induced travel due to the new facility as well as growth due to increases in population and travel. The primary problem was to forecast the diversion of travel from the existing facilities to the proposed new facility.

The individual route study required an estimation of the traveler's choice of a route to complete his trip. Various parameters were used to compare travel using the proposed facility to travel without the facility in place. The parameters considered by different users included travel time, distance, and user costs. Except when a toll facility was involved, early application of the assignment process generally relied on distance as a measure. This was because the minimum route between two points could readily be visualized from a map without the tedious and time consuming accumulation of individual section impedances necessary to find a minimum route if a parameter, such as time, were used. Even for the study of an individual facility, the traffic assignment process was an inefficient allocation of personnel time. However, there are still many cases where manual route allocation is effectively used.

Traffic Diversion

The assignment of traffic to a new facility required the calculation of routes between origin and destination pairs as well as the diversion of some portion of travel from the existing system to the proposed facility. The problem was to determine the proportion of travel to divert. Initially, the diversion was based upon intuition, personal experience, and judgement using measures such as travel time, travel distance, and costs via the alternate routes. Early study indicated that relative travel time between two facilities would provide the basis for a reproducible approach. Mr. Earl Campbell, of the Highway Research Board, theorized that an "S" shaped curve could be used to relate the percent use of a particular facility to the ratio of travel times between the new facility and existing competing facilities (3). Other approaches considered time savings between the proposed and existing facilities, combinations of time and distance savings, and combinations of time and distance ratios. Studies were made to support the proposed diversion approaches and applications were made in several locations. As a result, AASHO developed a standard traffic diversion curve as recommended practice for estimating use of urban freeways. This curve was based upon the travel time ratio between the proposed freeway and the quickest alternate route (4). Other techniques were developed and used by the various state highway departments. California, for example, developed time and distance savings curves which consist of a series of hyperbolas (5). These studies and approaches dealt generally with a single freeway and parallel existing routes. As the capability to handle individual facility study improved, the realization of the need for complete network study emerged. The techniques developed for individual route study were time consuming and impractical for application to entire networks.

Minimum Route Calculation

The two major steps in traffic assignment are:

- The calculation of routes through the network
- The accumulation of travel (O-D trips, generally) on the facility segments comprising the minimum routes.

The first step is the critical one if one realizes the thousands of possible alternate routes between each pair of zones in even a moderate sized network. The second step is basically one of bookkeeping in the accumulation of trips to individual facility segments.

Initial automation of the assignment process was accomplished on punch card tabulating equipment, but was only aimed at step b above. Likewise, initial electronic computer applications to traffic assignment did not provide for the minimum path calculation, but were, for the most part, tabulating programs that summarized the data developed by the engineer for route selection for each zone to zone movement. The route selection problem was the key. The computer could try all combinations of segments to determine minimum paths, but the costs would be prohibitive.

The breakthrough in the network path determination came from work undertaken to solve the route selection problem of the telephone systems for direct dialing of long distance telephone calls. Algorithms were developed which greatly reduced the computational time necessary for route selection. Two papers published in 1957 provided the impetus for computerizing the route selection process for traffic assignment: The Shortest Path Through A Maze, by E. F. Moore; The Shortest Route Problem, by G. Dantzig. Soon after, an assignment process by computer for a very small network was developed by the Chicago Area Transportation Study. A series of programs for large networks was later developed for the IBM 704 computer through a cooperative effort of the Bureau of Public Roads, The Washington Regional Highway Planning Committee, and the General Electric Computer Department at Phoenix. This version could assign trips using the travel time ratio diversion technique or by assigning all trips to one minimum route between an origin and destination.

Computer Application

Many features were soon incorporated into the various assignment systems developed. Refinements such as specifying penalties for turns, prohibiting turns, and the use of other diversion techniques were incorporated. Most of the features could be considered only because of the availability of computer systems.

The initial assignment packages served for some ten years. During this time one of the more serious problems encountered was being able to reflect the affects of system congestion in the assignment process. Segment speeds had to be specified without knowing the volume assigned to a segment. The feedback process incorporating a speed to capacity function was incorporated in the assignment techniques and is known today as capacity restraint.

transit assignment

Most of the assignment technique development was aimed at highway system work. In the mid 1960's, however, the firm of Alan M. Voorhees developed a transit planning package of assignment programs which considers the special network problems related to transit assignment (6). This system was later prepared for the "3rd generation of computers" which is based upon solid state circuitry. Processing speeds and data storage capabilities were therefore significantly increased. In addition, manufacturers provided for program compatability between different computer models and relied more heavily upon direct access storage devices (i.e., disks). The Urban Mass Transportation Administration has further developed the Transportation Planning System (UTPS) (7).

special problems handeled

One of the more critical problems encountered by several transportation planning agencies was the inability of the assignment systems to handle very large networks. The State of Texas developed a network partitioning system which allowed portions of a network to be handled by the computer, but with results as if the entire network was considered simultaneously (8). The Tri-State Regional Planning Commission (N.Y., N.J. & Conn.), also faced with the problem of size (8000 sq. mile study area), decided that no existing procedure could serve properly since:

- The network was too large for available systems.
- A system was required where results could be obtained for a portion of a network or even a single segment.

This resulted in the development of the Direct Traffic Estimation Method which allows assignments to single links or any grouping of links as required (9).

Another problem of increasing importance is the necessity to study route locations and street systems in detail, as well as to simulate detailed vehicular movements in small areas. Some users have adapted the general assignment technique to this small area or detail study. Creighton, Hamburg, Associates has developed "Micro Assignment", which provides for assignment of traffic to a finely coded network and which incorporates traffic control features (10).

special applications

There are many special applications that have developed because of computer solution to the assignment process. This includes selected link analysis (to determine trips using specified segments), spiderweb assignments to aid in developing systems, and automatic graphical display of alternate assignments. Other developments based upon computer availability that have added to assignment capabilities include work done in speeding up the route selection process such as the Road Research Laboratory Algorithm (11), multi route assignment techniques such as probabilistic assignment (STOCH) (12) and incremental loadings as an approach to capacity restraint (13). In addition, automatic plotting capabilities have vastly increased the ability of traffic assignment users to assimilate the data produced by computer assignment. New features and capabilities are being added continuously and assignment techniques are being used for many planning purposes not envisioned five years ago.

This document does not provide detailed information required to process traffic assignments with any of the traffic assignment computer systems available. For detailed information concerning the FHWA urban planning system 360 program battery refer to the two manuals Urban Transportation Planning - General Information (14) and Urban Transportation Planning - Program Documentation (15).

computer system reference

OTHER USES FOR MINIMUM ROUTE DATA

Input to Other Models

Although the basic results of the traffic assignment process (segment loads) receive a considerable amount of exposure, secondary results are used as input to other planning tools and for special studies.

other uses

Many modal split techniques require zone to zone costs for a transit and highway network. These are based upon the minimum route information output by the assisgnment technique.. The minimum routes might be based upon travel time, with related costs added, or they might be based on cost coded to the transportation facility segments. Other modal split techniques utilize accessibility indices which are based upon zone to zone travel impedances and some measure of trip attractiveness.

Trip distribution models also require some measure of zonal impedances. Some techniques use the zone to zone impedance to order zones from a point in question. Other techniques use the zone to zone impedance as a direct input to the trip distribution process.

Recently developed land use models require the calculation of accessibility indices as a required input to land use distribution (1). Likewise, some practitioners have used accessibility indices as a variable in their trip generation analysis.

Network routing input to the calibration and application of the various models for transportation planning requires some decision as to the segment impedance values to utilize. There is a wide variation in the use of speeds for current and future networks. The possibilities used for highways, for example, include:

Current Networks (model calibration)

- Actually measured speeds
- Speeds based upon a sample of measured speeds classified by functional classification and area type
- Desired speeds
- Free flow speeds
- Some function of signed speeds

Future Network (model application)

- Speeds based upon current network capacity restrained speeds
- Current network speeds classified by functional class and type of area
- Desired level of service speeds

Regardless of the choice of initial segment impedances, it is important that the final application of the models be based upon impedances reflective of the conditions one is trying to represent. If a "desire" level of analysis is required for planning purposes, uncongested input speeds for segments might be indicated. If the use is for design volume development purposes, it is important that congestion level impedances on segments be used to obtain zone to zone impedances as input to the models used. This implies a feedback process to account for system congestion, which in current practice is based mostly upon capacity restraint techniques.

Special Studies

The minimum route data produced by the traffic assignment process has been used for a wide variety of special studies. The purpose of this report is to describe applications in urban areas, statewide and national studies. However, a listing of some special applications made may be of interest.

- Obtaining "official" distances for rate bureaus between points throughout a state.
- Aiding in the determination of locations for public services such as fire stations, ambulances, etc., to best serve some estimated demand distribution in an area.
- Scheduling the most economical routings for a trucking system for solid waste pick-up and disposal.
- Determining the effects of special generators, such as shopping centers and major office complexes, on the surrounding street system.
- Providing information necessary for the evaluation of alternate locations for shopping centers, filling stations, etc.
- Studying the pollution effects of automobile exhaust emissions throughout an urban area.

DATA REQUIREMENTS

Network Geometry

The three basic data requirements for any traffic assignment technique are: network geometry; network parameters; and interchange trip values. Although these are consistent between techniques, there are some very significant differences in the form of these data.

<u>link-node system</u>

Network geometry refers to the segments of a transportation network and their interconnections. For most assignment techniques, the geometry description represents the network as a collection of nodes (numbering of intersections) connected by links (transportation facility segments between nodes). The description of network geometry is similar to viewing a map of a highway system. A sample highway network is shown in Figure I-2.

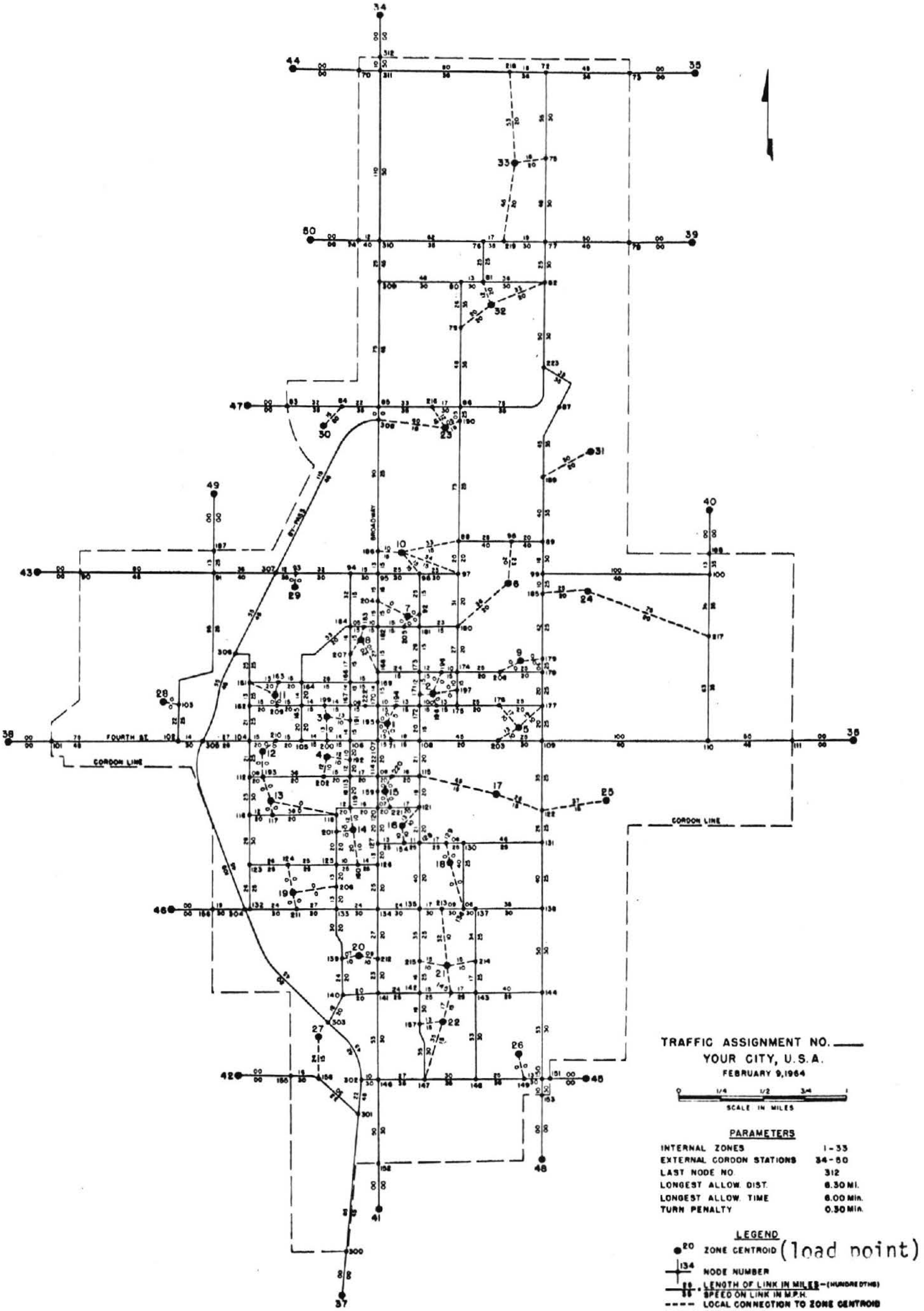
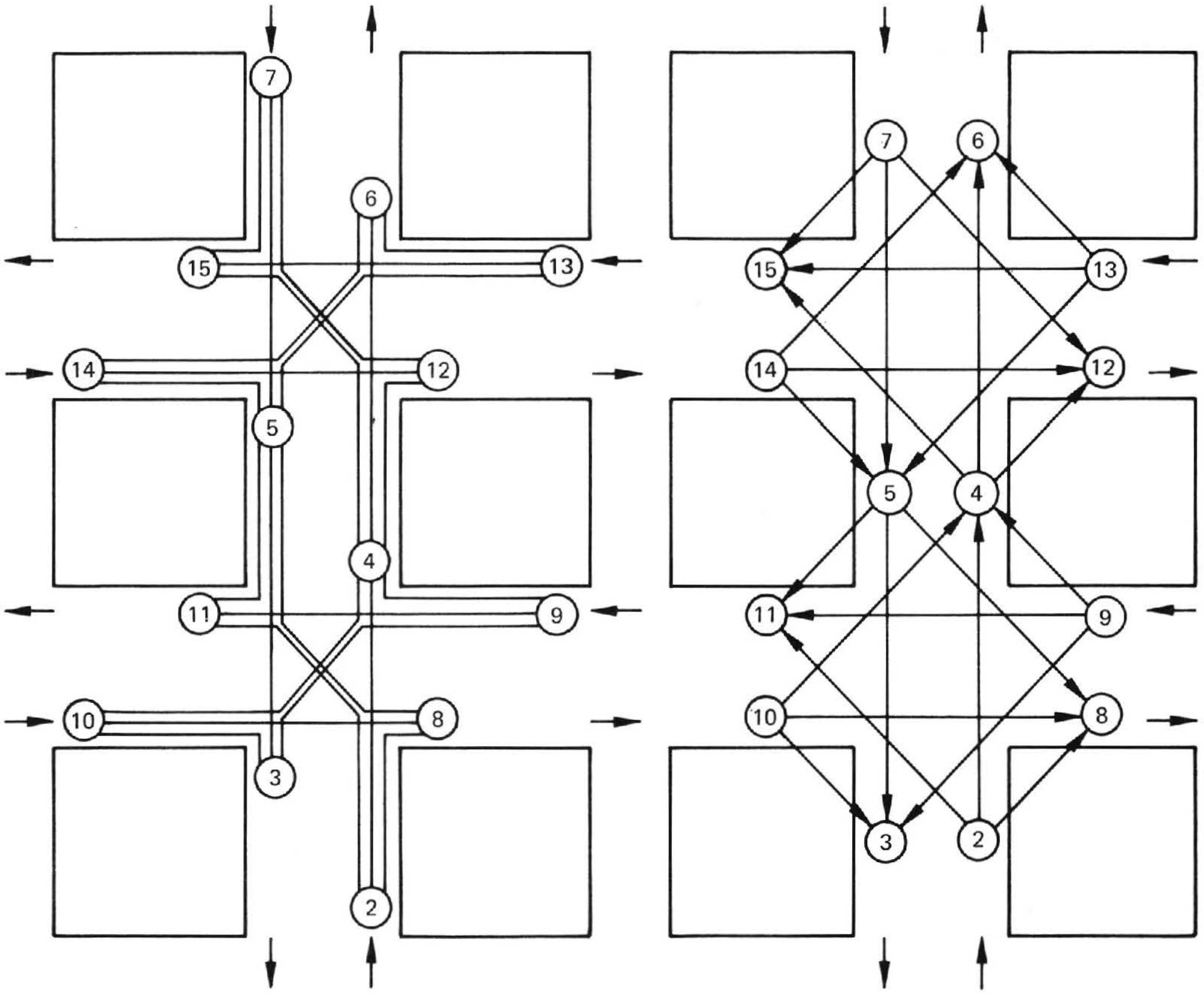


Figure I-2
Sample Highway Network Map (14)

In addition to defining the interconnection between segments, the network geometry describes the interconnection between loading points (points at which trips are loaded onto the network) and the network.

The network geometry is described differently for special assignment techniques such as "Micro Assignment" and the UMTA Transportation Planning System (UTPS). The Micro Assignment deviates from the more general assignment techniques in that it deals with each intersection in detail resulting in a set of links each of which represent one of the possible movements through an intersection. The road segment leading to the intersection is considered to be an integral part of the network. A schematic view of this concept is shown in Figure I-3.



CONCEPTUAL LAYOUT

LAYOUT FOR CODING

FIGURE I-3

INTERSECTION LAYOUT FOR MICRO ASSIGNMENT (10)

Because of special transit operation considerations, the transit system deviates from the more general assignment processes. The network geometry for the transit system is route oriented. The package allows each transit line to be identified separately. Likewise, there may be up to eight links, one to each mode, between any two nodes. In addition, nodes are coded only at load and transfer (station) points between transit lines. Example of network geometry for a transit network is shown in Figure I-4. For detailed coding instructions for the various assignment techniques the reader is referred to items (7, 10, 14, 15) in the References section of this report.

Network Parameters

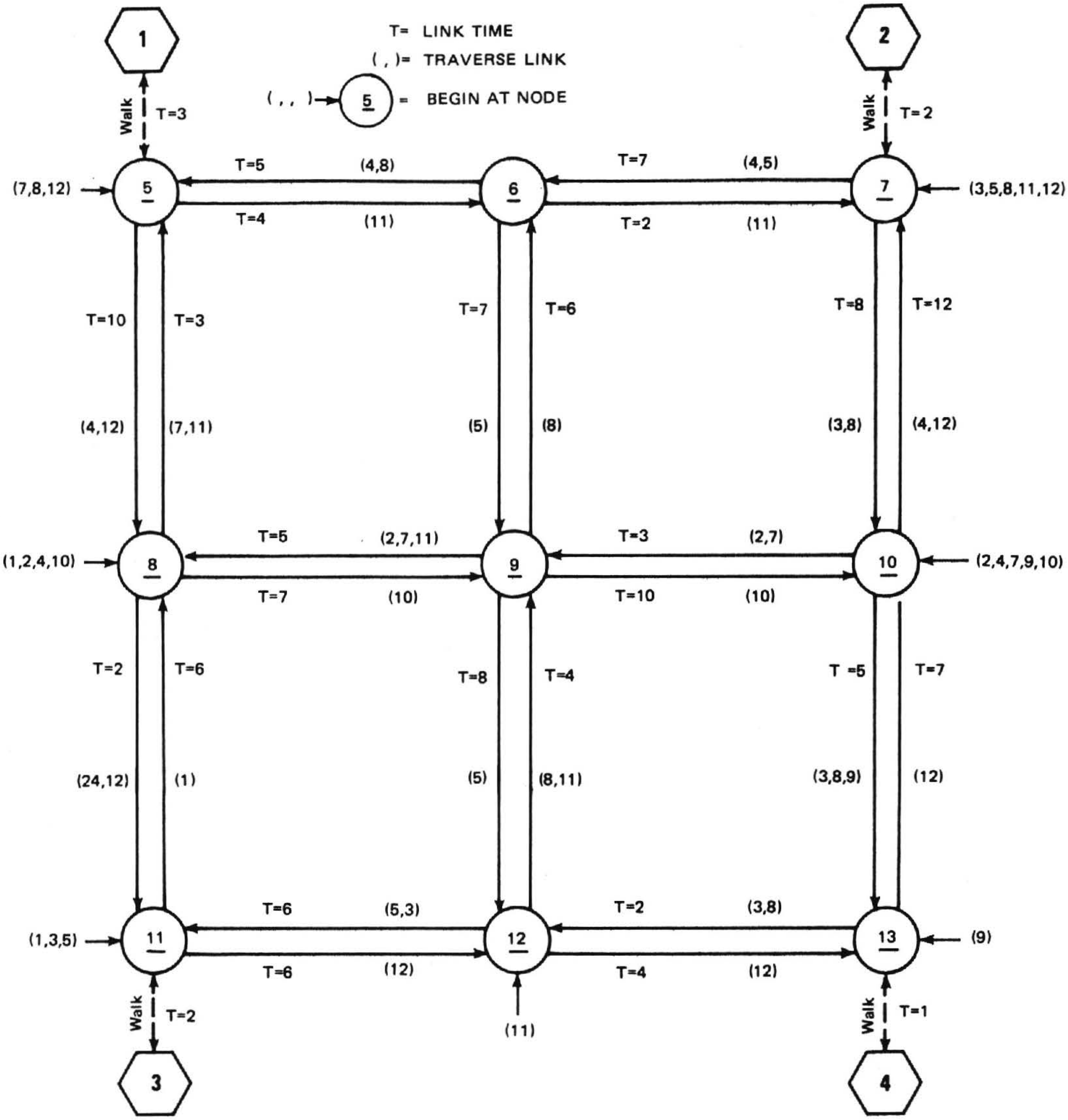
The single item necessary for assignment purposes on each network segment is an impedance value for minimum path calculations. This impedance might be travel time, distance, cost, or some derivative function of these. Assignments can be made without any additional network parameters. Other data, such as turn penalties and turn prohibitors, however, allow the development of more realistic assignments and more meaningful reporting of results.

impedance

The traffic assignment packages used for highway networks usually incorporate data for link volume under current conditions as actually measured in the field, link capacity, facility classification data, and other descriptive data. Link volumes are used as a check on the assignment process to indicate proper selection of the network and interconnection with load points. Link capacities calculated using techniques described in the Highway Capacity Manual - 1965 (16) are used to provide a feedback during the assignment process in representing system congestion via some capacity restraint technique. Descriptive data, such as functional classification, administrative classification, type of area the segment traverses, and type of facility description, allow summaries to be developed which detail the assignment output by these categories. Figure I-5 shows the input that might be coded for each segment of a highway network. The minimum data required for assignment include the node numbers and impedance values for each link (i.e., travel time and/or speed and distance).

Because of special operating characteristics, transit assignment requires a different set of network parameters to result in a meaningful assignment and summary results. Included are values for headway, transfer points, type of operation indicators (i.e., one-way, peak hour operation, etc.), and speed of operation. Figure I-6 shows the input data format used to code for the UTPS (UMTA Transportation Planning System).

The micro assignment technique recognizes traffic control features. On this basis, in addition to link distance and speed, the system requires traffic control input such as cycle times, green times, type of control indication, movement prohibition, lane operating features such as special turning lanes, lane reversal indications and parking information. The input format for the micro assignment package is shown in Figure I-7.



LINE FREQUENCIES

Line No	1	2	3	4	5	7	8	9	10	11	12
Buses/Hour	6	10	5	2	6	3	3	10	6	6	3

Figure I-4

Example Transit Network Geometry (7)

Card Columns	Column 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
* 18	T or S for time or speed (A-B)
*19-21	Time or speed (A-B)
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)
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

* Minimum data items that must be coded for an all-or-nothing assignment

Figure I-5

Highway Network Data -- FHWA Urban Transportation Planning Battery (14)

TRANSIT LINK DATA CARD

UTPS
UMTA Transportation Planning System
UTPS TRANSIT LINK DATA CARD

PROJECT__________ CONTENTS__________ PAGE_____ OF_____

WORK REQUEST SEQUENCE__________ __________ DATE__________

1	2–6	7–11	12	13	14	15	16	17	18–21	22–24	25–27	28–30	31–33	34–36	37–39	40	41–44	45–47	48–50	51–53	54–56	57–59	60–62	63–72	73–80
CARD NO.	A NODE	B NODE	UPDATE CODE	MODES ON LINK					A NODE → B NODE							2 IF A-B=B-A	B NODE → A NODE							IDENTIFICATION	THESE COLUMNS WILL BE IGNORED
									DIST. MILES	A.M.		P.M.		OFF PEAK			DIST. MILES	A.M.		P.M.		OFF PEAK			
				1st	2nd	3rd	4th	5th		SPEED	TIME	SPEED	TIME	SPEED	TIME			SPEED	TIME	SPEED	TIME	SPEED	TIME		
1																									
1																									

TRANSIT LINE DATA CARD

UTPS
UMTA Transportation Planning System
UTPS TRANSIT LINE DATA CARD

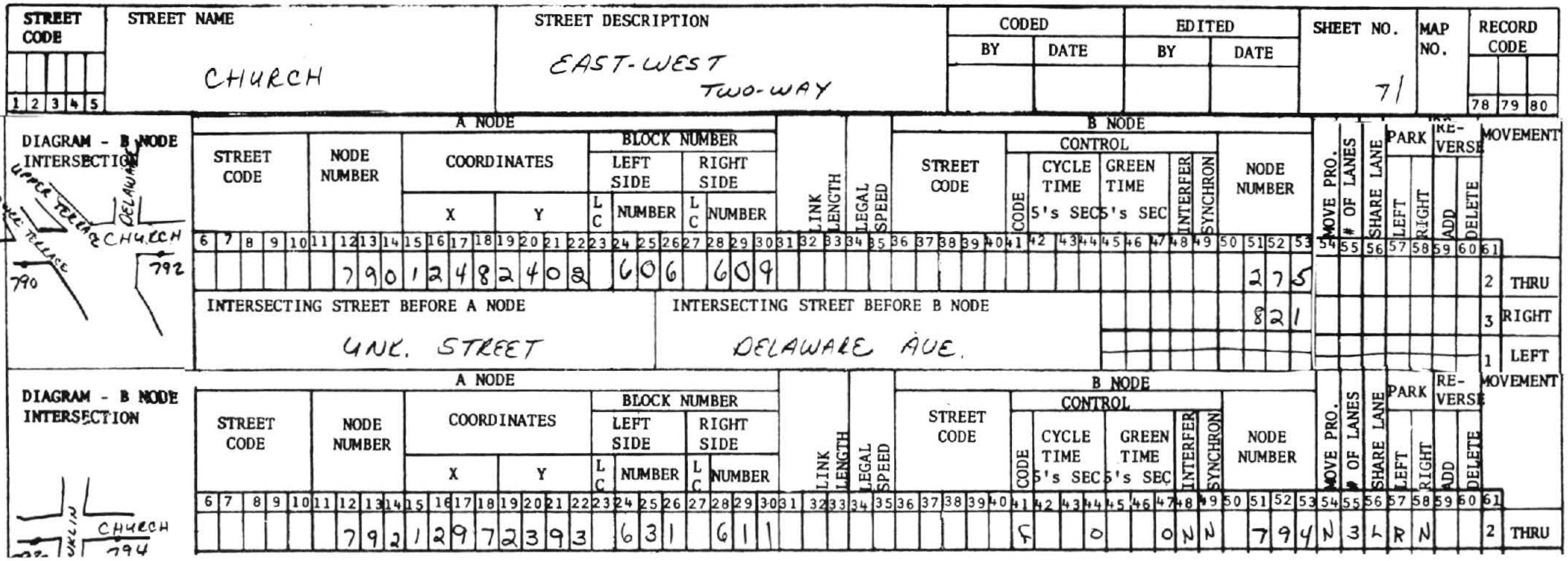
PROJECT__________ CONTENTS__________ PAGE_____ OF_____

WORK REQUEST SEQUENCE__________ __________ DATE__________

1	2–3	4	5–7	8	9	10–12	13–15	16–18	19–21	22–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–71	72	73–80
CARD NO.	TRANSIT CO.	MODE	LINE NUMBER	CARD SEQ.	DIRECTION	HEADWAY					ROUTE DESCRIPTION AS A SEQUENCE OF NODE NUMBERS									▨	T	USER IDENTIFICATION
						A.M.	P.M.	MID	NITE	Minimum	1st NODE	2nd NODE	3rd NODE	4th NODE	5th NODE	6th NODE	7th NODE	8th NODE	9th NODE			
																				▨		
																				▨		

Figure I-6 (7)

Transit Network Data - UTPS (7)



STREET CODE (1 2 3 4 5)	STREET NAME	STREET DESCRIPTION	CODED BY	CODED DATE	EDITED BY	EDITED DATE	SHEET NO.	MAP NO.	RECORD CODE (78 79 80)
	CHURCH	EAST-WEST TWO-WAY					71		

DIAGRAM - B NODE INTERSECTION

A NODE – STREET CODE (6–10)	
A NODE – NODE NUMBER (11–14)	790
A NODE – COORDINATES X (15–18)	1248
A NODE – COORDINATES Y (19–22)	2408
BLOCK NUMBER – LEFT SIDE – LC (23)	
BLOCK NUMBER – LEFT SIDE – NUMBER (24–26)	606
BLOCK NUMBER – RIGHT SIDE – LC (27)	
BLOCK NUMBER – RIGHT SIDE – NUMBER (28–30)	609
LINK LENGTH (31–33)	
LEGAL SPEED (34–35)	
B NODE – STREET CODE (36–40)	
CONTROL – CODE (41)	
CONTROL – CYCLE TIME 5's SEC (42–44)	
CONTROL – GREEN TIME 5's SEC (45–47)	
CONTROL – INTERFER (48)	
CONTROL – SYNCHRON (49)	
B NODE – NODE NUMBER (50–53)	275 (2 THRU) 821 (3 RIGHT) (1 LEFT)
MOVE PRO. (54)	
# OF LANES (55)	
SHARE LANE (56)	
PARK – LEFT (57)	
PARK – RIGHT (58)	
REVERSE – ADD (59)	
REVERSE – DELETE (60)	
MOVEMENT (61)	2 THRU 3 RIGHT 1 LEFT

INTERSECTING STREET BEFORE A NODE: UNK. STREET

INTERSECTING STREET BEFORE B NODE: DELAWARE AVE.

DIAGRAM - B NODE INTERSECTION

A NODE – STREET CODE (6–10)	
A NODE – NODE NUMBER (11–14)	792
A NODE – COORDINATES X (15–18)	1297
A NODE – COORDINATES Y (19–22)	2393
BLOCK NUMBER – LEFT SIDE – LC (23)	
BLOCK NUMBER – LEFT SIDE – NUMBER (24–26)	631
BLOCK NUMBER – RIGHT SIDE – LC (27)	
BLOCK NUMBER – RIGHT SIDE – NUMBER (28–30)	611
LINK LENGTH (31–33)	
LEGAL SPEED (34–35)	
B NODE – STREET CODE (36–40)	
CONTROL – CODE (41)	5
CONTROL – CYCLE TIME 5's SEC (42–44)	0
CONTROL – GREEN TIME 5's SEC (45–47)	0
CONTROL – INTERFER (48)	N
CONTROL – SYNCHRON (49)	N
B NODE – NODE NUMBER (50–53)	794
MOVE PRO. (54)	N
# OF LANES (55)	3
SHARE LANE (56)	L
PARK – LEFT (57)	R
PARK – RIGHT (58)	N
REVERSE – ADD (59)	
REVERSE – DELETE (60)	
MOVEMENT (61)	2 THRU

Figure I-7 MICRO ASSIGNMENT NETWORK INPUT
DATA FORMAT (10)

Trip Interchange Data

trip table

All assignment techniques (except direct assignment methods which require trip ends) require an origin-destination trip matrix which contains the number of trips from each origin to each destination in an area. This trip matrix is loaded onto the assignment network through "load points" which may be either on or off the assignment network (i.e. may be intersections of the network or may be external points connected to the network by a line).

The trip matrix may be developed for any type of characteristic (e.g., time of day, origin-destination combinations, etc.). Twenty-four hour trips may be loaded, or any portion of a day such as the morning peak hour. Trips may be for persons, for vehicles, for transit riders, or any subgrouping. The matrix may include origin-destination movements for only some portion of an area, such as trips to the central business district. The matrix used for assignment may be developed from a field survey or may be generated by a model.

The trip matrix used for micro assignment includes a starting time within the micro area for each trip considered since the technique assigns small increments of traffic over a period of time. Likewise, since small area detail is a key reason for use of micro assignment, the trip matrix should be available at a block or block face level rather than the zonal level required for the previously described assignment techniques. Because of these requirements, micro assignment is most useful in study of present day operations rather than in study of future conditions.

CHAPTER II
METHODS

The objective of this Chapter is to provide a basic description and sufficient detailed information to allow an evaluation of the various traffic assignment techniques that are now available. References are made to reports and documents that provide additional information on the use of computer programs and systems which apply these techniques for those who may wish to make use of a particular system. Other documents referenced will provide more detailed theory description and, in some cases, results of applications made. In addition to the description of the more traditional assignment techniques for highway and transit (i.e., trip interchanges assigned to minimum paths), information is provided on other traffic assignment methods. Included are traffic diversion theories, capacity restraint, a multi route probabilistic approach, direct traffic estimation, as well as small area assignments using the newly developed "micro assignment", adaptation of network methods and other simulation techniques.

chapter overview

MINIMUM PATH AND DIVERSION TECHNIQUES - HIGHWAY ASSIGNMENT

Minimum Routes

Much of the early development in traffic assignment was related to highway transportation. During the last several years, there has been increasing development and application of techniques for other modes of travel. But, the greatest amount of available techniques and facilities are still related to highway networks.

Assignment techniques are based upon the premise that users of a transportation network wish to optimize some measure(s) of their travel. Generally, the characteristics of travel considered are travel time, distance, and cost. Most applications of traffic assignment utilize one basic measure of travel and convert other measures to the basic measure -- if necessary. For example, travel time on network segments is the most widely used value. Should there be toll facilities on the system, the tolls are converted to a corresponding time impedance for network coding. This conversion is based upon adopting some value of time measure. Since such conversion is at best an educated guess, there have been only a few applications of traffic assignment using travel cost as the basic network segment impedance.

Since minimum path assignment techniques are based upon the determination of routes, efficient methods had to be developed. One can easily visualize the problem of manual route determination if a four street by four street regular grid pattern network is to be studied. To find the minimum time path from one corner of such a network to the diagonally opposite corner, forty different paths must be tested. The problem becomes uneconomical to solve if all routes must be tested to find the minimum routes in a large urban area network of say 5,000 network segments. This is true whether computation is done manually (a virtually impossible task) or by computer (a task one could hardly afford).

minimum route algorithm

tree

The breakthrough in computation which allowed traffic assignments to complete networks--rather than for testing a single proposed route--came from work undertaken to solve the route selection of the telephone systems for direct dialing of long distance telephone calls. Algorithms were developed which greatly reduced the computational time necessary for route selection as applied to highway networks. The first and most widely used algorithm, although modifications have been made for special purposes, is referred to as the Moore algorithm. This algorithm does not require all possible routes between an origin and destination to be individually investigated to find the shortest route. Rather, a minimum "tree" is developed by fanning out from the origin to all other accessible nodes in increasing order of their impedance summation from the origin. A tree is defined as the set of shortest routes from an origin to all other points in a network. A centroid is the point used to represent the origin or destination of all trips to or from a zone. Generally, it is the center of trip activity rather than the geographic center. The following example is offered to illustrate this process. Figure II-1 is a sample network, and we wish to determine the tree for node 1. Figure II-2 is a visual representation of the tree building process along with a step by step description.

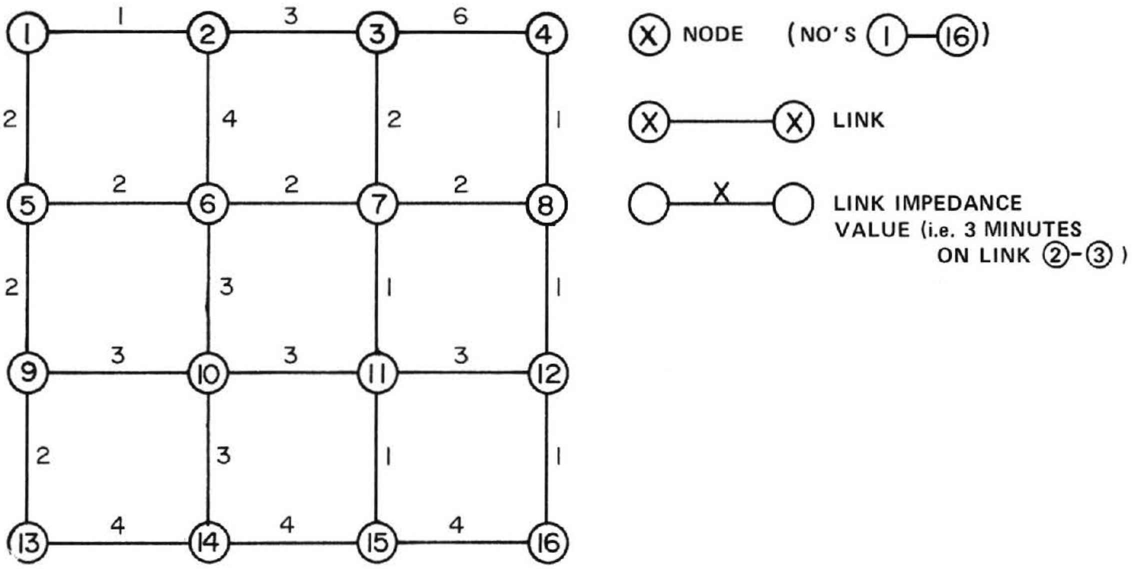
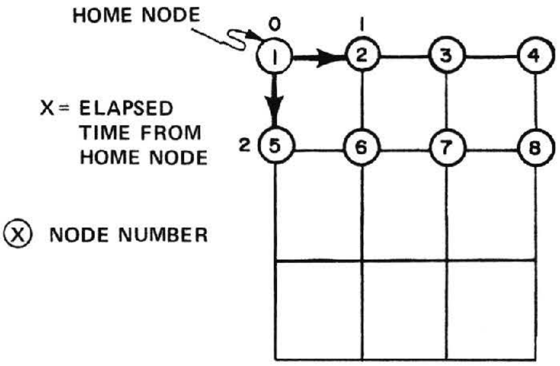


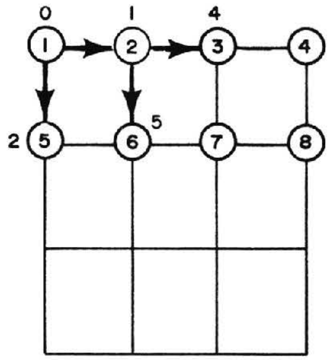
FIGURE II-1

SAMPLE NETWORK TO ILLUSTRATE TREE-BUILDING PROCESS

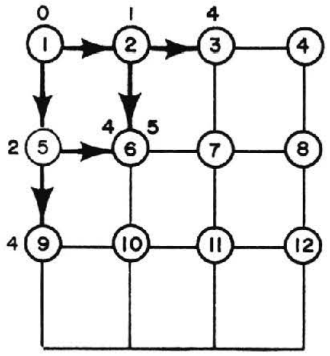
Step 1. Determine the time to the nodes connected to node 1. The time to node 2 is 1 and to node 5 the time is 2.



Step 2. From the node closest to the home node 1, which is node 2, the connections are to nodes 3 and 6 (backtracking is not permitted). The corresponding times are the time to node 2 plus the outbound link times from node 2 which are 4 and 5 minutes respectively.



Step 3. The node now closest to the home node is node 5. Proceeding from node 5 to node 6 the time is the time to node 5 plus the link time on 5-6, or a total of 4 minutes. Likewise the time to node 9 is 4 minutes (time to node 5 plus link time 5-9).



Step 4. The time to node 6 via link 5-6 is less than the previous route via link 2-6. Therefore, the link 2-6 is deleted from the tree.

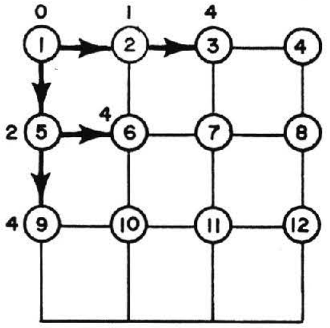
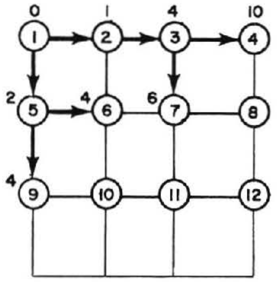
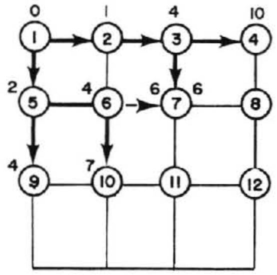


FIGURE II-2
THE TREE-BUILDING PROCESS

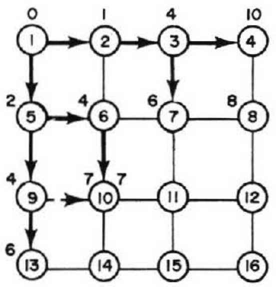
Step 5. The node now closest to the home node is node 3 which is 4 minutes away. Adding the corresponding link time to nodes 4 and 7 the corresponding times are 10 and 6 minutes, respectively. By convention, the node with the lowest number of those equidistant from the home node is taken first.



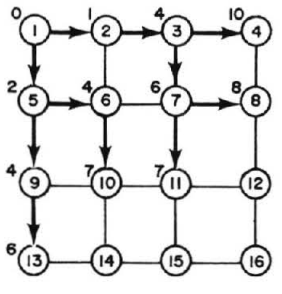
Step 6. The node closest to the home node is now node 6. The times to nodes 7 and 10 are 6 and 7 minutes respectively. Since node 7 was reached previously in 6 minutes, there is no time savings via the route entering on link 6-7. For this reason the connection is shown in dashed lines and will not be part of the tree as can be seen in step 7.



Step 7. Building proceeds from node 9 to nodes 10 and 13, with respective times from the home node of 7 and 6 minutes, respectively. The dashed line indicates that link 9-10 will not be in the final tree for the same reason mentioned in step 6 above.



Step 8. Building proceeds from node 7 to nodes 8 and 11.



Step 9. Building proceeds from node 13.

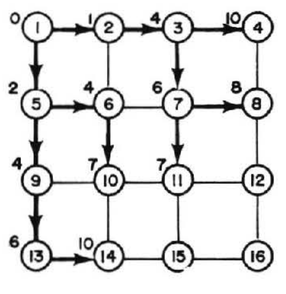
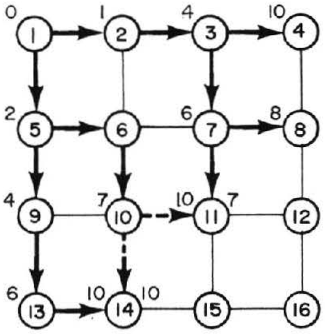
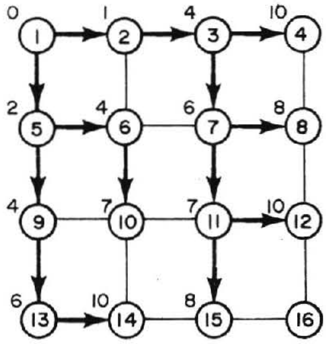


FIGURE II-2 Continued
THE TREE-BUILDING PROCESS

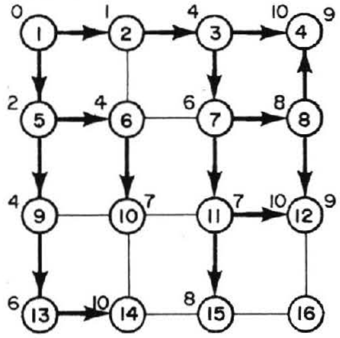
Step 10. Building proceeds from node 10. The time to node 11 is longer than a previous entry so that link 10-11 will not be in the tree. The time to node 14 is the same as a previous entry so that link 10-14 will not be in the tree.



Step 11. Tree building proceeds from node 11.



Step 12. Tree building proceeds from node 8. Note that the time via node 8 to nodes 4 and 12 are less than previously.



Step 13. Links 3-4 and 11-12 are removed from the tree due to finding in step 12.

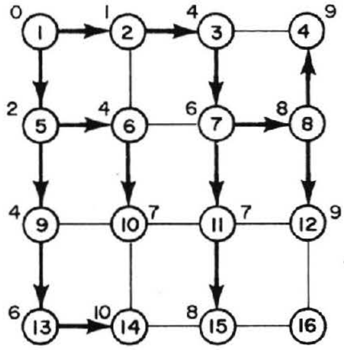
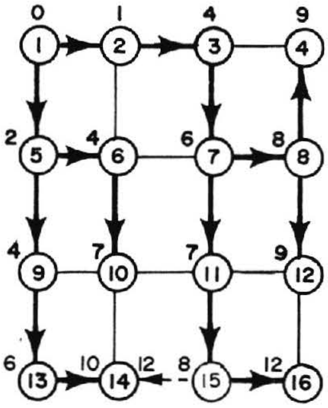
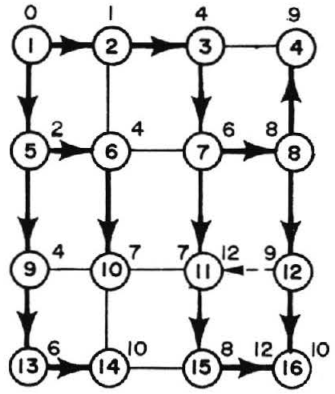


FIGURE II-2 Continued
THE TREE - BUILDING PROCESS

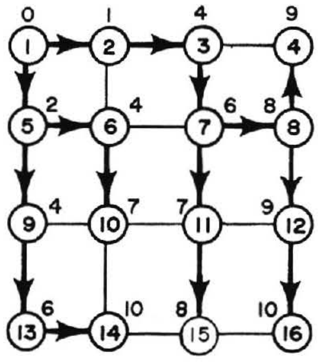
<u>Step 14</u>. Building proceeds from node 15.



<u>Step 15</u>. Building proceeds from node 12.



<u>Step 16</u>. This is the final tree as built by the process. To find the minimum time path between any two nodes, the links are followed backward from the destination node to the origin node. For example to go from node 1 to node 4, the route would be found by first looking at node 4 and proceeding to backnodes 8, 7, 3, 2, 1.



FINAL TREE

FIGURE II-2 Continued
THE TREE-BUILDING PROCESS

The Moore Algorithm described has been modified to allow turn prohibitions to be included in the network as well as time penalties for turns to reflect conditions on a highway network. These features help in realistically coding the operation of a network and may result in more accurate assignment results. Turn prohibitions, however, sometimes result in unrealistic paths or, in the extreme, no path between two points. The use of turn prohibitors results, on occasion, in the need for using a node more than once in the tree building algorithm. This is specifically excluded in the Moore algorithm as described above. This algorithm builds paths which are sequences of links with a restriction that a node cannot be used more than once. A tree records the routings in such a manner that there is only one entrance link to a node and that entrance link is on the minimum path to the node.

trees & vines contrasted

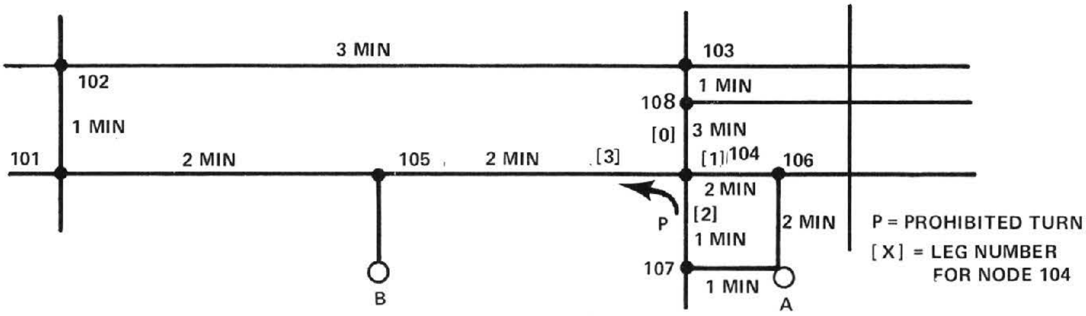
A recent development in the route building algorithm results in a "vine" as opposed to a tree. A vine records the routing such that all four links connected to a node may be traversed, if necessary, to produce the minimum path. Whereas the tree is calculated to each node, the vine is calculated to each of the legs from a node (which are numbered in some sequential manner). This process is shown in Figure II-3(a). Outbound links from a node are called legs and are identified by number (0-3 in the FHWA assignment system). This identification of outbound links is used to facilitate the use of multiple turn penalties as well as turn prohibitors. In the following discussion it is assumed that the tree building process described previously is understood.

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 (Figure II-3(b). Under the tree option, the back 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, 108, 103, 102, 101, and 105. (Figure II-3(c)).

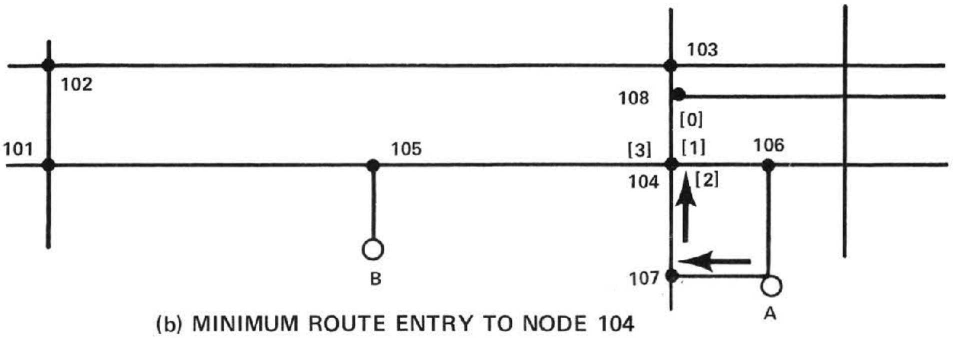
Under the vine option the program will calculate the traveltime to each leg at node 104. In proceeding from centroid A the vine building process would build to legs (0) and (1) in proceeding from node 107 to node 104. Likewise, through node 106 the legs (0), (3), and (2) would be reached. Therefore, under the vine process, the path from A to B would be via nodes 106, 104, and 105 (Figure II-3(d)) a more realistic path than previously.

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 about twice as much computer time to determine. If many intersections have prohibited turning movements, or large turning penalties associated with them, vines should probably be used. Otherwise, trees may be used.

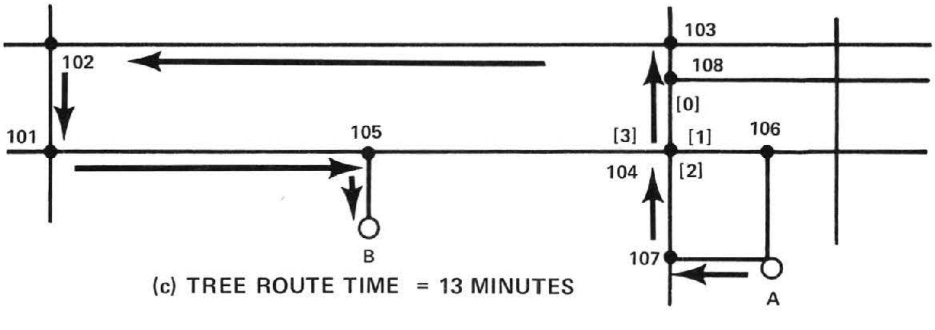
In addition to the Moore algorithm and its variations, other minimum route approaches have found use in transportation planning applications. The most widely used of these algorithms are: the Road Research Laboratory algorithm (RRL); the Shimbel algorithm; the Origin and Destination algorithm (O-D); and the Transit Pathfinder algorithm. A short description will point up the major differences in these.



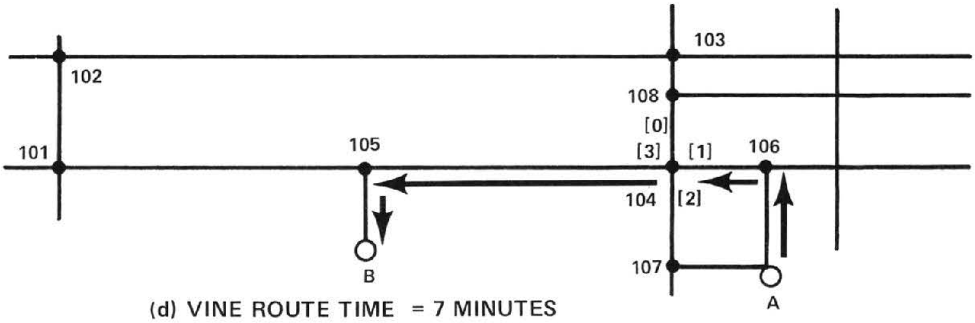
(a) NETWORK CONFIGURATION



(b) MINIMUM ROUTE ENTRY TO NODE 104



(c) TREE ROUTE TIME = 13 MINUTES



(d) VINE ROUTE TIME = 7 MINUTES

FIGURE II-3
VINE ROUTING VERSUS TREE ROUTING

As described above, the Moore algorithm computes minimum paths for one origin at a time with the procedure repeated for each tree required. The tree is built by successively using the terminal node nearest the origin of the tree as the next branching node. All links connected to the branching node are added to the tree and their terminal nodes become new terminal nodes of the tree. It is possible that the first time found to a node from the origin of a tree is not the minimum time and will have to be changed sometime later in the computation if a shorter path is found. For this reason, some iteration is involved in the Moore algorithm.

other minimum route approaches

The RRL algorithm is similar to the Moore algorithm (17). The tree is formed by successively adding the terminal node nearest the origin of the tree but not already on the tree. The links emanating from nodes added to the tree are entered in a table and their terminal nodes become candidates for adding to the tree. The first time assigned to a node is defined as the minimum time from the origin and no other paths to that node are considered.

The Shimbel algorithm (17) differs from the above two in that it uses matrix representation of the network and matrix operations to determine minimum paths. All origin zones are considered in one operation.

The Origin and Destination algorithm is a special formulation of the RRL algorithm that computes minimum paths between specific origins and destinations (17). The algorithm computes from both origin and destination of the required path simultaneously, thereby creating two paths which join to form the required minimum path.

The Transit Pathfinder algorithm is a modification of the Moore algorithm (18). Changes in the Pathfinder algorithm result in the necessity of providing for the peculiarities found in Transit minimum paths. The details of this algorithm are discussed starting on page 47.

The Moore, RRL, Shimbel, and O-D algorithms have been programmed in FORTRAN for the IBM 7090 and IBM 1620. This was done at MIT in order to test the relative efficiencies of these algorithms (17). Six different networks were used for the test. Tree comparisions were made for the Moore, RRL, and Shimbel algorithms while single paths were compared for the RRL single path and Origin and Destination algorithms. The results of this experiment can be seen in summary form in Table II-1.

Table II-1

COMPUTER TIME COMPARISONS FOR MINIMUM PATH ALGORITHMS (17)

NETWORK		TREE COMPARISONS		SINGLE PATH COMPARISONS	
NODES	LINKS	Algorithm	Seconds	Algorithm	Seconds
9	24	Shimbel	0.27	RRL	0.083
14	38	Moore & RRL	0.33	RRL	0.076
21	70	RRL	0.37	RRL	0.093
35	98	RRL	0.46	RRL	0.104
84	376	Moore	1.55	O & D	0.242
366	990	RRL	8.7	RRL	3.1

A summary in diagram form is seen in Figure II-4, showing the optimum algorithm as a function of the number of nodes, number of links, and the ratio of links to nodes in the network. In general, transportation networks have link-node ratios between 3.5 and 4.0 which seems to indicate that the RRL algorithm would be preferable in terms of computer run time.

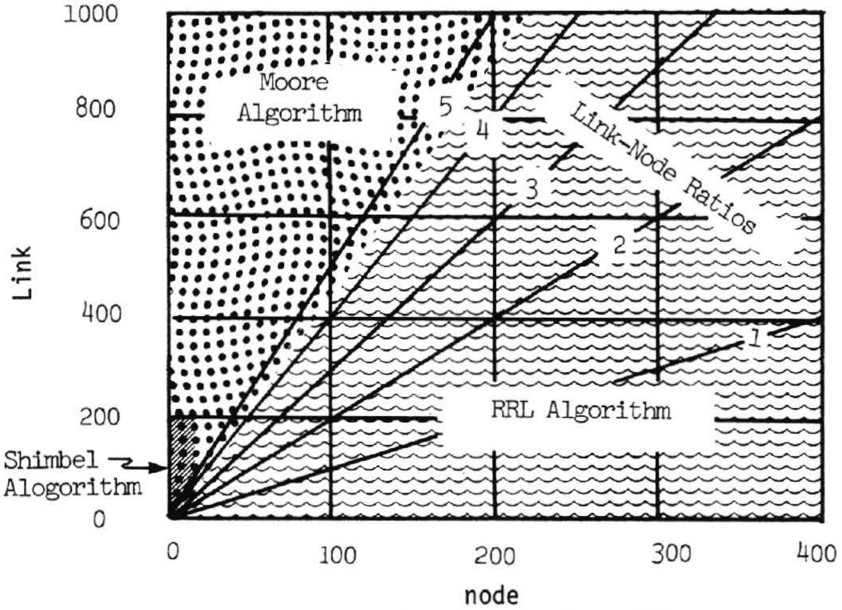
Computer storage required by the various algorithms was almost the same except for the O and D which required almost three times the storage. Data storage space was almost identical for all except the Shimbel algorithm which required 10-20 times the storage, depending on the network. It was found that the Moore and RRL were convenient to program, the O and D less convenient, and the Shimbel rather inconvenient.

Diversion Techniques - Multi Routes

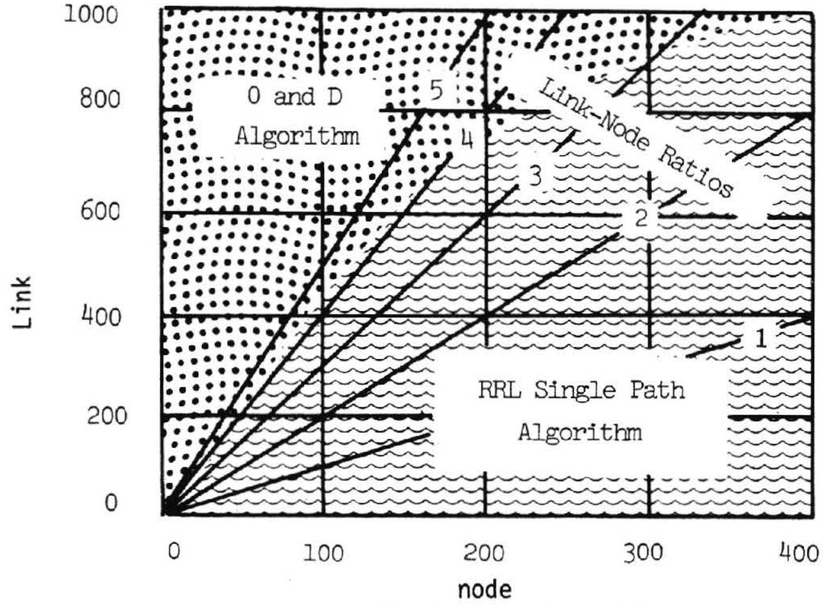
diversion

Initial traffic assignments were made manually to determine the use of a single proposed facility. These estimates were made considering normal traffic growth, new traffic induced by the proposed facility, and traffic "diverted" from other facilities. This diversion considered that some proportion of automobiles would be diverted from an existing arterial route to a freeway based upon the relative savings in time, distance, or cost in using the new facility. The diversion technique required the determination of the minimum routing between origins and destinations via a route containing the proposed facility as well as via a route not utilizing the proposed facility. The travel between each origin and destination would be proportioned between the two routings based upon the relative impedance values on the two routes.

One of the more widely used diversion curves was that theorized by Mr. Earl Campbell (3). A graph of this for urban arterial highways is shown in



Result for Computation of Trees



Results for Computation of Paths

The charts have been constructed from the 7090 results and indicate what is likely to be the best algorithm (minimum running time) for different network configurations.

FIGURE II-4

Summary of Results From Testing the Relative Efficiencies of Several Minimum Path (17)

Figure II-5. The curve is based upon relative travel time between the new facility and the quickest alternate route. The curve shows, for example, if travel time between two points is equal via a proposed freeway route and the quickest alternate route, then approximately 48% of the travel would use the new facility. For a major street facility, about 35% of the travel would divert. Although the time diversion curve received wide acceptance, others were developed and used in many applications.

The state of California developed a function that incorporates both time and distance savings as the criteria for diversion to a proposed freeway route as shown in Figure II-6 (5). Each zone to zone movement that may be a candidate for assignment to a new freeway route(s) must be routed through the existing street systems and the travel time accumulated for the route. The total distance for each existing street routing must also be accumulated. Each zone-to-zone movement must also be routed over the proposed freeway systems even though the time and distance may be adverse to the routing. The California time and distance curves consist of a family of hyperbolas. With equal time and distance on the freeway and on the best alternate arterial route, 50 percent of the trips are assigned to the freeway. In Figure II-6, the curves are entered with time (t) and distance (d) saved, and where these values cross, the percent freeway use (p) is obtained.

The Detroit area transportation study developed diversion curves relating the percentage of freeway use to speed and distance ratios (19). These curves are also S-shaped for normal conditions. The curves represent a three dimensional surface with an undefined mathematical relationship.

As can be seen from the diversion curves in Figures II-5 and II-6, there is a diversion to a new freeway route even when the time and/or distance is longer than the best non-freeway route. Since minimum path algorithms produce, generally, the single best route, the application of diversion techniques was not easily accomplished by computer. The approach taken was to try and "fool" the minimum route algorithm into producing the two routes required for diversion. A complete description of this approach is discussed in an article by William L. Mertz in the July 1960 issue of <u>Traffic Engineering</u> magazine (20). To obtain the non-freeway routes, the freeway links were eliminated from the network under consideration and trees built to reflect the non-freeway minimum time paths. Next, trees were built with the freeways in place but with the times to traverse each freeway link reduced considerably to "force" the minimum path algorithm to select routes containing freeway links, although the freeway routes might be actually longer than non-freeway routes. This process assured obtaining travel time ratios greater than 1.0 (see figure II-5) where there is still some diversion to the freeway route. The basic problem with the approach was that in many cases very unrealistic routes were obtained.

<u>diversion example</u>

Much of the application of diversion techniques via computer considered the diversion at a point-of-choice rather than between each origin and destination. These points of choice between an origin and destination are where a route diverges and converges between a freeway and arterial path. Figure II-7 and the results in Table II-2 show the differences obtained using an all-or-nothing approach and a travel time diversion curve (see Figure II-5) between

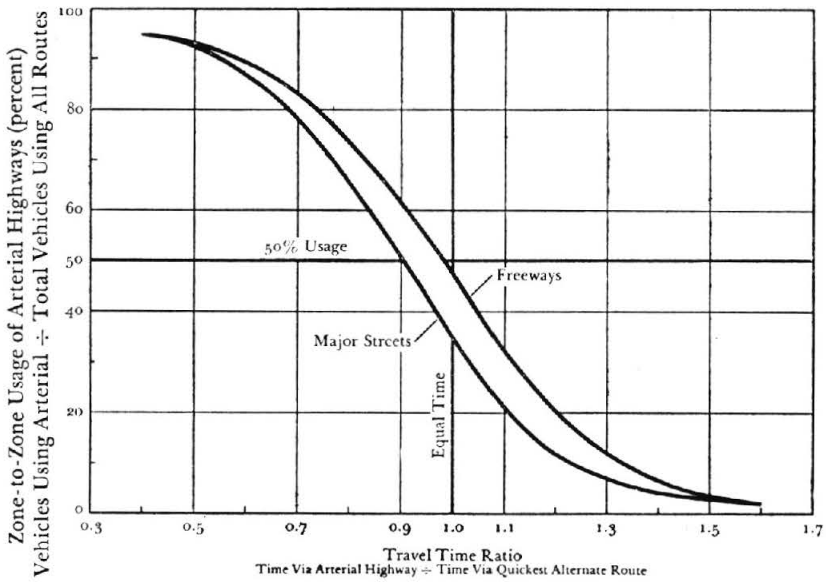


FIGURE II-5

Time Ratio Diversion Curves (4)

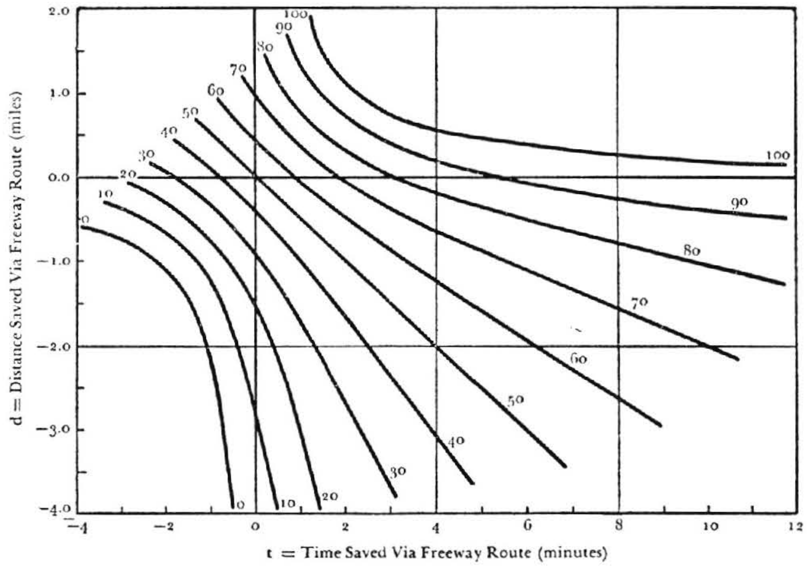
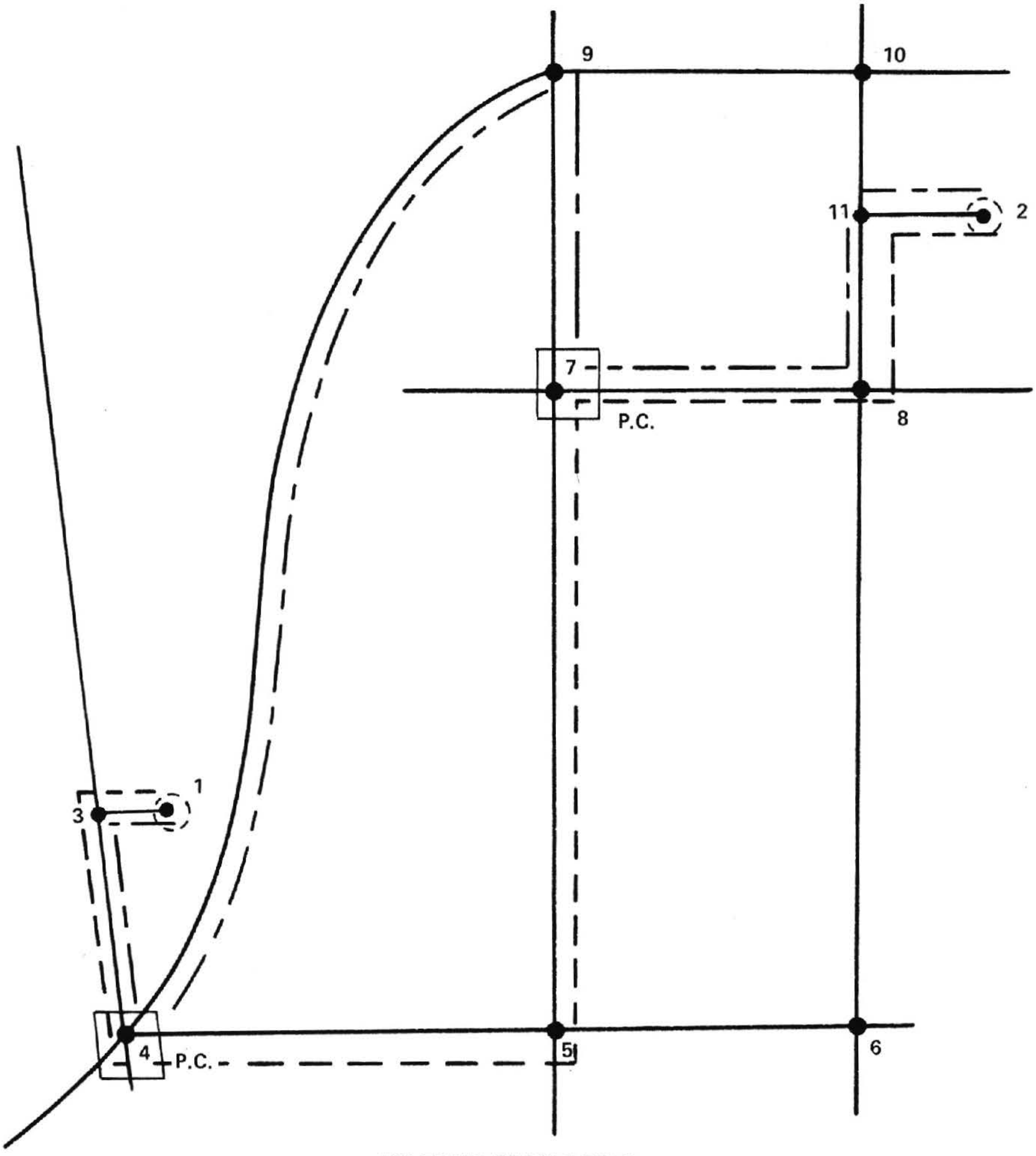


FIGURE II-6

California time and distance savings diversion curves (5)



100 TRIPS FROM 1 TO 2
BEST ARTERIAL ROUTE (– – –) 10 MINUTES
BEST FREEWAY ROUTE(–·–) 11 MINUTES
BEST ROUTE IS ARTERIAL ROUTE – 10 MINUTES
TIME BETWEEN POINTS OF CHOICE
5 MIN. ARTERIAL
6 MIN. FREEWAY

NOTE: P.C. is point of choice between Freeway and Arterial

FIGURE II-7
EXAMPLE OF TRAFFIC ASSIGNMENT DIVERSION

an origin and destination or between points of choice.

TABLE II-2

EXAMPLE OF TRAFFIC ASSIGNMENT DIVERSION

LINK	ALL-OR-NOTHING	DIVERSION O-D($\frac{11}{10}$=1.1)	DIVERSION BETWEEN P.C. ($\frac{6}{5}$ =1.2)
1-3	100	100	100
3-4	100	100	100
4-5	100	74	85
4-9	0	26	15
5-7	100	74	85
7-8	100	100	100
8-11	100	100	100
9-7	0	26	15
11-2	100	100	100

Figure II-7 shows the "best" arterial and the "best" freeway routes from the standpoint of minimum time (10 minutes and 11 minutes, respectively) from origin to destination. The points of choice are numbered 4 and 7 with minimum times between these of 5 minutes by arterial routes and 6 minutes by freeway routes. The time ratio between O and D is 11/10 or 1.1 resulting in a 26 percent diversion to the freeway route sections (links 4-9 and 9-7) and 74% to arterial links (4-5 and 5-7). Where a link is on both the arterial and freeway minimum paths, 100% of the travel is assigned (links 1-3, 3-4, 7-8, 8-11, 11-2). The time ratio between points of choice is 6/5 or 1.2, resulting in a 15% diversion to the freeway route links and 85 to the arterial links (see Table II-2).

Diversion techniques were widely used in the early 1960's, especially before the use of restraint techniques (discussed in the next section). Their advantage was a spread of traffic between routes that appeared to be more realistic than all-or-nothing assignments. Their disadvantages were considerable increases in computer costs and, upon occasion, unreasonable results. With the advent of restraint techniques, it was found that restraint application was desirable whether or not diversion techniques were used, and, in effect, restraint techniques do actually result in a diversion between routes. Likewise, most practitioners do not believe there is a significant enough difference in results when using capacity restraint to warrant the extra cost involved in diversion assignments. There is little application of diversion techniques in network assignment in today's practice, although its usefulness can be shown for corridor type applications (see Chapter IV).

Through the last decade there have been many attempts to develop a multi-route assignment technique which would proportion traffic between pairs of zones in a realistic manner. It is obvious that all drivers between two points do not take the same route. In assignment practice, the development of a multi-route procedure is hampered by the ability to produce alternate routes that are truly different--but reasonable. Most attempts result in alternate routings to the minimum paths that are small deviations from the minimum paths rather than truly different routes. A new technique, which determines and assigns to alternate paths, is described beginning on page 38 of this chapter.

Capacity Restraint

Capacity restraint techniques are based on the finding that as traffic flow increases the speed of traffic decreases. Most research into this area has been relative to highway facilities, but the same holds true for other types of facilities, such as a very heavily used subway system in New York City. A considerable amount of work has been accomplished in the area of highway capacity and is reported in the Highway Capacity Manual published as Special Report No. 87 by the Highway Research Board (16).

speed-volume relationships

There is a relationship between speed and volume on all types of highway facilities, both for interrupted and uninterrupted flow. On facilities such as freeways, there is a constant decrease in speed with increase in traffic volume up to a point of critical density (density at maximum flow). Beyond this point, however, both volume and speed decrease with an increase in density (vehicles per mile). The situation is similar at interrupted flow type facilities (i.e. signalized intersections). Here, however, speed is influenced by external influences such as signal progression, speed limits, and the conditions on adjacent sections. Examples of the speed flow relationships for interrupted and uninterrupted flow are shown in Figure II-8.

The traffic assignment process assigns trips in accordance with impedances coded on each network segment. These impedances are usually travel time or some derivative of time. The assignment process results in the traffic load (volume) on each network segment. Since there is a very direct relationship between travel time (or speed) on a section and the volume on the section, a process is necessary to allow consideration of this relationship. This process is referred to as capacity restraint. Specifically, the capacity restraint process attempts to bring the assigned volume, the capacity of a facility, and the related speed into the proper balance.

There are several problems in the application of speed-flow relations in the assignment process. Most important is the assignment of trips for some extended period of time, such as a day, or for some shorter period, such as a two hour period encompassing the peak hours. Most critical flow problems actually occur over shorter time spans. Secondly, the assignment process may load a facility far in excess of capacity based upon some originally coded speed. Observed conditions are limited to some maximum capacity. Because of this, capacity restraint functions are theoretical extensions beyond some critical capacity point.

capacity restraint formulas

Several capacity functions have been utilized. The one used most widely (FHWA) takes the form:

$$T = T_0[1+0.15\ (V/C)^4] \qquad (1)$$

where T = balance travel time (at which traffic (V) can travel on a highway segment).

T_0 = free flow travel time; observed travel time (at practical capacity) times 0.87

V = assigned volume

C = Capacity

Others include that developed by Smock (52).

$$T_A = T_o e^{(V/C-1)} \text{ where } T_A \le 5T_o \qquad (2)$$

T_0 = original travel time (when volume equals capacity)

T_A = adjusted travel time

V = assigned volume

C = computed capacity

e = base of napierian logarithm

Schneider (52) developed a function as follows:

$$T_A = T_0(2)^{(V/C-1)} \text{ where } T_A \leqq 4(T_0) \qquad (3)$$

T_o = travel time at free flow conditions and T_A,

V & C same as above

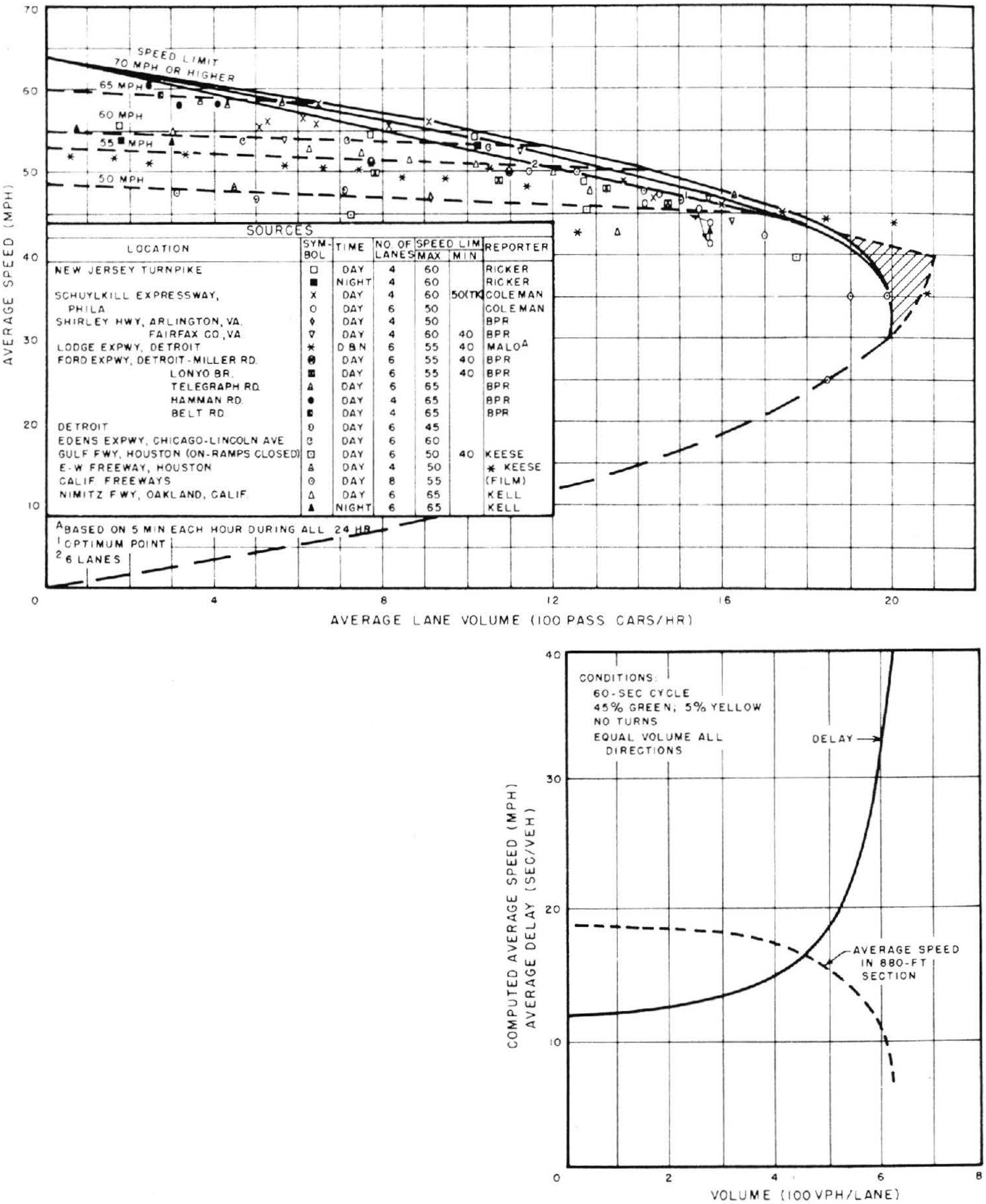
The functions produced by the three approaches are shown in Figure II-9. As can be seen, the functions turn out to be not too dissimilar. Mention should be made that the Schneider function was specifically developed for the opportunity model approach. This is a one pass model with link volumes ranging from zero for the first sequential zone to loaded for the last sequential zone. This is different from iterative techniques. The differences in these applicational approaches are described below:

iterative assignments

Iterative techniques consist of a successive number of route selections, loadings, and speed adjustments to obtain a balanced (speed, volume, and capacity) load on a transportation network. There are various theories on which results of the successive runs best approximate actual conditions. Practice dictates some weighting of the results of the first 3 or 4 runs. Research (51) work into the application of capacity restraint techniques using the FHWA function found:

- capacity restraint reduces the overall error in traffic assignment
- it is desirable to apply capacity restraint at least three times (four loadings)
- reasonable assignments are obtained by using the average of four loadings

The application of capacity restraint actually functions in a manner similar to a diversion type of assignment. Since network segment speeds are changed during each capacity restraint application, trips between any pair of origins and destinations may be loaded on different paths between successive assignments. Sinçe the results of each "n" number of assignments are weighted to obtain the final load, there is a diversion of O-D movements between different paths from each assignment. Because of these successive changes in speeds, careful consideration should be given to their effect on other models (see discussion beginning on page 93).



SOURCES

LOCATION	SYMBOL	TIME	NO. OF LANES	SPEED LIM MAX	SPEED LIM MIN	REPORTER
NEW JERSEY TURNPIKE	□	DAY	4	60		RICKER
	■	NIGHT	4	60		RICKER
SCHUYLKILL EXPRESSWAY,	x	DAY	4	60	50(TK)	COLEMAN
PHILA	○	DAY	6	50		COLEMAN
SHIRLEY HWY, ARLINGTON, VA.	◊	DAY	4	50		BPR
FAIRFAX CO., VA	∇	DAY	4	60	40	BPR
LODGE EXPWY, DETROIT	*	D & N	6	55	40	MALO[A]
FORD EXPWY, DETROIT-MILLER RD.	●	DAY	6	55	40	BPR
LONYO BR.	▣	DAY	6	55	40	BPR
TELEGRAPH RD.	▲	DAY	6	65		BPR
HAMMAN RD.	●	DAY	4	65		BPR
BELT RD.	■	DAY	4	65		BPR
DETROIT	⊖	DAY	6	45		
EDENS EXPWY, CHICAGO-LINCOLN AVE	C	DAY	6	60		
GULF FWY, HOUSTON (ON-RAMPS CLOSED)	⊡	DAY	6	50	40	KEESE
E-W FREEWAY, HOUSTON	Δ	DAY	4	50		* KEESE
CALIF. FREEWAYS	⊙	DAY	8	55		(FILM)
NIMITZ FWY, OAKLAND, CALIF.	Δ	DAY	6	65		KELL
	▲	NIGHT	6	65		KELL

[A] BASED ON 5 MIN EACH HOUR DURING ALL 24 HR

[1] OPTIMUM POINT

[2] 6 LANES

CONDITIONS:
60-SEC CYCLE
45% GREEN; 5% YELLOW
NO TURNS
EQUAL VOLUME ALL DIRECTIONS

FIGURE II-8

Examples of interrupted and uninterrupted speed flow relationships (16)

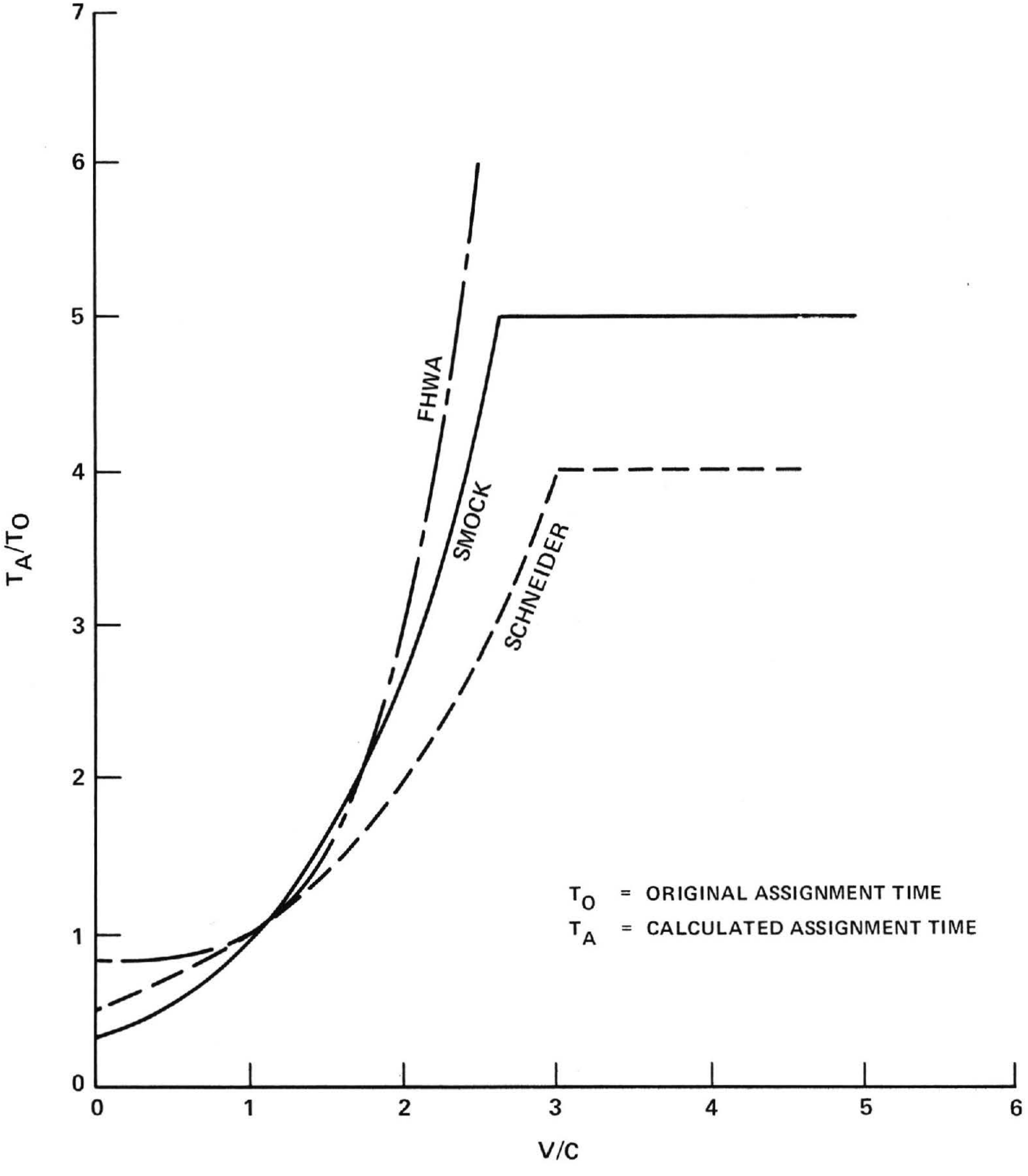


FIGURE II-9
CAPACITY RESTRAINT FUNCTIONS(52)

incremental assignments

Incremental Assignments are of two general types: (1) minimum routes between each pair of origins and destinations are calculated once and trips loaded once, and, (2) several route building steps and loadings must occur during the capacity restraint application.

The first listed capacity restraint technique was developed by the Chicago Area Transportation Study. In this process trees are built in a randomly selected order and trips loaded to the built trees. For example, a tree would be built for some zone(s) and trips loaded for this zone(s). The base travel times on the individual network segments would then be adjusted using some capacity restraint function and trees built for another randomly selected zone(s) and corresponding trips loaded. This process would continue until all zone to zone trips were loaded onto the system. The advantage of this technique over the iterative approach or the next type of incremental approach to be discussed is that trees are built only once and trips loaded only once, thereby greatly reducing computer costs. The disadvantages include the variability in results depending upon the order of zone selection and the loss of a "diversion" effect between pairs of zones.

The second type of incremental loading, developed by Control Data Corporation (21), overcomes the above disadvantages but at the cost of requiring several tree building and loading steps. In this method, minimum path trees are built using the travel time provided for the original network. Each network segment is loaded with the first increment of all zone-to-zone movements passing through it. This increment is some percent of total trips (say 20%). Each network segment is then adjusted based on a capacity restraint function (with the increment loaded on each segment factored to 100% for the calculation). A new increment of total trips is then assigned (say 40% of total trips). This increment is added to the first increment (20%) and factored to 100% to obtain a new set of network segment speeds for the next assignment. This continues until 100% of all trips are loaded.

Most applications of capacity restraint assignments rely upon one capacity restraint function; although, several computer systems for capacity restraint allow application of different functions for different types of facilities. Research is currently underway to develop and test the use of capacity restraint functions for different types of facilities as well as to determine if such capacity restraint functions are related to city size and system related characteristics.

Multi Route Probabilistic Assignment

A recent development which holds some promise in the area of multi-path assignment uses a probabilistic approach to try to circumvent the path enumeration problem. This approach was developed by Robert B. Dial of Alan M. Voorhees and Associates, Inc., and reported in the paper "A Probabilistic Multipath Traffic Assignment Model Which Obviates Path Enumeration" (12). A working computer program of the approach is available in the FHWA transportation planning package for S360 (15). As of this date, no full scale application allows comparison of results with the more historic all-or-nothing assignment technique.

multi-path assignment

The technique is a two pass Markov Model in which node/link transition probabilities are calculated in one (forward) examination of the network and trips are assigned in a second (backward) examination. The assignment consists of diverting trips entering a node to all reasonable links beginning at the node. The model never explicitly examines a path and, on this basis, is a computationally efficient multi-path approach.

The model developed has the following features:

- The model gives all "reasonable" paths between an origin and destination some probability of use, and unreasonable paths receive no use.
- All reasonable paths of equal length receive an equal probability of use.
- When there are several reasonable paths of unequal length, the shorter has the highest probability of use.
- The user has some control over the path diversion probabilities.
- The assignment algorithm probabilistically diverts trips at each node encountered to the competing links entering the node.

There are several ways to define a "reasonable" path. For the operational model available, a reasonable path is one which, as it progresses from node to node, gets further from the origin. A path is efficient if every link in it has its initial node closer to the origin than its final node. Figure II-10 is an example of all reasonable paths from a common origin node 1 (referred to as a "bush"). The time to the left of the node number in circles is the

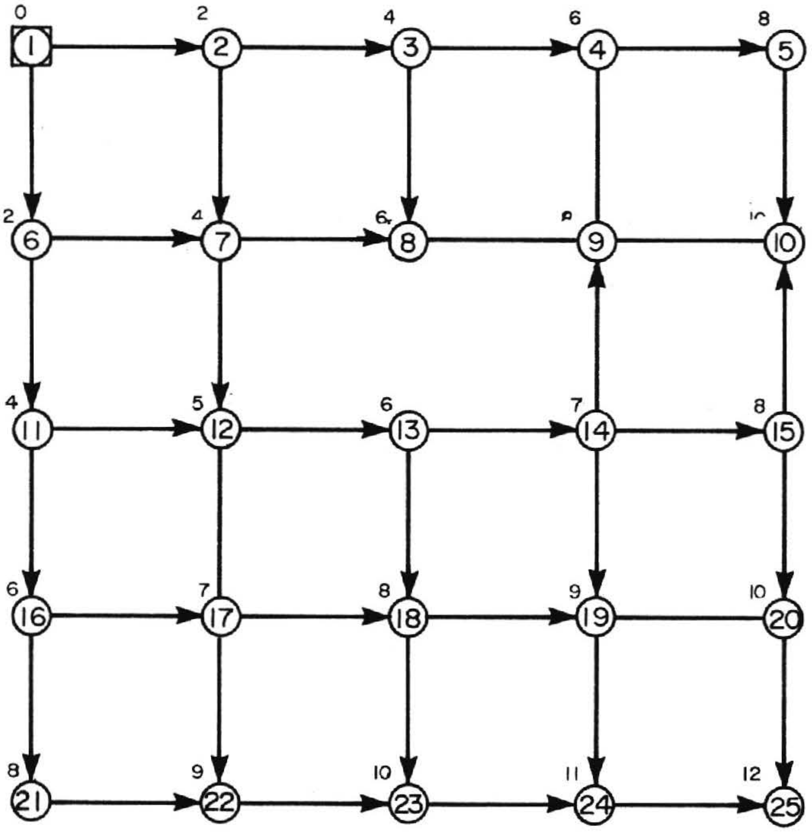


FIGURE II-10

EXAMPLE OF ALL REASONABLE PATHS FROM A COMMON ORIGIN(12) minimum time path from node 1. The link between nodes 8 and 13 is not in the bush since both ends are 6 minutes away from the origin thus not fulfilling the requirement of a reasonable path.

The approach assigns all trips originating at a given node to all efficient paths in a single execution of its assignment algorithm. This results in a model with good computational efficiency. The computer running time is approximately two times that required by an all-or-nothing assignment using conventional traffic assignment approaches.

There are three link determinations to be made in calculating the volume using a link. These are:

Link Likelihood of Use = $a[e] = e^{\theta \Delta t}$ (4)

Where: $[e]$ = link $[i, j]$

e = base of napierian logarithms

θ = diversion parameter

Δt = difference between minimum time path time to the node and the time via another reasonable path

$t = M_j - M_i - M_t$

where: M_j = minimum time to node j
M_i = minimum time to node i
M_t = time to traverse link i-j

If $\Delta t = o$, then the link i-j is on the minimum time path. If M_i is greater than M_j, then link i-j is not on a reasonable path and has a zero likelihood of use.

(note: $a[e] = 0$ if link not on a reasonable path)

Link Weight = $W[e] = a[e] \cdot \Sigma W[e']$ (5)

e' considers the link end closest to the origin and the links connected at that end

The equation is applied in proceeding outward from an origin node in the bush building process.

(note: if at the origin node $w[e] = a[e]$, then:

Trip Volume $x[e] = y[j] \cdot W[e] / W[e']$) (6)

$[e']$ considers the link end closest to the destination and the links connected to that end

$y[j]$ = number of trips terminating at j

This equation is applied after equation (5) is applied to all links in arriving at the destination. Equation (6) is then applied until the origin is reached. In other words, two passes are made. In the first, link weights are calculated from an origin to all destinations. Then, volumes are assigned backwards from the destinations until the origin node is reached.

An example will best indicate the process for a probabilistic assignment. Figure II-11(A) shows the network under consideration in this example. Figures II-11(B) and (C) illustrate how trees could vary. The differences are caused by being able to reach nodes in equal time by more than one route.

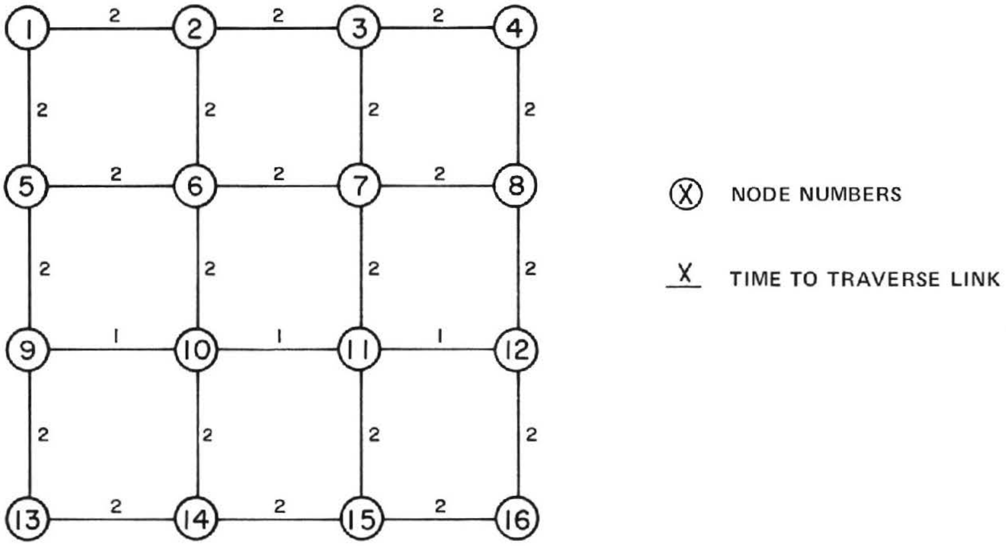


FIGURE II-11(A)
EXAMPLE NETWORK TO ILLUSTRATE THE PROBABILISTIC ASSIGNMENT PROCESS(12)

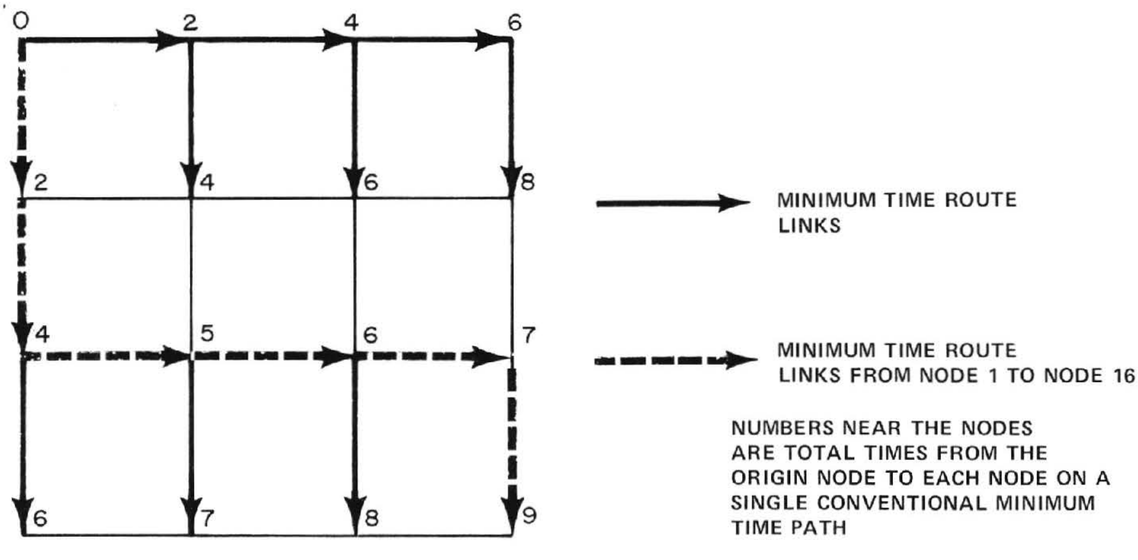


FIGURE II-11(B)
MINIMUM TIME PATH-TREE(12)

It should be apparent that there are other routes to many nodes with the same elapsed time as those shown in Figure "B". For example, another set of paths to the nodes of the network above might be as follows:

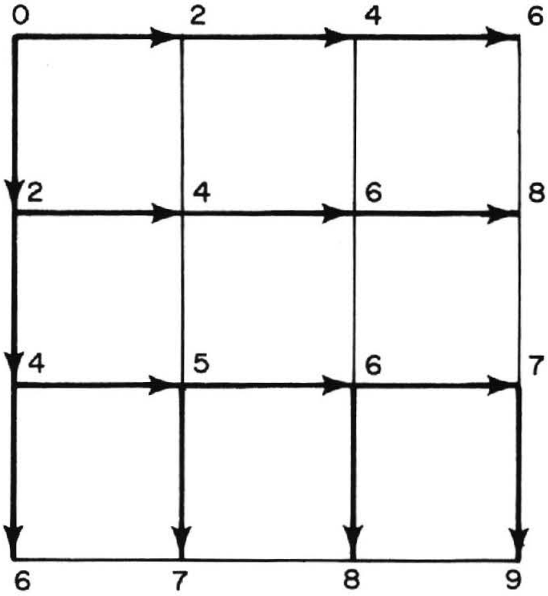


FIGURE II-11(C)
ALTERNATE MINIMUM TIME PATHS

Also, there are other paths to nodes via a longer than a minimum path that still might be reasonable and should have some traffic assigned. One such set might look as follows:

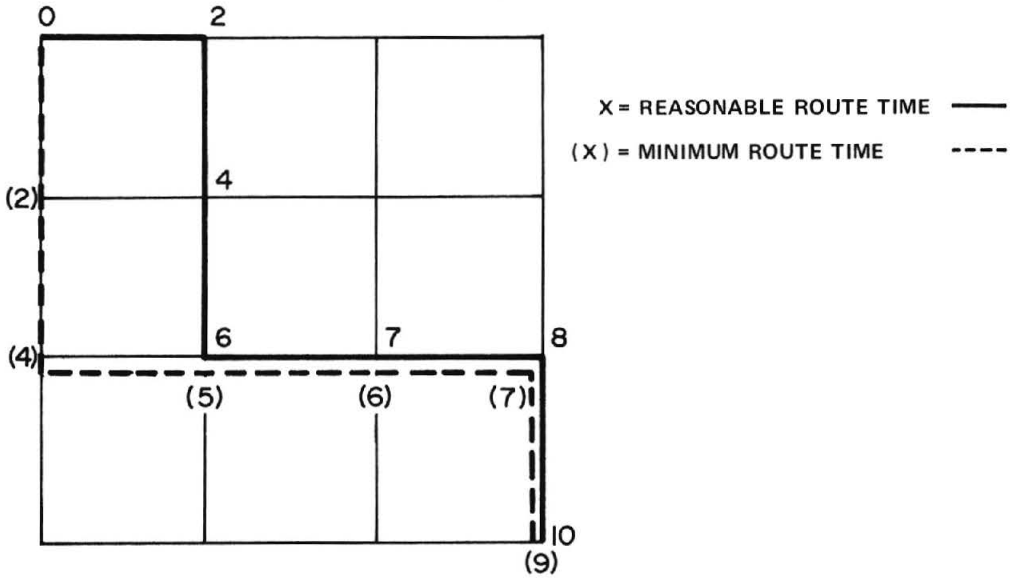


FIGURE II-11(D)
REASONABLE TIME PATH(12)

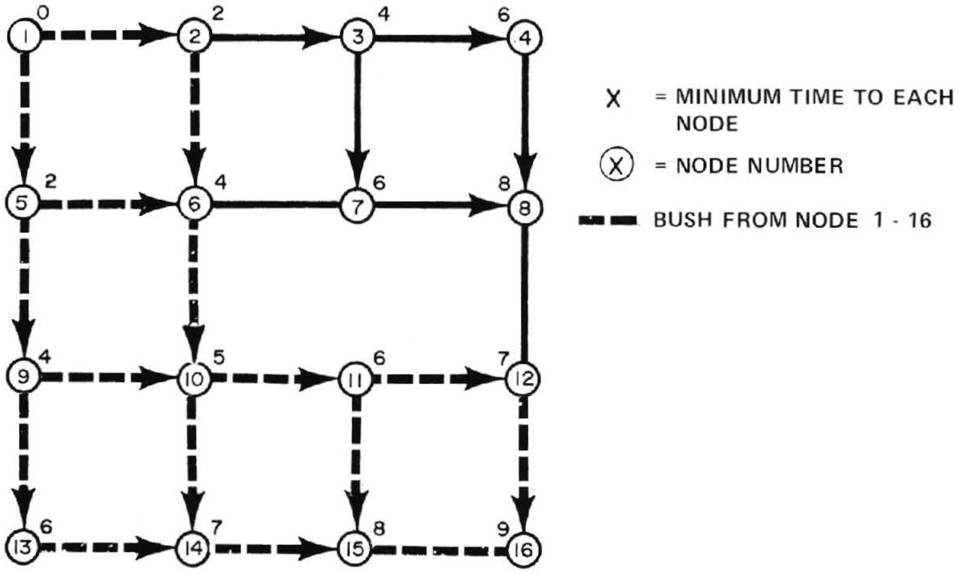


FIGURE II-11(E)
ALL REASONABLE TIME PATHS-BUSH(12)

Figure "E" represents all "reasonable" paths between origin node 1 and destination node 16. If these paths are compared to Figure "B", it can be seen that the criterion for "reasonable" paths has been observed (i.e., as the path progresses from the origin, the minimum time to a node increases). Also, note that all links on reasonable paths have their entrance node closer to the origin than their final node.

STOCH example

The equations presented above will now be applied to the network to obtain traffic loads. The results obtained are shown in Table II-3. The exponent θ is assumed equal to 1. For any node arrived at where the entry link is on a minimum time path ($\Delta t = 0$), the likelihood of use of the link a[**e**] is equal to 1. For any node arrived at where the entry link is not on a minimum time path, there is some Δt (the difference between arriving on a minimum time path and the time on the path in question). For these links, a [e] is equal to $e^{\theta t}$. As bush building proceeds all a[**e**] values are calculated. For example, in the presentation above, node 10 can be reached on a minimum path in 5 minutes.

Node 9 can be reached by some minimum time path in 4 minutes. The time to traverse link 9, 10 is 1 minute. Therefore:

$$\Delta t=(5-4-1)=0$$

Hence the likelihood of use for link 9, 10 is

$$a[9,10]=e^{\theta\,\Delta t}=e^{1(0)}=1$$

The same calculations for link 6, 10:

$$\Delta t=(5-4-2)=-1$$

and

$$a[6,10]=e^{1(-1)}=e^{-1}=1/e=0.37$$

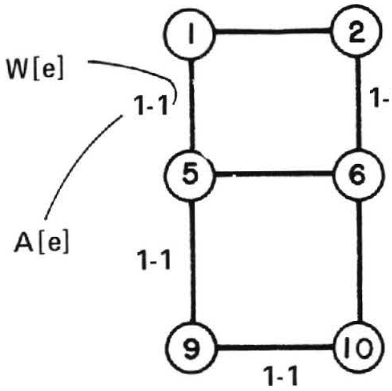
TABLE II-3

Example of Probabilistic Assignment Results

(Trips from 1-16=1000)
(REFER TO FIGURE II- 11A)

Link (e)		On Minimum Time		Likelihood of Use	Link Weight	UNRESTRAINED	
i node	j node	Path	Δt	a [e]	w [e]	Link Volume x [e]	All or Nothing Volume
1	2		0	1	1	208	0
1	5	X	0	1	1	792	1000
2	3		0	1	1	0	0
2	6		0	1	1	208	0
5	6		0	1	1	209	0
5	9	X	0	1	1	583	1000
3	4		0	1	1	0	0
3	7		0	1	1	0	0
6	7		0	1	2	0	0
6	10		-1	0.37	0.74	417	0
9	10	X	0	1	1	564	1000
9	13		0	1	1	19	0
10	11	X	0	1	1.74	892	1000
10	14		0	1	1.74	89	0
4	8		0	1	1	0	0
7	8		0	1	3	0	0
13	14		-1	0.37	0.37	19	0
11	12	X	0	1	1.74	652	1000
11	15		0	1	1.74	240	0
12	8		-1	0.37	0.64	0	0
12	16	X	0	1	1.74	652	1000
14	15		-1	0.37	.78	108	0
15	16		-1	0.37	.93	348	0

To obtain the link weights w[e], the link likelihood a[e] is multiplied by the sum of the link weights of the links entering the end of the node closest to the origin as follows:



to obtain the link weight for link 6-10, the link likelihood value is multiplied by the sum of the link weights of link 5-6 and 2-6. The likelihood value is 0.37. The weight is 0.37(1+1)=.74

This process is continued until the destination(s) is reached. After this is completed, the calculation of the link volume can proceed. This process starts at the destination end. The total number of trips at each node is proportioned to the corresponding links in relation to the link weights of the links entering the node. For example, the load on links 15-16 and 12-16 of the above network are calculated as (see Equation 6):

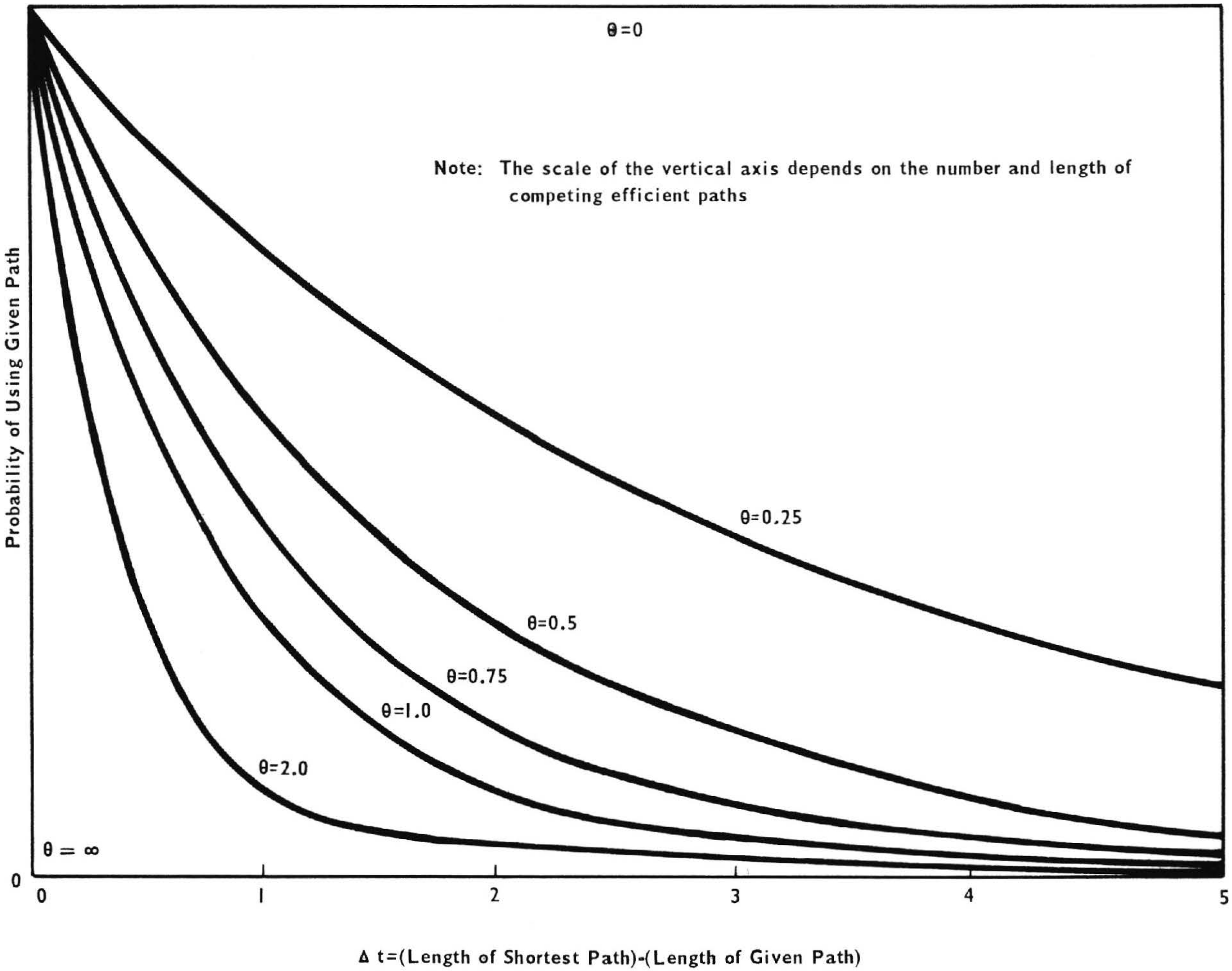
$$\text{link } 15\text{-}16 = 1000 \times \frac{.93}{1.74 + .93} = 348$$

$$\text{link } 12\text{-}16 = 1000 \times \frac{1.74}{1.74 + .93} = 652$$

Now the load leaving node 15 is known so that the link volumes on 11-15 and 14-15 can be calculated. This continues back towards the origin node until it is reached and the process is completed.

As can be seen from Table II-3, there are a greater number of links loaded than with an all-or-nothing conventional assignment. However, if capacity restraint were used and loads weighted for a number of iterations, there would probably be additional links loaded indicating a "diversion" between links. For STOCH, the diversion between paths can be controlled by the user by varying the θ values. Figure II-12 shows the effects of variations in θ. The lower the value, the greater the probability of using the given path.

The assignment technique described above is one of the more promising approaches in multipath assignments. The improvement in results versus all-or-nothing techniques using capacity restraint must be studied in more detail especially since this probabilistic approach will also probably require some capacity restraint function to account for the relationship between speed, volume, and capacity. Also, it should be understood that STOCH may be used with capacity restraint also, and does not have to be used in the single multi-path assignment mode. It can be used iteratively in an incremental loading mode.



Note: The scale of the vertical axis depends on the number and length of competing efficient paths

FIGURE II-12

DIVERSION FUNCTION Θ FOR PROBABILISTIC ASSIGNMENT (12)

TRANSIT NETWORK ASSIGNMENT

Special Considerations

Traffic assignment computer systems developed basically for highway networks have been applied to transit system assignments. These applications have often been deficient because of several major differences between highway and transit analysis. These differences fall into three distinct areas:

- Need to consider several lines of a transit system operating on a single link
- Need to handle special characteristics of a transit system, such as, passenger waiting time and transfer time
- Need for summary statistics that are transit oriented

UMTA Transportation Planning System

A single comprehensive Public Transportation Planning System has been developed, known as the UMTA Transportation Planning System (UTPS) (7). This system consists of a battery of programs that can be grouped into three categories:

- Network Analysis
- Modal split model development and application
- Passenger loading

transit assignment

The basic feature available in this system that is not available in the highway developed assignment programs is the facility to more easily describe transit links. In addition to time and distance on a link, other descriptors utilized in the process include: maximum and minimum headways, auto connectors and walk links, several transit modes, and many transit lines for each mode. Output from the system includes: (1) volumes on walk and auto connector links; (2) a summary of mode-to-mode transfers; (3) total trips assigned; (4) loads by line between stops; (5) passengers off and on at each stop; and (6) summaries of passenger miles, passenger hours, and peak loads.

A description of network coding should indicate the special advantages in coding as compared with highway oriented assignment packages. Generally, the network coding procedures for the UTPS package are not too different than for the highway oriented packages. The differences are:

- Each transit line can be identified separately throughout the coding and transit analysis.
- More than one link is allowable between two nodes. Five of the links may have up to 31 transit lines.
- Nodes are coded only where there is a transfer possible between two or more transit lines. Links on a transit network may be as long as 25.5 miles.
- Line cards are coded in addition to link cards to allow inclusion of transit specific characteristics. The transit line is defined as the route or path of a particular type of transit operation distinguished by a transit company number, a mode category, a set of headways, and a sequence of nodes of transfer points through which the line passes.

An example of the mode categories that may be considered (these may be varied within the limit of eight modes) by the transit assignment are:

- Non transit categories
  - Walk to transit
  - Auto connector
  - Other non transit
- Transit categories
  - Surface transit
  - Express surface transit
  - Other surface transit
  - Rapid transit
  - Commuter railroad

In addition to the major features of the UTPS package relative to transit assignment, there are major advantages in the minimum route algorithm. Analysis of the deficiencies and economics of a proposed transit system require knowledge of the path of passengers travelling between any two points of the system. This path is best approximated by the minimum weighted time path, where the times to traverse various link types are weighted to reflect differences in the values the transit user places on the time spent walking, waiting, or riding by various modes. Transit system analysis has been severely handicapped by the lack of an algorithm that copes with the aforementioned problem while allowing sufficient size to permit a detailed description of the transit system. There has also been a deficiency in existing algorithms to handle such transit parameters as waiting time and transfer time.

transit pathfinder program

The important characteristics of the pathfinder program for calculating the minimum route paths in the transit network are:

- The transit network is input as two items (a) link description similar to existing transportation networks, and (b) a line description which resembles a bus schedule or train timetable.
- The network is stored as a set of "trunk-line links". Each trunk line is defined as (a) a pair of nodes, (b) a time, (c) a mode, and (d) a set of line numbers representing all routes traversing the link in the given time via the given mode. The trunkline description reduces computation time and increases the size of network that can be input.
- Transfer penalties do not have to be coded into the network but are determined by the program based on relative frequencies of operation.
- Restraints can be placed on the minimum paths such that specific mode-mode transfers are prohibited, maximum number of transfers is limited, and maximum and minimum wait and transfer time are allowed.

The basic assumptions of the algorithm are:

- the time to traverse a trunk line is constant
- the time spent waiting to transfer is satisfactorily approximated by one-half the inverse of the frequency of the recipient line(s).

Use of Highway Package

Where a significant amount of transit analysis is to be undertaken use of the UTPS package is well worth investigation. Input preparation is simpler and the system may be more realistically portrayed than if a highway package is used. Output reports are more specific and descriptive than those available with highway oriented systems. Where transit analysis is not a significant problem, say in small and moderate urban areas, the practitioner may find it more desirable to apply the computer system being used for highways based upon his experience with it and the relatively minor extra work in system development for computer application and review of assignment results.

highway assignment package applied to transit

Transit networks can be considered as a special form of the "traditional" link-node highway network but require special handling during coding. The major difference is that individual links are not completely independent in a transit network. A bus line or rail route, composed of many links, actually has certain special properties. One of these properties is that a passenger tends to remain on a single transit facility for as long as possible (to reduce the number of transfers) whereas an auto driver is free to weave through a system of links and nodes with almost no restrictions.

Restricted transfers are caused by several factors: (a) transit fares, (b) transfer waiting time, and (c) limited number of transfer points. It is necessary when dealing with transit networks to account for the penalties incurred by transfers and also to limit the number of transfers made between origin and destination.

In order to account for fares imposed on a transit line it is necessary to code entrance and exit penalty links, where half the fare is imposed at each end of the line segment. These penalty links can also contain a value to account for waiting time. The penalty for waiting time is based on vehicle headways and is usually no greater than half the headway. Per-mile type fares are prorated over the individual links on a transit line to restrict transfers. It is necessary to code transfer links that account for time lost transferring, extra fare costs, waiting time, and general passenger inconvenience.

There are several problems inherent in the above approach:

- The number of extra links required quickly becomes large, meaning additional costs for computer time and subsequent analysis.
- Calibrating the network can be quite difficult
- The network can not be easily adjusted to account for several transit lines that utilize common network links.

DIRECT TRAFFIC ESTIMATION

Direct Assignment Formulas

Traditional assignment approaches have been highly computerized over the last several years and, along with other planning tools, allow the testing and evaluation of alternate transportation systems. The techniques of trip generation, trip distribution, and traffic assignment are based on the direct relationships that exist between travel and land use characteristics. For testing of alternative systems and development of volumes useful for stage planning and design, the computer traffic assignment approach is applicable. However, there is another level in the long range planning activity where a short cut, less accurate, technique would be useful. This is in the area of plan formulation (sketch planning) and evaluation of possible alternates for detail testing and evaluation. Here, "correct order of magnitude" estimates of traffic volumes are acceptable - with more detailed and accurate assignments made at a later stage.

direct assignment

Morton Schneider, while with the Chicago Area Transportation Study, developed a short-cut method which could manually be applied in estimating volumes on a street system (22). These estimates are made for local streets, arterial streets and expressways. The formulas developed are based upon the relationship between traffic volumes on the various levels of facility and: 1) the spacing of the facilities by type; 2) the trip destination densities in the region for which the estimates are being made: and 3) the mean trip length for vehicles using the system.

The Schneider equations are as follows:

$$V_1 = er/2[(1/Z_1)+(1/\bar{r})+(Z_2/\bar{r}(Z_1-Z_3))] \qquad (7)$$

$$V_2 = Z_2V_1/\bar{r} \qquad (8)$$

$$V_3 = V_2Z_3/(Z_1-Z_3) \qquad (9)$$

where e = Trip destination density (trip destinations/sq. mile)

$\bar{r}$ = Average trip length

V_1 = Volume on expressways

V_2 = Volume on arterial streets

V_3 = Volume on local streets

Z_1 = Expressway spacing (miles)

Z_2 = Arterial spacing (miles)

Z_3 = Local street spacing (miles)

The use of these equations will be illustrated by the following example:

assume an area with:

e = trip destination density = 10,000

$\bar{r}$ = average trip length = 6 miles

Z_1= expressway spacing = 5 miles

Z_2= arterial spacing = 1 mile

Z_3= local street spacing = 0.5 miles

then:

<u>direct assignment example</u>

$V_1 = 10{,}000(6)/2(1/5 + 1/6(5-0.5))$

$= 60{,}000/.808 = 74310$ veh/day

$V_2 = 1/6\ (74310) = 12385$ veh/day

$V_3 = (0.5/5-0.5)(12385) = 1376$ veh/day

The reader, if interested in the above approach to "getting a handle on traffic volumes" for various densities and spacing, is referred to Schneider's article "A Direct Approach to Traffic Assignment" (22). Several assumptions are made in the development of the previous equations which are fully explained in the article. The basic assumption is that the region for which trip estimates are made is very large, square, and has a constant trip density per square mile. In obtaining spacings, the user is reminded that average spacing for such a condition can be calculated from the formula:

$$Z = 2A/\ell \qquad (10)$$

where: Z = spacing

A = area of region

ℓ = length of facilities in region in miles/square mile.

For example, if there were 100 miles of freeway in a large region of say 1000 square miles, the average spacing would be 20 miles.

The Upstate New York Transportation Study has developed a set of tables for various combinations of spacing and trip length using the Schneider equations (23). In addition, calculated travel costs per square mile based upon spacings, volumes, and vehicle operating costs, time costs, and accident costs are included. One such table is reproduced as Table II-4 and contains the combination of spacing and trip length used in the example presented above.

TABLE II-4

VOLUME AND COST WHEN TRIP LENGTH = 6 MILES; DENSITY = 1,000 TRIPS DESTINATIONS/SQUARE MILES

LOCAL STREET SPACING = 0.5 MILES

(23)

ARTERIAL SPACING IN MILES		EXPRESSWAY SPACING IN MILES									
		1	2	3	4	5	6	7	8	9	10
0.2	EXPR.										
	ART.										
	LOCAL										
	COST										
0.4	EXPR.										
	ART.										
	LOCAL										
	COST										
0.6	EXPR.	2,195	4,091	5,556	6,738	7,714	8,534	9,233	9,836	10,361	10,823
	ART.	220	409	556	674	771	853	923	984	1,036	1,082
	LOCAL	220	136	111	96	86	78	71	66	61	57
	COST	460	458	470	481	490	499	506	512	518	523
0.8	EXPR.	2,093	3,971	5,422	6,597	7,570	8,390	9,090	9,695	10,223	10,688
	ART.	279	529	723	880	1,009	1,119	1,212	1,293	1,363	1,425
	LOCAL	279	176	145	126	112	102	93	86	80	75
	COST	477	469	479	488	497	504	511	517	522	527
1.0	EXPR.	2,000	3,857	5,294	6,462	7,431	8,250	8,951	9,558	10,088	10,556
	ART.	333	643	882	1,077	1,239	1,375	1,492	1,593	1,681	1,759
	LOCAL	333	214	176	154	138	125	115	106	99	93
	COST	493	480	487	495	503	510	516	521	526	530
1.2	EXPR.		3,750	5,172	6,332	7,297	8,115	8,816	9,424	9,957	10,427
	ART.		750	1,034	1,266	1,459	1,623	1,763	1,885	1,991	2,085
	LOCAL		250	207	181	162	148	136	126	117	110
	COST		490	495	502	509	515	521	526	530	534
1.4	EXPR.		3,649	5,056	6,207	7,168	7,984	8,685	9,294	9,829	10,301
	ART.		851	1,180	1,448	1,673	1,863	2,027	2,169	2,293	2,404
	LOCAL		284	236	207	186	169	156	145	135	127
	COST		499	503	509	515	521	526	530	534	538
1.6	EXPR.		3,553	4,945	6,087	7,043	7,857	8,558	9,168	9,704	10,179
	ART.		947	1,319	1,623	1,878	2,095	2,282	2,445	2,588	2,714
	LOCAL		316	264	232	209	190	176	163	152	143
	COST		508	510	515	521	526	530	534	538	541
2.0	EXPR.		3,375	4,737	5,860	6,807	7,615	8,315	8,926	9,464	9,942
	ART.		1,125	1,579	1,953	2,269	2,538	2,772	2,975	3,155	3,314
	LOCAL		375	316	279	252	231	213	198	186	174
	COST		525	524	527	531	535	539	542	546	548
2.5	EXPR.			4,500	5,600	6,532	7,333	8,029	8,640	9,180	9,661
	ART.			1,875	2,333	2,722	3,056	3,346	3,600	3,825	4,025
	LOCAL			375	333	302	278	257	240	225	212
	COST			540	541	544	547	549	552	554	557
3.0	EXPR.			4,286	5,362	6,279	7,071	7,763	8,372	8,913	9,396
	ART.			2,143	2,681	3,140	3,536	3,882	4,186	4,456	4,698
	LOCAL			429	383	349	321	299	279	262	247
	COST			554	554	555	557	559	561	563	564
3.5	EXPR.				5,143	6,045	6,828	7,514	8,120	8,660	9,144
	ART.				3,000	3,526	3,983	4,383	4,737	5,052	5,334
	LOCAL				429	392	362	337	316	297	281
	COST				566	566	567	568	569	571	572
4.0	EXPR.				4,941	5,827	6,600	7,280	7,883	8,422	8,906
	ART.				3,294	3,885	4,400	4,853	5,255	5,615	5,937
	LOCAL				471	432	400	373	350	330	312
	COST				576	576	576	577	577	578	579

use of direct assignment

The tables are extremely useful for general planning on a preliminary basis. For example, say the local street spacing in an area is 0.5 miles and the arterial spacing is 2.0 miles and the planner is interested in determining freeway spacing such that the average daily traffic will be no greater than 90,000. If the trip density is 10,000 trip destinations/square mile, all volume estimates would be multiplied by 10 (table based upon a density of 1,000 trip destinations/square mile). Review of the table will indicate an expressway volume of 89,260 at a spacing of 8.0 miles. If the region under consideration was 1000 square miles, the length of expressways would be 250 miles (from Equation (10): $Z = 2A/\phi$).

aid to system development

The above technique is not offered as a replacement for computer traffic assignments to a detailed network which is more specifically oriented to actual system geometry and the detailed demands provided by origin-destination trip movements within portions of a region. However, the Schneider approach provides a tool which may be used to aid in the development of alternative systems and in the pre-evaluation of alternative density patterns.

Some recent work accomplished for the FHWA has resulted in improvements to the Schneider approach (24). The new approach (Schneider-Scott Direct Assignment Model) considerably improves the results obtained as can be seen from Table II-5. The Schneider formulation tends to over-estimate expressway use whereas the improved approach more closely matches actual conditions. Table II-6 presents the new model's calculations for various combinations of ramp spacing, trip length, and facility spacing.

TABLE II-5

COMPARISON OF VMT ON FREEWAY ESTIMATES

SCHNEIDER VS SCHNEIDER-SCOTT METHOD (24)

TEST AREA	ACTUAL DATA	SCHNEIDER METHOD	SCHNEIDER-SCOTT METHOD
Buffalo	16.4	27.1	19.3
Chicago	10.1	13.3	11.4
Pittsburgh	8.6	11.3	9.2
Louisville	32.2	39.6	32.1
Hartford	18.6	27.9	26.5
Bridgeport	41.6	41.0	38.6
Tucson	16.6	14.0	13.6

Table II-6

SCHNEIDER - SCOTT TABLES (24)

```
TRIP LENGTH =  7

     % CMS ON FWY = 50

               RAMP SPACING = 2.0                  DENSITY = 15000.
                   % FVMT = 45.2    VE =132810.   VA = 24760.    VL = 656.    SE =  8.3    SA =  1.0


     % CMS ON FWY = 60

               RAMP SPACING = 1.0                  DENSITY =  5000.
                   % FVMT = 56.9    VE = 37209.   VA =  6501.    VL = 219.    SE = 54.5    SA = 30.5
                                                   DENSITY = 10000.
                   % FVMT = 56.5    VE = 73859.   VA = 13095.    VL = 437.    SE = 47.6    SA = 29.7
                                                   DENSITY = 15000.
                   % FVMT = 57.2    VE =112457.   VA = 19363.    VL = 656.    SE = 30.6    SA = 15.1

               RAMP SPACING = 1.5                  DENSITY =  5000.
                   % FVMT = 54.3    VE = 35201.   VA =  6838.    VL = 219.    SE = 54.9    SA = 30.4
                                                   DENSITY = 10000.
                   % FVMT = 53.8    VE = 69726.   VA = 13788.    VL = 437.    SE = 48.5    SA = 29.6
                                                   DENSITY = 15000.
                   % FVMT = 55.8    VE =109228.   VA = 19904.    VL = 656.    SE = 35.1    SA = 11.5

               RAMP SPACING = 2.0                  DENSITY =  5000.
                   % FVMT = 51.9    VE = 33384.   VA =  7142.    VL = 219.    SE = 55.2    SA = 30.4
                                                   DENSITY = 10000.
                   % FVMT = 51.4    VE = 66095.   VA = 14398.    VL = 437.    SE = 49.3    SA = 29.5
                                                   DENSITY = 15000.
                   % FVMT = 54.6    VE =106302.   VA = 20395.    VL = 656.    SE = 37.0    SA =  8.1


     % CMS ON FWY = 70

               RAMP SPACING = 1.0                  DENSITY =  5000.
                   % FVMT = 67.3    VE = 28233.   VA =  4917.    VL = 219.    SE = 56.0    SA = 30.6
                                                   DENSITY = 10000.
                   % FVMT = 67.1    VE = 56278.   VA =  9878.    VL = 437.    SE = 51.2    SA = 30.1
                                                   DENSITY = 15000.
                   % FVMT = 66.7    VE = 83768.   VA = 14972.    VL = 656.    SE = 45.2    SA = 29.5

               RAMP SPACING = 1.5                  DENSITY =  5000.
                   % FVMT = 64.9    VE = 26966.   VA =  5219.    VL = 219.    SE = 56.2    SA = 30.6
                                                   DENSITY = 10000.
                   % FVMT = 64.7    VE = 53635.   VA = 10509.    VL = 437.    SE = 51.7    SA = 30.0
                                                   DENSITY = 15000.
                   % FVMT = 64.2    VE = 79781.   VA = 15924.    VL = 656.    SE = 46.2    SA = 29.4

               RAMP SPACING = 2.0                  DENSITY =  5000.
                   % FVMT = 62.7    VE = 25808.   VA =  5496.    VL = 219.    SE = 56.3    SA = 30.6
                                                   DENSITY = 10000.
                   % FVMT = 62.5    VE = 51336.   VA = 11058.    VL = 437.    SE = 52.1    SA = 29.9
                                                   DENSITY = 15000.
                   % FVMT = 62.0    VE = 76295.   VA = 16756.    VL = 656.    SE = 47.0    SA = 29.3

IHC002I STOP        0
```

The portion of the table shown is for a trip length of 7 miles. "% CMS on Fwy" is the percentage of capacity miles of the arterial system that is on freeways. "% FVMT" is the percentage of freeway vehicle miles of travel on the arterial system. "VE" is the expressway volume, "VA" other arterial volume, and "VL" local volume. "SE" and "SA" are the expressway and arterial speeds, respectively. In using these tables, the data and other input decisions for entry are the trip length, percent of capacity miles on the freeway, ramp spacing, and trip destination density. The output consists of the speeds and volumes.

Direct Traffic Estimation Method*

<u>DTEM</u>

The Tri-State Regional Planning Commission has developed a computer approach which deviates considerably from the traffic assignment procedures discussed previously, although there are significant similarities. The most significant differences from the more traditional assignment techniques described are:

- A trip end density surface is the travel input rather than and origin-destination trip matrix.
- Trip distribution and assignment are handled as a single process.
- Traffic estimates can be made for a single link, for a group of links, or for an entire network. The traffic estimate is made on a link by link basis with each link's volume estimate being an independent assessment based upon the geometry and spacing of the network and the array of trip ends.

The Direct Traffic Estimation Method (DTEM) is based on the premise that the traffic volume at a point on a highway network is dependent upon the trip generating potential of the surrounding area and the access of the point in question. The trip generation potential is expressed in terms of vehicle trip ends. Access is considered to be a function of travel time, distance, and tolls.

The mathematical derivation of the DTEM will not be presented (9). Here, an attempt will be made to provide sufficient information to allow an understanding of the approach.

The volume at a point in a network is equal to the product of three factors:

$$\text{Volume} = \begin{pmatrix}\text{Accessibility}\\ \text{Index}\end{pmatrix} \times \begin{pmatrix}\text{Balance}\\ \text{Factor}\end{pmatrix} \times \begin{pmatrix}\text{Competitive}\\ \text{Factor}\end{pmatrix} \qquad (11)$$

The accessibility index is based upon the location of the point in question relative to trip ends surrounding it. Trip ends to the DTEM are provided on

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* Most of this section has been obtained from Interim Technical Reports developed by the Tri-State Regional Planning Commission.

DTEM approach

a grid basis.* It should be pointed out here that the grids closest to a point in question are smaller than those further away based on the idea that the effects of distant land use characteristics are less than the effects of close-by characteristics on the volume of a facility. Referring to Figure II-13, a tree (minimum path routes) built from the point in question results in two branches, one passing through the north end of the link for which volume is to be estimated, and one passing through the south end.

The size of these north and south accessibility indices in terms of their portion of the total accessibility index, affects the volume estimate. A function relating these accessibilities is referred to as the "Balance Factor". The above two terms (Accessibility Index and Balance Factor) assume that the link in question is the only link crossing the "domain" boundary (see Figure II-13) line. To account for other links, the competitive factor is introduced.

The Accessibility Index is calculated in terms of integral values. An integral value I is calculated based upon the following formula for each grid relative to the point for which traffic is to be estimated.

$$I = f(Cn+Ca) \cdot TE \qquad (12)$$

where f(Cn+Ca) = a function of total cost between the traffic estimation point and the grid for which I is being calculated.

Cn = cost of travel on coded network

Ca = the approach cost, used to approximate the cost of travel on roadways which are not coded in the highway network.

TE = the number of trip ends in the grid.

An I value is calculated for each grid, and the summation of all I's is equal to the accessibility index.

In computing the minimum costs, a tree is built to provide minimum cost paths from the point in the network for which the volume is being estimated to some representative point (load node) within each grid. Figure II-13 shows the tree built for a point in the network. The tree has two main branches. All grids associated with the upper branch are considered to be in the "North Main Domain" and those below in the "South Main Domain". If I values were summed by domain we would obtain an In and Is. If, as is shown in Figure II-13, the link in question were the only one crossing the main domain boundary, the

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* Work is currently being done under contract to investigate the applicability of the DTEM to an arbitrary (traditional zones) geographic analysis unit system rather than a uniform grid system, and to smaller urbanized areas.

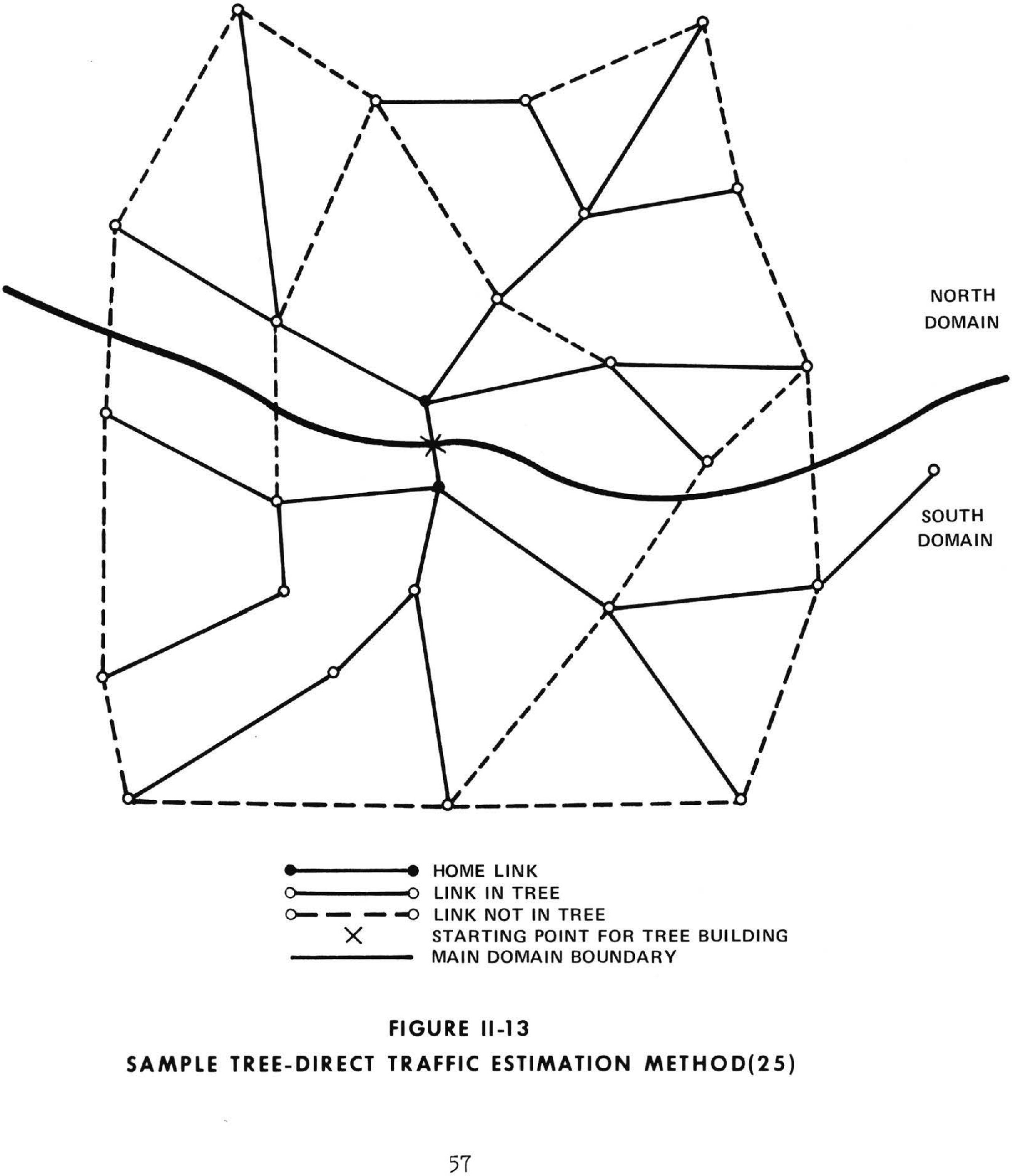


FIGURE II-13
SAMPLE TREE-DIRECT TRAFFIC ESTIMATION METHOD(25)

the volume on the link would be expressed as:

$$\text{Volume} = Q = 2\ \text{In Is}/(\text{In}+\text{Is}) \qquad (13)$$

$$Q = (\text{In}+\text{Is})\left[2\left(\frac{\text{In}}{\text{In}+\text{Is}}\right)\left(\frac{\text{Is}}{\text{In}+\text{Is}}\right)\right] \qquad (14)$$

where (In+Is) is equal to the accessibility index described above.

The right hand part of the above equation,

$$2\left(\frac{\text{In}}{\text{In}+\text{Is}}\right)\left(\frac{\text{Is}}{\text{In}+\text{Is}}\right),$$

is the "Balance Factor" indicating the effect of the main domain integrals on the link volume. If In and Is are equal, the balance factor is equal to 0.5. This becomes smaller as the difference in In and Is becomes larger. If the link in question was the only one crossing the main domain boundary, its volume would be estimated by:

$$\text{Volume} = (\text{Accessibility Index}) \times (\text{Balance Factor}) \qquad (15)$$

Generally, the link in question will not be the only one crossing the main domain boundary. To account for the effect of competing crossings a "competitive factor" is considered. If minimum cost trees are built from each of the competing links (links on the main domain boundary) those nodes (grids) that are closer to the link in question can be determined. These load nodes define sub-areas of the main domains and are called "North" and "South Prime Domains". This is illustrated by Figure II-14 which shows that node A lies within a prime domain while node B does not.

I values can be summed for the prime domains to obtain I'n (integral value for north prime domain) and I's. The competitive factor can then be expressed as:

$$\text{competitive factor} = \frac{1}{2} \times \left(\frac{I'n}{In} + \frac{I's}{Is}\right) \qquad (16)$$

DTEM formulation

Putting this all together, we obtain the DTEM formulation.

$$Q = \underbrace{(I_n + I_s)}\underbrace{\left(2\left(\frac{I_n}{I_n + I_s}\right)\left(\frac{I_s}{I_n + I_s}\right)\right)}\underbrace{\frac{1}{2}\left(\frac{I'_n}{I_n} + \frac{I'_s}{I_s}\right)} \qquad (17)$$

or

$$\text{Volume} = (\text{Accessibility Index}) \times (\text{Balance Factor}) \times (\text{Competitive Factor})$$

DTEM example

An example will indicate the operation of the model. The example and description above do not present all the detail associated with the Model. For more complete information, the reader is referred to the Interim Technical Reports of the Tri-State Transportation Commission (25). Figure II-15 presents a test network showing 16 grids, the main domain boundary and the prime domain boundaries. For the cost function, a Bessel function of the form $a\int K^{-2} e^{-(KC+a/K)}\,dK$ is used. This was decided upon as best by Tri-State although other functions may be used. Shown for the test network are the trip ends for each grid, as well as the cost from the link in question to each grid via the

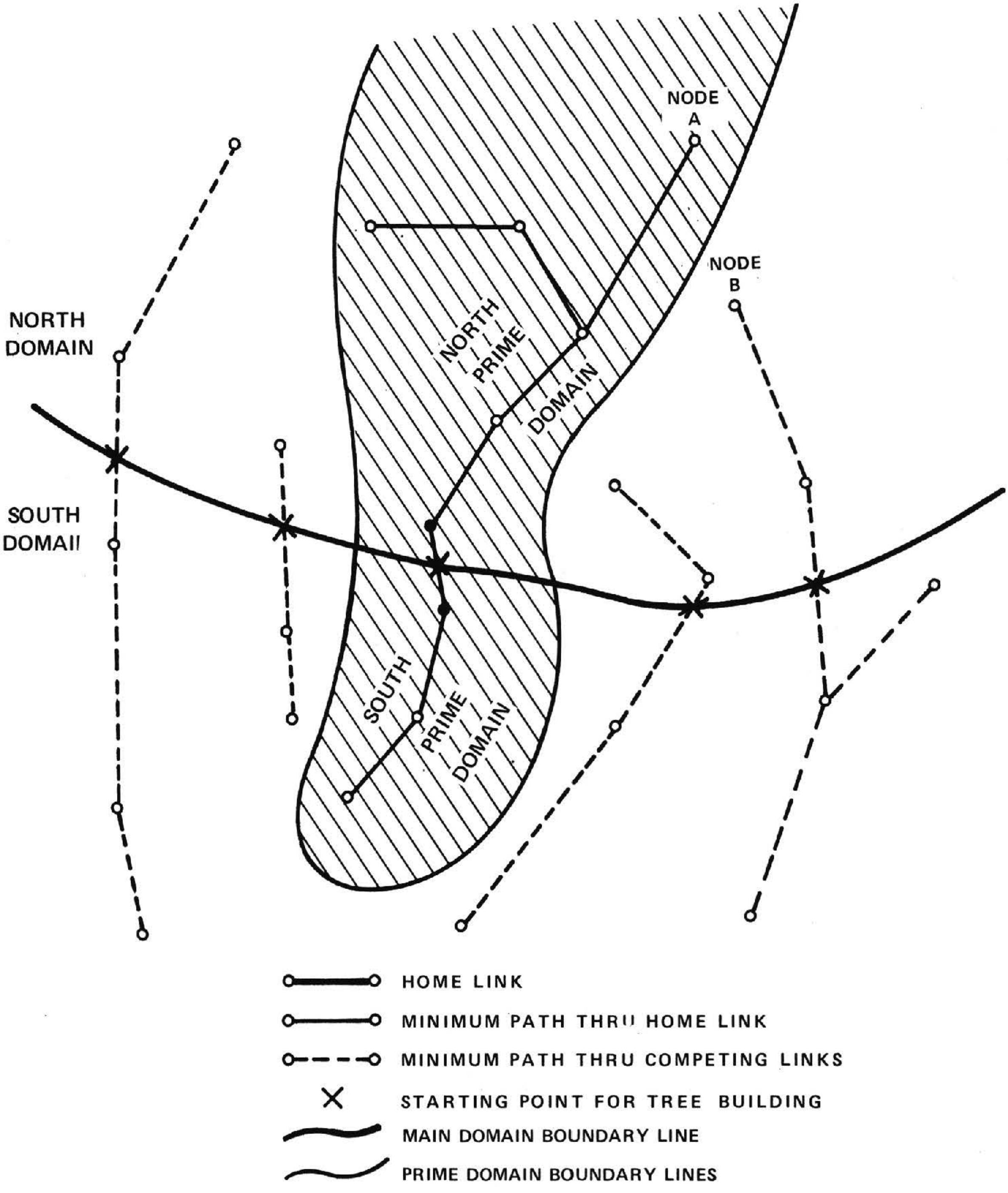
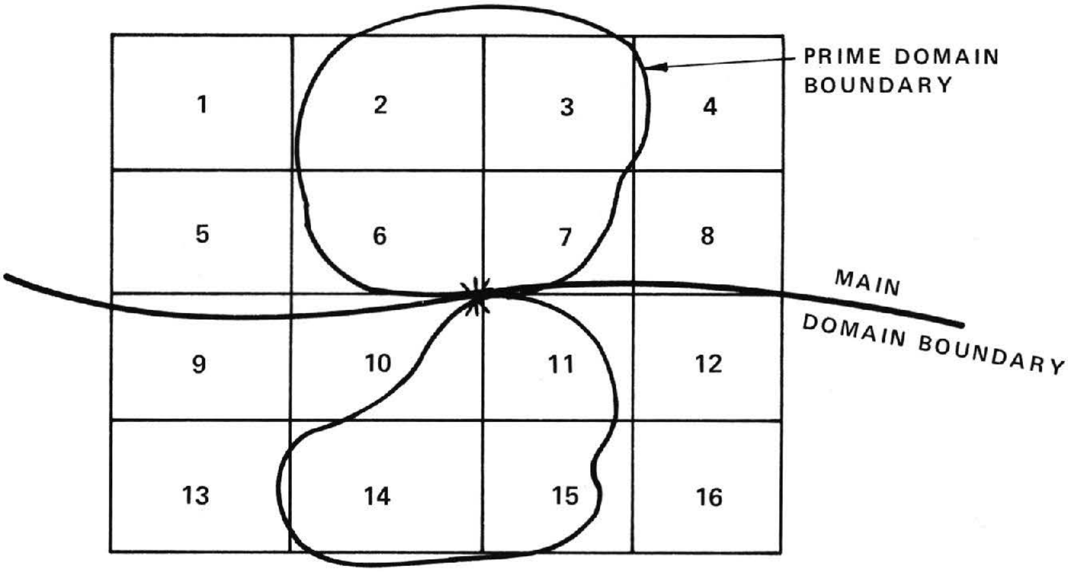


FIGURE II-14

PRIME DOMAINS-DIRECT TRAFFIC ESTIMATION METHOD(25)



GRID#	COST FROM HOME LINK(*)	f(COST)	TRIP ENDS	I
1	40	.40	1000	400
2	25	.50	1500	750
3	15	.60	5000	3000
4	25	.50	2000	1000
5	15	.60	1000	600
6	10	.70	3000	2100
7	10	.70	4000	2800
8	15	.60	1000	600
9	25	.50	4000	2000
10	15	.60	3000	1800
11	10	.70	2000	1400
12	15	.60	1000	600
13	30	.45	3000	1350
14	25	.50	2000	1000
15	25	.50	1000	500
16	35	.45	2000	900

Figure II-15
Sample Network for DTEM Calculations

minimum cost path. The values of I in the Figure are calculated as the trip ends times the cost function.

The following values can be determined:

DTEM example

$In = 11250$

$Is = 9550$

$I'n = 8650$

$I's = 2900$

Accessibility Index = $\Sigma I's = In + Is = 20{,}800$

Balance Factor = $(2 \cdot In/(In+Is) \cdot Is/(In+Is))$

$$= 2 \cdot 11250/20800 \cdot 9550/20800 = .497$$

Competitive factor = $1/2(I'n/In+I's/Is) = 1/2\left(\frac{8650}{11250} + \frac{2900}{9550}\right) = .536$

Volume = (Accessibility Index) x (Balance Factor) x (Competitive Factor)

$$= 20800 \times .497 \times .536 = 5540$$

The DTEM is computerized and currently being used by the Tri-State Regional Planning Commission. Calibration of the model is necessary as is true with other planning models. Tri-State chose vehicle miles as the control for calibration. The "a" value in the Bessel function shown above must be determined in the calibration process. Values which must also be set are:

- Approach costs. This is the travel cost assigned to the linkages between the density cell and the load node
- Vehicle operating costs
- Travel time cost
- Toll costs

To increase computer efficiency three levels of facility were coded by Tri-State. The Level 1 system includes all limited access roads. Level 2 highways include other important routes and, as a minimum, bisect the spacing between Level 1 facilities inside the Cordon Area. Level 3 facilities include everything else that was inventoried and are generally limited to the Cordon Area. Approximately 30% of the coded mileage within the Region is Level 1, 30% Level 2, and the remainder Level 3. Likewise 4 trip and density grid sizes are used: quarter square mile, square mile, four and sixteen square miles. In calculating the integral values close to the point for which an estimate is being made, all three levels of system are considered and the minimum cell sizes coded are used. As the calculation proceeds to more distant cells, less network detail and larger trip end cells are used.

In its current form, use of the DTEM to calculate the volumes on all links in a network takes considerably more computer time than use of the assignment procedures discussed previously. However, if significant testing within small areas of a region or within corridors is expected, and a large region is under study, the ability to calculate volume on individual links may result in a cost saving. It is too early to offer any comparisons of results from the DTEM as compared with more conventional assignment approaches.

SMALL AREA TRAFFIC ESTIMATION

sub-regional & small area applications

Traffic assignments have generally considered single routes or entire networks on a large area basis (i.e., an urbanized area). This has resulted generally in including the higher type facilities in the network considered (freeways, arterials, and a small amount of collectors) and analysis zones of a size commensurate with the network detail. Historically, this network approach has not permitted acceptable assignments to facilities below the arterial level. Likewise, one could not reflect the congestion problems which occur during rather short periods of time. The effects of altering traffic control measures, such as parking and signal control, could only be reflected in derived measures, such as speeds and capacity, rather than direct input of such conditions.

There is increasing demand for the study of traffic in finer detail than has been accomplished with traditional assignment techniques. The types of projects considered are:

- The effects on the surrounding highway system of a major traffic generator, such as a shopping center, airport, or office building
- The detailed examination of alternate locations of a facility within a corridor.
- The detailed examination of alternate ramp designs and the effects of these on the surrounding street system.
- The study of central business district street operation and the effects of changes in traffic control measures, street improvements, and the addition of office buildings and other major traffic generators.

The three types of approaches available for studying the above types of problems are:

- The adaptation of network assignment tools for detail study
- Micro-assignment approach
- Other computer simulation techniques

Adaptation of Network Assignment Methods

traditional techniques for sub-regions

Network assignment techniques are limited to the detail of network and fineness of zones which can be computer stored. On a regionwide basis, detailed zoning and complete network examination cannot be accomplished. However, the same technique can be applied to a small portion of a region in which all highway sections are included and zones commensurate with the network detail can be handled. Zones may be as small as a block or even a block face.

The computer assignment techniques available allow detailed coding of all streets within an area and any level of detail for zones as long as the computer storage limitations are not exceeded. For the type of problems discussed this can be accomplished. For example, if only the central business district of an area was to be examined, even large CBD's could be coded on a block level with all streets included.

Using current O-D data presents no problem for such an approach if the data were coded to a block or very small area basis which has not generally been the case. Trip tables and network could then be developed for any quickly needed detailed study. When considering future conditions, or where small zone O-D data are not available, the problems increase. In most current transportation studies the approach has been to develop regionwide transportation systems and corresponding analysis zones. The problem then becomes the development of a detailed network and the corresponding development of a detailed set of analysis zones within the region constraint.

Figure II-16 presents an example problem. There is a small area within the region to be examined in detail with network coding and zoning on a region basis. The general approach is simple: detailed zones are to be developed perhaps on the block level and all streets are to be included in the network. The two approaches which have been utilized are described below.

2 approaches

cordon area

Isolate the detailed study area and consider the boundary of the area a new cordon area. Where links on the region-wide system cross the boundary, these become external stations. Trips into and through the area would be handled from these external stations as is done on the region cordon. The trips to and from the small zones could be developed from the regionwide trip matrix by a proportioning method or by developing and applying a trip distribution model. The network for the detailed area would be isolated from the region and updated to include the detailed street system. Programs for accomplishing this are available in some traffic assignment batteries. The reader is referred to the document "Urban Transportation -- General Information" (14) which describes the programs in the FHWA system of assignment programs to accomplish the above.

zone adjustment

Another, but similar, approach eliminates any boundary conditions near the cordon defined for the detailed study area. Here, the concept is to handle the complete region area but produce large zones outside the area of detailed consideration and small zones (i.e., blocks) within the detailed area. Likewise, if including a detailed network within the detailed area exceeded core storage when combined within the regionwide network, portions of the regionwide network would be eliminated outside the detailed area. Figure II-17 illustrates

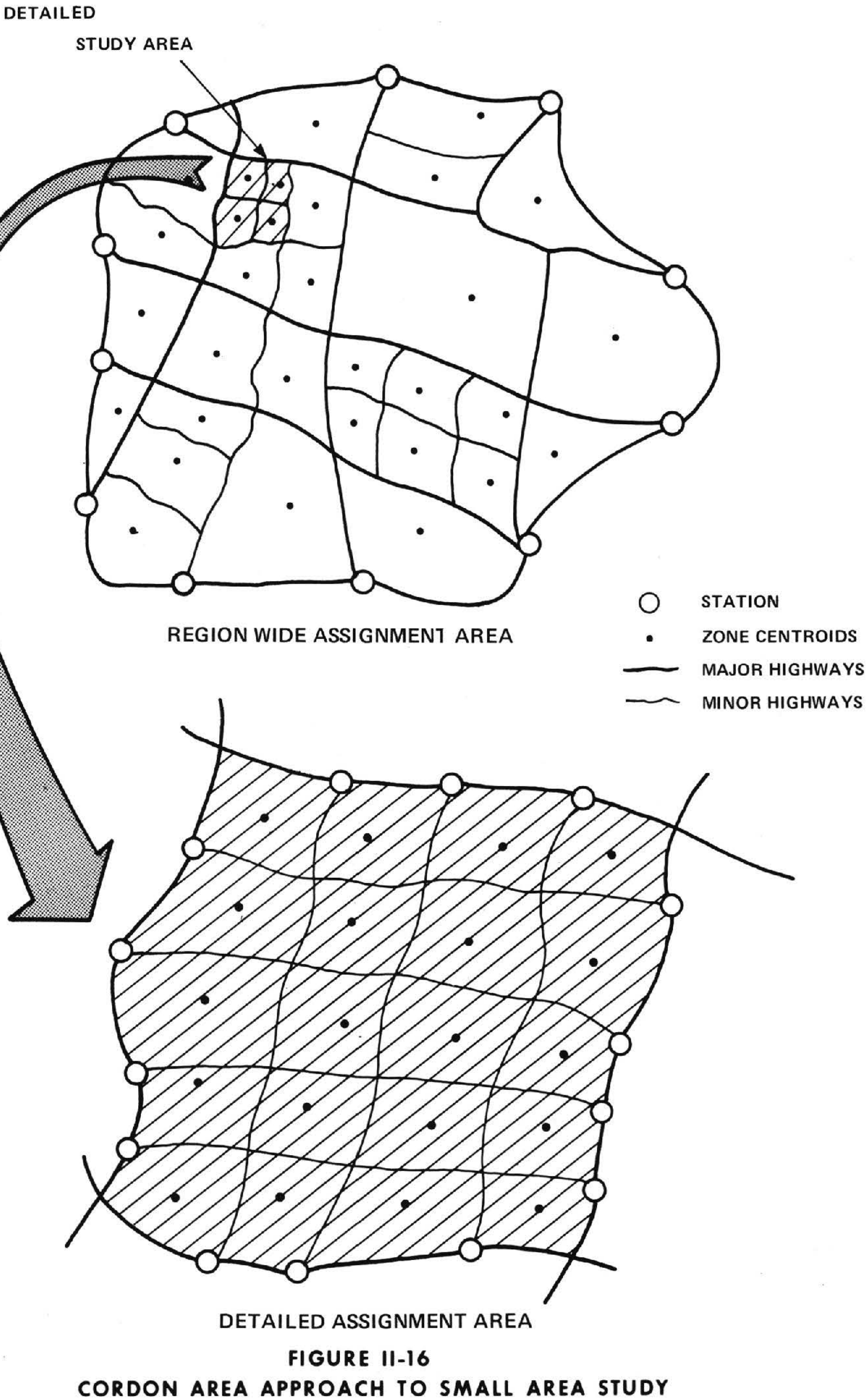
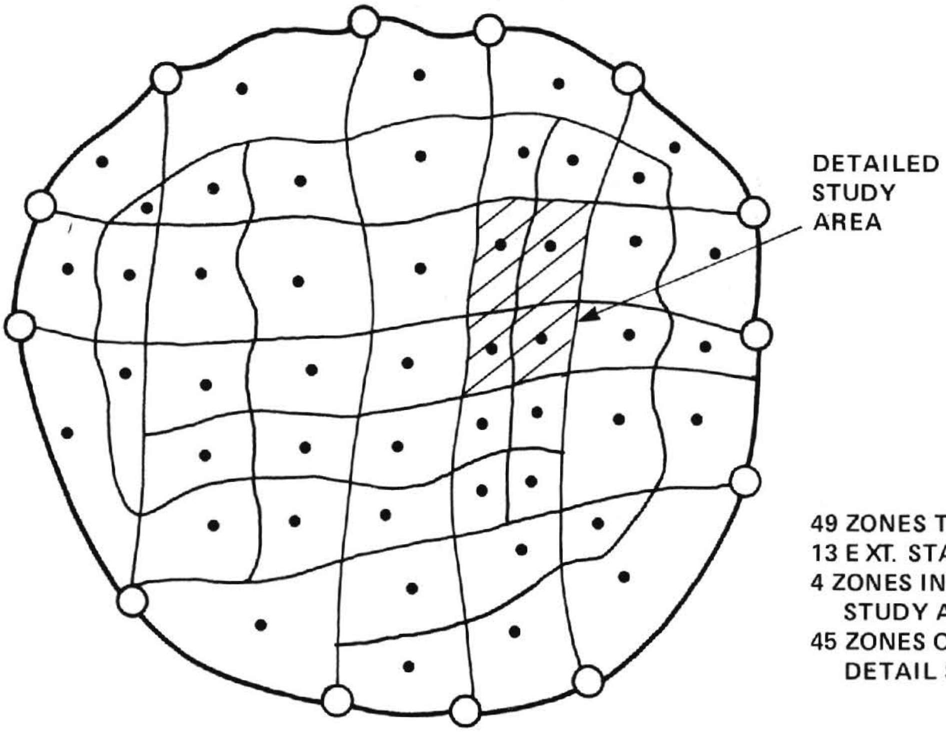
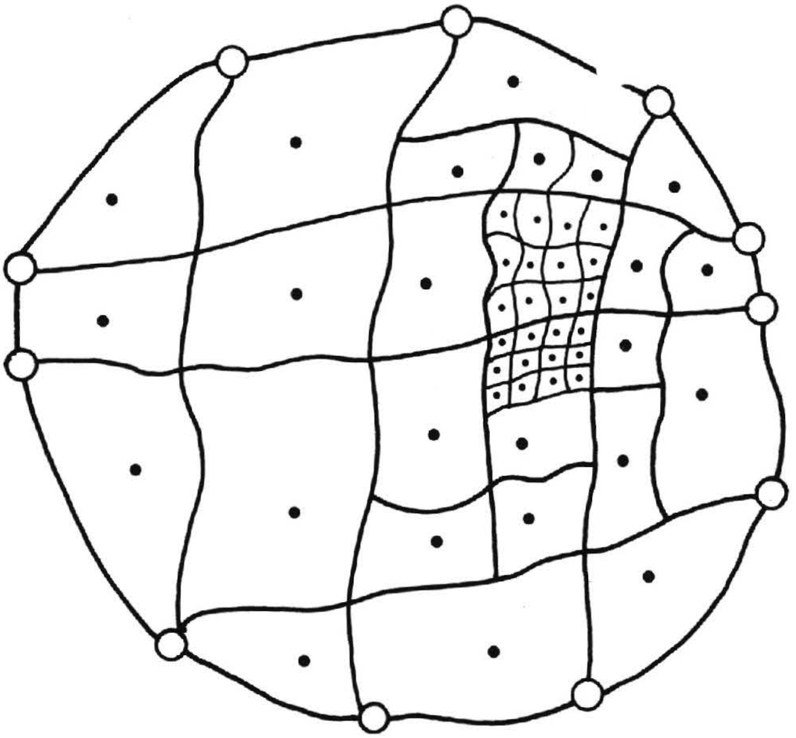


FIGURE II-16
CORDON AREA APPROACH TO SMALL AREA STUDY



49 ZONES TOTAL
13 EXT. STATIONS
4 ZONES IN DETAILED STUDY AREA
45 ZONES OUTSIDE DETAIL STUDY AREA

AREA WIDE ASSIGNMENT SYSTEM



24 ZONES INSIDE DETAILED STUDY AREA

24 ZONES OUTSIDE DETAILED STUDY AREA

DETAILED ASSIGNMENT SYSTEM

FIGURE II-17
ZONE ADJUSTMENT APPROACH TO SMALL AREA STUDY

the approach. Again, application of this approach is possible with available traffic assignment packages.

The adaption of regionwide assignment techniques is most applicable where daily or perhaps even hourly assignment results are required and where the smaller time increment congestion possibilities are not of consideration. The effects of traffic control features and/or system improvements cannot be directly considered but must be simulated in speed changes or capacity measures.

Micro Assignment

detailed street assignment

Micro assignment is a recently developed procedure for simulating detailed vehicular movements in small areas (10). The model has the ability, unlike regionwide assignment approaches, of assigning to a finely coded street network for various time periods throughout the day. The time periods can be of short enough duration to reflect congestion realistically and are limited only by the practitioner's ability to obtain trips by short time periods. Most O-D surveys have time reported to the nearest one-tenth of an hour (six-minutes).

Traffic control features are directly input to the model and vehicles are affected by acceleration and deceleration for turns, stop signs, yield signs, and the encounter of stop controls (red lights) as well as the stop time due to the stop control. In addition to these types of delays, the assignment includes time in queues waiting for a green light or suitable gaps in cross traffic, reaction time, and conflict losses due to traffic in lanes, intersection space, and green time being shared with vehicles making different but interacting movements. The major feature of the assignment approach, which has not been considered in other simulators, is the consideration of changes in demand for sections of the system which may result when adjustments are made to particular intersections.

Input to the system are the origins and destinations of vehicles entering the system. Vehicles are routed in accordance with calculated minimum paths, which may be changed as congestion increases. The control systems that can be considered include signal control, sign control, and progressive signal systems. The types of delays which may be simulated include:

- Acceleration, deceleration, and stopping
- Reaction time
- Waiting for suitable gaps in the traffic stream.
- Unimpeded right turns
- Left turn movement in conflict with opposing through traffic
- Through movement with left turn vehicles in the stream
- Delays for control systems (four-way stop, two-way stop, yield, signal, progression).

To take full advantage of micro-assignment capacilities, all streets within the detailed study area should be included in the micro network and all zones in the micro area should be at the block or even block face level.

micro assignment procedure

Assignment proceeds by assigning trips from a zone(s) based upon speed limit, travel time, and zero volume delay trees. The model calculates the arrival rate of trips at each intersection and, with the intersection characteristics coded, computes the congestion delay for each movement through the intersection. The network is then updated by adding the resulting congestion delay to the previous link times. Tree(s) are next built to load trips from another set of zones(s) based upon the updated network. The resultant loads are added to the loads during the first loading and new congestion delays calculated. This process continues until all trees are built and assignments made. This process is for one time period only whether the time period be six minutes, an hour, or 24 hours. If successive time periods are to be assigned, the result of one time period does not affect the result of the next time period. This is probably the major disadvantage of this technique as compared to the simulator approach described below where vehicles moved through the system are affected by previous vehicles coming from similar origins.

The primary output of the micro assignment model is a table providing for each link a complete description of the input link characteristics plus selected items computed during the assignment including:

Computed delay
Vehicle arrival rate and volume
Operating speed and cost
Vehicle miles of travel
Vehicle minutes of travel

The above items are summarized by type of intersection control, type of movements through an intersection (i.e., left turn), and by number of lanes. The programs available allow automatic plots of network traffic volumes and trees (see Chapter V on Automatic Plotting).

The micro area network must be specially coded and does not conform to the coding specification for any region-wide type of assignment programs. The trip matrix, however, can be derived from the regional ADT trip table and the trip survey records.

The micro-assignment technique is of recent development and has not undergone sufficient testing for any findings to be made concerning accuracy. Also, the detail for travel information required to allow accurate simulation for testing and evaluating traffic control techniques is significant-thereby limiting use to testing of current street systems and current O-D movements.

Some of the additional features incorporated into the micro-assignment technique are:

Pedestrian Interference. At intersections which have heavy pedestrian volumes and no separate pedestrian traffic phase, delays are experienced by turning vehicles. These delays are incorporated in the total delay calculations of the affected turning links. This will of course have implications for the other links of the approach leg, the intersection, and the routes of vehicles.

Transit Vehicle Stops. Transit vehicle stops which use a lane of highway (typically buses and streetcars) reduce the capacity of that lane due to stopped time to board and discharge passengers. This effect has been incorporated into micro assignment. The delays encountered are functions of transit vehicle arrival rates and numbers of passengers boarding or alighting.

Weaving Sections. The delays and reduced speeds caused by the necessity for vehicles in adjacent lanes to merge through one another into gaps in the other lane (i.e., weave) has been incorporated in the model. These delays normally occur on expressways. To handle this situation, intersection control was introduced, network coding devised, and delay algorithms developed.

Progressive Light Systems. When traffic volumes permit, synchronized traffic lights can reduce traffic delays and increase speeds. Micro Assignment contains a synchronous intersection control code. During assignment traffic volumes are monitored on the progressive system.

Other Simulation Techniques

traffic simulation

Many computer programs have been developed to simulate traffic through a highway network or along a freeway type facility. These simulators differ from the previously mentioned techniques in that O-D trip tables are not assigned, but rather vehicles are entered at loading points and move through the network based upon turn probabilities at each intersection. Their major advantage in detailed study is that vehicles are constantly fed into the system at all entry points throughout the simulation thereby allowing congestion conditions to be shown through queue growth and decay. These type of simulators are most useful for testing and evaluating traffic control techniques rather than as planning tools. They would appear to be useful to the planner, however, in testing alternative means for handling vehicles in densely developed detailed areas. In this situation traffic assignment output providing loads on the entry links to an area can be tested to determine the ability of the street system with alternate traffic operation and control features (i.e., one-way streets, eliminating parking, alternate signal timings, etc.) to handle the imposed load. Perhaps this melding of traffic assignment and simulation is best accomplished in short range planning (say under 5 years).

Generally, there have been three types of models developed which can be considered useful for testing and evaluating traffic control techniques. These can be broadly classified as:

- Intersection models
- Arterial street models
- Network models

These models may be further classified as microscopic models and macroscopic models. Microscopic models allow simulation in minute detail and account for the position and action of individual vehicles. Macroscopic models are more limited in the detail considered and handle vehicles in groups rather than as individual entities. On this basis, micro-assignment may be considered a macroscopic model.

traffic control models

An excellent example of the intersection model is one developed by James H. Kell (26). This model handles two two-lane, two-way streets. Vehicles are generated randomly by Monte Carlo techniques. Traffic control is either a stop sign or traffic signal. For stop sign control the model considers gap acceptance as well as acceleration, deceleration, slowing, stopping, and queue delays for each approach. The signal model can consider a fixed time system or an actuated control. The model has been used to simulate thousands of hours of traffic. This has provided extensive data under controlled conditions relating delay to varying traffic volumes and control situations.

The Stark model is a good example of an arterial street simulation model (27). It was developed to simulate a nine-block section of 13th Street, N. W. in Washington, D. C. It is not a generalized model since it cannot be applied to other cases in its current form. Cars are handled individually by the model and carry out maneuvers, including stopping for red lights, yielding right-of-way at stop signs, and manuevering into position for turns. The vehicles take on different speeds, accelerate, decelerate, shift lanes to pass slower cars, and form queues. An interesting feature of the model is an output which presents traffic flow in a map-like manner and can be photographed for a movie representation of flow.

A rather interesting simulation model of the network variety was developed by A. M. Blum (28). This simulator handles up to 37 intersections and follows individual vehicles, which are allowed to change lanes, turn, change velocity (including reaction and acceleration delays), and merge. Various size vehicles can be handled. In addition to turn probabilities, vehicles may be routed through the system (which may be useful for simulating bus movements).

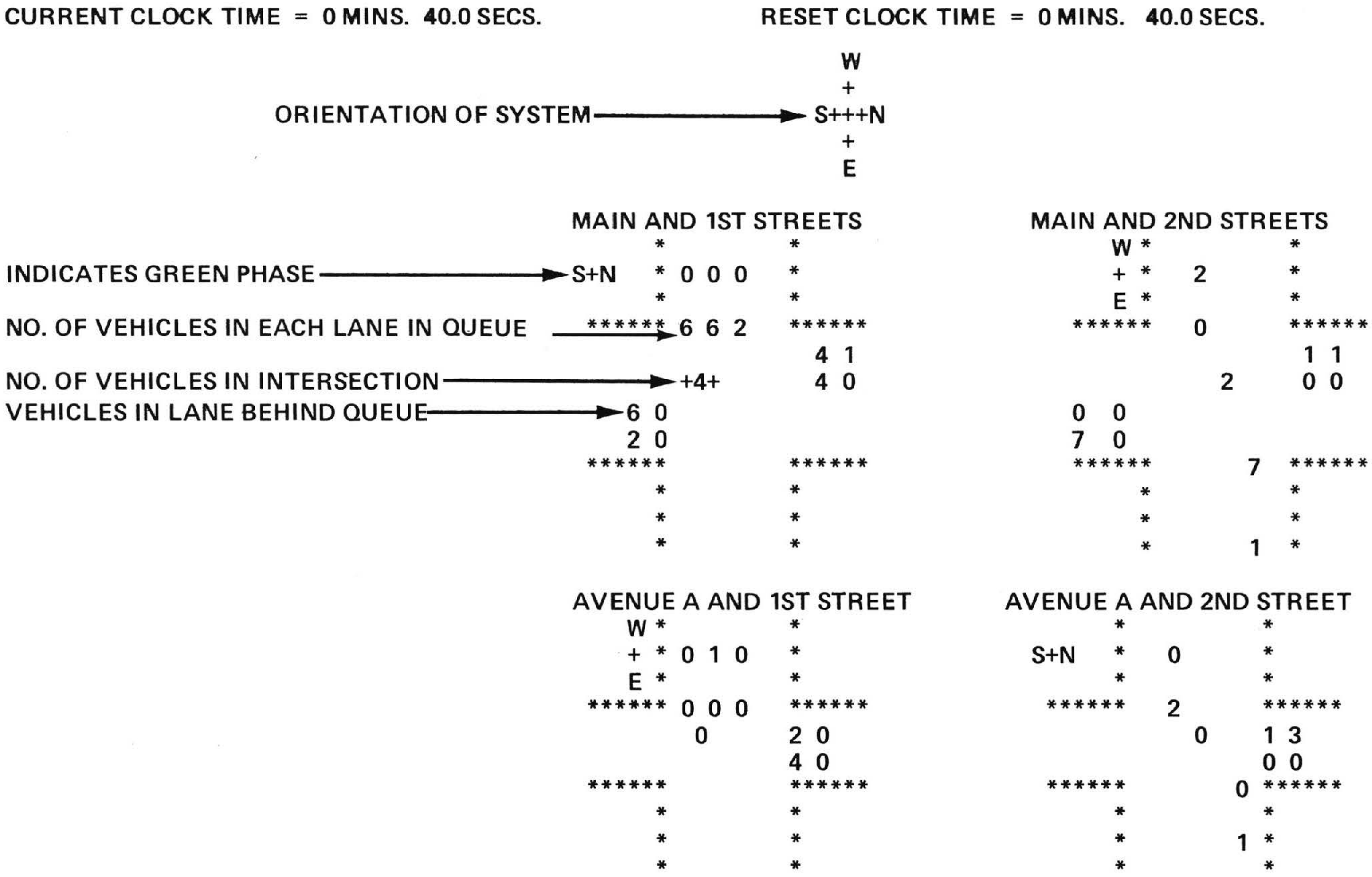
The three types of input to the system are:

- The geometry of the system
- Vehicle characteristics, such as velocity and vehicle length
- Signal control

The output possibilities are also of interest. There are three types of output that may be requested at any time of simulation:

- Network display
- Detailed tabular listings
- Histograms

These outputs may be requested for the entire system being simulated and/or for individual intersections within the system. Figure II-18 presents an example of the network display, which is analagous to a photograph of the network at some instant during the simulation. The detailed listings and



```
CURRENT CLOCK TIME = 0 MINS.  40.0 SECS.            RESET CLOCK TIME = 0 MINS.  40.0 SECS.
                                          W
                                          +
                                        S+++N
                                          +
                                          E

                        MAIN AND 1ST STREETS               MAIN AND 2ND STREETS
                             *         *                       W *          *
                        S+N  * 0 0 0   *                       + *   2      *
                             *         *                       E *          *
                        ****** 6 6 2   ******               ******   0      ******
                                    4 1                                      1 1
                               +4+  4 0                                2     0 0
                           6 0                              0  0
                           2 0                              7  0
                        ******         ******               ******      7   ******
                             *         *                         *          *
                             *         *                         *          *
                             *         *                         *      1   *

                        AVENUE A AND 1ST STREET            AVENUE A AND 2ND STREET
                           W *         *                         *         *
                           + * 0 1 0   *                    S+N  *    0    *
                           E *         *                         *         *
                        ****** 0 0 0   ******               ******    2    ******
                                 0     2 0                              0   1 3
                                       4 0                                  0 0
                        ******         ******               ******      0  ******
                             *         *                         *         *
                             *         *                         *     1   *
                             *         *                         *         *
```

FIGURE II-18

NETWORK DISPLAY - BLUM MODEL (28)

histograms provide information as follows:

- Queue delay times for specific lanes
- Queue lengths for specific lanes
- Cummulative queue delay times for all lanes
- Cummulative queue lengths for all lanes
- Cummulative travel times for all vehicles
- Average speeds for all vehicles
- Speed of platoons
- Average time signals are red and green
- Average occupancy of each lane
- Average occupancy of each intersection

The Blum model is a microscopic-type network simulator. Two serious drawbacks of the model are:

- It has not been utilized in any large scale testing
- It consumes computer time at the rate of approximately 3.5 times real time (actual in the field time) on an IBM 7090 computer for 37 intersections.

The most widely tested network simulation model was developed for the District of Columbia Department of Highways and Traffic and for the Bureau of Public Roads, under the direction of D. L. Gerlough (29, 30). It is called "TRANS"* and has evolved through four versions (TRANS I - TRANS IV), each containing refinements over previous versions. It is a macroscopic model, handling groups of vehicles in scan intervals of 1-5 seconds. During each scanning cycle, four major operations are performed:

- Vehicles are generated on the input links
- Vehicles are moved from one link to another (interlink movements)
- Vehicles are advanced within each link (intra-link movements).
- Traffic signal states are updated.

Input to the simulation model includes a description of the system geometry (link lengths, widths, capacity of left turn pockets, free flow speeds, and identification of connecting links), a description of arrival and departure characteristics, and a description of the signal control system. Output from the simulation includes traffic volume output, initial network population, final network population, vehicles processed, average distance travelled per vehicle, average delay per vehicle, average travel speed per vehicle, vehicle miles of travel, average density, and traffic volume by link.

In moving vehicles between two links the model considers if:

- Vehicles are stopped for a traffic light
- Vehicles are in a queue at a light
- Vehicles are in a free flow state
- The source link has a left turn pocket
- The last zone of the new link is full

---

* Not to be confused with the TRANS (Transportation Resource Allocation Study) work conducted by the FHWA.

Other inputs to the simulation model include:

- Turning probabilities for each approach lane
- Launch rates from a queue
- Lane distributions by link
- Free flow speeds by link
- Effective vehicle length (one value)
- Increase or decrease in volume along a link due to parking characteristics
- Pedestrians (effect on turns only)

The signal system states that may be considered by the model are full red, full green, green arrow straight, green arrow left, green arrow right, and green arrow diagonal.

There are two major parts to a simulation run. "Fill time" is a period during which traffic is generated and pumped through the network creating an initial network population. "Observe time" begins after initializations are made at the end of fill time.

Testing of the TRANS model, developed by Gerlough, has been accomplished almost exclusively with changes in signal timing, although some runs have tested the sensitivity of the model to changes in turning probabilities, lane distribution, pedestrian volume, and consideration of trucks. The TRANS authors have recommended future research using the model to test changes in parking regulations, turn prohibitions, street widening, channelizations, special signal phasing, special pedestrian treatment, and special traffic patterns. These types of tests would appear necessary to fully evaluate the validity of the model. The TRANS model has an important virtue of being "fast" as far as computer time is concerned, with many simulations running at a computer speed four times greater than real time.

summary

Various methods have been discussed which can generally be referred to as traffic assignment techniques. The difference in methods vary more in the uses to which they are applied than in approaches to a single application. For example, traditional highway assignment techniques are most useful for regionwide assignment applications. The technique may be adapted to transit assignments or small area traffic estimation, but other approaches have been developed which are more specific to these problems (i.e. UMTA Transportation Planning System and Micro assignment). The background description of techniques presented here is an introduction to the types of decisions that must be made by the practitioner in using them. Some of the major decisions to be made are presented in the next Chapter.

CHAPTER III
DEVELOPMENT OF ASSIGNMENT CAPABILITIES

chapter overview

There has been considerable application of traffic assignment techniques over the past decade with many variations as to technical and operational approaches. The basic application in the 1960's was to regional networks utilizing what has been referred to as traditional traffic assignment techniques. This traditional approach consists of loading an origin-destination trip matrix to the minimum path routes determined for a transportation network. A wealth of experience and development has resulted, although the variation in approach is wide due to the large number of applications in over 200 urbanized areas throughout the United States and in foreign countries. This Chapter will attempt to present the variations in approach in some of the most important aspects of traditional traffic assignment, as well as to indicate in some cases, a recommended approach.

Although some of the new techniques described in Chapter II will be utilized to a great extent in the future, their discussion in this Chapter is necessarily limited. This results from limited field experience with these techniques and from an expected predominant use and adaptation of traditional assignment techniques to special problem areas. However, much of what is discussed is applicable to the newer developments as well as the traditional assignment approach. Any limited discussion relative to the new approaches is due primarily to a lack of operational experience rather than any bias toward the traditional approach.

ZONE-NETWORK RELATIONSHIPS

zone-network capability

"Geographic analysis units" are established for various purposes in a transportation study. The basic unit might be the block for data coding. An aggregation of blocks might be used for forecasting and display purposes. For traffic assignment, the geographic analysis unit should be established in accordance with the purpose of the assignment(s) to be made and the network established. For ease of discussion and as a result of usage, the term "zone" will be used as the description of geographic analysis unit in terms of traffic assignment area units.

The establishment of zones and a traffic assignment network should basically be developed in accordance with the objectives of the assignment. For regionwide planning level assignments, a coarser network and larger zones are typically needed than when a more detailed study is being made of a specific transportation corridor. Within this context, however, there is still considerable agreement on the premise that within practical limits of accuracy and reliability, the smaller the zones and the more detailed a transportation network established for a particular assignment objective, the better will be the results.

However, this must be tempered by cost considerations and other pertinent factors. The more zones and greater network detail, the higher will be the cost of making an assignment. Regional assignments for development of an overall transportation plan require assignments to high level facilities (i.e., highways-freeways and major arterials). Assignments made for detailed design purposes require as high an accuracy as possible in relatively small parts of an urban area. Small area studies, such as a CBD, require assignments to all levels of facility. As a general rule, the network and zones should be established to allow the achievement of accuracy commensurate with the objectives of the traffic assignment to be made.

In addition to the effects on assignment results, selection of zones and network are dependent upon non-assignment considerations, such as, the availability of data, either forecasted or collected, to some level of area detail.

regional vs. sub-area assignment

To be most efficient, considering cost and accuracy, assignment networks should be chosen in relationship to the objectives of the transportation study. In the past, application of assignment techniques on a region-wide scale were prevelant when the emphasis was placed on plan development. Now it is expected that considerably more work will be accomplished in sub-areas of a region for detailed assignments related to design, major traffic generator analysis, and corridor analysis in response to surveillance, reappraisal, and service functions of transportation studies. There is a relationship between zones and network, as well as a relationship of these to the level of assignments contemplated. Therefore, it is necessary to design the zone and network base systems to allow efficient tailoring to each specific purpose.

Experience in traffic assignment application indicates that this zone-network compatibility helps insure that assignment results will be as accurate as possible regardless of the level of detail and the objectives of the study. If the traffic assignment process is considered as a function isolated from other planning functions, it appears that zones should be determined basically as a result of the assignment network developed and that the assignment network be developed based upon the purposes of the assignment application. This must, however, be tempered by other considerations.

network development

In the purest application of the above statement (i.e., zones depend on the assignment system chosen according to purpose of assignment) the network would be chosen as follows:

- Functionally classify the transportation system.
- Include in the system a level of facility one classification below that for which assignment results are required. This must be considered carefully since, for example, adding collectors to an arterial network might increase the miles coded by 50 percent and double the numbers of nodes. A plot which may be valuable is one of accumulated percent of vehicle miles of travel versus accumulated percent of miles of facilities which will show changes expected as functional systems are added to the network.

- Insure that sufficient sections are included to provide network continuity.
- Connect zones to this lowest level of facility.

zone-network development

The zone system, then, would be based upon the selected network. Ideally, the zonal system would include at least one zone within each land area delimited by the selected network. This would result (using one zone per land area delimited) in four directional links (or two physical sections of facility) for each zone. If there were, for example, 2000 physical sections in a network, there should be 1000 zones. The above does not consider any link connectors between zone centroids and the selected network and the subdivision of the network links caused by centroid connectors. If each zone defined by the above were connected to the system by 4 links, there would result a total of one zone for each 8 links. Table III-1 shows the relationship between zones and links based upon the above approach.

TABLE III-I

Desirable Relationship Between Links and Zone

Number of Centroid Connectors	Number of Physical Links per Zone
0	2
1	4
2	5-6
3	7
4	8

Based on experience of operating transportation agencies, it would appear that 10 links per zone is the average, which indicates that in many instances a zone covers more than one network defined area.

The approach described is most relevant to regional study. When a more detailed study, within corridors for example, is undertaken, the relationship will change due to coding of additional operating features such as ramps.

The above described development of the zone-network relationship does not consider other analysis and planning requirements. However, the same approach can be applied whether the assignments are to be made to a regionwide network with only high level facilities included, to a corridor where greater facility detail is required, or to special generators such as a shopping center area where perhaps all facilities might be included.

other considerations

In considering the above approach, limitations placed on assignment procedures by data development and other uses must be considered. Generally, the following is of concern:

- Municipal and/or political boundaries must be considered due to the variations in data available from these and the general requirement for reporting data for such entities.
- Census tract boundaries should be considered based upon the large amount of data collected on this basis.

-Model city area boundaries should be considered if relevant.
-Zones should contain sufficient activity to allow the development of travel by the trip generation and distribution processes. Homogeneity should also be a consideration.* Further discussion of this aspect may be found in "Guidelines for Trip Generation Analysis" and several HRB publications.(2,31,32)
-Zones should not contain so much activity that unrealistic network loadings on links near zone centroid connectors may occur.
-Geographical barriers often limit traffic circulation and are therefore desirable zonal boundaries.

formally structured zone-network development

A formally structured approach to the idea of zone-network compatability has been described by Mr. Eugene Muhich (33). The concept is referred to as the Basic Geographic Analysis Unit (BGAU) concept. Criteria related to the types and purposes of planning and the kinds of analyses to be undertaken are applied to delineate geographic areas which can serve as analysis units capable of meeting the reliability requirements of a given planning effort. The implicit assumptions, the types and forms of information, and the procedures involved inherently define the size, shape, and character of BGAU needed to accomplish this planning to a specified degree of reliability or precision. Hence, to do a given type of planning for a given purpose under a given set of circumstances, a relatively specific number of BGAU's is required. These differences are illustrated by a comparison of the general types and purposes of planning that might be expected in a region as shown in Table III-2. In addition to the scale and types of planning, the size and character of BGAU's are related to the types of tools and analyses used and whether concern is with a current or forecasted situation. For example, some portion of a current study area might now be rural whereas in the future it is forecast to be urban. The requirements for BGAU's would differ due to this change in land use.

To illustrate the BGAU concept as related to traffic assignment, the following discussion outlines the factors to be considered and procedures to be followed in developing BGAU's associated with an arterial highway analysis. The objective, then, is to produce reliable information for highway location and design purposes for all facilities in the arterial system. Table III-3 shows an example of primary design factors for 11 functional design classes of arterials and 2 classes of collectors that might be used in an urban area. Most State highway departments have developed such "standards". Assuming the objective of the study is to produce a certain degree of precision for design class 6 and above, the BGAU size is related to the amount of activity by area (trip ends) and the number of centroids used to simulate via traffic assignment. In order to determine the amount of activity which could be allowed in a BGAU and still achieve compatibility with the network detail (class 6), it was determined that the ADT average daily traffic (converted to a weekday basis to be compatible with the survey information) could be used. It was recognized that this was design information relating the capacity of facilities and a certain level of service. Since the critical segments of the arterial system were operating at near this level of service, it was decided that this could be used as a measure of the level of activity that could be permitted

TABLE III-2

Illustration of BGAU's associated with various planning situations.(33)

Planning			Types of Tools	Number of BGAU's	Convention Designation
Scale	Type	Purpose			
Regional (3 county SMSA with one urban area)	Urban Rural	Central Land Use & Transportation Corridor Planning	Traditional including Traffic Assignment	89 Urban 38 Rural 127	Super Districts
Urban	Urban	General Land Use and Major Arterial (Expressway)	Same	178	Districts
Urban	Urban	Detailed Land Use and Total Arterial System	Same	534	Traffic Analysis Zones
Urban	Urban	Transit Operations and Attendant Land Use	Same Including Transit Assignment	378	Transit Analysis Zones
Urban	Urban	Metro Sewer Planning	Simulation & Design Models	235	Sewer Service Modules

TABLE III-3

URBAN DESIGN CRITERIA & "STANDARDS" - AN EXAMPLE

Functional Class	Classification	No. of Lanes	Directional Split	DHV	K	ADT
13	Freeway	10 8	60-40	8,350	9%	92,800*
12	"	6	60-40	6,080	9%	67,600*
11	"	4	60-40	3,830	9%	42,600*
10	Expressway(w/10'SH)	6	60-40	3,830[1]	10%	38,300**
9	"	4	60-40	2,830[1]	10%	28,300**
8	Principal Arterial— Divided, 2' SH.	6	60-40	3,180[1]	10%	31,800**
7	w/left-turn lanes —	4	60-40	2,120[1]	10%	21,200**
6	Minor Arterial — Divided	6	60-40	2,420[2]	10%	24,200**
5	w/Lt.-turn lanes —	4	60-40	1,570[2]	10%	15,700**
4	Minor Arterial —	6	Undesirable			
3	Not divided	4	55-45	1,490[2]	11%	13,600**
2	Collector —	4	50-50	1,230[3]	12%	10,250**
1	Not divided —	2	50-50	580[3]	12%	4,850**

Table conditions

5% Trucks - - - -	Class	1 thru 13
10% Lt. turns - -	"	1 thru 10
10% Rt. turns - -	"	1 thru 10
No parking - - - -	"	1 thru 13
Metro. Pop. - 750,000"		1 thru 10

1 50-50 greentime/hr
2 40-60 greentime/hr
3 30-70 greentime/hr
* For 0% Trucks + 10%
For 10% Trucks - 8%

**

For Residential Area + 11%
For C. B. D. - - − 9%
For 0% Trucks - + 5%
For 10% Trucks - − 6%
For Metro. pop. 500,000-5%
For Metro. pop. 1,000,000 + 5%

in a BGAU. Since some variability of traffic flow characteristics, and hence design, exists for various portions of the area, separate tables were developed for the CBD and residential areas as reflected in the footnotes of Table III-3. If the system had been operating significantly below capacity, a different set of volume criteria would have had to be developed. The fact that the system was operating at or near capacity in this instance was fortunate, since these BGAU criteria could then be used for forecasting purposes.

Additional items to be considered might include:

- Effect and influence of natural barriers.
- Compatibility with data units established for information system purposes.
- The shape of the BGAU should be such that trip activity can be represented by a point.
- For trip generation, distribution, and other modeling purposes there should be homogeneity by BGAU.
- The amount of activity (trips) to be permitted in a BGAU will be controlled by the design volume of functional class 6 (minor arterial).

Once all the criteria to be considered are assembled, the procedure for defining BGAU's (assuming the interest is in design class 6 and above) is as follows:

method of zone-network definition

- Assemble a set of base maps. The maps and overlays should show topographical features including physical barriers, existing land development, land currently committed to new development, and civil division boundaries.
- Using a street and highway system map of the same scale, identify the functional design classes of the arterial facilities. Using an overlay, plot the class 6 through 13 facilities to be included in the analysis network.
- On another overlay, plot all pertinent planning boundaries.
- Review the above maps and overlays to determine that all physical barriers including railroads, mass transit facilities, etc., are shown.
- By superimposing the appropriate maps showing the network and physical barriers, lay out a tentative set of BGAU's corresponding roughly to the "holes" between the major barriers and major arterial facilities.
- Working on an area by area basis, refine these BGAU's by using the maps and information on land use, planning boundaries, information system area units, and associated information taking into consideration the shape of the BGAU and the character of development.
- The amounts of activity in the refined BGAU's should be checked to determine if any activity control has been exceeded. This will necessarily involve the inspection of facilities not included in the analysis network to determine if some lower classes should be added to the network in order that the centroid connectors can properly load traffic to and from the BGAU. Some simplified Trip Generation relationships should be used in conjunction with the land use, population, and employment information to estimate the total number of trips in the BGAU.

This total trip activity should then be compared to the traffic volume controls to make a preliminary determination of the number of centroid connections that will be necessary to accomodate this amount of trip activity. The maps and other information should then be reviewed to determine the proper number and location of centroid connectors in order to simulate the travel to and from the BGAU.

-A final review of the BGAU's should be made to assure that the BGAU's satisfy the established criteria to the maximum degree.

consideration in multi-level assignments

The implications of the above discussion on zone-network compatibility in data development and processing are significant. The problems inherent in a number of zoning systems and conversion of data between them are considerable. In addition, forecasts made on a very small area basis may hold such inaccuracies as to cause questionable assignment results. The ability to estimate land use characteristics and develop meaningful travel forecasts on a small area basis must be considered here.

The two general approaches that might be considered for handling multi-level assignments are:

2 approaches

- -development of a regionwide network to the finest detail expected to be used in any specific analysis with corresponding zones, data, and forecasts.
- -Development of a network on a regionwide scale (detail required for regionwide analysis) with corresponding zones, data, and forecasts.

Each of the above approaches has advantages as well as disadvantages. The first procedure requires that network data be collected for the fine network for an entire region. This includes characteristics such as capacities, ground counts, and speeds. All zonal attributes required for trip generation, trip distribution, and modal split would have to be gathered and forecast at a fine level of detail over the entire region. Once done, however, the ability to make regionwide assignments by aggregating zones, and small area assignments for special generators and in corridors becomes a rather simple data handling process.

The second procedure requires that data be gathered and forecast for a coarser network and less zones areawide. For detailed study, additional detailed data would be gathered and forecast in the specific area of a special generator or corridor. The increase in work necessary here would be the redevelopment and/or application of developed forecasting procedures and models on the new level, an additional data collection effort, and the addition of more detailed network data in the specific area of interest. Again, data handling and calculation processes exist for accomplishing the necessary work if this approach is taken (see Chapter II, pages 62-68 on small area traffic estimation).

Both of the above approaches have been successfully applied. The basic goals and objectives of the region for which a study is undertaken as well as the types and number of assignments expected to be made must be considered. In addition, the cost and time effectiveness of each approach, as well as any theoretical consideration deemed important, are considered.

At least one state has decided to approach the above problem by developing two zonal-network systems for the purposes of detail area assignments and assignments made for regional planning purposes. One system has 1700 zones, 12,500 link sections, and is used for detailed area and corridor analysis. The second zonal-network system contains 850 zones, 9000 links, and is used on the regional level. Generally, the 850 zones are groupings of 1700 zones.

examples of zone - network relationships

This section contains no guide relative to the number of zones and links recommended depending upon the area or population of an area. Discussion with practitioners in the field has indicated that each urban area must be handled separately based upon its own characteristics of topography, network configuration, land use characteristics, and study purpose. A review of a number of zones and links in a sampling of regional studies bears this out. As an example of this, Table III-4 provides information for a number of urbanized areas within a single state where the networks were basically established for regional planning purposes. The wide variation in zones and links per population is readily apparent. There is a narrower limit on links and zones as related to area and a rather narrow limit on the links per zone relationship. A possible determinant here was the specific objectives of each of the studies which may have varied considerably. Also, the effects of urban area size and intensity of development enter into the considerations on zone-network relationships.

TABLE III-4

Zone-network relationships in studies within a single state.

Urban Area	Base Year Popul.	Area Sq.-miles	No. of Links	No. of Zones	Links per Zone	Pop. per Link	Links per Sq.Mile	Pop. per Zone	Zones per Sq. Mile
A	533000	439	5114	489	10.5	104	10.4	1090	.99
B	333000	461	5246	527	10.0	63	11.4	632	1.14
C	721000	539	6322	765	8.3	114	11.7	942	1.42
D	80000	139	1317	162	8.1	61	9.5	494	1.16
E	515000	650	5779	616	9.4	89	8.9	836	0.95

Further evidence of needed tailoring of zones and network to specific urbanized areas is available from some nationwide data available on zones, area, and population as shown in Table III-5.

TABLE III-5

Zone Relationships - Nationwide sampling
(74 urbanized areas)

Population Range (Study year)	Sq. miles per zone		Persons per zone	
	Average	Range	Average	Range
Less than 75,000	0.55	0.11-2.10	954	120-2700
75,000-150,000	1.07	0.24-3.39	872	357-1692
150,000-300,000	1.32	0.24-4.01	1296	545-2400
300,000-1,000,000	2.22	0.81-10.27	2828	1316-7175
Greater than 1,000,000	3.13	0.58-13.33	7339	2214-24569

Although the table indicates a general trend toward less zones per population and area as the population increases, there is a wide range in the number of zones within any one population grouping. One would suppose that the general trend is based on economic realities where assignment computer costs increase geometrically with the number of zones, as well as the computer packages previously available which strictly limited the number of links and zones which could be used.

checking zone-network compatibility

The discussion in this section should provide information useful for establishing a compatible zone-network system. A check of this compatibility is a necessary step and can be easily accomplished. A series of synthetic screenlines (gridlines) traversing the entire study area (refer to Figure III-7) can be used to accumulate ground counts and assigned origin-destination trips. A comparison of the count and assignment volumes on links crossing these gridlines indicates whether there is too much or too little network per zone. If the network were too coarse in a particular area of the region, trips that would actually use that part of the system not included in the link network in the area would actually be assigned to the included links. Therefore, the total assigned O-D volume would be greater than the total ground counts across the gridline. The addition of more network links relative to the number of zones would adjust for the above condition. If the network were too fine relative to the zones, the total O-D assigned volume would be less than ground counts.

A number of such gridlines would serve as an area-wide indicator of zone-network compatibility. Since an ideal zone-network configuration would define as a zone each area surrounded by network segments (links), a rough check of zone-network compatibility can be made by counting the number of zone boundaries and network segments crossed by each gridline. A compatible system would be one in which zone boundaries crossed equaled network segments crossed by each gridline. These checks would not directly indicate where spot additions to or deletions from the network were needed, but would rather indicate generally if the procedure used in establishing the zone-network system needed review and/or revision.

incompatibility- an illustration

An interesting illustration of the results caused by zone-network incompatibility was developed using two micro-assignment runs (34). The first run used very fine zones where the two block faces on a street comprises a zone and the centroid was the middle of the street. The second run was made with larger zones twice the size of the first run zones. The network was the same in both cases, consisting of local and arterial facilities spaced at 1/3 of a mile. A uniform trip-end density of 10,000 per square mile was used. The results showed that intrazonal trips (which are not loaded on the assignment network) increased from 0.25% for the fine zones to 13% for the larger zones - a significant difference. Average trip length for the fine zones was 2.93 miles and for the large zones 3.60 miles. Vehicle miles of travel on the arterials increased from 61% to 93% of total VMT in going from fine zones to large zones (with a corresponding decrease of 39% to 7% on the locals).

Corrections to the zone-network system, if they are to be effective, must be undertaken with care. If the network is found to be coarse for the zones used, zones may be enlarged where necessary or additional network may be included. From a practical point of view, the usual method is to add network since there are usually more constraints placed on the zone configuration by other factors. These efforts should all be guided by the desirable zone-network configuration for compatibility and the goal of the study area as they relate to the network analysis. If the network is found to be too fine, either more zones should be designated or less network included, again following the desirable configuration guidelines and the goals of the study area.

correcting for zone-network incompatibility

It can be shown that for certain zone-network configurations, the subdivision of a land area delimited by the network into more than one zone does not completely alleviate the artificial overload problem. This would seem to indicate that additional network must be included to reduce the trip ends in each land area delimited. The resulting new land areas may each be one or more zones as necessitated by other considerations, such as, homogeneity of land use activity.

In updating transportation study data and techniques, the opportunity to reevaluate the zones and network established initially should be considered. The types of criteria described for establishing zones and network discussed in this section should certainly be considered in any updating - reevaluation process. The goals and objectives of the future work might be different from the work previously accomplished, resulting in the need for reestablishing zone-network compatibility.

The establishing of zone-network compatibility is also important in the calibration of the assignment model. Calibration usually consists of adjustments to the network parameters (i.e. speed) and/or extent of system included. Comparisons are made of assignment volume and ground counts accumulated to some level of aggregation (see Chapter V) or compared with ground counts on a link by link basis. The zone-network relationship should insure that the proper trips are loaded onto the system being used for assignment (i.e. intrazonal trips being of a proper magnitude). Adjustments made to the network and/or zones during calibration should be made within the framework of the zone-network compatibility established. Hopefully, if this is properly established, the calibration of the assignment model should proceed with few zone and/or network changes being necessary and being limited to minor changes in system parameters. A checklist that may be used to accomplish the above follows:

zones & network related to assignment model

calibration of assignment technique

- Check the network - counts and capacity
  - Build and trace trees - logic of trees
  - Logic of counts and capacity
- Locate imbalances
  - Gridline analysis
  - Check fineness and coarseness
- Corridor analysis
  - Check VMT, assigned volumes versus counts
  - Adjust speeds in corridor (i.e., if under assigned, increase speeds in corridor to make it more attractive)
- Analysis of specific links
  - Look at speeds and turn penalties

NETWORK REPRESENTATION AND SPECIAL FEATURE CONSIDERATIONS

Chapter I presented the input data requirements for several assignment systems now available (the highway packages, the transit planning package, and micro assignment). The intention of this section is not to provide the detail necessary to code a network using the various assignment systems available. Rather, the purpose is to provide some background information to augment the coding instructions that are pertinent to any of the computer systems available for traffic assignment. The reader should reference the pertinent instructional manuals for detailed coding instructions (7,10,14,15).

network coding

The level of detail and special features to be considered in the coding of an assignment network should be based upon the type of assignments to be made. For example, for broad regionwide planning-type assignments there is usually little need for detailed geometric definition of the system and use of turn penalties or prohibitors. Turn penalties allow the specification of travel time in addition to link times during the route building process to assess time for making movements such as right and left turns. Turn prohibitors do not allow certain movements as specified by the user during the route building process. Corridor analysis and small area study generally benefit from detailed coding of geometry and use of turn penalties and prohibitors. Likewise, the basic coding and special feature considerations will vary by type of system coded, i.e., transit, highway, micro area, etc.

The use of appropriately scaled maps for coding is extremely important. The information used for coding a network should be placed on the maps for coding and future reference. Map scale should be chosen so that very few major links on a network will be less than one inch long, thereby allowing annotation with necessary information. However, this sometimes results in requiring different scales for the central business district, surrounding city, and suburbs. A typical set of maps might consist of: 1"=2000' maps for outer suburban areas, a 1"=1000' scale for the inner suburbs and outer city, and a 1"=400' map for downtown.

With properly selected base maps, the following network data (if all used) would be placed on the maps for subsequent coding on sheets for keypunching (refer to Chapter I, Data Requirements Section and Figure III-1 for illustrations of terms used below):

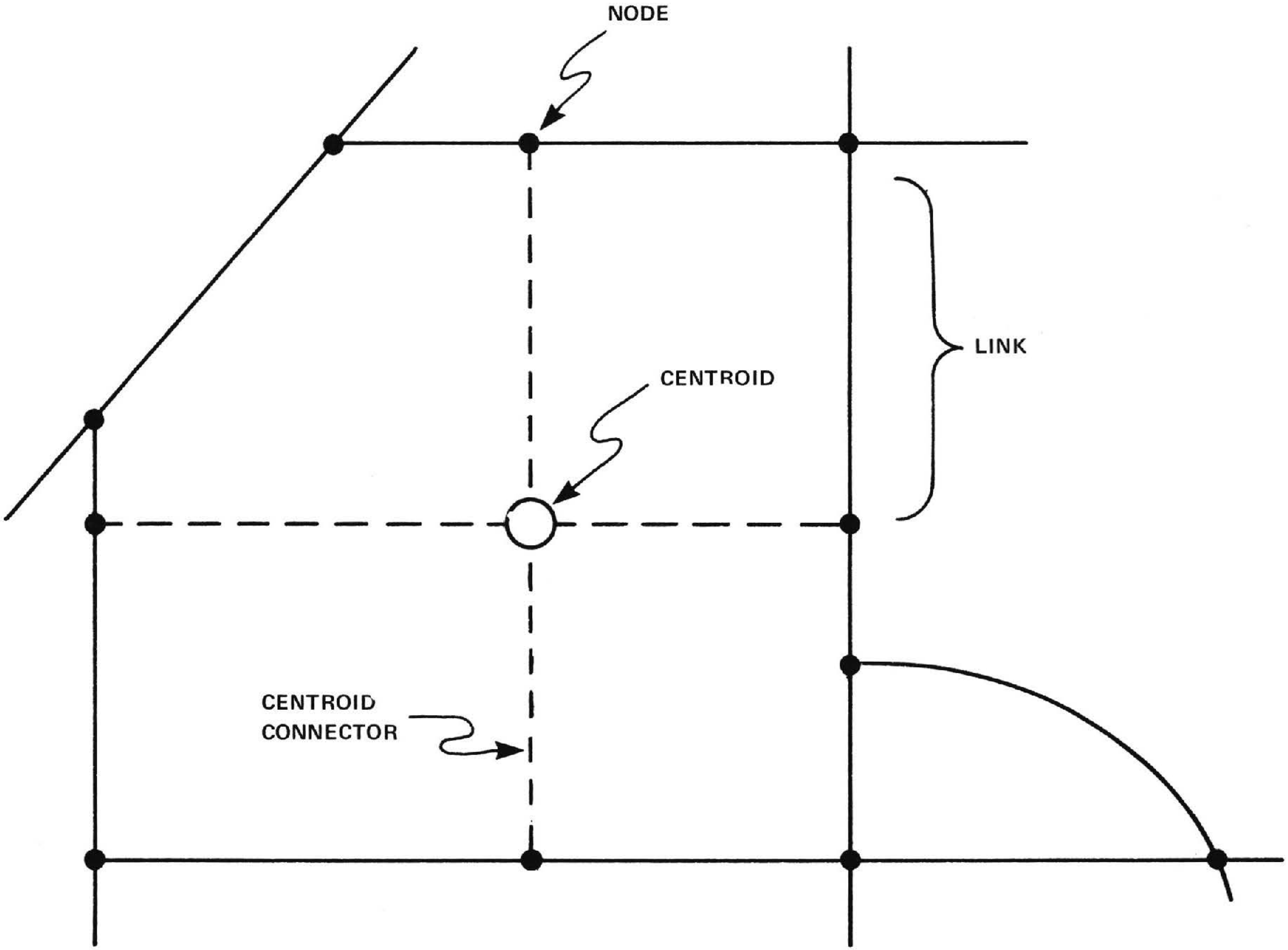


FIGURE III-1
NETWORK DATA DEFINITION

- Definition and location of the transportation system for assignment purposes
- Location of zones and their centroids
- Centroid numbers
- Links connecting the centroids to the network
- Network nodes
- Node numbers
- Turn penalties and prohibitors if utilized
- Link parameters (e.g. distance, speed, **etc.**)
- Special coding features for interchanges, external stations, etc.
- Map identification for storing and future use

For futher details on these items the reader is referred to the manual "Urban Transportation-General Information" (14) prepared by the Federal Highway Administration as well as Chapter I and references (7, 10).

detailed directional coding

The amount of realism that may be achieved by representing a real transportation system by a coded network varies with the intent of the assignments. If the system coded contains high type facilities, and corridor type analyses are to be made, the facilities and their interchanges may be coded directionally. In directional coding, turning movements and weaving movements may be specified as links in the system. In this level of coding, the longer distance and traveltime inherent in the loops of a cloverleaf interchange, for example, may be simulated by directional coding. Examples of the possibilities that may be considered are shown in Figure III-2 for freeway type interchanges.

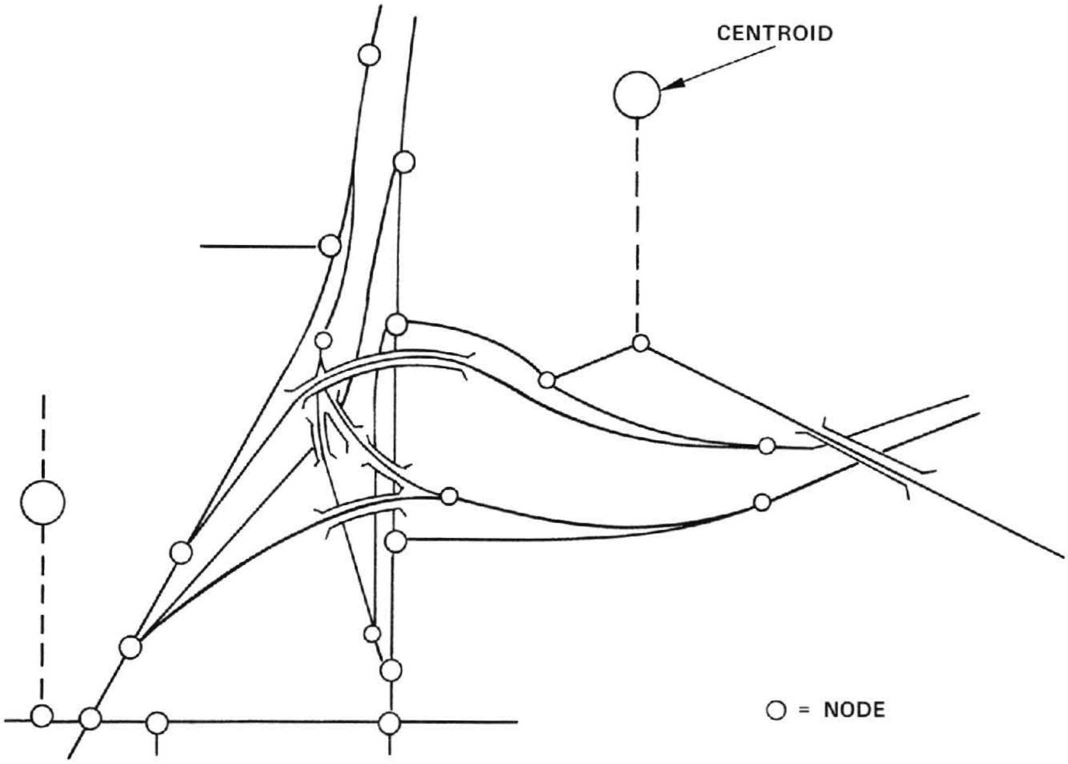
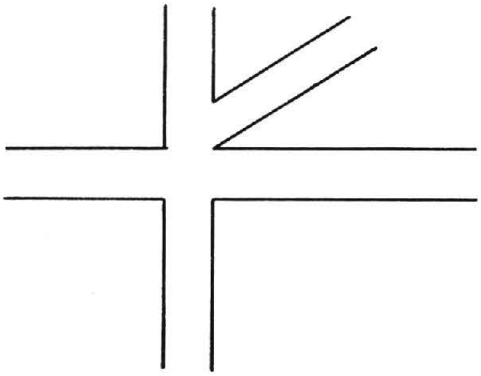


FIGURE III -2

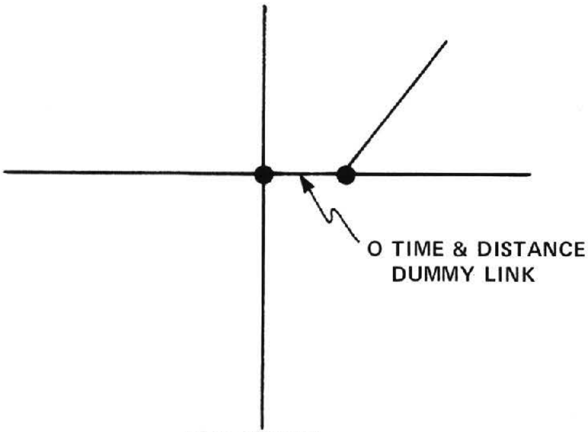
EXAMPLE OF DIRECTIONAL DETAILED NETWORK CODING-HIGH TYPE FACILITIES(14)

Similar detail may be coded for intersecting streets to account for detailed traffic control, time of turning, and turning prohibitions. Figure III-3 shows that eight nodes may be used in place of a single node at an intersection to allow the separate identification of each movement. Turns can be prohibited and different penalties used for each movement if desired. This scheme can be used with most assignment systems, including those that do not allow use of turn penalties and prohibitors. Where prohibitors are available, the detailed coding described above can handle these prohibitors as shown in Figure III-4. In considering the above concerning realism and detail, the practitioner should be objective concerning the degree of accuracy that may be achieved at ramps and intersections.

Many computer packages limit the number of links that may be connected to a node. Some limit this to four links. When intersections of more than the maximum number of allowable links are encountered, it is necessary to add extra nodes in such a way that the link limitation is not exceeded. This is accomplished by adding a dummy link (a link with zero time and distance) so that the time to the intersection during the route building process is not affected as shown below:



ACTUAL CONDITION



FOR CODING

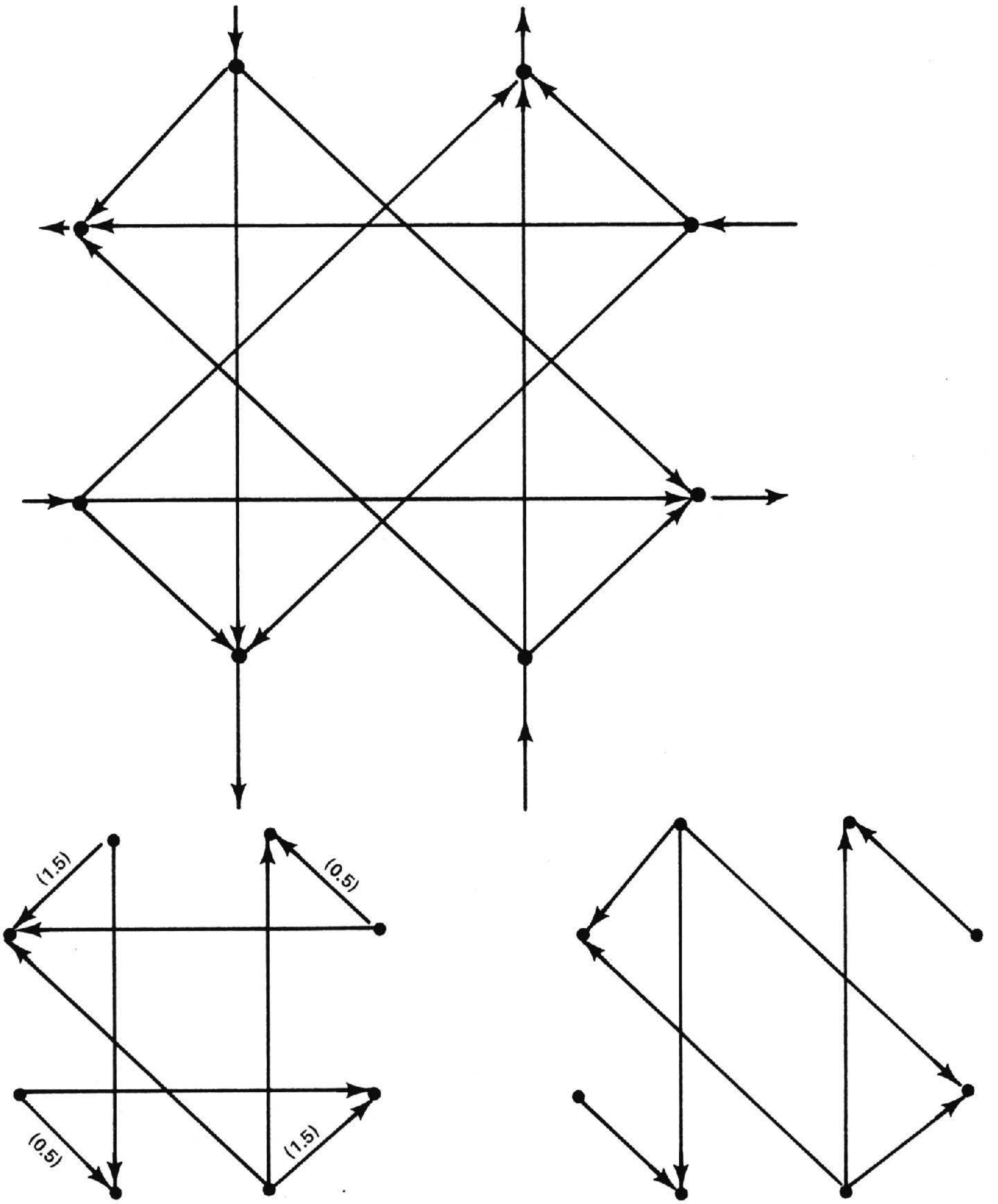
turn penalty & prohibitors

Turn penalty and prohibitor features of some assignment systems allow more direct coding of these characteristics than described above. However, there are still cases where detailed analysis may warrant special coding of an intersection or freeway interchange. For example, miles of travel and speeds on ramps may be desired. In addition, most computer systems limit the number of turn penalty values that can be used. Direct coding allows use of different values between intersections.

Figure III-5 shows two design situations that may warrant special handling during the assignment process. This special handling may utilize turn prohibitors if available (as shown) or use detailed coding which requires use of additional nodes.

vines vs. trees

The coding used for networks becomes directly involved in the routing process. Chapter II describes routing algorithms and the differences between "vines" and "trees". Vine routings are more accurate, ensuring minimum paths where there are prohibited movements and penalties in a system. If many intersections have prohibited turns or large turning penalties associated with them, vines should be used. However, about twice the computer time required to build trees



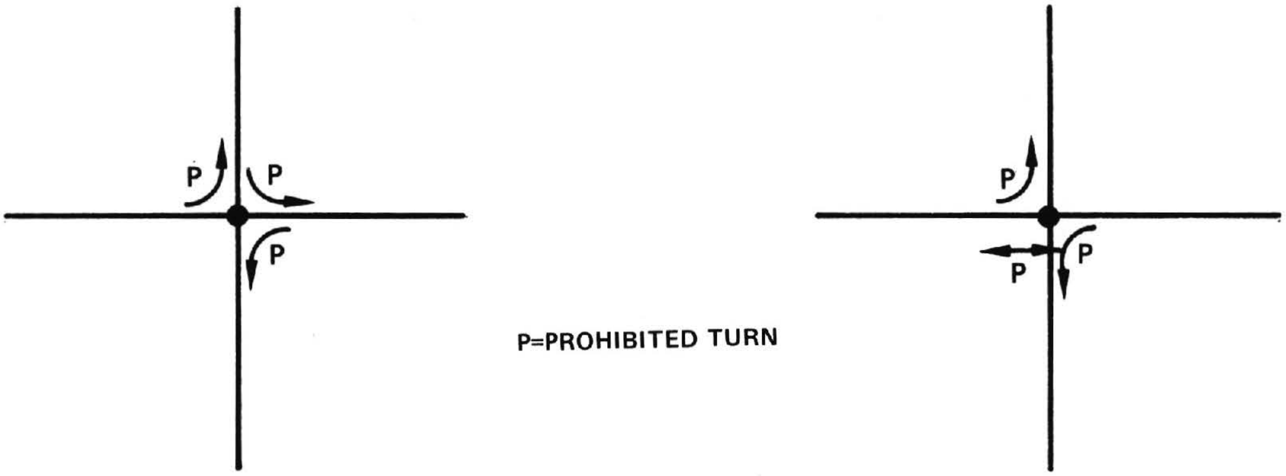
SITUATION A

ALL LEFT TURNS EXCEPT 1 PROHIBITED WITH RIGHT TURNS HAVING DIFFERENT PENALTIES (X.X)

SITUATION B

TWO THROUGH MOVEMENTS AND TWO LEFT TURNS PROHIBITED

FIGURE III-3
EXAMPLE OF DETAILED INTERSECTION CODING



SITUATION A

SITUATION B

FIGURE III-4

USE OF TURN PROHIBITORS IN PLACE OF

DETAILED CODING SHOWN IN FIGURE III-3

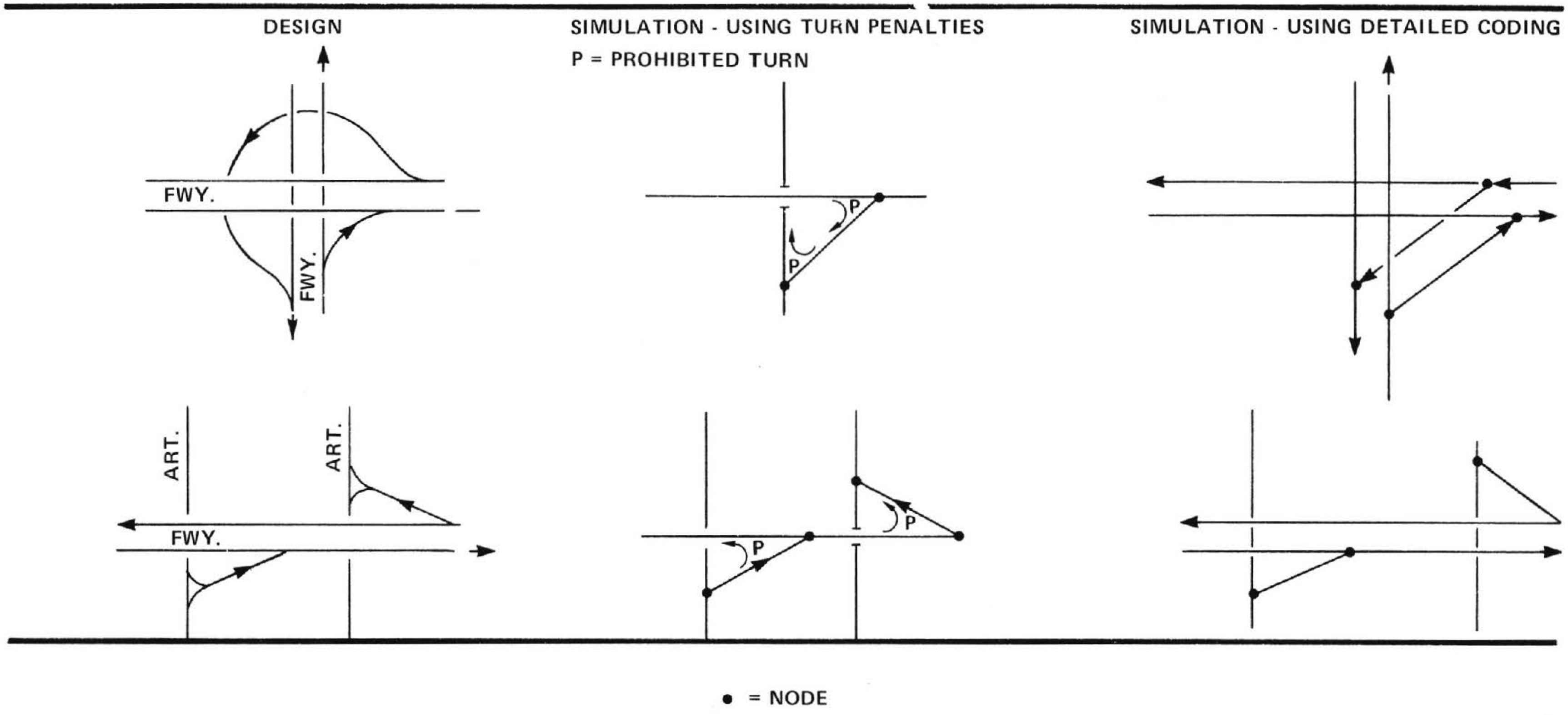


FIGURE III-5

NETWORK GEOMETRY USING TURN PRHIBITORS OR DETAILED CODING(14) is required to build vines. Field experience would indicate that most users do not employ the vine option when it is available. This is probably due to more familiarity with the tree option, desiring the savings in computer time and generally not requiring the increased accuracy. However, if many intersections have prohibited turning movements, or large turning penalties associated with them, vines are recommended. Otherwise, trees should probably be used.

network data

The amount of data which must be coded for traffic assignment purposes is very limited. There are three major data items necessary: 1) network geometry - which may be a very abstract reproduction of the actual system, or a detailed description of actual geometric characteristics; 2) trip data; and 3) network parameters. The only network item required for assignment purposes is an impedance value on each link for optimal route calculations. For some systems, distance must be coded (15). More data can be coded to increase assignment usefulness where required: 1) operational characteristics such as prohibitors and turn penalties, and 2) descriptive characteristics such as functional classification of facility, administrative class, type of area, etc. The last items allow more meaningful and useful summaries of assignments to be produced.

A series of computer programs has been developed to deal with transit networks (7). These programs are commonly referred to as the UTPS (UMTA Transportation Planning System) and were described in Chapter II, **page** 47. They provide the means to handle the unique characteristics of a transit system.

transit networks

With the UTPS, there are two types of data supplied for a network. Links are coded as in the "traditional" highway network. The only additional information that is supplied is the mode(s) of travel serviced by the link. The continuity of individual transit routes is maintained by supplying "line cards". These "line cards" define a transit route as a series of nodes. In addition, headways are supplied for each transit route (line) to provide for the computation of waiting time.

Once a transit network has been established, several variables can be altered for calibration purposes. These variables are: maximum and minimum transfer penalties; number of transfers permitted on a path from origin to destination; weighting factors for running time and waiting time; and mode to mode transfer prohibitors. Since these variables are supplied during the minimum path building process, it is not necessary to modify the network each time one of the variables requires change.

The use of the UTPS programs makes the analysis of relatively large transit systems practical. Reports obtained from the battery of programs are tailored to transit analysis problems and provide information that is unique to transit planning such as: number of vehicles required to serve a route under given headway conditions, passenger miles, passenger hours, peak loads, minimum headway necessary to serve passengers, and vehicle idle time.

automatic plotting

The desirability of automatic plotting should be considered when coding of transportation systems is undertaken. Chapter V describes automatic plotting, including the necessary digitizing of coordinates that must be done as well as plotting devices and types of display. Automatic plotting programs are available with traffic assignment packages and reference should be made to the pertinent documentation for the system being used (7, 10, 14, 15). A. short description of the plotting capabilities in the FHWA transportation planning system should provide indicative background for consideration.

automatic plotting

Traditionally, a tremendous expenditure of man-power has been necessary to prepare a network for analysis purposes. This time has been spent manually reviewing network print-outs and maps. Further time has been spent manually plotting minimum path trees to establish the reasonableness of the coding. A series of programs are included in the battery to produce plots on a drum or flatbed plotter. These programs are quite flexible, allowing the user to specify scale, physical plotter size, number of plates to be plotted, and the manner in which the information is plotted.

The potential user should decide early in the study development whether he will utilize the automatic plotting features of the battery. Although x-y coordinates can be coded at any point in the process, considerable time and cost savings will result if coordinates are obtained during the network coding phase. The programs that generate the off-line input to a plotter require special subroutines. The user should be sure he will have access to these subroutines at the computer installation he is utilizing. They are not included in the planning battery since they vary depending on both computer system and plotter model. Usually, an installation that has a plotter will also have the necessary subroutines.

Data plotting within the urban planning battery is accomplished in three phases:

- Insertion of coordinates in the historical (computer network description) record - The main function is to insert or update coordinates in a traditional historical record. This is accomplished by providing a deck of coordinate cards for all nodes in the historical record.
- Preparation of data for plotting program - An intermediate program in the plotting system accepts networks or trees/vines and arranges links in an efficient manner for plotting. Many options are available to the user at this point such as plotting of range values in different colors; annotation of plotted links with one or two variable data fields, such as volume, speed, distance, etc.
- Generation of plot tape - A single line graphic display of the information contained is prepared. The study area or portion thereof may be plotted on as many plates as required based on desired scale and plotter size limitations. The data output tape is arranged in sequentially numbered blocks. Multi-color plots will result in more than 1 block per plate so that individual passes of the plotter can be made with the specified colors.

The above description provides some background as to the utility of automatic plotting of traffic assignment data. Further detail concerning plotting is contained in Chapter V.

NETWORK IMPEDANCES

chance of network impedances

The choice of initial network impedances for traffic assignment purposes and the adjustment of these during the calibration and application of traffic assignment techniques is important since not only are the traffic assignment results affected directly, but also most other planning models are affected. Zone to zone impedance summations are used for most planning models including those for trip distribution, modal split, land use distribution, and in some instances trip generation. These zone to zone impedances may be used directly, as in the gravity model or intervening opportunity trip distribution models, or as a part of some other calculation, such as, accessibility measures which are used in some modal split models and land use models. Choice and use of impedance measures is one of the more important factors relating to the results obtained from planning models. It is not, however, one of the areas where there is general agreement as to approach. Discussions with practitioners in the field indicate a wide variation in practice concerning impedance measures. In addition, it does not appear to be an area of activity to which a sufficient level of consideration is given in many cases.

The choice of impedance measures and their adjustment affects:

- Network calibration
- Trip distribution, land use, and modal split model calibration
- Future application of trip distribution, land use, and modal split models
- Future assignment results

The effects of changes in speed (or in error of measurement) on traffic assignment results have been studied on the basis of assignments made to a test network (34). The network consisted of 18 streets running north-south and the same number east-west. Streets are assumed to be spaced one mile apart. Four streets running east-west are expressways spaced 5 miles apart and the same assumed for north-south expressways. The spacing is shown in Figure III-6. Table III-6 presents the results of the study. Changes were made in individual streets and expressways as well as changes to all expressways. Expressway free speed was set at 60 mph and arterial free speed was set at 30 mph for the base assignment. Table III-6 shows changes in pertinent system characteristics due to the speed changes. This table provides an indication of what the effects might be of variation in impedance values on traffic assignment results. For example, by increasing the speeds on all expressways from 60 mph to 70 mph the percent VMT on expressways increases from 57.5 to 62.0.

initial link impedances

For base year initial link impedances, most practitioners utilize link travel time based upon observed travel speeds along a section of system. Generally, for highway networks, this is obtained by some level of field work utilizing floating car techniques. The procedure manual on "Determining Travel Time" developed by the National Committee on Urban Transportation is used by many in setting up their speed studies (35). Except in small study areas, say under 150,000 persons, a sampling of facilities is undertaken with the sample results analyzed and used to estimate link times. Either the actually measured times can be used directly for the sampled links and estimates based on the samples used for the non-sampled links or the measured times need not be used directly for any links.

The sampled link speeds are generally analyzed by classifying them by facility type and type of area and obtaining average speeds for these classifications from the sample speed runs. These speeds are then assigned to the non-sampled

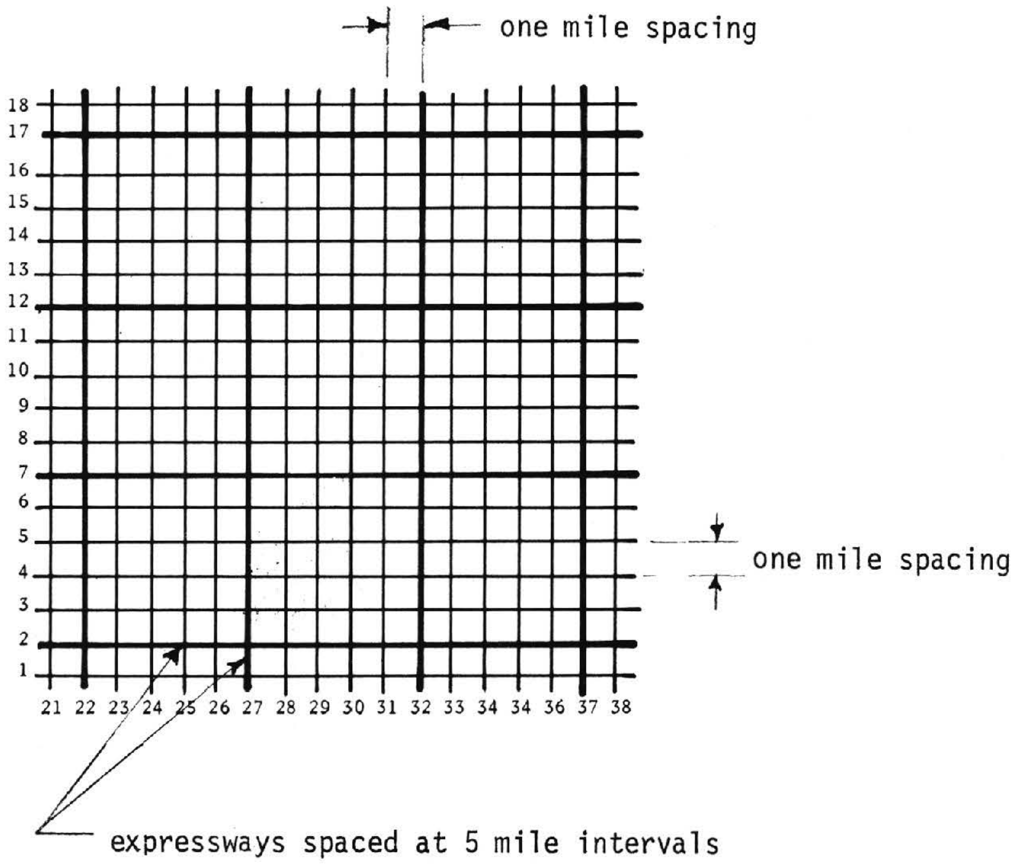


FIGURE III-6
TEST NETWORK FOR SPEED VARIATION EXAMPLE (34)

TABLE III-6

EXAMINATION OF ASSIGNMENT SENSITIVITY TO SPEED CHANGES (34)

CHARACTERISTIC	BASE ASSIGNMENT	TEST 31 [a]	TEST 32 [b]	TEST 33 [c]	TEST 34 [d]	TEST 35 [e]	TEST 36 [f]
VMT	8,807,373	8,819,266	8,796,666	8,795,847	8,861,008	8,578,432	9,072,957
Exp. VMT	5,060,404	5,053,338	5,018,502	4,999,942	5,153,191	4,433,665	5,626,158
Art. VMT	3,746,969	3,765,928	3,778,164	3,795,905	3,707,817	4,144,767	3,446,799
VHT	407,053	410,890	407,258	409,653	411,911	414,408	403,274
Exp. VHT	212,826	212,536	208,173	211,952	216,730	190,567	220,884
Art. VHT	194,227	198,354	199,085	197,701	195,181	223,521	182,390
Speed (mph)	21.6	21.4	21.5	21.4	21.51	20.7	22.4
Exp. speed	23.8	23.8	24.1	23.6	23.78	23.3	25.5
Art. speed	19.3	19.0	19.0	19.2	19.00	18.5	18.9
Cost ($)	327,367	328,454	328,966	324,498	333,805	289,504	352,511
Exp. cost	213,093	212,996	210,405	208,417	219,675	159,972	246,007
Art. cost	114,274	115,458	118,561	116,081	114,130	129,532	106,504
Cost/VMT (¢)	3.72	3.72	3.74	3.69	3.77	3.37	3.89
Trips	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498	1,362,498
Avg. trip length (miles)	6.46	6.47	6.46	6.46	6.50	6.30	6.66
VMT/exp. mile	35,142	35,093	34,851	34,722	35,786	30,789	39,071
VMT/art. mile	7,434	7,472	7,496	7,532	7,357	8,224	6,839
VMT/street mile	13,592	13,610	13,575	13,574	13,674	13,238	14,001
% VMT on exp.	57.5	57.3	57.1	56.8	58.2	51.7	62.0

[a] Legal speed on street 09 lowered to 15 mph.

[b] Legal speed on street 09 increased to 45 mph.

[c] Legal speed on street 12 (exp.) lowered to 45 mph.

[d] Legal speed on street 12 (exp.) increased to 75 mph.

[e] Legal speed on *all* expressways lowered to 45 mph.

[f] Legal speed on *all* expressways increased to 70 mph.

links. Another approach would use the classified data by relating operating speed to posted speeds. Other methods involve classifying facilities by system, area, and signal control and within these classifications developing relationships between speed and volume/capacity ratios. Still in other approaches the density of an area (trips, population, employment) has been substituted for type of area.

impedance error

In determining a classification matrix for obtaining speeds (i.e. geography and facility type) it is important that the classification matrix or "speed table" be such that the standard deviation of the speed is a minimum within each cell. For example, a mean speed in the 50-70 mph range should probably not have a standard deviation greater than 10 percent. In the 10-30 mph range, perhaps a standard deviation of 20 percent should be strived for. In any case, large cell standard deviations should be examined and one of the following approaches considered for reducing these standard deviations:

- Further subdivision, perhaps on an additional characteristic (i.e., v/c ratio).
- Equations based on data within the cell relating the speed to factors such as posted speed, stops/mile etc.

A sample table of average running speeds by facility tape and location is contained in the FHWA "Urban Transportation General Information" manual (36). Table III-7 shows the speeds and standard deviations obtained for another classification which has been used.

TABLE III-7

Standard Deviations in Speeds

Route Type	Area Type	Mean Speed	% STD Deviation
Full Access Control	All	43	24
Multilane Streets	Rural, Res. Suburban	30	27
	Res. Intermediate	19	34
	Res. Urban, Comm., Industrial	15	56
	CBD Office Bldg.	9	60
Single Lane Streets	Rural, Res. Suburban	25	32
	Res. Intermediate	18	50
	Res. Urban Comm., CBD	16	49

In this study, regression analysis was accomplished for each subgroup. It was found that the standard deviation of the computed values for speed about its mean was less than the standard deviation of its observed values in each of the sub groups. For limited access facilities, the posted speed limit was used as the independent variable. The desirability of using the speed limit as a variable should be carefully considered. Many studies have found this variable to be important in developing speed relationships. However, speed limits are often changed as a result of studies of vehicle operation. For non-limited access facilities, the posted speed limit, signalized intersections per mile, and the link length were used as independent variables. These types of analyses may be accomplished for total daily flow speed or for separate determinations of peak hour and off peak speeds.

impedance selection examples

A few practitioners find the use of travel costs more appropriate than travel times for network impedances. This is generally true for study areas where there are many toll facilities to be considered. Link costs are generally based upon calculating operating and time costs by factors related to the speed of a link and perhaps control information (average stops per mile and speed change cycles). To this, the tolls are added at the appropriate links. Except where toll costs are of particular significance, the use of speeds (travel times) results in a more readily applied and easily understood assignment process.

The speeds used for traffic assignment purposes should not be spot speeds, but should be reflective of overall travel time between nodes in the transportation system. For signal controlled streets, the effect of stops and speed changes should be reflected in the overall travel time (or speed) measurement. Since most measurements in the field are obtained in terms of time, it is recommended that time be coded if measurements are directly used for coding since this is the value used for route building.

Experience would seem to indicate that for initial network impedances, actual measured speeds are the most used, although "level of service" speeds have provided good results in some cases. Sampling of links and analysis to apply these to the universe is done for economic considerations. In sampling speeds, it would appear that two factors should be considered in selecting the sample: (1) the number of links in each functional classification and geographic area reflected in the assignment network, and (2) the volume of traffic on the links. A stable sample is required for each classification used. Secondly, more accuracy is warranted for the high volume facilities. However, one must keep in mind that lower volume facility speeds also affect the assignment results of the higher volume facilities.

impedance sampling

For assignment networks coded to represent 24 hour travel time, some averaging of link times through the day is necessary. Most who consider this traditionally weight their peak runs 1/3 and off peak runs 2/3 to represent an average based upon the volumes in the peak and off peak periods. The number of runs made on each facility will normally vary by study. For example, a single run can be made in each peak period with two off peak runs or three peak and three non peak runs could be made.

Assuming travel times for all links in a system are obtained as described above, the question arises as to what values of zone-to-zone travel times to utilize for model (mode split, trip distribution, etc.) calibration. Should they be the originally coded times or those resulting from the traffic assignment calibration process? Adjustments are generally necessary in at least some of the original network impedances to obtain assignment loadings which replicate actual link volumes. As described in the next section, this calibration may be based on the use of manual adjustment to some links, or use of automatic processes, such as, volume (count) or capacity restraint. The purpose of this adjustment is to obtain loads representative of the existing traffic volumes.

impedances for other models

The models used for distributing trips, distributing land use, etc., utilize zone to zone travel times from the network which are calculated as the minimum time path through the network. The assumption can be made that the initial network coded speeds are most representative of link travel times since they are based upon actually measured speeds on the system and that link speed adjustments are accomplished to overcome rather large differences in link loads which are generally due to rather minor (say 1/10 of a minute) differences in routes between points. On the other hand, it may be argued that the network impedances providing the best assignment are most representative of zone to zone impedances. If sufficient care is taken in developing networks and zones which are in the proper balance, it is believed that either approach to link time use for model calibration is acceptable. This is based on the assumption that there is little difference in the trip length distribution obtained by assigning survey trips to an original coded impedance network or to a calibrated impedance network. A check of change in the trip length distribution between original network impedances and calibrated impedances should be made to satisfy the practitioner that the magnitude of zone to zone time change is not significant. Generally, if the same criteria are met in comparing trip length distributions between the initial and calibrated impedances as used for calibrating a trip model, either the initial or adjusted system speeds may be used and could be expected to give very close results. The criteria are: 1) the trip length curves should coincide as nearly as possible; 2) the average trip lengths should be within ± 3% of each other; and 3) person hours of travel (or vehicle hours) should be within ± 3%.

impedances for future networks

In looking at future networks, the choices in initial network impedances becomes wider. Listed below are speeds that have been used for calculating zonal times for application of trip distribution, land use distribution, modal split models, etc., in the future year.

- Free flow speeds or design speeds based upon level of service criteria.
- Speeds based upon the matrix (speed table) developed for the calibration (base year) network.
- The calibrated base year speeds either by individual link or speed (impedance) table resulting from the restraint or manual adjustment process.

The choice of speeds to use should be based upon the purpose of the future assignments. For example, if future travel desires are to be used for developing a future transportation system, then level of service or "policy" speeds should be used. This would result in a desired level of zone to zone travel times for model application. After a trip interchange matrix has been developed through application of these desired times, these trips are assigned to the network. Overloads and underloads throughout the system then are evaluated and decisions made concerning the addition of new facilities or acceptance of reduced speeds on over loaded facilities. This process may utilize the capacity restraint technique. Somewhere in the assignment process, perhaps when the system appears to be in balance (speed vs volume/capacity), the trip length distribution resulting from the developed trip matrix and the assignment should be compared with that developed from the initial application of the trip and land use models. If there is a large difference in the actual shapes of the two distributions or in the average trip lengths or in the person (or vehicle) hours of travel, consideration should be given to a feedback loop where the final network impedances are used through the models developed for land use and trips with a new set of assignments made. If instead of future travel desires, assignments are to be made to see how future trips would load on the existing base network as a start for deciding on alternate future highway locations, then the final impedances resulting from the base year calibration of the network would be utilized.

The use and application of speeds for network assignment purposes requires careful consideration. As will be described in the next section, calibration of a network may include adjustment to input speeds to provide assigned volumes which are consistent with actual conditions. The results of adjustment to the speeds may be a set of relative impedances which provide acceptable assignment results but which are no longer truly representative of speeds. Absolute values may have no real bearing on assignment results since relative differences in impedances can result in acceptable assignment volumes. Because travel time is used for other purposes, such as, input to distribution and other travel models, and for economic evaluations of alternative systems, it is extremely important that the use of speeds and/or adjusted speeds (impedances) be carefully considered.

ADJUSTMENT OF SYSTEM IMPEDANCES

assignment calibration

Once a zone-network compatibility is established and realistic impedances are developed for a base network, the ability to realistically portray existing volume conditions through the assignment process must be examined. In the following discussion, it is assumed that the zone-network adjustments described in the first section of this chapter have been made.

The assignment process, whether using a single route procedure or a multi-route process, must select routes between an origin and destination and either load all trips on the single best path or proportion these between alternate routes based upon some relative impedance comparison. Quite often, one route is selected as shorter than others based upon the minimum time value that may be coded on a link, i.e., 1/10 of a minute. Small time differences may result in routings that are unrealistic when viewed in relation to what people actually do.

Adjustment of system impedances is but one phase involved in the "calibration" of a traffic assignment model. The calibration consists of adjustments made such that the assignment model will reproduce actual system loads as accurately as possible. This process is based on the philosophy that if reasonable results can be obtained with a reproducible process on the current system, reasonable results can be obtained on future systems. The ability to reproduce such travel is related to three elements: 1) the trip data; 2) the network coded; and 3) the assignment procedure itself. Trip data checks are discussed in detail in the revised "Home Interview Manual" (37) of the Federal Highway Administration. Network considerations include: 1) the obtaining of system inventory data allowing the selection of a network which will fulfill the objectives of the work to be accomplished; 2) selection of those links to be in the assignment network based upon the objectives of the work; 3) establishing a zone-network compatibility; 4) coding as accurately as possible the geometrics and operational characteristics such as volumes, speeds, capacities, interchange geometry, street patterns, turn penalties, turn prohibitors, etc.

error from assignment procedure

The assignment procedure itself will have deficiencies which tend to cause inaccuracies when making comparisons with existing conditions. In most techniques trips are loaded to and from load points (zone centroids) which may cause difficulties at the surrounding links. These difficulties may be caused by not having the proper relationship between zone size and network detail. Reference should be made to page 73 of this chapter for suggestions relative to achieving zone-network compatibility. Most assignment procedures assign by some routing rule which does not necessarily reflect peoples actual travel choices. For example, picking the single best route and loading trips on these is not necessarily the way actual travel occurs. The system impedance is generally a single parameter (i.e., time, dist., etc.) or a combination parameter (i.e., cost or time and distance) which does not include all the considerations made in picking a travel route. These other considerations might include the number of signal controlled intersections, pedestrian interference, type of facility preferred, etc.

Some work (38) has been completed in the use of a combination function of time and distance which has been found to improve assignment results. This work considers a TD (time-distance) factor based upon the function:

combination functions

$$\text{TD factor} = TP + D(1.00 - P)$$

where T = time, min;
D = distance, miles; and
P = decimal fraction of weight assigned to time.

Between the values of $P = 0$ and $P = 1$, any value of P can be tried until one is found that will give the best results as determined by the root-mean-square error for the entire network. Once a value of P is determined, the same value is used for the entire network assignment. Another function tested is based on a combination of distance and speed raised to an exponential power, as follows:

$$\text{Exponential factor} = D(K/V)^n$$

where D = link distance;
V = speed, and
K = arbitrarily selected constant

compare assigned volumes with ground counts

To determine the ability of the assignment method to represent reality, checks should be made in the base year by comparing assignment results with ground counts. The differences in comparisons may be due to inaccuracies in the trips used for assignment, in the zone-network compatibility established, in the coding of geometrics and operational characteristics (i.e., travel time), or in the counts being used for comparative purposes.

Checking of assignment volumes with counts is usually done by:

1) Comparing VMT and VHT from the assignment with ground counts over the entire study area and in subdivisions of the study area (i.e. corridors, rings, zones, or districts) by functional class of

facility.

2) Comparing volume counts and assignments across synthetic screenlines. This may be done across long gridlines traversing the entire area done basically for trip data checking and across short cutlines for checking corridors, which generally checks the assignment technique. Refer to Figure III-7.
3) Compare volumes on specific links - generally of high volume.
4) Root-mean-square error comparisons by volume group (see Chapter 5 - Statistical Measures).

The reader is referred to the revised Home Interivew Manual for the application of the above technique to trip evaluation and to pages 73-83 of this chapter for discussion of zone-network balance checking. Assuming trips are acceptable and the zone-network balance achieved, there still may be differences between the assigned and counted volumes due to inaccuracies in the model as discussed above, inaccuracies in counted volumes, and inaccuracies in network impedances and other coding parameters. The assumption is generally made that counts are to be used as a base, accepting the fact that there are inaccuracies in them (39). Counts should be examined and a determination made as to a range of probable error in various volume groupings based upon the counting procedure used. This knowledge will aid in evaluating the assignment comparisons.

coding errors

The assignment model and its input parameters (geometry, impedances, etc.) can be checked in a variety of ways (screenlines, VMT in small areas, individual link comparisons). The usual method is to build a set of sample routings ("trees") and plot at least part of them for visual examination. This may indicate errors in coding as well as problems caused by impedance measures. Once coding errors are eliminated any remaining errors are assumed to be in the impedance measures.

impedance adjustment

In most cases, impedance measures must be adjusted after all other checks and adjustments are made. These adjustments are made manually or by automatic adjustment procedures such as capacity restraint or volume restraint based on ground counts. The choice for manual adjustment of link impedances is based upon the reasoning that after all other checks and changes are made, relatively few impedance changes must be made and that better control and understanding of what is occurring is achieved. The more automatic adjustment procedures tend to examine and perhaps change most, if not all, impedances. The use of manual adjustment appears to be done most frequently in the smaller urban areas. If the magnitude of changes appears such that an efficient manual adjustment process can be achieved, this is recommended over an automatic restraint process. In areas with population less than 100,000 - 200,000 this appears to be the most used procedure. The adjustments are made based upon a knowledge and "feel" of the network and its operation using sample tree plots and comparison of volume counts and assignments. Volume/capacity or volume/count ratios could be used to help determine the direction and magnitude of any required adjustment. In areas where capacity is not exceeded on most or all facilities, automatic capacity restraint procedures generally do not improve assignments and may result in unusable impedances.

Volume (count) restraint or capacity restraint automatic impedance adjustments are usually made when a large network must be adjusted and the ability to become very familiar with the character of a network and the effects of impedance changes become difficult. Some other advantages are that the process

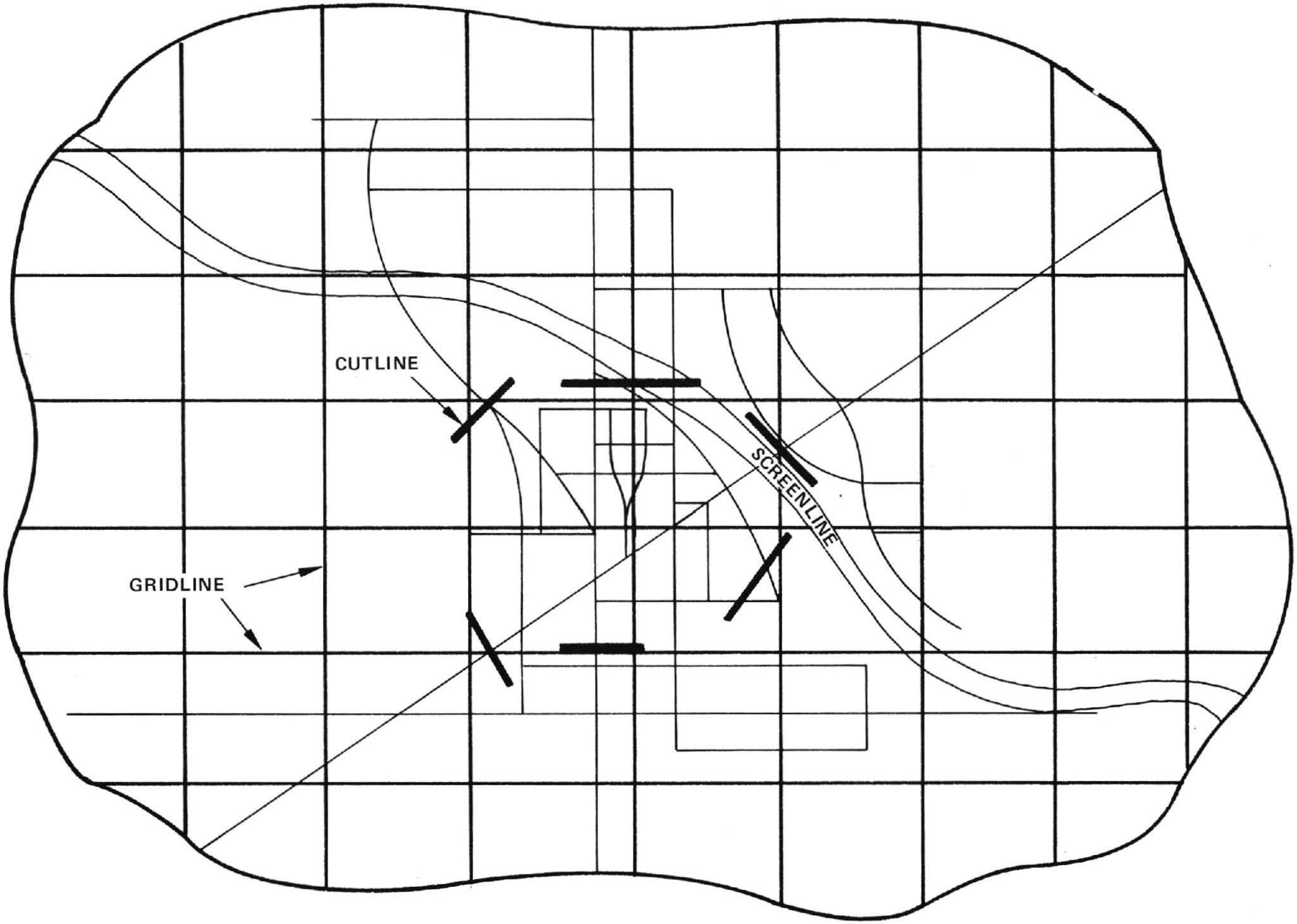


FIGURE III-7

ILLUSTRATION SHOWING GRIDLINES AND CUTLINES is reproducible and can be accomplished at a much faster rate than manual adjustment processes.

Checks should also be made for corridors and individual links. Within corridors, vehicle miles of travel (VMT) should be compared for assigned volumes versus ground counts, Based upon this comparison, speeds would be adjusted on facilities within the corridor (i.e., if under assigned, increase speeds in the corridor to make it attract additional travel). Individual links should be evaluated by comparing volumes assigned versus ground counts. Here adjustments may be made in speeds and/or turn penalties.

purpose of adjustment

The purpose of the network calibration where impedances are changed is of importance since the process affects other planning processes and may affect future year forecasts. In most cases, the application of restraint in the base year is to "prove" that the process can reproduce actual conditions satisfactorily which provides a basis for utilizing the procedure in the future. The resulting network impedances, however, may never be used for any purpose. In some cases, the finally calibrated network is used for input to calibrate other planning models, such as for trip distribution and modal split. In other cases, the uncalibrated input impedances are used. In applying the traffic assignment procedure to future conditions, the calibration process may never be repeated in a fashion similar to that used for calibration. For example, if a volume count restraint approach is used in network calibration there is no question that the assignment results will be improved. However, if the resultant impedances are not used for other planning model calibration or for the development of future network impedances, there appears to be no justification for count restraint application. If, however, capacity restraint is used in calibrating a network, and even if the results are not used for other model calibration or future impedance development, the application would be worthwhile. It would prove the process was operating correctly and, as always done in model calibration and testing, would substantiate that the process will work on future networks. The same comments apply to manual adjustments made to impedances for calibration purposes. If the results of the calibrated impedances are not used or the process is not usable on future networks, then the calibration has not been worthwhile.

use of speed table

The use of speed tables in calibration of a network and for the development of input impedances for future year networks will be used as an illustration of how calibrated speeds may be used for future system applications. As described in the previous section of this chapter, speed tables are generally produced by accomplishing sufficient field study to classify speeds by functional classification and location within an urbanized area. Within this classification, further relationships or sub-classification may be made, for example, by volume-capacity ranges. The table is used for coding system impedances for current year systems. If, during the calibration, updates of impedances are required, the speed table is updated each time and the updated values used for the subsequent assignment. The finally developed table can then be used as a starting point for future year system coding.

An extension of this approach would be to develop a "policy level" or desired level of speeds by functional classification and area location. In the development and testing of alternative systems, one objective might be the development of a system where a speed table built from the system matches, as closely as possible, the policy table.

summary

The purpose of this Chapter was to provide the reader some insight into the considerations and decisions that must be made in using traffic assignment techniques. The discussion is not exhaustive due to differences between assignment techniques that are available and the specific purposes of the assignments to be made. The areas of zone-network relationships, considerations for network coding and development, and adjustment of network impedances are, however, basic to the application of most assignment methods. Application of these methods to urban area, statewide and national study will be discussed in the next Chapter.

CHAPTER IV
APPLICATIONS

The traffic assignment methods described have been used for a wide diversity of applications. These include applications in urban areas as well as to statewide and national systems.

Traffic assignment techniques are important tools in the development and testing of alternative transportation systems. Priority planning procedures rely very heavily upon assignment results. More and more sub-area and corridor study and evaluation is being undertaken. Results are used in some fashion in the design of transportation facilities. The purpose of this chapter is to describe the application of traffic assignment techniques as accomplished in the field. Where possible, alternate approaches are described and recommendations are made when applicable.

APPLICATIONS TO URBAN TRANSPORTATION PLANNING

The application of computer techniques for traffic assignment has been accomplished mostly in urban areas as part of the urban transportation planning process. Only recently has use been expanded to statewide and nationwide study. Initial applications in urban areas (and probably still the reason for most traffic assignments) are for regional planning purposes. This includes the development and testing of alternate transportation systems. In recent years, more emphasis is being placed on the development of an implementation program or priority schedule. In addition, more detailed study is being made of small areas and corridors within a region to obtain more precise facility locations and to provide more specific volumes for design purposes.

traffic assignment applications

The developing, testing, evaluating, and selecting of alternative plans is often referred to as the "Systems Analysis" phase of the urban transportation planning process. The aim of this phase is to develop a transportation system plan for an urban area which best contributes to the overall goals and specific objectives of that area. To accomplish this, numerous alternative systems must be developed, tested, and evaluated.

Developing Future Systems

network evaluation tool

The traffic assignment process is most useful as a network evaluation tool in the testing and evaluation of alternative systems. Future systems can be developed using traffic assignment results as an input to the decision-making process used to establish alternate systems. However, there is no existing methodology for designing the "best" plan based upon any set of evaluation criteria. The planner must develop and test alternative systems to search for workable solutions. By developing and evaluating alternatives, the planner may investigate and analyze numerous possible outcomes and further refine them.

In addition to the development of target year alternatives, intermediate year transportation systems and priority planning are needed to establish short range expenditure programs.

development of future systems

Two general approaches have been utilized in practice to establish future systems. One considers analysis of deficiencies in the existing plus "committed" system in some short range period, the necessary facility improvements and additions to reach stated goals and objectives as well as system performance, and a further extension of this to another intermediate year or to the target year. The term committed has different meanings to different people. In some cases the committed system is one where right of way has been purchased or preliminary design has started. In other cases it may be lines on an official map developed through some previous process. The step by step process would be as follows:

incremental build up approach

- Evaluate the existing transportation system and determine additions and improvements required to reach some stated level of service and which helps attain the goals and objectives established.
- Assign a future year trip matrix, perhaps one-third of the way between the present and target year, to the system established in step 1. Evaluate that assignment and determine additions and improvements required for desired levels of service, goals, objectives, etc.
- Do the same for a period two-thirds of the way between the present and target year, evaluating the intermediate system developed above.
- Using the target year trip matrix, assign to the system established in step 3 and evaluate to develop alternate systems for the target year.

short-range subset approach

The alternate approach, and the one most used by operational transportation planning agencies, is to assign target year trips to the existing and "committed" transportation system. This assignment is used as the basis for establishing alternate target year networks for testing purposes. Intermediate year networks are developed as subsets of the system(s) developed for the target year with testing accomplished to establish the intermediate year plans. The steps in this approach would be as follows:

- Assign target year trips to the existing plus committed transportation system. The results would be evaluated considering established goals and objectives as well as performance desired.
- Alternative transportation systems would be established considering additions and improvements. These would be tested to arrive at a target year transportation plan.
- Within this plan, subsets would be evaluated in intermediate years (to establish a staging schedule) to develop alternative possibilities for transportation system development and intermediate year transportation plans would be established.

advantages-disadvantages

There are advantages and disadvantages in each of the approaches described. The latter approach does not interrelate short range objectives which may be in conflict with the long range objectives in the development of a desirable long range plan. Depending upon point of view, this may be an advantage or disadvantage. One school of thought believes development of a long range plan should not be influenced by shorter range needs. The long range goals and objectives are met by the target year plan without adjustments that might be interjected by shorter range planning. As described on pages 121-126 of this Chapter (Priority Planning) the shorter range intermediate year plans are developed as integral parts of the target year plan with each intermediate year plan including some portion of the long range plan facilities. However, the short range plans developed in this manner may not be implementable or may not be the short range implementation program that has already been established by an operating agency (i.e., highway department). This problem can be overcome through the continuing planning reappraisal process which aims to keep planning viable with changing conditions. Regardless of the approach taken for the development of alternative systems, the reappraisal process insures that target year as well as intermediate year plans are evaluated and adjusted as time passes and indications point to necessary changes.

short-range vs. long-range plans

A problem that should be considered for intermediate year plans is - should the system be located and designed considering that the target year plan will be fully implemented or should it be designed considering that the entire plan may never be fully implemented. The difference in location and design for an intermediate year system may vary considerably whether traffic demand estimated for that year is used and whether the target year system or only the intermediate system is included for testing and evaluation. Consideration must also be given to the fact that interrelationships between land use and system in intermediate years may invalidate future land use plans and future system needs. This only strengthens the need for continued plan reappraisal as mentioned above.

The approach of building up to the target year has the advantage of considering short range needs as the more critical and developing each incremental year plan based upon specific period requirements. The current year is evaluated and serves as a bench mark against which improvement to future periods can be evaluated. This approach may aid in integrating the planning process with the decision making process at an earlier stage.

planning-programming interrelated

Operating agencies must usually develop short range capital expenditure programs (i.e., 2-8 years). Much too often these programs are divorced from planning study findings since target year only plans are developed. In addition, in some instances intermediate year plans cannot be programmed due to funding limitations. It is most important that the planning-programming process be interrelated. Programs should be based upon building portions of desired plans. Likewise, the planning process should be sensitive to the requirements for short range program development.

recommended assignments

Regardless of the approach taken, it is recommended that, as a minimum, the two traffic assignments that should always be undertaken are:

- Current trips to the existing (current) system
- Future trips to the existing plus committed system

There are at least three advantages to assigning current trips to the current system. These are: *

current trips to current system

- Appraising the Performance of the Existing System. Performing an evaluation of base year conditions represents an excellent method for determining and reporting upon the existing performance characteristics of the regional transportation system. Measures

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* Much of the discussion on the following several pages have been taken from references 55 and 56.

current trips to current system

such as accessibility, speed, volume to capacity ratios, and so on can be used to isolate current deficiencies, which can provide the factual basis needed for an immediate action program. Such a program may be advocated by a transportation study well in advance of developing or updating the long range regional land use/transportation plan. Thus, a useful service is provided, and the credibility of the entire planning process may be improved.

- Testing Evaluation Procedures. The process of developing, testing, and evaluating a land use/transportation plan may consume many months, if not years. The process can be streamlined to a certain extent by developing evaluation criteria and an evaluation technique in advance of their application to future systems, and testing the utility of these criteria and procedures by applying them to base year conditions. This enables the fine tuning of the evaluation system and builds experience with and confidence in the procedures on the part of both the technical staff and the policy groups.
- Providing a Key Benchmark Against Which Future Alternatives May Be Compared. A major problem with much of the planning information provided through evaluation of future alternatives lies in the difficulty in placing all this data within a comprehensible context. For example, a range in system speeds among future alternatives from 25 to 30 miles per hour may have little meaning unless current average speeds are known for the sake of comparison. Similarly, an annual consumption of 150 acres of land for transportation purposes under a proposed alternative becomes a much more meaningful number if it is known what the average annual rate for the past few years has been. Thus, by comparing future alternatives, not only to each other, but to current conditions, a valuable frame of reference is provided facilitating more intelligent judgment.

future trips to current system

Traffic assignment of future travel to the existing plus committed system provides an indication of the do-nothing alternative. Too often planners fail to clearly indicate to policy officials and to the public the consequences of completely halting the program of transportation improvements within an urban region. While such an action may appear unthinkable, recent experience with controversial transportation projects within urbanized areas has shown that the burden of demonstrating the need for a sustained program of capital improvements rests squarely with those government agencies and officials who have such responsibilities. Unless we can demonstrate the consequences of doing nothing, it will become increasingly difficult to do anything. However, it is important to consider that such an assignment of future trips to the existing plus committed system can be misleading as well as helpful, since the future trip table is based on a projected land use pattern which probably would not develop if the transportation facilities were not built to provide the appropriate level of access.

committed system

This assignment should be handled carefully. Committed systems may be committed to various degrees. For example, a line on a map where no other action has been taken, such as location, design, and possibly right-of-way purchase, should not be considered as committed since the planning process may find other facilities better suited to meet the goals and objectives established. Plan development should not be constrained by facilities established by some ad-hoc process that located facilities which really do not fit an overall transportation plan.

plan development

While the evaluation of current conditions and the do-nothing alternative are to be strongly advised, the principal focus of the evaluation process should be the discrete number of land use/transportation alternatives which emanate from the plan development and testing phases. These alternative plans should become the object of an intensive series of probing analyses which are designed to evaluate the worthiness of each and result in the selection and adoption of the most desirable plan.

It is important to consider as broad and as imaginative an approach as possible when developing alternative solutions to transportation problems. A first step is the identification of community values and goals. The second step is coordinated land use and transportation planning. Actual plan development and the generation of alternatives result from sketch planning, which is the drawing of possible alternative networks. Another technique involves the concept of composite network (see below). These networks are then tested using the various analytical planning tools.

A prerequisite for the development of a comprehensive transportation plan is a thorough knowledge of the land use patterns which the transportation network will serve. The land use plan is usually developed as an integral part of the transportation planning process but may come from other sources. Regardless of the source, implementation of the transportation and land use plan must be done jointly since one plan will have a direct effect on the outcome of the other.

There are many different patterns of growth which may evolve in a number of urban areas. The future transportation system should be designed to implement as well as serve the land use plan that has been determined to be the most desirable for the urban region. There are numerous types and varieties of land use plans or patterns of urban growth. Every city represents a unique variation of one kind or another.

sketch planning

Sketch planning is a popular and widely practiced technique used to develop alternative plans. The method, which is more an art than a science, relies heavily on the skill, understanding, and wisdom of the people involved. A team of experts develops alternative plans using information on desirable standards, and receives guidance through the actions and policy statements of the local elected officials. A sense of community values, needs, likes, and dislikes are also important. The designers should also try to emphasize different types of networks. Consideration should be given to freeways, arterials, traffic engineering projects, and transit to serve the travel demand. One set of alternatives should emphasize a freeway solution, another arterials, and a third, transit. The fourth set of alternatives should look at combinations of the other three. The desirability as well as the feasibility of major vs. minor construction should be considered.

A more analytical approach to sketch planning has been developed by Koppelman (40) for the Tri-State Transportation Commission and expanded for application nationwide by the FHWA (41). In this approach, various mixes of facilities transportation needs evaluation

are postulated on an urbanized area basis (may have subareas such as CBD, rest of central city, inner suburbs, remainder). These would consider ranges of transit use as well as mix in freeways versus other arterials, etc. For each mix, user as well as non-user benefits and costs may be derived and evaluation of differences performed. The results of this process would be a starting point for the development of alternative networks for more exhaustive testing by traffic assignment methods. The process is also useful in examining impacts, resulting from mixes in facility types, such as air pollution. The Washington Metropolitan Area Council of Governments has utilized such an approach for sketch planning and development of pollutant emissions (42).

approaches to systems evaluation

The following is an example of an approach taken by several agencies. An assignment of target year travel is made to the existing plus committed system. The system is evaluated by comparing volume to capacity on the system links as well as evaluating system speeds. System criteria established might be that overall system speed (total travel distance on the network divided by total travel time) should be greater than XX miles per hour and that the volume to capacity ratio should be better than that expressed by level of service C as defined by the "Highway Capacity Manual - 1965" (16) on at least XX% of the system. The first changes to the system are traffic engineering improvements aimed at increasing capacities and speeds. After these are made, the traffic engineering improvements are broadened to include some reconstruction and extensions of system. An assignment might now be made to allow evaluation of the improved system using the v/c and speed criteria. If the goals established were now not met, new facility additions would be made in developing alternate systems for testing.

Another approach which has been utilized is to develop a number of conceptual plans where each concept is a different mix of facility types and/or types of improvements (i.e., freeways, arterials, traffic engineering improvements). These concepts are developed based upon an evaluation of target year trips assigned to the existing plus committed system. The concepts are tested and evaluated and one concept selected for further evaluation. A number of alternative plans are developed and tested within the constraints of the concept selected. Three concept types might be: 1) Freeways - high traffic service; 2) Surface street improvements and additions - limited new freeways; 3) Intermediate traffic additions and new freeways.

An interesting method used for evaluating capacity deficiencies in both existing and future networks is the assignment of O-D desires to a system of gridlines (43). An accumulation of desires across each gridline segment is compared with an accumulation of capacity across each gridline segment. Figure IV-1 illustrates a set of gridlines and desire lines and the summarization accomplished. Figure IV-2 shows a comparison of accumulated desires and capacities on the basis of lane deficiencies and surplus at each gridline or "analysis line". This result would be evaluated to determine the corridors where additional capacity might be required.

composit network analysis

An approach which has considerable merit in the development of alternate systems is referred to as "Composite Network Analysis". This entails gathering plans for future systems from the jurisdictions in a planning area and testing alternatives which are primarily combinations of these proposals. The most important plus of this analysis is that all jurisdictions are involved and can contribute

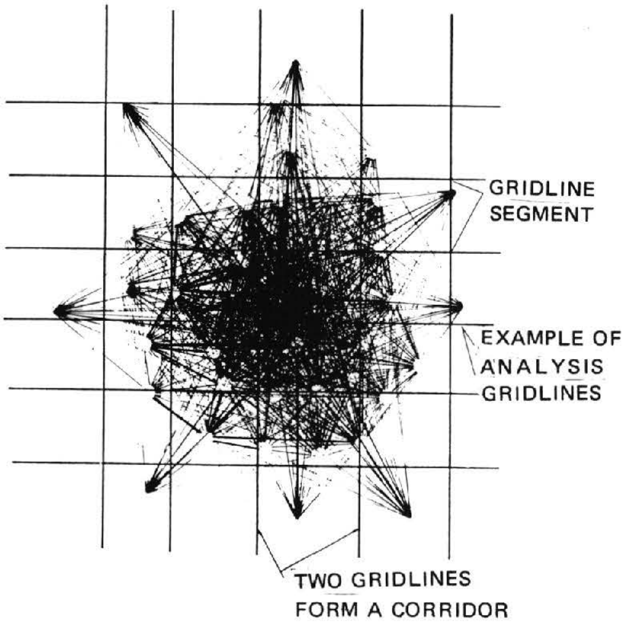


FIGURE IV-1 (A)

GRIDLINES SUPERIMPOSED ON TRAVEL DESIRES "(43)

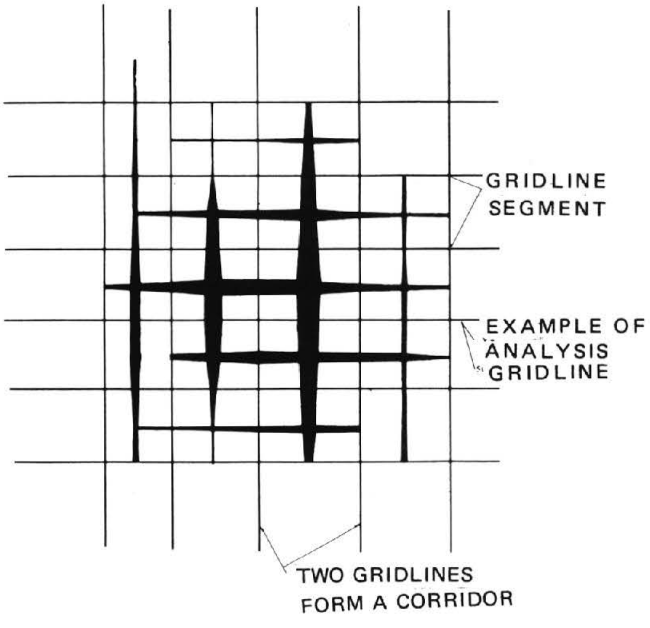


FIGURE IV-1 (B)

TRAVEL DESIRES SUMMARIZED AT EACH SEGMENT TO FORM CORRIDOR RESIRES (43)

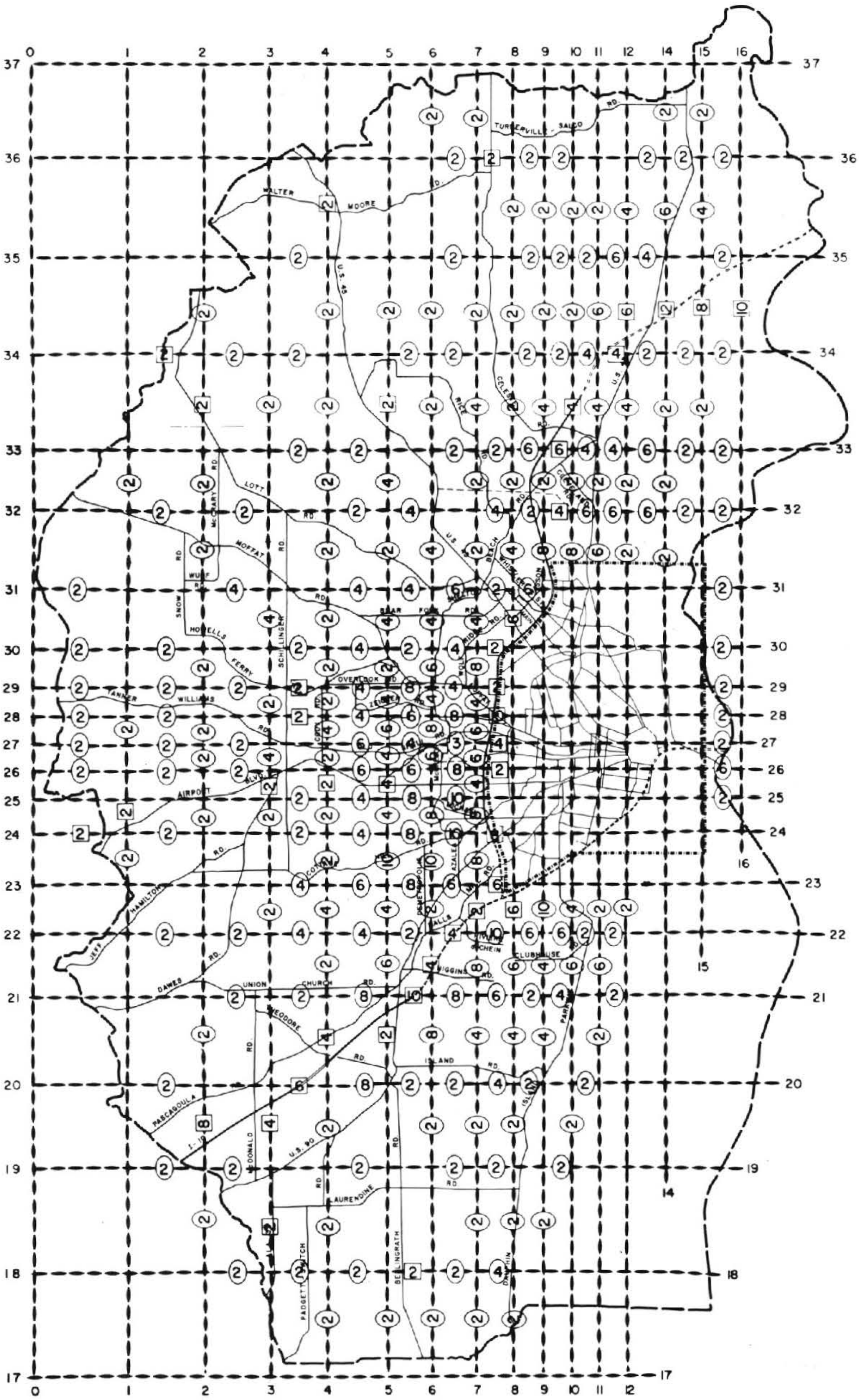


FIGURE IV-2

LANE CAPACITY DEFFICIENCIES OR SURPLUS
AT EACH GRIDLINE SEGMENT (43)

ideas as to system to be tested. This may result in support of the idea through the planning process resulting in inclusion of the idea in the plan. Modifications to the idea or exclusion of the idea from the plan based upon evaluation through the regional planning process may also result. The basic steps in the process are:

composit network analysis

- Gather plans from jurisdictions and agencies. All the local jurisdictions, agencies, and institutions, such as, county and city governments, the State highway department, department of parks, etc., are contacted and asked to elaborate on any proposed new or improved transportation facilities they would like to see constructed within the next 20-25 years.
- Superimpose these over an existing plus committed plan in the assignment network.
- Have the regional planning staff speculate on other system possibilities that they would like to test and which were not previously included.
- Define links and "planning links". Planning links are logical combinations of regular links along a route.
- Code the existing plus committed plus composite links.
- Call for alternative combinations via the computer for testing and evaluation.

A computer program "Composite Network" has been written to develop these alternative networks from the composite. The program appears to be very efficient and makes it easier and quicker to prepare alternative networks for testing. It also reduces the chance of network errors. Another important aspect of this approach is that all affected jurisdictions are able to participate. Each has their "say", their plans are tested and supported by factual data, and are either incorporated wholly, modified, or excluded from the feasible alternatives which enter the evaluation phase.

tools for systems analysis

In addition to the various approaches to plan development described above, many tools and analyses have been developed to aid in plan analysis and development. Some of these are:

- Selected link analyses - a segment of network is evaluated in relation to the origins and destination of the trips using that segment. These trips may then be displayed and the true beginning and ending of each (by zone or group of zones) shown. This may well bring out ideas for improvement apparently unrelated to the congested route, but well suited to the true travel desires of trips using the route.
- Spiderweb network assignment - a spiderweb network is a purely hypothetical connection of equal speed links connecting zone centroids to form a rather dense net over the region. Trips assigned to such a network give a better display of desires than those assigned to the existing and committed system, since the spiderweb network is not constrained by where routes are located or the time it takes to traverse them. Thus, while such an analysis does not show the true origin and destination of trips, it is a good representation of accumulated desires for travel.
- Display of selected trip interchanges - it is possible simply to display all trips between selected areas. For example, one may want to examine the origins of all trips ending in the "downtown" area (helpful in developing transit improvements). Or, one could

determine how many trips go from the central business district to the airport, or what trips pass through downtown but are not really going to or from there (bypass possibilities). In its various forms, this tool is quite useful in system development.

- Assignments by purpose or trip length - it is sometimes useful to examine the purpose (work? shop? recreation? etc.) and the length of trips. An assignment of only work trips, for example, would be helpful in developing transit improvements. An assignment of only trips longer than X miles could be helpful in determining whether an improvement should be a freeway (for longer trips) or a series of arterial upgradings (for shorter trips).

The development of future systems described above is an integral part of plan development, testing, and evaluation. Testing and evaluation include economic and goal oriented measures and for this reason have been separated from plan development in the next section.

Testing and Evaluating Alternative Systems

testing alternative systems

Testing and evaluating alternative systems is an integral part of the plan development - testing cycle. The process consists of the development of alternatives, testing and evaluating the alternatives, and developing additional alternatives based upon the testing and/or evaluation. The steps in a single cycle that might be used through alternative development, running the models, and testing may be summarized as follows:

Step 1. Make a crude forecast of travel (either future year - target or intermediate depending upon network development procedure used) and assign to the existing plus committed system.
Step 2. Identify overloaded corridors and facilities.
Step 3. Develop a system to serve this excess demand guided by the goals and objectives which have been adopted.
Step 4. Develop an immediate action plan.
Step 5. Using the heavy auto travel corridors as a guide and analyzing the existing transit service in each corridor, develop a transit system to operate in conjunction with the highway system.
Step 6. Using the system developed, distribute the urban activities.
Step 7. Generate and distribute person trips.
Step 8. Split the mode of travel.
Step 9. Convert persons in autos to vehicle trips and assign to the highway network.
Step 10. Assign trips to the transit network.
Step 11. Test the systems and adjust to insure proper operation.
Step 12. Recycle 1-11 above.

To begin the testing phase, all the forecasting models (i.e., trip generation, modal split, land use, etc.) which were prepared are "run" (executed), usually using the "existing plus committed" system or perhaps just the existing system as a first trial network. The zonal land use distribution (land use model or procedure) is estimated and the trip ends by zone (trip generation model) are estimated from the land use inputs. Inputs to the trip distribution model are the trip ends by zone and the impedance from this first trial network. In practice, the modal breakdown of these trips may be determined (modal split model) or may be ignored for this first trial, depending on how "significant" the transit portion of travel is thought to be in the area. This results in an estimate of travel demand (by mode or total) for this particular trial system, the "existing plus committed" - or just existing system. A "free" assignment of these trips to the network ends the usual conduct of the model run portion of the testing phase.

The next portion of the testing phase entails the determination of whether this trial system is at least acceptable in light of the evaluation criteria and constraints. In practice, it is usually only necessary to apply the most fundamental of the travel service type evaluation criteria to this existing plus committed system to identify deficiencies. This is usually the "minimize congestion" objective, with its measure, (volume over capacity), and its constraint (some level of service). Other goals and objectives and trade offs between these should also be considered, where required. Some useful displays have been developed by various studies to help identify capacity deficiencies. Examples are:

- Simple displays of volume to capacity on links.
- Displays of volume to capacity in grid corridors.
- Displays of volume to capacity in radial corridors.
- Other selected corridor displays.

The above displays may be actual values or values converted to a color range for display, converted to band widths, or a combination of color and band width. Assuming (as is usually the case) that this measure shows deficiencies, then it is not necessary to examine all the other evaluation criteria for this trial. However, examination of the other evaluation criteria may be desirable to provide insight into values developed prior to going back to the development phase for the formulation of a new trial system.

evaluating alternative systems

This process continues with the development and testing of more and more refined alternates. Alternates which appear unacceptable are weeded out as the number of alternates expand. The development and testing ends with a manageable number of alternatives. These alternatives are then treated in the evaluation phase. The evaluation phase usually includes detailed evaluation of the alternatives using the goals and objectives established as well as an economic evaluation of the systems passing the development-testing phase.

The evaluation of alternative transportation plans is a process which attempts to measure the ability of plans to achieve stated transportation goals and objectives. It, therefore, is necessary to delineate transportation goals and objectives within the framework of more general development objectives before the evaluation process begins. Actually, goals and objectives should be developed early in the planning process and used in plan formulation as well as in evaluation.

The goals of a region should be those of the people and not of the planning staff. It is, therefore, desirable to involve the largest possible number of people in their formulation. Policy committees, technical committees, and broadly based citizen committees representative of the community have been used successfully in this area. Some studies have taken surveys, sponsored discussion groups, or held public hearings to assist in developing community goals and objectives. It is important that these goals and objectives be formally adopted by the policy making bodies of the region.

evaluation criteria

Evaluation criteria represent the standards by which alternative plans are judged in terms of their ability to satisfy adopted goals and objectives. As such, they are the basic yard sticks for measuring those attributes of each alternative which have been identified as having a strong bearing on the ultimate selection of a plan. As stated earlier, it is the responsibility of the professional staff to indicate possible criteria in each goal area, to develop the necessary information in an objective and reliable way, and to furnish this information to policy groups in a comprehensible manner. The final selection of evaluation criteria, however, should be made by the policy group after it is fully briefed as to what possibilities exist.

There are three basic types of evaluation criteria: costable, quantifiable, and qualitative. They may be defined as follows:

- Costable Criteria - Those criteria which can be measured in terms of dollar costs and benefits.
- Quantifiable Criteria - Those criteria which may be measured directly in terms of numerical quantities.
- Qualitative Criteria - Those criteria which may be described directly only according to subjective means (but may ultimately be quantified somewhat through ranking and scaling techniques).

Table IV-1 shows several examples of each type of evaluation criteria as they reflect system, user, and external attributes of each plan alternative.

Many of the evaluation criteria shown in Table IV-1 are either output from the assignment process or are input to the traffic assignment process. For example, private vehicle operation costs are dependent upon the volumes assigned to each classification of facility. Traveltime costs are developed from the total vehicle hours spent on the system. Accident costs are derivative of vehicle miles of travel by class of facility. Miles of system by class and location may be summarized by most assignment program systems as well as transit seat miles. Air pollutant emission estimates result from application of emittant rates to volumes, speeds and vehicle mix. Average freeway spacing and transit vehicle headways are input to the assignment systems. Accessibility measures are derivatives of minimum route calculations, vehicle miles of travel, trip length, and effective speed. All of these are direct results of the assignment process.

Much of the evaluation accomplished in the past considered economic characteristics and paid little attention to non-costable criteria. New techniques have evolved over the last several years which incorporate non-costable criteria.

economic evaluation

Before discussing these newer techniques, a summary of economic evaluation will be provided since it is here that direct traffic assignment input and output are used. Much of the information has been summarized from notes prepared as part of an FHWA Urban Transportation Planning short course.

The economic evaluation usually consists of the following steps:

1) - Identification of testable criteria. These usually include: direct costs (R.O.W., construction, maintenance); user costs (accidents, time costs, operating costs); non user costs (loss or gain of taxable lands, changes in economic activity, etc.).

TABLE IV-1

EXAMPLES OF EVALUATION CRITERIA (56)

Type of Attribute	Costable	Quantifiable	Qualitative
System	• Construction • Right-of-Way • Transit Vehicles • Maintenance • Transit Operations	• Miles of System by Class and Location • Transit Seat Miles • Average Freeway Spacing • Transit Vehicle Headways	Aesthetics
User	• Private Vehicle • Operation • Accident Costs • Traveltime Costs (Through Value of Time) • Fares	• Accessibility Measures • Vehicle-Miles of Travel • Percent Transit Use • Trip Length • Effective Speed	• Comfort • Convenience • Visual Aspects from the Road
External	• Change in Property Values • Tax Base • Extra Relocation Payments • Construction of Replacement Housing	• Air Pollution • Number of Dislocations • Land Consumption • Noise	• Neighborhood Disruption • Psychological Attitudes

2) - Estimation of costs over time for each alternative -

- Direct Costs - These are usually calculated for additions to the existing and committed system that are necessary to complete each alternative.
- User Costs - After an assignment to some alternate, speeds are adjusted to be compatible with the volume/capacity ratio on each link. With a knowledge of the volume, length, facility type and speed, costs per vehicle mile for accidents, travel time, and vehicle operation can be calculated based upon tables summarizing such costs. Computer programs are available for taking assigned loads and calculating user costs based upon supplied cost value functions (15). Excellent information on user costs can be obtained from the book Economic Analysis for Highways by Robley Winfrey (44). Travel time costs are based upon network time between zones and some measure of cost/hour or cost/mile for time expended in travel. Often, the time measure is varied by trip purpose.
- Non user Costs - These are usually not included in economic evaluation since it is very difficult to arrive at actual cost figures to use. These are discussed later.

3) - Reduce costs to a common time base - selection of an interest rate is the prime determination. The three primary considerations in this selection are: What the tax payer could realize from other investment; what government could realize from other investment; relative risks between types of investment. The common time base to which costs are reduced is usually either the equivalent uniform annual cost (EUAC) or the present worth (P.W.).

4) - Compare the Alternatives. There are four commonly used methods of making such a comparison. If correctly carried out and interpreted, all will yield the same "best" plan on a costable criteria basis. These are:

- Equivalent Uniform Annual Cost Method - - In this method, the total EUAC (ROW + construction + maintenance + road user) is computed for each alternative, and the alternative having the lowest total EUAC is selected.
- Present Worth of Costs Method - - In this method, the total PW (ROW + construction + maintenance + road user) is computed for each alternative, and the alternative having the lowest total PW is selected.
- Benefit/Cost Ratio Method - - Benefits and costs are always in terms of one alternative compared to one other alternative. Benefits are the road user + maintenance EUAC of one alternative minus the road user + maintenance EUAC of the other alternative. Costs are the ROW + construction EUAC of one alternative minus the ROW + construction EUAC of the other alternative. The ratio of benefits to costs defines the incremental benefit cost ratio of one alternative over the others. The method of selecting the "best" plan is to begin with the existing plus committed system and, proceeding stepwise to higher cost (EUAC of ROW + construction) alternatives, calculate the incremental benefit cost ratio for each consecutive pair of alternatives. Alternatives not having at least an acceptable B/C ratio (usually = 1.0) are deleted (unless non-costable criteria indicate otherwise) as this stepwise process is conducted. The last plan encountered and not deleted in this stepwise procedure is considered economically the "best".

- Rate of Return Method - - This method proceeds incrementally as with the B/C method, except that one solves for the interest rate which makes the benefits equal the costs for each consecutive pair. The "best" plan selection procedure is similar to that for the B/C method, except that 1.0 is not used as the cutoff of acceptability, but the acceptable interest rate (say 10 percent) is used. This method is a good tool in aiding decisions, but the computations become quite difficult cash flow problems.

evaluation procedures

In addition to the type of costable economic evaluation undertaken as described above, there are others which may prove valuable in evaluating alternate systems. Much of the information has been summarized from notes prepared as part of an FHWA Urban Transportation Planning Short Course.(55,56)

- Plan Information Matrix - this method involves listing of all previously established evaluation criteria (costable, quantifiable, qualitative) and the tabulation of all raw unadjusted data associated with each plan for each criterion. There are no weights, rates, ranks, or scores applied to these. This facilitates the process of tradeoffs and compromise in terms understandable by everyone.
- Value Profile Method - This consists of the drawing of profiles for various plans showing their relationship to evaluation criteria in a graphical form. In applying the process, each criteria is represented by one element corresponding to satisfactory fulfillment of the goal and a reciprocal value representing an undesirable situation. By plotting more than one profile on the same figure (each representing a plan), a graphical presentation of alternatives may be made which appears to have particular merit in presentations to laymen.
- Rank-Based Expected Value Method - In this method, plans are ranked in accordance to their ability to satisfy standards within a given objective. The objectives are ranked in order of importance. In both cases, the most desirable situation is assigned the highest rank number. The probability of implementing a plan is brought into the analysis through an adjustment of the plan score by the probability of implementation.
- The Value Matrix - This method is an extension of the rank-based expected value method in which the goals, objectives, and evaluation criteria are weighted to reflect their relative degree of importance.

Once plans have been tested and evaluated, a plan is proposed for adoption. Using this plan for future work includes priority planning, detailed studies in small areas and corridors, as well as, development of design volumes.

continuing evaluation

The plan development, testing and evaluation, as well as, the more detailed study should not be considered a static process which once done is completed. There should be a continuing reappraisal of work accomplished. The continuing plan evaluation process may be shown by the flow in Figure IV-3.

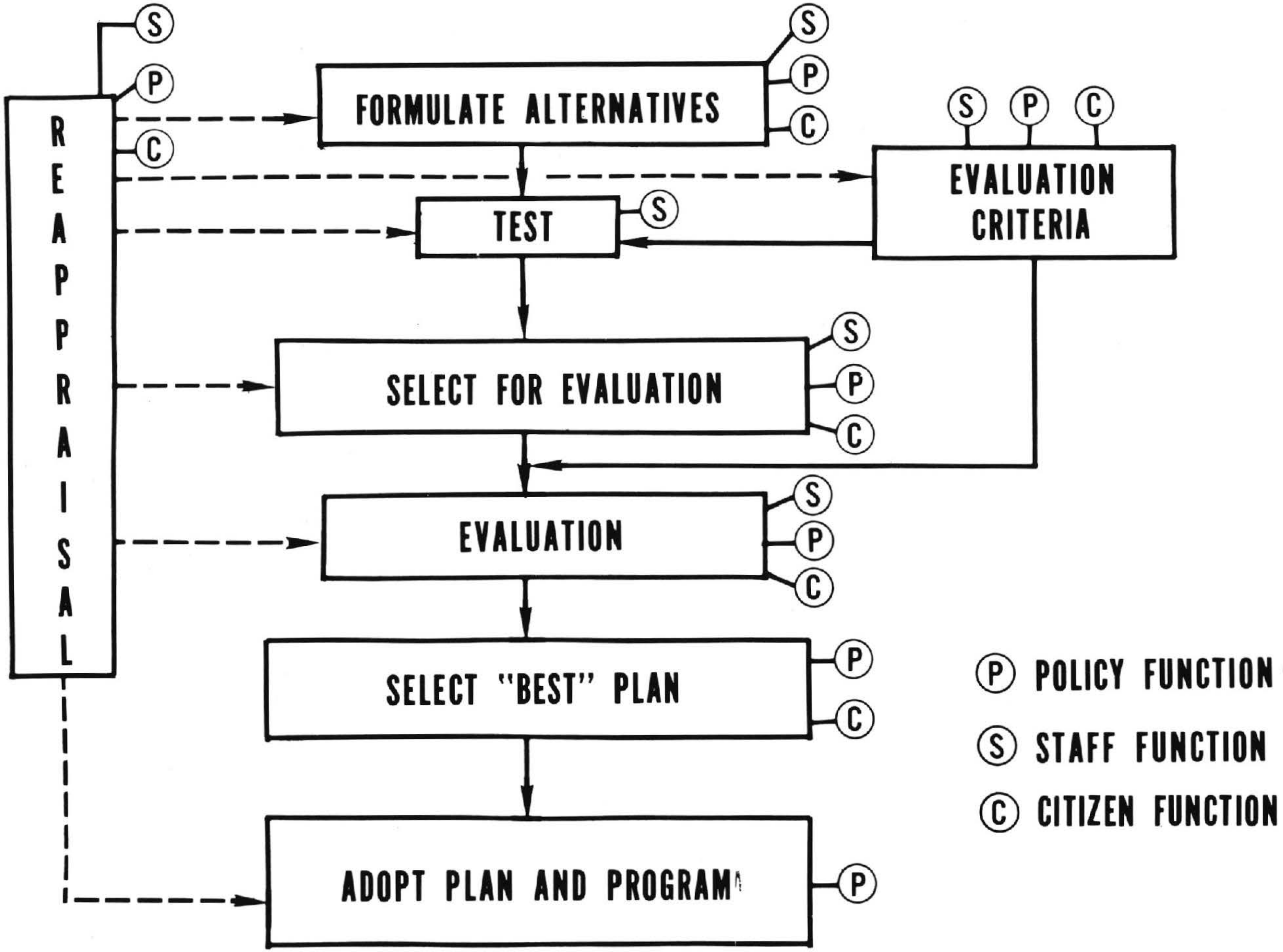


FIGURE IV-3

CONTINUING PLAN EVALUATION PROCESS (56)

Priority Planning

priority planning analysis

The Urban Transportation Planning Process represents a systems approach to the problem of developing and implementing balanced transportation systems capable of handling travel demand. The steps in the process, briefly stated, are as follows (see Figure I-1):

step 1 - Collect planning data
step 2 - Develop and calibrate planning models
step 3 - Forecast travel demand
step 4 - Develop alternate transportation networks
step 5 - Evaluate alternate transportation networks
step 6 - Recommend network for implementation
step 7 - Develop implementation program
step 8 - Implement recommended facilities
step 9 - Continuing elements

A great deal of work has been accomplished and computerized procedures established to assist the transportation planner in accomplishing steps 1-6 above. In reference to step 7 - Develop Implementation Program - the absence of a generally used procedure (in particular a computerized procedure) is noted.

This section discusses the problem of developing an implementation program or priority schedule. It attempts to point out the complexity of the problem and discusses some approaches. The methods discussed have been successfully applied and have been computerized.

The development of an implementation program follows the adoption of a recommended transportation system. The program is developed as a result of a Priority Planning Analysis. The objective of this analysis is to develop a priority program such that the facilities that come closest to maximizing benefits are implemented first. This analysis is necessary since all proposed facilities cannot be implemented simultaneously.

The obvious question at this point is - what are the factors that should be included in the Priority Planning Analysis? Transportation system user cost is a pertinent factor; safety is obviously another. Among the somewhat more intangible factors are disruption to the community, system continuity, and service to the disadvantaged. Other criteria that may be considered include:

- Usefulness in correcting existing problems
- Service Provided
- Enhancement of functional systems
- Integration of improvement into existing system
- Effect on land use development
- Consistancy of annual expenditures
- Coordination with other urban programs
- Degree of importance of right of way acquisition

When considering short range priority improvement programs the following criteria might be considered:

- Total Annual User Costs
    - Traveltime costs
    - Vehicle operating costs
    - Accident costs

- Number of accidents
- Dwellings taken
- Business disrupted
- Vehicle-miles of travel
- Vehicle-hours of travel
- Route cost
- Potential increase in route cost
- Rate of traffic growth

An expanded list of priority planning factors does create a problem for the transportation planner in determining the combined effect of all pertinent factors on the priority rating of an individual facility. For example, the transportation planner, given five proposed facilities, could quantify and rank the link that maximizes the reduction in travel cost or some other pertinent factor by including each link, one at a time, in a traffic assignment analysis and quantifying the individual results. It can be seen that as the number of facilities increases, the cost of this type of assignment approach would be prohibitive. Furthermore, it does not allow for the combined effect on the priority rating of more than one factor; e.g., travel cost and safety. In addition, it would not consider the effect of varying importance of the individual factors. For example, safety may be considered as say four times more important than travel cost in the priority rating.

The scope of the problem is great and there is need for an automated, reproducible method of developing priority ratings considering more than one factor and factors of varying importance.

<u>approach to developing a priority program</u>

One approach which has been applied to developing a priority implementation program is to develop a computer program capable of evaluating hundreds of links each containing priority ratings for up to 20 pertinent factors simultaneously (45). The approach is generally as follows:

- A set of factors considered pertinent is selected. Some of these factors represent typical planning process output; e.g., volume, capacity, user cost, etc. Others represent typical sufficiency type data; e.g., life of structure, life of pavement, etc. Still others are included to account for factors such as safety and service. In practice, these factors should be developed to be consistent with and representative of the objectives of the study.
- Each link in the transportation system is then quantified in terms of the selected factors. The quantification is expressed in terms of ratings, for example:

Link	Factor	Scale Used	Rating Assigned
A_1-B_1	Life of Structure	0-30	10
	Life of Pavement	0-20	15
	Time	0-10	1
	Safety	0-100	53
	(Etc.)		
A_2-B_2	(Similarly)		

For example, the life of a structure may be set at 30 years. The rating would be based on the actual age, in the above case 10 years.

- The priority planning data are then input to a computer program that has the capability of converting all ratings to a common base (different scales were employed for user-ease of operation), processing all links and generating a table of priority ratings; e.g.,

Rank	Link	Priority Rating
1	$A_1 - B_1$	3.92
2	$A_2 - B_2$	3.86
n	$A_n - B_n$	3.01

- Other runs are made to account for varying importance of individual factors. For example, safety could receive a weighting value of 4.00 while other factors were held to 1.00. Output similar to that shown above is generated except that the priority rating now represents a weighted value. This program capability also allows for sensivity type analyses; e.g., what impact does doubling the effect of community disruption have on the implementation sequence? Community disruption might be measured in terms of number of families and business establishments moved due to a new project. In practice, the weighting factors should be developed to be consistent with and representative of the goals of the study.

The technique described above is but one that has been employed. It was used as an example because it has proven satisfactory, is computerized, and accounts for such things as weighting and semi-quantifiable factors.

priority planning schedule

Once a plan has been selected, a priority planning schedule using a scheme similar to that described above should be established to allow phasing of construction. Assuming a 20 year plan, it would be desirable to determine those facilities to be constructed over shorter time periods, perhaps considering 5-7 year increments. This can be based on short range forecasts. "The Developing Future Systems" section of this Chapter describes some methods of developing long range plans and short range subsets within the long range plan. Obviously the dollar availability for implementing portions of the plan must be established for each increment. If facilities are listed in order of priority, along with their implementation costs, the facilities that can be built with available funding can be established. There are two general approaches which might be considered in applying a priority planning procedure.

(1) Considering the target year (i.e., 20 year plan), array facilities in order of priority established and determine facilities to be built in each period depending upon funding availability. This procedure assumes the plan will actually be completely built. However, the process is not straightforward. The priority developed is based upon the entire plan being in place. If for example, a plan consisted of 25 projects, the first 5 in the priority order might not be the most desirable to implement first if the projects 6-25 are

priority of program modules

not in place. The priority schedule is dependent upon a total system. An approach to overcome this difficulty might be as follows. Assuming a target year plan, projects are grouped considering factors such as continuity of route, serving of special objectives and goals, the results of the priority ranking system, funding available, etc., into some smaller group of program modules (i.e., less than 5). Traffic assignments are made to combinations of these modules being in place and the ranking system is then utilized to determine a priority planning scheme between modules.

The following example illustrates this approach. Assume a target year plan consists of the 25 projects listed in the Table IV-2.

TABLE IV - 2

PRIORITY RANKING EXAMPLE

LINK	RATING	RANK	CONTINUITY OF ROUTE	LINK	RATING	RANK	CONTINUITY OF ROUTE
100-101	8.0	1	A	908-910	4.3	13	D
101-102	7.9	2	A	1008-961	4.0	14	E
286-529	7.8	3	B	962-963	3.9	15	E
831-833	7.5	4	C	963-964	3.6	16	E
102-103	7.0	5	A	964-965	3.2	17	E
833-834	6.5	6	C	910-922	3.0	18	D
834-835	6.2	7	C	922-940	2.9	19	D
835-836	6.0	8	C	940-941	2.7	20	D
529-530	5.8	9	B	941-942	2.3	21	D
530-531	5.2	10	B	421-422	2.0	22	F
531-532	5.1	11	B	422-423	1.9	23	F
103-104	4.7	12	A	423-424	1.8	24	F
				424-425	1.7	25	F

The rating would result from a priority ranking system as described previously. This would establish a project ranking. The other factors (here continuity of routes was used) would be used to group the projects into program modules. The result of this might be a table as shown below:

PROGRAM MODULE	AVERAGE RATING	$ COST
A	6.9	$ 8,067,000
B	6.0	14,622,000
C	6.5	6,037,000
D	3.0	8,230,000
E	3.9	4,800,000
F	1.8	6,200,000
		$ 47,956,000

If, for example, the funding to be available for three phased periods were $15,000,000 per period, a logical grouping of programs could be established. The possible groupings might be:

PROGRAM MODULES	$ COST
A + C	$14,104,000
B	14,622,000
D + E	13,030,000
F	6,200,000

In grouping modules, one should strive to maintain high priority ratings. To group module A with F ($14,267,000) would result in a lower rating than if A was grouped with C. Likewise grouping D and E should result in a higher rating than grouping D and F. Using the above four groupings of program modules, traffic assignments to the system containing reasonable combinations of the module groups could be undertaken to determine the most efficient priority planning schedule.

The result of this analysis would indicate the program module to be implemented first and would consider both the inclusion and absence of other program modules of the total plan. This information should be sufficient for the recommendation of an implementation schedule.

(2) Once a target year plan has been developed, the shorter range effects of implementing portions of the plan can be examined to aid in developing a priority program. The approach described above (1) can be utilized to develop the program modules. The program modules are then used in traffic assignments to the intermediate year to determine priority on a shorter forecast basis.

Since differential growth may be occurring geographically in an urban area over time, it is very possible that the intermediate year assignment would indicate a different priority plan than the target year analysis. The traffic assignments to the target year system (all modules in the system) would be compared to the assignments to the projects in the module programmed for the first period. It may well be that volumes in the intermediate year will be greater than shown for the target year since all planned facilities would not be available at that time. These differences would be evaluated and a determination made of capacity to be satisfied dependent, to a great extent, on the probability of the entire plan being finally implemented. One school of thought considers that the higher capacity requirements which may occur on intermediate year links if the entire system is not constructed, should be accomodated since this will handle the traffic whether or not the entire system is ever constructed. Others argue that the programmed modules should always be considered part of the entire plan and capacity be provided on this basis.

incremental plans

A more traditional approach to priority planning which has been used is to develop incremental plans (5 year, 10 year, 15 year) within an adopted 20 year plan. This process would proceed as follows. After alternate target year plans are developed and evaluated, a 20 year plan is selected (see **pages 105-120** of this section). A five year trip table is developed and assignments are made to the existing plus committed network to determine congested locations. Sections of the 20 year plan are introduced and tested in establishing a five year construction schedule. The next step is to develop a 10 year trip table and assign this to the existing plus committed plus 5 year required development network. The system is evaluated and additional sections are selected from the 20 year plan to arrive at a 10 year construction schedule. The same process is followed to establish the 15 year construction schedule. The construction (or priority) schedules established are constantly monitored and updated along with other transportation study updates in the continuing reappraisal of systems and forecasts. A diagram of the above process is shown in Figure IV-4.

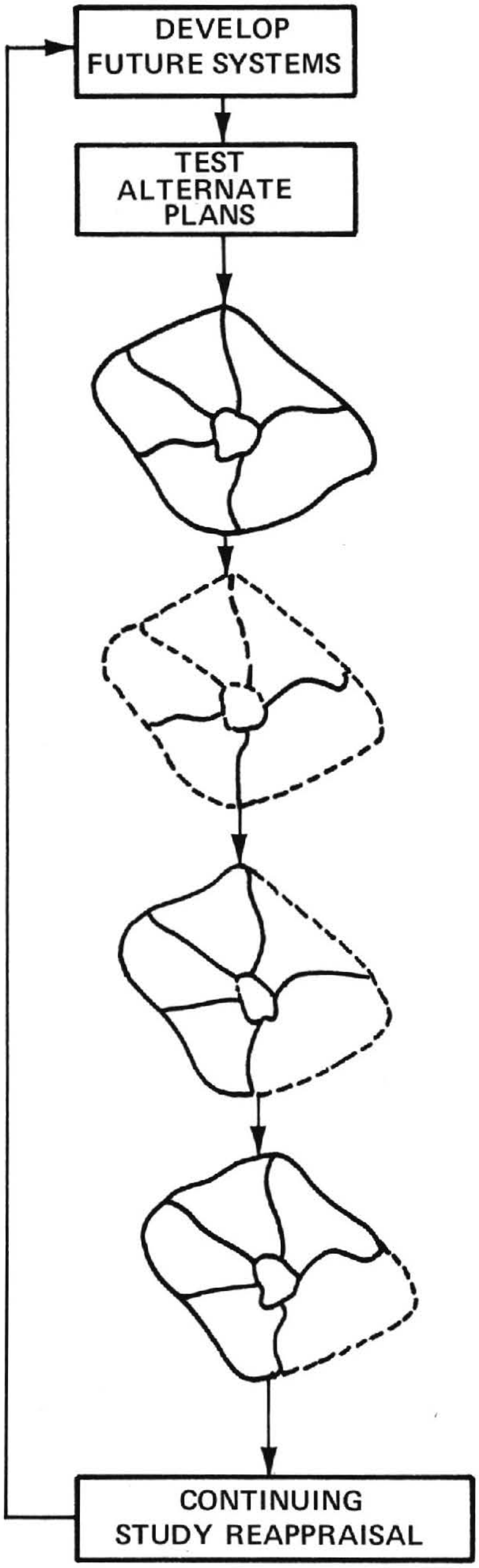
The beginning of this chapter has discussed the development and testing of alternate transportation systems. The remainder of this section will provide information on sub-area study and corridor analysis as well as the development of design volumes.

Sub-Area Study, Corridor Analysis

small-area analysis

There appears to be increased interest in and application of traffic assignment techniques to detailed analysis of specific network and related problems. This has resulted from a change in emphasis from plan development to the evaluation of specific corridor needs, special detailed area study, and other service functions, such as, providing volumes for design purposes. Recognizing the use of transportation planning results for design purposes provides strong impetus to such detailed analysis. Assignment techniques applied on a small area basis provide a host of study possibilities. The following areas of application have been used in the field:

- Evaluation of the ability of a local arterial system to handle freeway ramp discharges.
- Examination of transportation demands resulting from the redevelopment or rezoning of areas within a city.



(1) 20 YEAR PLAN

(2) ASSIGN 5 YEAR TRIP TABLE TO EXISTING + COMMITTED SYSTEMS

TEST ALTERNATES FROM 20 YEAR PLAN

5 YEAR CONSTRUCTION SCHEDULE

(3) ASSIGN 10 YEAR TRIP TABLE TO EXISTING+ COMMITTED + 5 YEAR PLAN

TEST ALTERNATES FROM 20 YEAR PLAN

10 YEAR CONSTRUCTION SCHEDULE

(4) ASSIGN 15 YEAR TRIP TABLE TO EXISTING+ COMMITTED + 10 YEAR PLAN

TEST ALTERNATIVES FROM 20 YEAR PLAN

15 YEAR CONSTRUCTION SCHEDULE

FIGURE IV-4

METHOD FOR ESTABLISHING PRIORITY SCHEDULES

- Determination of the impact of a large plant on the surrounding transportation system.
- Determination of intersection design and control equipment that would be necessary to handle changes based upon a new freeway or expected land use changes.
- Study of access to proposed large sites such as a college or university.
- Development and analysis of new town plans.
- Detailed evaluation of ramp spacing and facility location within a corridor.
- Development of detailed information for interchange design.
- Supply data for air pollution studies.

The detailed analysis appears to place emphasis on the need for small zones and detailed networks in the special area under study. Also, a greater significance must be placed upon use of capacity restraint functions and the coding of detailed network characteristics such as turn prohibitions, turn penalties, and geometrics. In many small area analyses peak hour assignments must obviously be considered.

There has been considerable study of detailed areas in the past. However, these have generally relied upon results from regional level assignments. Evaluation in the detailed areas has been accomplished through the use of hand analysis, adjustments, and distribution to facilities not in the region-wide network. In the future, it appears that assignment techniques will be used to a greater extent in detailed area evaluation and study. Indeed, this will be necessary as emphasis is changing from regional plan development to a viable and workable process that relies heavily on short-range corridor analysis and design impact studies.

Much of the increased interest in small area detailed study appears to be from counties, cities, and towns within regional transportation study boundaries. The regional studies have of necessity developed zones and networks on a level required for regional study. This generally does not provide what the sub-area counties and cities require relative to detailed planning characteristics. There is much interest at this level of government to study, in detail, the transportation implications of the regional systems being developed on their areas. Many regional studies have already geared up to support these local applications through providing data, computer support, and technical know-how.

Chapter III, **pages 73-83** , Zone Network-Relationships, provides some background relative to zoning and network selection for detailed area study.

In application in one regional study, sub-regional studies are generally based upon a 3 or 4 to 1 increase in the number of zones and corresponding increase in network links. The detailed area network usually includes all arterial streets and most collectors, but generally few local streets. It is estimated in this particular study area that approximately 25% of the total street system is coded for the regionwide assignments and about 60% is coded for sub-regional assignments.

In most current studies trip characteristics for the subdivided zones and trip distributions are obtained in the two following ways:

small area trip allocation

- Large-zone data, used for trip generation, are either forecast for the smaller zones maintaining the large zone total as a control or the large zone data are allocated directly to the smaller zones. The trips are generated for the smaller zones using trip generation formulations. The distribution model is then rerun to obtain the trip matrix for assignment purposes on the smaller zone basis; or,
- After the future trip generation for the subdivided zones is determined, the proportion each subarea is of the regional zones is determined and a factoring of the trip matrix is accomplished. This is usually accomplished as shown in Figure IV-5 for a 3 zone system. Matrix A shows trips between the region-sized zones 1 through 3. Matrix B shows the trip ends summed for these zones. The calculation of trips between the new subdivided zones is shown in D for 3 example movements. Trips between two new zones are equal to trips between the larger zones in which the new zones are located, multiplied by the proportion of trip ends each new zone is of its old larger zone. This computation can also be carried out using separate calculations for each zone for productions and attractions, or origins and destinations, rather than trip ends.

micro assignment

In addition to the application of more traditional approaches to sub-area study and corridor analysis, other specially developed techniques for these applications are being used. An interesting application of the Creighton-Hamburg Incorporated Micro-Assignment technique described in Chapter II has been undertaken in the Pittsburgh Area. Micro-assignment of traffic is accomplished in the central business district (Golden Triangle) and the north side. To obtain an accurate simulation in these areas, the micro area cordon line is extended to include some area between the Monongahela and Allegheny Rivers to the east of the CBD, some residential areas in the north side, and a strip of the south hills leading into the CBD.

The Micro-assignment procedure is first used to simulate 1967 traffic flows in the CBD. Since the Southwestern Pennsylvania Regional Planning Commission has travel data for that period, it is possible to test the accuracy of the modified program and to make changes if necessary.

When the model is tested and is simulating traffic behavior with the desired accuracy, future trips are assigned to the future networks. Micro-assignment is also used for testing and planning a wide variety of TOPICS improvement projects. These include parking restrictions, channelization, signal settings, intersection design, and one way street systems.

The types of projects being evaluated with the micro-method include:

- One-way street pattern in CBD.
- Impact of opening of U. S. Steel building on Origins and Destinations in the CBD.
- Evaluate effect of Three Rivers Stadium on traffic flow.
- Optimum bus network
- Evaluate proposed convention center sites.
- Ramp location and design.
- Best location for parking facilities.

A - Trip Matrix - Regional Zones

Zone to Zone	No. Trips
1 - 1	50
1 - 2	100
1 - 3	200
2 - 1	200
2 - 2	100
2 - 3	400
3 - 1	300
3 - 2	500
3 - 3	50
Total	1900

B - Trip Ends - Regional Zone

Zone	No. Trip Ends
1	900
2	1400
3	1500
Total	3800

C - Trip Ends - Subdivided Zones

Original Zone	New Zone	Trip Ends
1	A	400
1	B	500
2	C	0
2	D	400
2	E	1000
3	F	1500
Total		3800

D - Computation Based Upon Factoring

Example

$$T_{A-D}=T_{1-2} \times \frac{TE_A}{TE_1} \times \frac{TE_D}{TE_2}$$

$$= 100 \times \frac{400}{900} \times \frac{400}{1400} = 12.7$$

$$T_{C-F} = T_{2-3} \times \frac{TE_C}{TE_2} \times \frac{TE_F}{TE_3}$$

$$= 400 \times \frac{0}{1400} \times \frac{1500}{1500} = 0$$

$$T_{E-E} = T_{2-2} \times \frac{TE_E}{TE_2} \times \frac{TE_E}{TE_2}$$

$$= 100 \times \frac{1000}{1400} \times \frac{1000}{1400}$$

$$= 51.0$$

Figure IV-5

Trip Distribution Proportioning--Example for Three Zones

E FINAL CALCULATED TRIP MATRIX

Zone to Zone	Trips	Zone to Zone	Trips
A - A	9.9	D - A	25.4
B	12.4	B	31.7
C	0	C	0
D	12.7	D	8.2
E	31.7	E	20.4
F	88.9	F	114.3
B - A	12.3	E - A	63.5
B	15.4	B	79.4
C	0	C	0
D	15.9	D	20.4
E	39.7	E	51.0
F	111.1	F	285.7
C - A	0	F - A	133.3
B	0	B	166.7
C	0	C	0
D	0	D	142.9
E	0	E	357.1
F	0	F	50.0
		Total	1900

Figure IV-5 (Continued)

The Southwestern Pennsylvania Regional Planning Commission views Micro Assignment as a design tool to be used on a short range basis and not as a longer range planning tool.

Development of Design Volumes

<u>design volumes from assignment</u>

It would appear from discussions with practitioners in the field of urban transportation planning that traffic assignment volumes developed are used to provide highway designers data useful for design purposes. For transit purposes, assignments are usually made to peak periods specifically (sometimes only work trips are considered) to provide information for system design. Although those applying traffic assignment techniques believe the basic applicability is for location planning, priority planning, etc., there is considerable use of the results of traffic assignment for design purposes. This is true even though design people find considerable fault with the results of the process. They rely upon the results of the process quite heavily, and sometimes exclusively, in the development of design volumes.

<u>peak hour volumes</u>

There are two general approaches used to develop peak hour traffic - generally used for design purposes:

- Assign total daily travel to a network and factor the resultant loads to peak-hour directional values.
- Develop peak-hour travel and assign to the network.

The application of factors to total daily assignment volumes appears to be the most frequently used procedure. The differences in application between studies appears to be in the tailoring of factors to specific network sections and the group (i.e., planners, designers, etc.) developing the design volumes. In many organizations the traffic assignment practitioners turn over total daily assignment volumes to the design groups, who then develop design volumes from the data. Others develop the peak-hour directional volumes prior to turning these over to the design people. In this latter case, truck factors may be supplied by the planners or developed by the design staff. The organizational arrangement is not too important as long as there is an awareness by the design people of how the volumes are developed and an awareness on the part of the planning people of the use of the data. There appears to be growing sentiment that the planning people should produce the design volumes since they are most familiar with the basis of the data from which the design hourly volumes are developed. In any case, there must be close cooperation between the design and planning people. The belief that traffic assignment volumes are only useful for planning purposes and that their subsequent use for design is not necessarily of concern is not entirely correct. It appears that traffic assignment results are used almost universally in development of design volumes. This being the case, it is imperative that those applying traffic assignment techniques recognize this most important application and consider this use in their development of assignment networks and in application of transportation planning tools.

There is a wide range in the detail of work undertaken to convert total daily traffic to peak hour directional volume. At one end of the scale, areawide-systemwide factors are developed and applied to assignment results. These factors are based upon traffic counts and result in a single peak-hour factor (i.e., 10%-12% of total daily traffic) and a single directional factor (i.e., 60-40). An improvement to this very basic approach is to classify sections of facility by area type and facility type and develop peak-hour (K) and directional (D) factors for each category. For highway facilities a table similar to Table IV-3 might be constructed.

TABLE IV-3

AREA TYPE

	CBD		Surrounding Fringe		Outer City		Inner Sub		Outer Sub	
	K	D	K	D	K	D	K	D	K	D
Freeways										
Expressways										
Other Arterials										
Major Collectors										

Other work which may provide useful information on K and D factors was undertaken for the Federal Highway Administration as part of their TRANS Model Work described previously in this document (46).

effect of variation in K & D

The importance of accuracy in the application of factors may be illustrated by Table IV-4. The table assumes an assigned total daily traffic of 125,000. The variation in the number of lanes required assuming various values of the peak-hour and directional factors is from 3 lanes to 5 lanes. This is based upon what might appear to be small variations in the factors. If a 10% peak hour factor and .55 directional factor is assumed, four lanes are indicated in the heavy direction. However, just the change to a 12% peak hour factor and .60 directional factor would indicate 5 lanes as being required. This example is presented to illustrate the necessity for care in the development of peak hour and directional factors, since rather small variations in the factors may cause a larger error in design values than is inherent in the traffic assignment process itself.

Chapter V, Section on "Precision of Estimates", discusses the effects of errors in traffic assignment results on resultant design volumes. The errors may be in the basic AADT estimates or in the conversion to DHV. An excellent discussion of this may be found in the HRB publication Data Requirements for Metropolitan Transportation Planning (34).

development of K & D factors

Some using traffic assignment results for design purposes have developed rather substantial operational procedures for developing peak hour and directional factors. These operational procedures can be used as an adjunct to the development of factors by facility and area type or as a separate analysis. One such process will be described below:

STEP 1 - Familiarity with the area of the proposed facility or improvement is obtained by a review of land use and trip generation estimates in the area affecting the facility.

STEP 2 - Count data is obtained from facilities in the area of the proposed facility and reviewed in relation to the development of peak-hour and directional factors. If data similar to that shown by Table IV-4

TABLE IV-4

EXAMPLE OF VARIATIONS IN PEAK HOUR & DIRECTIONAL FACTORS

TOTAL DAILY TRAVEL	PK-HOUR FACTOR (K)	DIRECTIONAL FACTOR (D)	PEAK-HOUR DIRECTIONAL VOLUME	NUMBER OF LANES @ 1800 CAPACITY (1 DIRECTION)	
				Calculated	Rounded
125,000	8	.55	5500	3.0	3
125,000	9	.55	6187	3.4	4
125,000	10	.55	6875	3.8	4
125,000	11	.55	7562	4.2	5
125,000	12	.55	8250	4.6	5
125,000	8	.60	6000	3.3	4
125,000	9	.60	6750	3.7	4
125,000	10	.60	7500	4.2	5
125,000	11	.60	8250	4.6	5
125,000	12	.60	9000	5.0	5

is available, differences from the area of the proposed facility are examined and, if possible, a determination made of the reasons.

STEP 3 - A field visit is made to the area of the facility to evaluate the details of land use, locations, etc.

STEP 4 - Both current and future assignments for the area of the proposed facility are examined and comparisons made of current assignments to ground counts.

STEP 5 - The land use changes estimated are reviewed.

STEP 6 - A corridor is established surrounding the facility being handled and cutlines are placed across the corridor. Traffic assignment volumes are then examined for their distribution between facilities in the corridor. Adjustments are made between facilities if this appears warranted.

STEP 7 - Daily volumes are established for the facility and the applicable peak-hour and directional factors applied.

As an example of other work undertaken, one state has developed statistical relationships between peak hour volume and average daily traffic on city streets. In this procedure, Friday counts were obtained for 2, 3, and 4 lane facilities in one direction. These were one-way peak-hour volumes and ADT in the direction of the heavier flow. The assumptions made were that Friday volumes tended toward high volumes and that left turn lanes did not affect through traffic. Both graphical and statistical analyses were applied to obtain the relationships. The results obtained by a linear regression analysis are shown in Table IV-5 and Figure IV-6.

assign peak-hour trips

The second approach to develop design volumes, that of developing and assigning peak-hour trips, has been used only to a limited extent. This is probably based upon the heavy concentration by urban transportation planners on developing and applying procedures and models for use in what may be referred to as macro planning efforts; e.g., regional transportation networks, major corridor studies, transit patronage models, etc. In these type analyses, the unit most often used to measure traffic is average daily traffic. As mentioned previously, in addition to providing ADT estimates, the need for providing peak-hour traffic for design purposes is apparent. This function is becomming increasingly important as transportation agencies proceed with the continuing effort of the urban transportation process and concentrate more on service functions to others and on performing special or micro studies such as those related to airport access, central business district circulation, etc. The use of peak-hour trips for special purposes and for design may become a more widely used approach. The basic advantages of this technique are:

- Peak period trips are assigned to a network which has been coded to represent the peak-hour both in traffic operation features (i.e., one way operation during the peak period) and peak-hour impedance measures for the system (i.e., link time).
- The capacity restraint technique can be applied directly and more accurately as compared with the inaccuracies in converting design hour capacities to represent daily capacities. Generally,

TABLE IV-5

EXAMPLE OF RELATIONSHIP BETWEEN ADT AND PEAK HOUR

Source: California Division of Highways

NO. OF LANES (ONE DIRECTION)	LIMITS OF ADT	EQUATION	CORR. COEF.	STD. ERROR EST.
2	0-9.9	$y=.097X + 142$	.77	170
2	10.0-20+	$y=.077X + 202$	.73	179
3	0-12.9	$y=.075X + 380$	.71	200
3	13-20+	$y=.021X + 241$	.24	228
4	0-20+	$y=.059X + 612$	.72	319
2+3+4	1-6.9	$y=.110X + 87$	.76	125
2+3+4	7-12.9	$y=.069X + 13$	.45	213
2+3+4	13-20+	$y=.052X + 670$	.65	226

Where: y= peak flow
x= ADT

This type of analysis was extended to produce the type of chart shown in Figure IV- 6 .

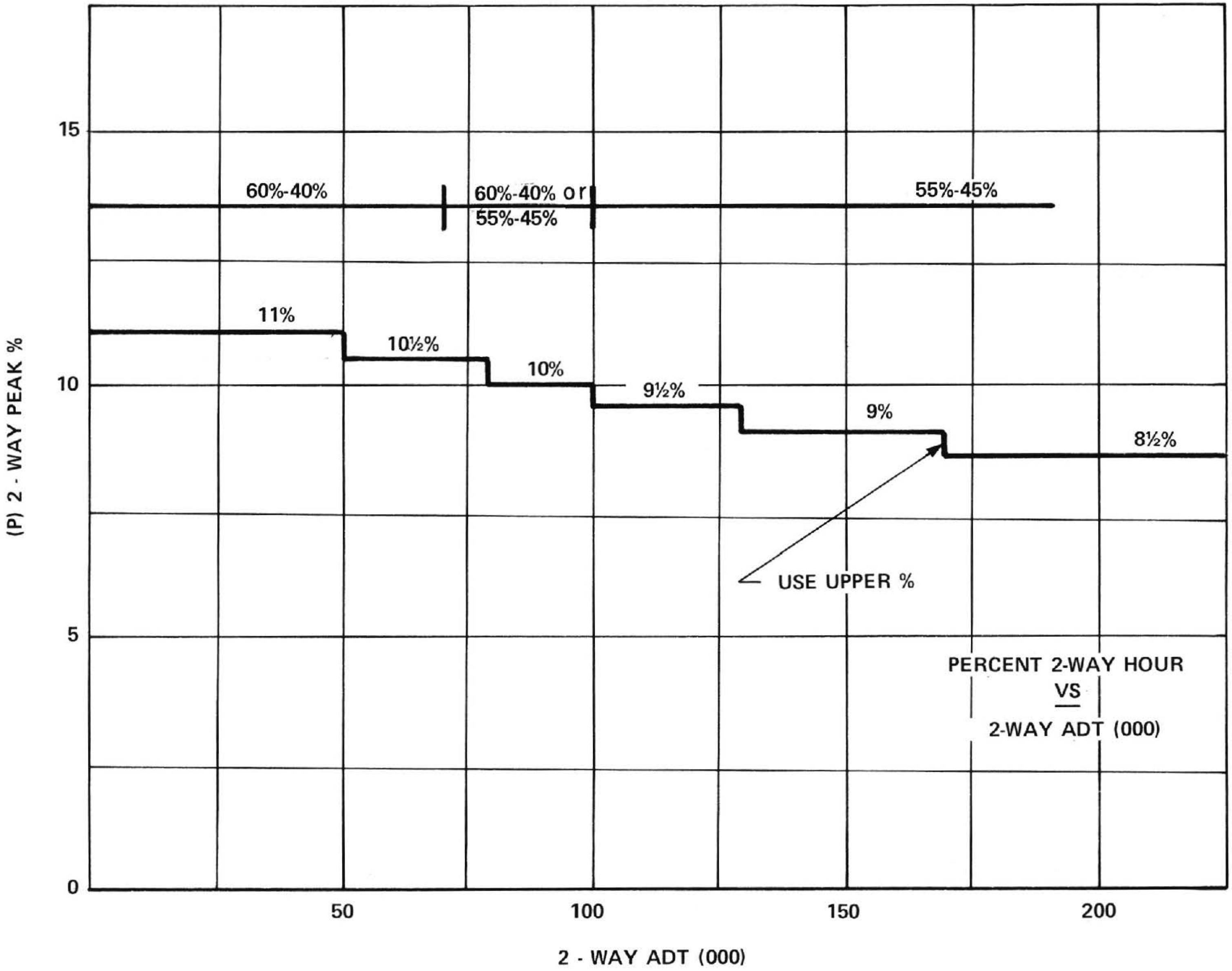


FIGURE IV-6

RELATIONSHIP BETWEEN PEAK HOUR VOLUME AND AVERAGE DAILY TRAFFIC design hour capacities are factored to represent 24 hour capacity by applying peak-hour factors and allowing a comparison with daily traffic assignment volumes. Since peak-hour volumes may distribute differently on portions of the network than result from factored 24 hour travel, there may be greater accuracy in the capacity restraint application.

- Directional peak-hour volumes result directly from the assignment process without the necessity for applying peak-hour and directional factors.

peak-hour models based on census data

The availability and use of the 1970 Census journey-to-work information may result in more peak-hour model development for assignment purposes. Urban transportation studies will be able to use the 1970 Census as a major source of data on population, housing, employment (by place of work), and the primary work trip. These data are being coded to block faces and will be aggregated by traffic zone. The FHWA in cooperation with the Census Bureau has developed computer programs to produce tabulations by traffic zone. The availability of primary home-to-work trips tabulated by traffic zone provides an additional incentive for the development of peak-hour/work trip oriented forecasting models that would aid in the continuing task of updating the base year transportation plan. In addition, peak-hour traffic models will be updatable at the time of each census. Research relative to application of census for this purpose is underway in Georgia and in Rhode Island. In this latter work, the following approaches are being evaluated:

(1) Census journey-to-work data is prepared in trip table format and this trip table assigned to the computerized network. Using 1961 origin-destination data, a relationship is developed between primary work trips and peak period trips for links in the computerized network grouped by functional class and by area type. Twenty-four hour volumes are then derived by link from the peak period trips using factors developed for FHWA by Peat, Marwick, and Mitchell (46). These factors are stratified by functional class, area type, and orientation of facility and should influence the categories set up in the previous step where the relationship between primary work trips and peak period trips are established.

(2) The census journey-to-work data in trip table format is assigned to the computerized network. Using 1961 origin-destination data, a relationship between primary work trips and 24-hour traffic volumes is developed for link groupings, stratified by functional class and by area. The resulting factors are applied on a link basis to the census journey-to-work assignment and the results compared to 1970 ground counts for verification of accuracy.

(3) Using 1961 origin-destination data, relationships are developed on a district basis between socio-economic variables and the ratio of work trips attracted to and produced in each district to the total trips attracted to and produced in each district. Thus, a series of equations result which will establish the relationship between land use and the ratio of work trip ends to total trip ends.

(4) Using 1970 socio-economic data derived from the census or other independent sources, 1970 values are forecast using the relationships previously developed. The resulting factors are then applied to the 1970 census work trip ends to obtain 1970 total trip ends. These total trip ends are then distributed

and assigned to the computerized network and the results compared to 1970 ground counts.

The use of peak period travel and networks has the advantages of being:

- Automatic and reproducible - one peak hour trip matrix can be produced and subsequently used for testing many network alternatives.
- Responsive to land use changes in an area.
  for example, as employment patterns change they are reflected in peak hour estimates.
- Well suited for special analysis - for example, that hour period during which shopping trips to the central business district peak can be isolated and studied in detail.

determining the peak hour

The procedure requires the development of peak-hour trip tables. These tables are developed by applying factors to the non-directional matrices usually developed by trip distribution models such as the gravity model. The factors are developed through processing and analysis of the base year origin and destination survey. This processing has been done in a number of ways. Some have determined the peak-hour by finding that hour period during which a maximum number of trips have say started, ended or reached the mid-point of their trip. A more precise method is to determine that period during which the maximum number of trips are in motion. An analysis which uses either a start-time, mid-point time, or end time of a trip assumes that the trip occurs wholly within that hour period. A table is then constructed by time interval(usually six minutes) and the trip is placed in its appropriate time interval. After all trips have been tabulated, the ten consecutive six minute intervals that produce the greatest number of trips is designated as the peak hour. With the trips in motion concept, both the starting and end time of the trip are interrogated to determine not only the time but also the duration of the trip. The trip is then placed in one or more intervals. For example, if a trip begins at 8:00 A.M. and ends at 8:30 A.M., it would be added to the time intervals indicated in Table IV-6.

As can be seen, a trip-in-motion for a one-half hour period has an effect on fourteen different peak hour periods.

As an illustration of the factors that are developed, Table IV-7 is presented. The factors are applied to a home based trip file (i.e., trips from home to work as well as from work to home are in the direction home to work). For example, assume that a 24 hour trip matrix showed 1000 home based trips between two zones. To determine the home to work trips in the A.M. peak we would apply the directional factor and A.M. peak factor resulting in 200 trips in the home to work direction during the A.M. peak. (1000 x .491 x .412). The number of trips from work to home in the A.M. peak would be 3 trips (1000 x .491 x .008).

There are also some disadvantages to the peak period approach. Primarily, a greater cost results from applying this approach since it does not replace the need for total daily assignment procedures. Part of the increased cost results from the additional data required. For example, link times must be developed for the peak period(s) and the capacity to be coded might vary due to differences in parking conditions, use of reversible lanes, different signal cycling, turning movements, etc. These same factors also provide some of the advantages listed previously. Peak-hour traffic assignments are also more expensive in terms of computer time and the effort involved in the evaluation of results. Forecasting is more time consuming and peak networks must be calibrated as well as the total daily assignment network.

TABLE IV-6

TRIPS IN MOTION CONCEPT

TIME	TRIP ADDED	TIME	TRIP ADDED
6.9-7.9	No	7.8-8.8	Yes
7.0-8.0	No	7.9-8.9	"
7.1-8.1	Yes	8.0-9.0	"
7.2-8.2	"	8.1-9.1	"
7.3-8.3	"	8.2-9.2	"
7.4-8.4	"	8.3-9.3	"
7.5-8.5	"	8.4-9.4	"
7.6-8.6	"	8.5-9.5	No
7.7-8.7	"	8.6-9.6	No

TABLE IV-7

Final Factors for Converting 24-Hour Trips to Peak Hour Washington, D.C.

(47)

Trip Purpose	Directional Factor	A.M. Peak Factor	P.M. Peak Factor
Home - Work	0.491219	0.41208	0.00803
Work - Home	0.508781	0.00674	0.41144
Home - Other	0.481144	0.05764	0.04543
Other - Home	0.518856	0.05768	0.10627
Home - Social Rec.	0.454918	0.01474	0.04109
Social Rec. - Home	0.545082	0.00327	0.06425
Home - Shop	0.436964	0.01474	0.05405
Shop - Home	0.563036	0.00064	0.11959
Home - School	0.489759	0.47620	0.00804
School - Home	0.510241	0.00022	0.07478
Non Home Based	1.000000	0.02411	0.13790

This section has discussed applications of traffic assignment procedures to urban area study. The application to developing and testing alternate systems, priority planning, sub-area study and corridor volumes, and development of design hour volume is also pertinent to statewide and national study described in the remainder of this chapter. Most application of assignment techniques to state and national study have been adopted from urban area experience.

APPLICATION TO STATEWIDE STUDY

statewide needs studies

Although initial planning efforts of the 1920's and 1930's were concentrated on the rural highway system and large amounts of data on the rural systems were collected, the application of computerized systemwide planning on a statewide basis was not undertaken until the 1960's. Initial statewide study efforts were in functional classification and needs studies which tried to determine the adequacy of the system, suggest improvements, and estimate costs to bring the system up to some standard. These studies concentrated on a functional classification study to determine a "plan" against which to estimate "needs" based upon the projected traffic and appropriate tolerable standards for each facility. Recently the urbanized area model approaches have been used in developing statewide traffic models.

statewide traffic models

Over one-quarter of the States have either completed or are in the process of completing a statewide traffic model involving statewide traffic assignments. These models are generally based upon the techniques developed for urban area transportation planning which are trip generation, trip distribution, and traffic assignment with modifications made for statewide application.

The uses made of statewide traffic assignments include:

- traffic assignments for national and state use such as functional classification and needs studies, the Interstate Cost Estimate, and the supplemental freeway system studies.
- Testing Alternative systems on a statewide basis.
- Analysis of traffic on a corridor basis.
- Use of traffic assignments for design purposes.

The State of Iowa was the first to complete a statewide traffic model. Their zones consisted of counties and towns. Every town with more than 150 persons was defined as a zone. Those with less population were grouped to form zones. The base year system consisted of 855 internal zones and 72 stations (total of 927 centroids). The initial network contained interstate sections opened to traffic, the state primary system and selected county roads and represented 10,221 miles. The future year system included improvements expected to be built, under construction, or programmed. Highway link distances were obtained from highway logs (to 0.1 mile) and link speeds from highway sufficiency ratings (to 1 mph). Five assignments were made to calibrate the assignment process on base conditions. This process included manual adjustments as well as volume restraint runs. The results indicated that 81% of actual vehicle miles of travel was represented, and that the missing travel was due to trips under 10 miles which were not represented. Iowa did not develop or test any alternative highway plans. The only system tested was the one programmed for construction.

Wisconsin developed a statewide transportation study with an assignment network of 10,434 miles of Interstate and trunk highway and 4,050 miles of county, town, and other facilities for the base year. The state was subdivided into 570 zones, with areas external to Wisconsin subdivided into 24 zones, and the cordon containing 49 station-centroids for flexibility in the assignment process, all totaling 643 centroids. Each internal zone was a township of at least 1000 population or groupings of those under 1000 population. Zones conformed generally to township lines and are aggregatable to counties.

The network was based upon those routes logically connecting zone centroids making sure that all roads designated as state trunk were included. Next, every rural highway with a 1960 ADT greater than 300 was added. As a final step, any facilities functionally classified as arterials or connectors were included.

statewide studies

Data for link coding were obtained from highway logs, speed studies, etc. A one minute turn penalty was initially coded but dropped as unnecessary. Sixteen planning schemes were developed in an attempt to look at a wide variety of ideas. The results of the study include the development of a 1990 State Highway Plan which for implementation was refined into a Freeway-Expressway plan, development of access type and spacing criteria, critical corridor studies, and proposed legislation on future right of way.

Rhode Island has undertaken a Statewide Comprehensive Transportation and Land Use program. There are 497 internal plus 53 external zones in the study. The zones are based upon enumeration districts and may be grouped by census tract. (The entire state is tracted). The Rhode Island assignment system contains 1600 miles out of a total of 4,380 miles of roads and streets. Nodes are placed at the boundaries of towns so mileages can be accumulated by towns. The 1970 committed system was used for the assignment of all future trips. Volume to capacity ratios are available for every link. Three calibration runs have been made and 97.8 percent of roads with ADT's over 200 are within ± five percent of traffic counts. All corridor movements agree with field counts within 5%.

Connecticut developed a comprehensive statewide study based upon two systems (zoning and network extent) dependent upon the purpose of a particular analysis - detailed for small area study and less detailed for statewide study. The detailed system contains 1725 internal zones, 52 external stations and 9100 miles of highway. The less detailed system consists of 806 internal zones and 6900 miles of highway. The network used for testing is generally the 1970 committed highway network. The interesting idea in Connecticut is that the urbanized areas are coded in with the rest of the state network and zones, resulting in the detail required for urbanized area study within the Statewide Study network and zones.

There are advantages to multi-level assignments where zones and networks can be combined or deleted so that the user can specify the level of detail desired. Computer programs have been developed to accomplish this.

Michigan in their report, "Michigan's Statewide Traffic Forecasting Model, Volume III, Multi-level Highway Network Generator Segmental Model," June 1971, documents their efforts. The preliminary model will combine two levels of detail by county for the State. The two levels are a 83 county zone and a 540 zone system with their related highway networks. The refined modal will combine four levels of detail. The third level is a 2300 zone system based on individual townships and the fourth level includes all of the urban study zones. Using this system the most detailed zone and network system should be coded initially.

The Texas Transportation Institute, under contract with the Federal Highway Administration, has worked on developing a link level edit program which will combine and renumber links and nodes from several states or a state and its urban areas. The level of network coarseness can be specified according to five definitions of level, as follows:

state-wide network development

Degree of Network Detail (Level)	Link Classes Included	General Size of Zones
1	1	State
2	1-2	SMSA & Rural Equivalent
3	1-3	County
4	1-4	Township, under 1000 zones
5	1-5	Enumeration Districts or State Sub-zones over 1500 zones.

Network levels can be selected based on any column in the card. In most cases, administrative or functional classification as shown in the coding instructions will be used. A column for link level is listed for those states that wish to code their network level at the beginning, and for coding the centroid connectors which have no administrative or functional classification. The centroid connector must be coded through the network at a given link level. For example, a State centroid connector would have to be coded through the network at level one until it reached a point of connection with an Interstate link, since according to the coding format both a State centroid and the Interstate network are level one. Presently the program uses a separate set of centroid connectors for each level of network.

Networks of varying detail may be combined according to the user's specifications; for example:

- A national group might use the level one network consisting of the interstate network and the State centroids, or level two network, consisting of the 490 internal zones described in the next section, in a nationwide assignment.
- A national or regional group might use the level three network and county centroids for an assignment.
- State A, in undertaking a statewide transportation study, could use a level four or five network for its own area, and combine this with a level two or three network for adjacent States and a level one network for the remaining States.
- An urban group could use its urban network, if coded in S360 format, in combination with a Statewide network for an assignment.

The TTI program has the capability of handling duplicate node and centroid numbers in adjacent States or urban areas. Both the Michigan and the TTI programs have the capability of deleting unnecessary nodes for efficient computer runs. Both programs have only been run by their developers and other States may experience some program "bugs".

To date, most statewide transportation studies in which assignment techniques are utilized, have considered only highway networks. Some work has been accomplished in the assignment of commodities as well as persons to these highway networks. Most statewide assignments have been accomplished with an all-or-nothing technique, with little belief in the usefulness of capacity restraint techniques on a state basis.

There are two general approaches to zoning. One approach is to zone the state with each urban area represented by a single loading centroid. In effect, the gaps between urban area studies is considered the statewide network. This approach is useful for describing large urban areas on the periphery of the state. The second approach is to forget urban area boundaries and develop zones for the entire state. This approach gives better traffic assignments on routes into the urban areas. The network level coded is used for the urban as well as non-urban portions of the state. Naturally, only the important through routes are included through urban areas. The urban areas would be subdivided into zones whose size would depend upon the analysis to be accomplished. For example, Connecticut has a statewide zone and network system which allows detailed study in the urban areas as well as statewide study. A diagram of their state system is shown in Figure IV-7. Others keep the urbanized area study separate so that in the statewide network only the major through routes are considered in the urbanized area. See Figure IV-8 illustrating this approach in Pennsylvania.

<u>statewide zoning</u>

Some general ideas that may be considered in designing a statewide network and zones are listed below:

- The zones in the rural and urban area portions of the state should be of a similar size. For example, if township size zones are used in the rural areas, urban sectors and the CBD are corresponding sized areas for urban areas. Where the state used detailed zones, say over 1500 statewide zones, the statewide study urban zone is a combination of up to six urban study zones.
- As a general rule of thumb, the statewide network should be able to reflect trip lengths over 5-6 miles. Nationwide, based on the 1969 National Personal Transportation Study (53)., for example, 45.6% of the trips made are over 5 miles in length and account for 88.9% of VMT for both urban and rural areas. 37.3% of trips are greater than 6 miles in length and account for 84.2% of total VMT. This trip length is consistent with use of townships, which average in many states about 36 square miles (6 x 6).
- For statewide planning networks a minimum of 10 - 15% of all miles of system should be in the assignment network. The network should include all interstate and non-interstate principal arterials and minor arterials, and those collectors necessary to provide good system interconnectivity.
- From the experience of practioners, the use of turn penalties of less than 1 minute duration does not appear to affect assignment results to any noticeable extent. Since the use of penalties of greater than 1 minute does not generally appear realistic, turn

<u>network zone development</u>

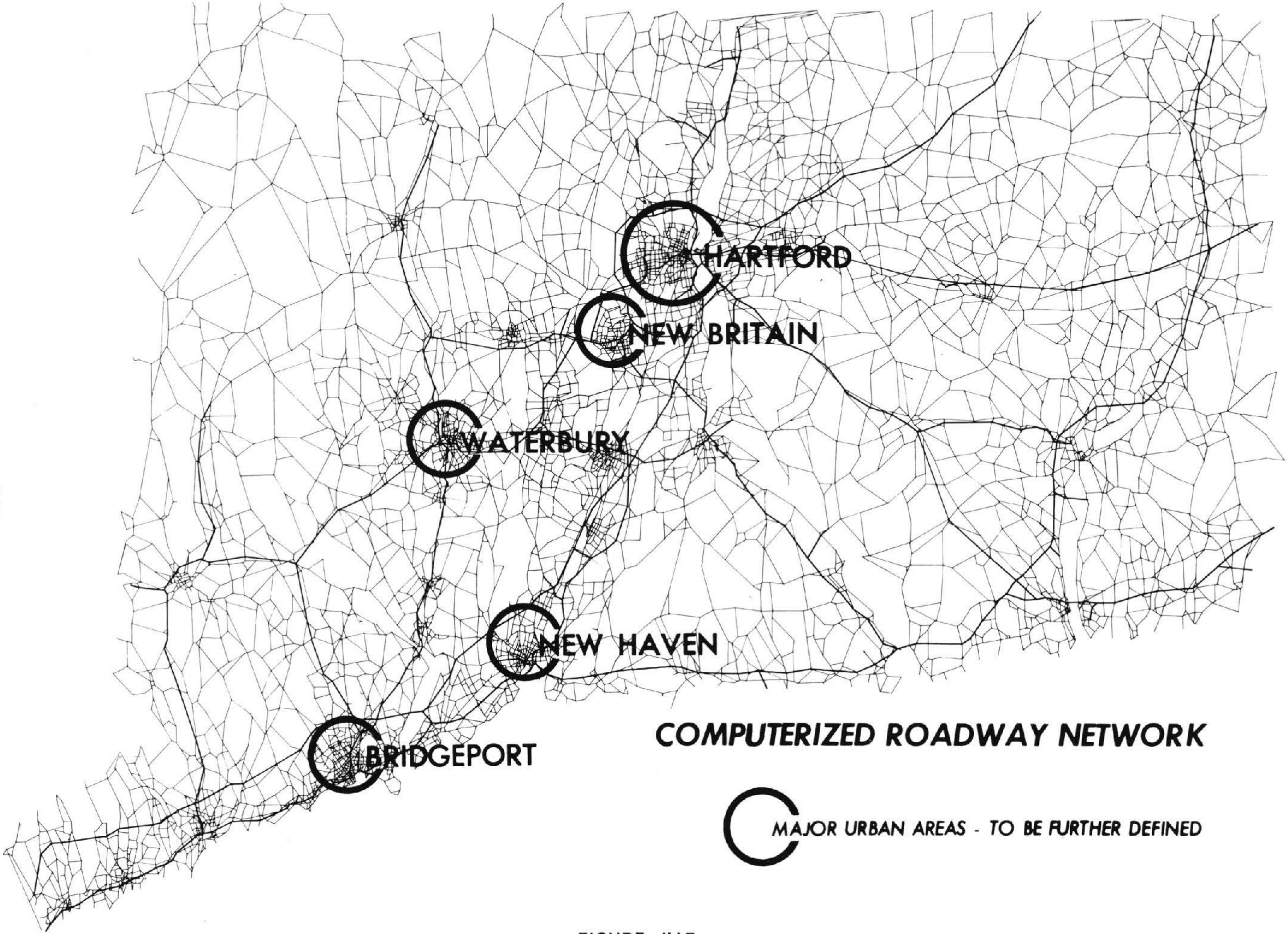


FIGURE IV-7

Example of a statewide network including a detailed urban network (57)

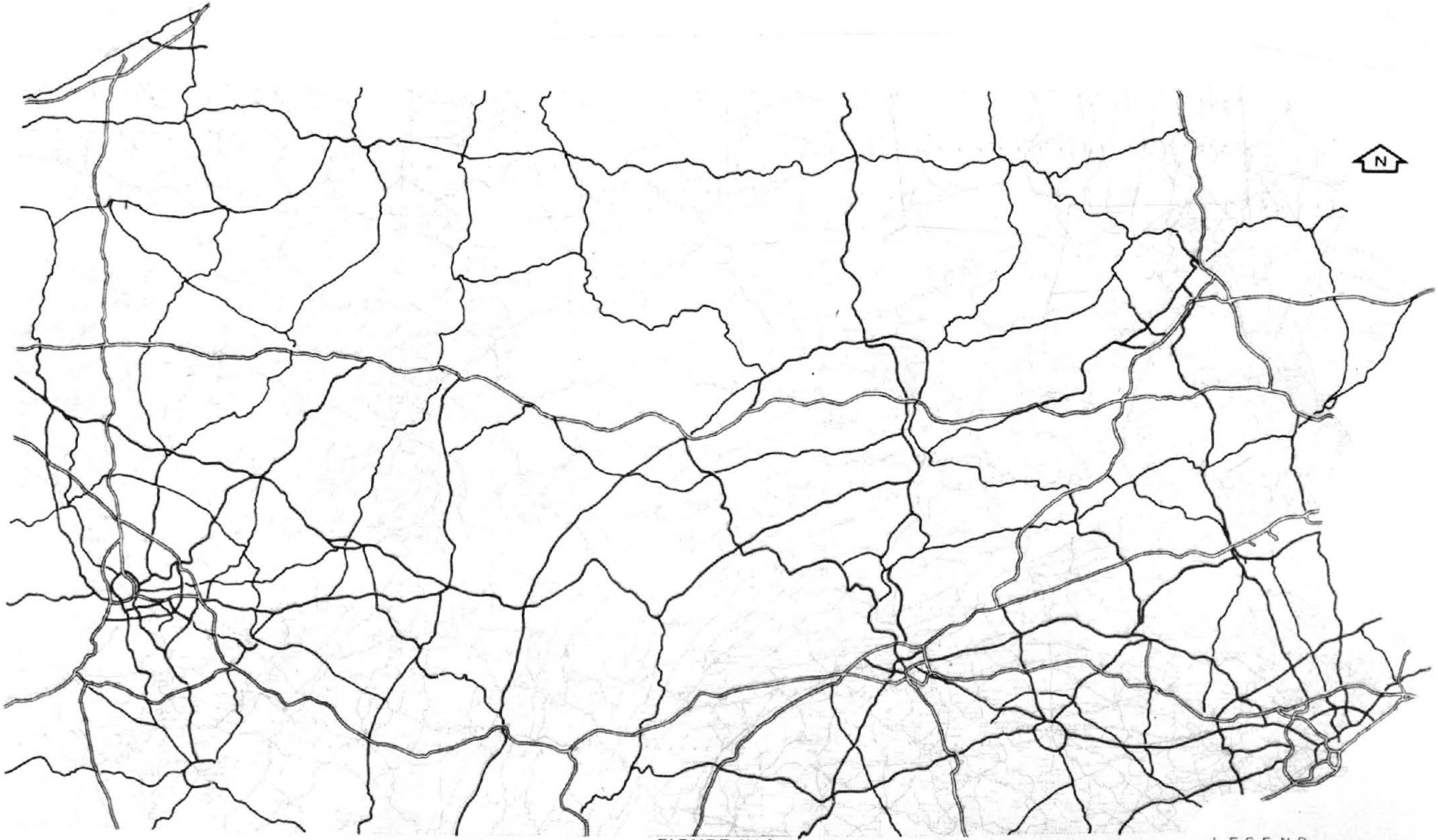


FIGURE IV-8
EXAMPLE OF A STATEWIDE NETWORK WITH
ONLY THROUGH ROUTES IN THE
URBANIZED AREA

EDWARDS AND KELCEY
ENGINEERS AND CONSULTANTS

penalties are probably not warranted.

- A statewide system can be coded with the minimum data required for traffic assignment, i.e., A node, B node, speed, distance, and ADT. Other information which may be considered to improve analysis includes capacity, DHV/ADT factor, federal aid class, functional class, link class, type of facility, rural vs urban section, access control and/or spacing, route number.

network-zone development

- There appears to be no advantage to coding detailed interchange design for a statewide network except when detailed study is to be made of a specific corridor for location and design purposes.
- From experience to date, the use of capacity restraint does not appear warranted. This is based on the few number of highways in rural areas over capacity and the fact that travelers in rural areas do not seem to be willing to accept urban type congestion.
- As in urban area study, zones should be compatable with the selected network and if possible conform with census designations, such as county, minor civil divisions, census county divisions and enumeration districts. Zones should be aggregatable by county for summary purposes.
- Unlike the principle followed in maintaining urban zone-network compatability, centroid connectors are generally located at intersections of major routes or along routes, since towns are usually centers of population as well as being at the intersections or along the major routes.
- It is good practice to locate link nodes at urban area boundaries since summaries can then be developed for rural routes separate from urban routes.
- To allow compatability between urban and statewide studies, new urban studies should consider the statewide zones and use them as external zones.
- Calibration of a statewide network should be handled similarly to urban networks using comparisons of assigned volumes with ground counts on gridlines, cut lines in corridors and on individual major routes. An independent estimate of state VMT should be made using estimates of population, car ownership, fuel consumption, and average trip length. The model estimates of VMT should match this within ± 10% as a general rule of thumb.

Most states have been developing ADT models and applying DHV/ADT factors to obtain design hour volumes. However, in many states the majority of high hour volumes occur on the weekend consisting mostly of recreational travel. These types of trips are long distance trips and have different characteristics than weekday recreational trips obtained in an urban study. More attention should be given to recreational travel since it is becomming increasingly important.

Table IV-8 presents some statewide system statistics that may be useful to those contemplating a statewide study.

A HRB paper by Mr. Philip Hazen of the FHWA (48) describes in greater detail the application of urban planning techniques to statewide study. Much of the information contained herein has been extracted from Mr. Hazen's work.

TABLE IV-8

SUMMARY OF STATEWIDE ASSIGNMENT NETWORKS AND ZONING

STATE	Year Started	Land Area of State (000 Sq. Miles)	Population 1960 (000)	Population 1970 (000)	Total Miles (Base Year)	Total Miles of Network	Type of System Included in Net	Number of Zones Internal	Number of Zones External	Zone Description
IOWA	1963	56	2757	2825	112029	10221	Interstate State Primary Selected County	855	72	Townships or Groups with >150 Population
WISCONSIN	1964	55	3952	4417	99869	14484	Interstate State Trunk County, Town, other	570	73	Townships with >1000 Population
RHODE ISLAND	1964	1	860	949	4380	1600	Interstate Federal Aid Prim. Other State Routes	497	53	Groups of Enumeration Districts
CONNECTICUT	1963	5	2500	3032	17274	9100	State System All Expressways and Arterials	1725	52	Groups of Enumeration Districts
ILLINOIS	1966	56	10081	11113	128389	11000	Rural Freeways, Major Hwys, & area service routes	526	0	Townships
MICHIGAN	1964	57	7823	8875	112912	e 10000(1) e 20000(2)	State Trunk Sys. All Arterials & Some Collectors	510(1) 2300(2)	29(1) 100(2)	(1) Groups of Townships (2) Every Township. 4 Urb.= 1 State
MISSOURI	1964	69	4320	4677	114012	9000	Hwys. >500 ADT. & Major Rural Hwy. Systems	536	137	Groups of Townships
PENNA.	1962	45	11319	11793	109908	8871(1) 12000(2)	Corridor Hwys. ASF Class 1-5 ADT > 500	149 1600	31	(1) Parts of Counties. Townships and Cities 500 Pop.

TABLE IV-8 Continued

MINNESOTA	1966	80	3413	3805	126385	e 8000	Trunk Hwy. System	1906	100	Townships or City with Pop. 2500
ARIZONA	1965	114	1302	1772	39087	8094	U. S. Numbered Principal Arterials	144	30	Based on Population
CALIFORNIA	1969	157	16717	19953	162223	20383	State Hwys. System	1443	45	Rural MCD's & 4 Urban=1 State
TENN.	1967	42	3567	3924	77182	e10000	Arterials & Some Collectors	535	150	Census County Divisions
NEW YORK	1967	48	16782	18237	102292	e14000	Interstate, expressway touring route system	640	e42	Groups of Townships
W. VIRGINIA	1967	24	1860	1744	35700	e12000	Int. State Primary County	778	unknown	Groups of Districts
KENTUCKY	1970	40	3038	3219	69071	12000	Int, Principal, Minor Arterials	663	unknown	Census County Div. Spec. Generation with 5000 veh. trips/day
NEBRASKA	1970	76	1411	1483	100,445	9730	Int., Primary	881	unknown	Groups of Townships
WYOMING	1967	97	332	330	78461	e6000	Int., Primary	e200	unknown	Census County Div.
DELAWARE	1967	2	446	548	4826	e2000	State Primary and Secondary	205	unknown	Combined grids outside Wilmington
GEORGIA	1969	58	3943	4589	99995	e6000	Spiderweb Connecting County Centroids	e158	unknown	County

e = estimated
(1) = where more than 1
(2) = Network Developed

An interesting and useful technique for dealing with traffic diversion to and from toll facilities has been developed by Pennsylvania. The technique developed for use in conjunction with the Pennsylvania Statewide Transportation Study is a rather unique method for solving traffic diversion problems. The method coincides with the traditional approach requiring similar input information which is travel times over the Turnpike (toll) and toll-free facilities, as well as a trip matrix. The major problem in using a diversion curve is to determine the turnpike path when the turnpike does not lie on the minimum path. Generally this has been accomplished by reducing the impedance on the turnpike links by one-half during calculation of trees. Forcing traffic to use the turnpike is accomplished in this way, but minimum path trees are usually very unrealistic. The Pennsylvania Statewide Study utilizes dynamic programming techniques in order to determine travel time over the Trunpike between traffic analysis zones. The necessary computation is based on the assumption that a Turnpike trip consists of two parts:

- From the origin zone to the Turnpike entrance.
- From the Turnpike entrance to the destination zone.

In order to force trips to use the Turnpike, at each Turnpike interchange a dummy centroid is coded together with turn prohibitors so that a tree built from a dummy centroid must enter the Turnpike. The Turnpike minimum path calculation is a two part process where minimum travel time is first calculated from an origin zone to all other zones (including dummy centroids). This method does not assume that trips will enter the Turnpike at the nearest interchange, but rather that trips will enter the Turnpike at interchanges which are shorter to arrive at by a non-turnpike route, rather than a Turnpike route. Interchanges where the tree enters the turnpike become possible "critical nodes". Next, minimum time paths from "critical nodes" are examined, and the cost from each critical node to a particular destination is added to the cost from the origin to the critical candidate. The costs are compared and the critical candidate having the minimum cost becomes the travel cost between these two zones via the Turnpike. Paths determined in such a way are no longer represented as a tree, so a method was devised to load trips using the turnpike. This was done by modifying the trip table in such a way that trips are loaded on the network between two points:

- between the origin and the critical node
- between the critical node and the destination

Most of the techniques for traffic assignment in urbanized areas for regional planning purposes are applicable for statewide study. The application of traffic assignment for system development, testing, evaluation and priority planning pertains in statewide study. In addition, corridor analysis is undertaken as well as necessary assignments to develop traffic volumes for design purposes. The information presented in this section was included to provide ideas as to work being done on a statewide basis which should prove useful to those contemplating such study.

APPLICATIONS TO NATIONAL STUDY

national planning

Transportation planning techniques for urban area study have been adapted for national transportation planning purposes by the U. S. Department of Transportation. The work has been accomplished for person travel as well as goods flow. This latter area may be of particular interest to those applying planning techniques to state and urban areas. For a more complete description of this work the reader is referred to two articles: "Developing A National Network Model of Intercity Freight Movement in the United States" (49) and "Nationwide Highway Travel" (50). Much of the material reported below has been gathered from these two articles.

The work accomplished on a national level is presented since a considerable amount of research and investigation of data sources was undertaken to allow development of person trip and commodity flow information to allow traffic assignments of both persons and goods to all modes of transportation. This information should prove valuable to those contemplating a statewide study of all transportation modes and who wish to consider goods flow as well as person movements.

purpose

The purpose of developing and utilizing national transportation networks and trip models for both persons and goods was to have an analytic tool with which the U. S. Department of Transportation could explore transportation issues and problems in support of policy and decision making on a broad national scale. The model permits investigation of system alternatives relative to:

- The size and nature of national modal systems.
- Levels of prevailing rates on regulated and nonregulated modes.
- Impact on travel as related to assumptions of the growth of the national economy.
- Inter-regional variations in economic growth and its effects on the relative growth of interzonal transportation demand.
- Technological advances.

Since the networks and models used are of an aggregate nature, all questions of local travel cannot be simulated. Also, the question of local access and delivery are poorly handled as well as are intermodal transfers. The model, as presently applied, ignores congestion effects and assumes an infinite supply of capacity over all modal networks.

National networks have been developed for highways, rail, pipelines, air and waterways. The number of links and miles in each network is shown in Table IV-9. Analysis is being done on intercity freight and passenger movements utilizing these networks. Much of the following discussion will be related to the freight movement work of the Department of Transportation.

The zonal system established for both person and freight assignments consists of 490 internal U. S. zones nationwide, consisting of each of the standard metropolitan statistical areas (1967) and aggregates of rural counties. There are an additional 43 centroids representing boundaries between the U. S., Canada, Mexico, and major ports on the coast. The process generally used in urban planning studies was used as the basis for coding each of the modal networks. The networks have several uses in the DOT work; they are used in developing the distances, times and costs for interzonal movements which are primary input into the mode choice model utilized. The network is also used in traffic assignment to route the simulated movements over the optimal paths in the network. Figures IV-9 and IV-10 show the highway and rail networks developed.

The highway network shown represents some 113,000 miles of facility including the entire Interstate System and other major arterial routes. The railroad network includes approximately 131,000 miles out of a national total of some 200,000 miles of main line mileage.

nationwide networks

The highway network links have distance and operating speed coded. The speeds are regionally based reflecting the slightly higher average speeds on western highways and the somewhat lower speeds in the densely developed northeast region. In addition, time impedances were added to the network at the urban area nodes to simulate the added times necessary to traverse such regions over free flow intercity speed times. The network coincides with the functionally defined principal arterial system defined by the states in 1968. Each link has coded its physical type (i.e., freeway, 4 lane divided, etc.) and a separate code describing the type of terrain (speed category) through which the link passes. These parameters are used in a table look up to define the operating speed on the link.

The railroad network has coded the number of tracks and type of signal system as well as the name of the railroad. These can be used for capacity calculations for the rail links. In place of a single impedance measure at the junction points, movement penalties have been developed into seven categories ranging from zero to 18 hours. One of these is used for movement prohibition, the remaining six are coded to each possible directional movement through the junction point. In addition, time penalties of 24 hours were added at nodes representing major rail classification yards.

The network development for the waterway system, including the inland river system, the intra coastal system, and the Great Lakes parallel those described for railroads and highways. The links include an average operating speed (coded by direction where currents prevail) and distance. The delays associated with locks are accounted for in the overall link speed.

The petroleum pipeline network is highly abstract and includes flow speeds and distances over the individual links. The air system has not been developed in a network form as has been for the other modes. Rather, times between zones are determined from a linear function of the straight line distance between them. Access times to the airports have been approximated and included in the intrazonal time matrix.

To provide some insight in the use of the networks in simulating national intercity freight movement, the following summary is presented. Figure IV-11 is a simplified flow diagram of the national network model. Trip matrices are developed for each of the modes of transport under investigation. These are eventually merged into total flow matrices without mode specification. Figure IV-12 describes the steps adopted for the synthesis of the interzonal freight trip tables. A very gross level of commodity detail is used primarily because it avoids much data manipulation. Commodities are coded into one of four groups as follows:

TABLE IV-9

NUMBER OF LINKS AND MILES IN NATIONWIDE NETWORKS

NETWORK	NUMBER OF LINKS (without centroid connectors)	NUMBER OF MILES REPRESENTED
RAIL	3272	131,000
HIGHWAY	4528	113,000
WATERWAY	1123	UNKNOWN
CRUDE OIL	892	UNKNOWN
REFINED PRODUCTS	1024	UNKNOWN

FIGURE IV — 9
NATIONAL HIGHWAY NETWORK (50)

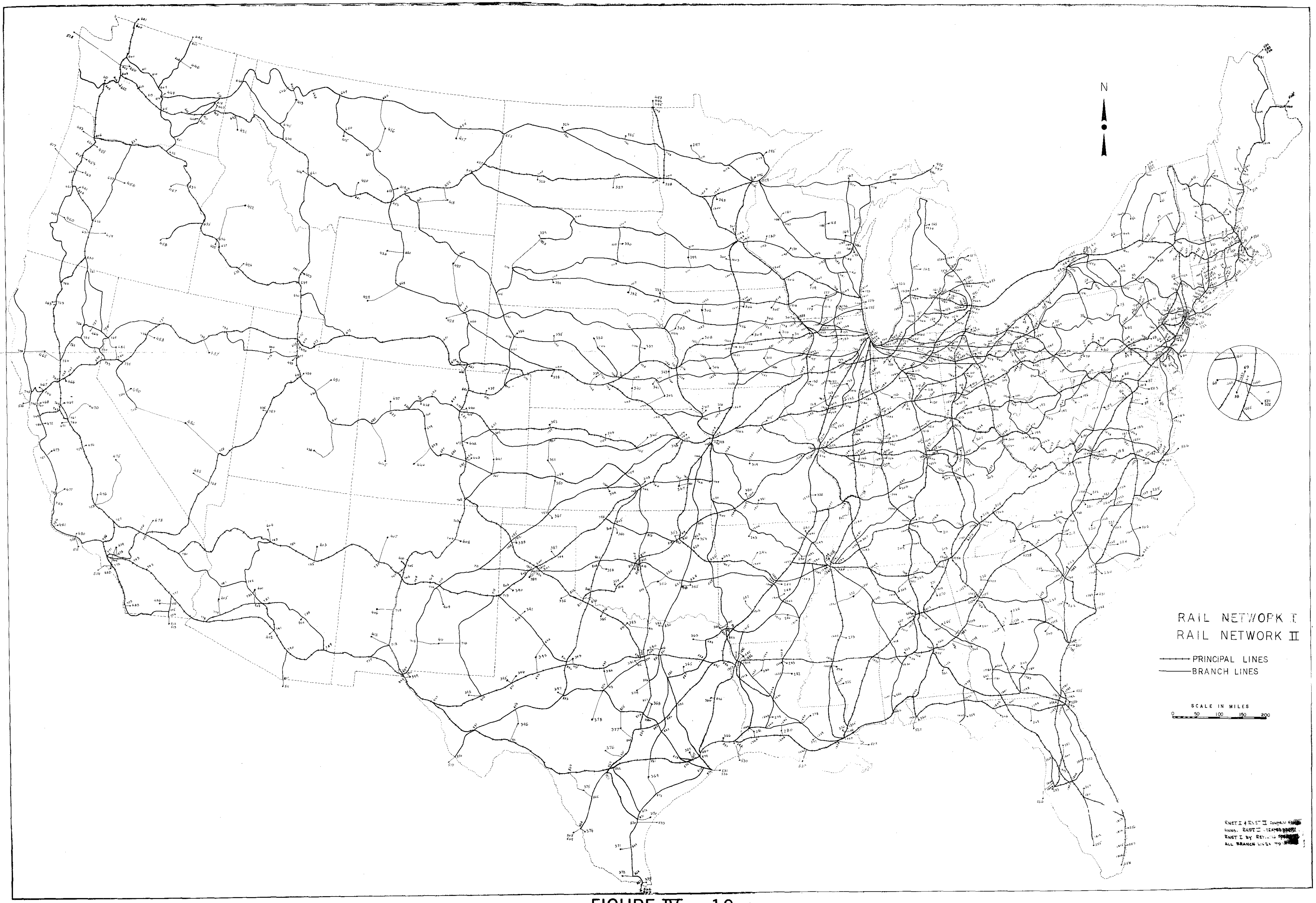


FIGURE IV – 10
NATIONAL RAILROAD NETWORK (49)

- Low value goods (with an approximate value less than $200/ton).
- Medium value goods (valued greater than $200/ton but less than $1,000/ton).
- High value goods (with an approximate value greater than $1,000/ton).
- Petroleum (crude oil plus the higher distillate products).

The products shown in Figure V-12 are eight trip tables, four (one for each commodity) for interzonal movements which are transported in small shipments arbitrarily selected as five tons or less, and four (one for each commodity) for movements which are limited to above five ton shipments. These eight trip tables are developed from four trip tables which describe total interzonal freight flows (regardless of shipment size) by commodity group. Information on intercity railroad freight shipments has been one of the more accessible and directly usable resources. The Interstate Commerce Commission has collected a one percent sample of rail waybills each year. The file for 1965 was manipulated into a form compatible with the four base matrices and expanded to the universe of rail movements and to the year 1967 based upon the observed growth rate in national rail activity.

There is no complete information on the movement of air cargo which could be used to directly establish desired interzonal trip tables. A simple modeling process was undertaken which utilized that partial data on domestic air cargo movement which was obtainable. The later data included a description of airport to airport air cargo movements for containerized freight only. In addition, Civil Aeronautics Board (CAB) published reports which include data on total air cargo activity at airports were used. From these data three statistical models were calibrated, one for the generation or origination of air cargo tonnage by zone, a second for the attraction or destination of air cargo shipments by zone, and finally a distribution model which linked the origins and destination of air cargo movement into interzonal flows.

By far the least satisfactory information available was for the motor carrier industry, including both for-hire trucking as well as private trucking. Two separate approaches are being pursued in developing the motor carrier trip tables. The first is centered about the synthetically derived intercounty motor vehicle trip table developed by the Federal Highway Administration. This table was recoded into interzonal motor vehicle trips and, by applying factors developed from roadside traffic classification counts, transformed into an interzonal truck trip table. The final step was to apply average truck carriage figures (from truck weight studies) to transform the truck flows into commodity flows for each of the four commodity groups. The assumptions, generalizations, and obvious weaknesses in this process do not require elaboration as they are large in number and probably result in major distortions. The second approach being investigated is the utilization of the sample of truck movements from the 1967 U. S. Census of Commodity Transportation. However, because the Census Bureau samples only manufactured goods, the resulting trip table must be supplemented with information on the flows of non-manufactured goods by truck which is proving to be a very difficult task.

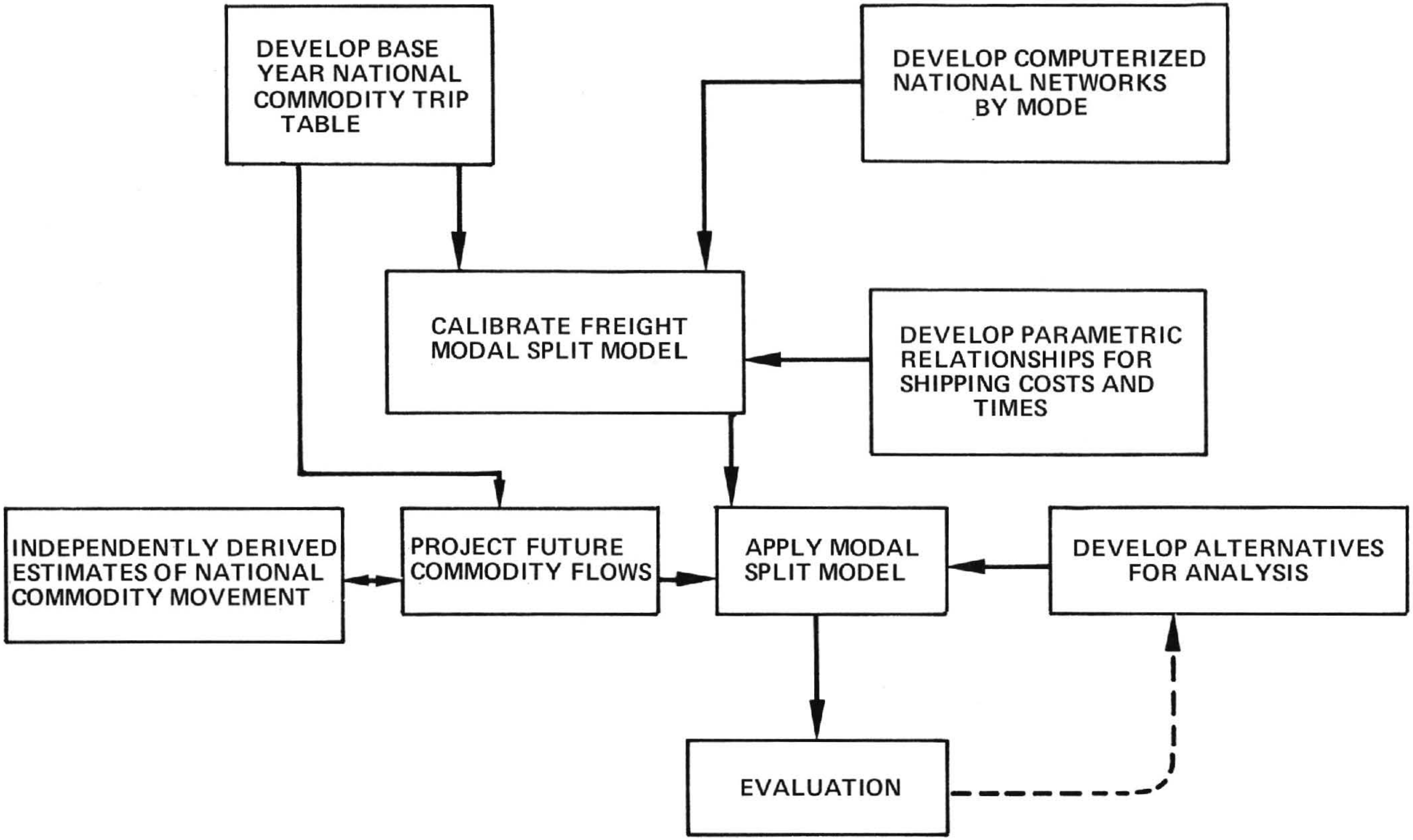


FIGURE IV-11

NATIONAL NETWORK MODEL(49)

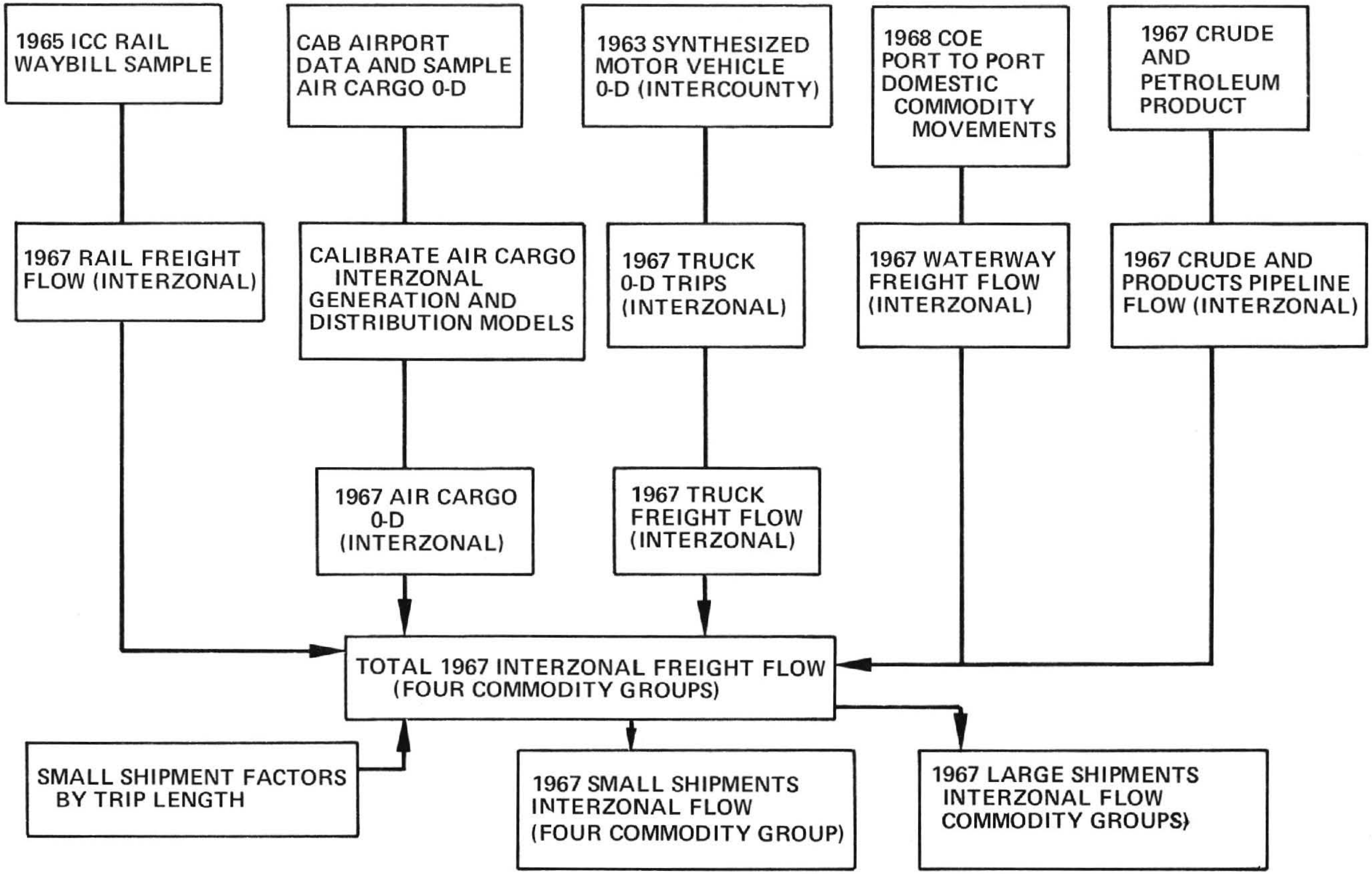


FIGURE IV-12

SYNTHESIS OF INTERZONAL FREIGHT TRIP TABLES (49)

The fourth input to the total freight trip tables is that of waterway commerce. This information was obtained in cooperation with the U. S. Corps of Engineers who collect information on the detailed movement of all domestic waterborne commerce on a highly detailed origin to destination bases. Summaries of these data are published yearly and constitute probably the best coverage of domestic freight movement of all the modes. The 1968 sample was recoded to the zones described previously as well as to the commodity groupings described yielding the four trip tables desired. These are factored to represent 1967 conditions.

There is scarce origin-destination information relative to the flow of crude petroleum and petroleum products carried by the extensive pipeline system in the United States. The U. S. Department of the Interior was able to supply state to state flows of crude petroleum. However, product origin/destination movements were only available on a highly aggregated basis, namely between five regions of the country, from the American Petroleum Institute. An approximating approach based upon a linear programming solution where the solution vector is a set of estimated flows on the pipeline system was applied. This yields zone to zone flows directly that satisfy the aggregate interregional flows and which minimize the total absolute error between the real flow on each segment of the pipeline and that estimated by the solution. Attempts to program and solve the problem were only partially successful due primarily to its large size which required certain compromises in the formulation. However the algorithm was used to get a feasible, but not optimal, solution which was then used as the basis for developing the final zone to zone flows for 1967.

The resulting intermediate modal trip tables are then merged into a single set of four trip tables, one for each commodity, of total domestic interzonal freight movement for 1967.

The purpose of this chapter was to present some applications of traffic assignment techniques to urban, state, and national planning functions. The ideas presented may be helpful to those using or planning to use assignment techniques on an urban or statewide basis.

CHAPTER V
PRODUCTS OF THE ASSIGNMENT PROCESS

The purpose of this chapter is to describe the evaluation of traffic assignment results - the checks made, the statistical measures used, and the levels of precision obtained - as well as the considerations necessary in presenting traffic assignment results.

The discussion presented assumes that the traffic assignment procedure being used has been calibrated and that the evaluation techniques and statistical measures presented are applied after a suitably calibrated network has been obtained. The calibration process has been discussed previously. Generally, the calibration process consists of obtaining traffic assignment volumes which match as closely as possible the volumes obtained from ground counts for existing conditions. A calibrated network should result from a proper zone-network relationship and minor adjustments of link impedances.

EVALUATION OF TRAFFIC ASSIGNMENT

Traffic assignment techniques must be evaluated to determine their ability to reflect reality. This is also the case with other modelling techniques such as trip distribution and modal split. Quite often traffic assignments are used to check other data and models such as O-D surveys and distribution model output by accumulation of assignment volumes across screenlines and in major corridors. Sometimes these checks are assumed to be for verifying the assignment results rather than the items really being checked. A great amount of care must be exercised so that one is quite sure he is actually checking traffic assignment accuracy when these checks are made.

The ability of asiignment techniques to reflect reality is generally accomplished by comparing assignments made with the most accurate travel information available (origin destination triptables) against the best estimates of actual traffic volumes on the assignment network. It is most important that the sources of error in both the base being used for checking (ground counts) and the travel estimates used as input to the assignment technique be known as accurately as possible.

Current practice in many studies calls for comparison of assigned base data with ground count information. These checks are generally:

Individual Link checks
Checks along routes (smoothing of individual link values)
Vehicle miles of travel checks by facility type and/or area
Major Screenlines and gridlines
Corridor checks - cutlines
Root-mean-square errors by volume group or along routes

<u>assignment checks</u>

These same types of checks are made for trip distribution model calibration, checking origin-destination survey results, as well as, for calibrating and checking traffic assignment techniques.

Obviously, the most critical check of assignment results would be comparisons of assigned volumes with ground counts on individual link segments. Here, it is most important that the counts be accurate and that count errors be known.

assignment checks

Checks along routes are usually preceded by the smoothing of assignment results for individual links along the route and the development of vehicle miles of travel for the facility from ground counts as well as from assignment results.

A less detailed check results in summarizing counts by facility type and developing vehicle miles of travel by facility type from both assignment results and counts. In addition, a geographic distribution of these summaries would insure that the checks are not being overly smoothed by compensating errors between areas. Some facility distributions that have proven valuable are as follows: 1) Access controlled, other principal arterials, minor arterials, 2) Freeway, expressway, major arterial, minor arterial, turnpike; 3) Major arterials, minor arterials. Some geographic stratifications that have been used include: 1) Central business district, inner city, outer city, inner suburbs, outer suburbs; 2) Rings, sectors. Checks may be made across segments of gridlines where assignment volumes are summed and compared with the summation of ground counts. This check is similar to corridor checks where a number of cutlines along a corridor are checked. See Figure III-7 for an illustration of gridlines and cutlines.

count accuracy

An attempt should be made to estimate the errors in counts used for checking. There are several sources of error that should be considered in evaluating counts, these include:

- Errors in counters
- Errors due to sampling technique used
- Errors due to sampling in time

With a properly established counting program, it should be possible to obtain areawide average traffic counts which have less than ± 5% error of estimate on the 68 percent confidence limit. This degree of accuracy is acceptable for evaluating traffic assignment results.

sources of error in assignment

The traffic assignment process has errors related to input data as well as errors related to the assumptions used for assignment. The characteristics which affect assignment results include:

- The selection of optimum routes based upon one impedance value only, such as, speed, distance, or cost.
- The use of a single impedance on each link to represent all variations in daily conditions, or at best 3 sets of impedances to represent A.M. peak, P.M. peak, and total daily conditions.
- Use of a single route (all-or-nothing) assignment or one that tries to assign to alternate routes.
- The loading of trips to and from single points (centroids) representing activity (zones) areas.
- The striking of a balance between zone size and network extent to bring intrazonal travel into some balance with the part of the street network not represented in the assignment system.
- Sampling errors inherent in the O-D survey trips or errors in the distribution model trips used for assignment. A set of curves that can be used to estimate the error in O-D survey trips is shown in Figure V-1.

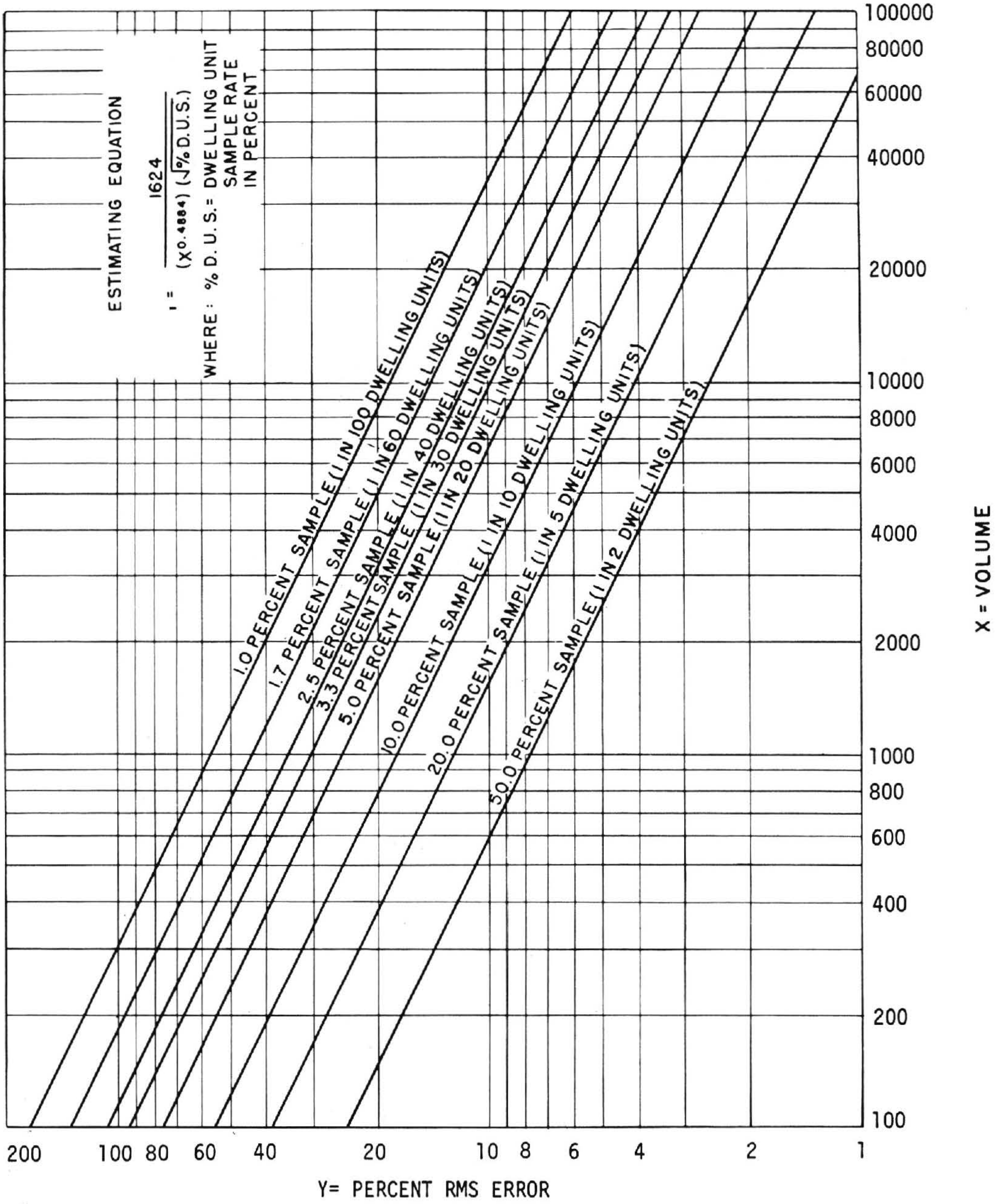


FIGURE V-1

RELATIONSHIP OF PERCENT ROOT-MEAN-SQUARE ERROR AND VOLUME FOR VARIOUS DWELLING UNIT SAMPLE RATES (58)

- Use of the same network for different vehicle types (i.e. trucks, taxis and autos) all assumed to use the same minimum path.

STATISTICAL MEASURES

Generally, five measures have been used to compare traffic assignment results with traffic counts for evaluation purposes. These five methods for measuring accuracy are:

1. A comparison of total counted volume to total assigned volume across some aggregation such as total study area, sub-area and/or facility types, or screenlines, gridlines and cutlines.

<u>statistical measures for assignment checks</u>

2. A comparison of total vehicle miles of travel (VMT) from ground counts to vehicle miles of travel from the assignment results. VMT is calculated by multiplying each link length by either the counted or assigned volume and summing these across some aggregation such as total area, sub-area, and/or facility type, specific route in a corridor, or by volume group.

3. The developing of the total weighted error between ground counts to assigned volumes at some level of aggregation. Reference should be made to Table V-1 for an explanation of this measure. The total weighted error is the summation of the individual weighted errors computed for each sub group (in the example shown, the sub-groups are volume ranges).

4. The calculation of root-mean-square (RMS) errors comparing ground counts and assigned volumes by link within the stratification chosen for comparison, i.e., total area, sub-areas, facility types, etc. Root-mean-square error is calculated by the equation:

$$RMS= \sqrt{\frac{\sum_i (Xgc - Xta)^2}{N-1}}$$

where: X_{gc}= ground count on Link L_i

X_{ta}= Volume assigned to Link L_i

N = Total number of links in aggregation group

i = 1 through N

The root-mean square error measures the deviation between two distributions, in this case traffic volumes. The percent RMS error is derived by dividing the RMS error by the average group count for a particular group.

RESULTS OF FIRST LOADING - ①

② TOTAL MEASURED VOLUME 1,777,278
③ TOTAL ASSIGNED VOLUME 1,515,252

④ AVERAGE PERCENT ERROR IN ASSIGNED VOLUME -14.7

ERROR BREAKDOWN, LATEST LOADING

⑤ VOL GROUP	⑥ NO. SECTS	⑦ AV COUNT	⑧ AVE DIFF	⑨ STAN DEV	⑩ PC STAN DEV	⑪ PC OF TOTAL	⑫ WEIGHTED
00-1/2	2	436	+ 718	189	43.3	.0	.0
1/2-01	3	686	+ 333	303	44.1	.1	.0
01-02	9	1,786	- 147	1,054	59.0	.9	.5
02-03	11	2,512	- 1,000	1,897	75.5	1.6	1.2
03-05	22	3,876	- 1,002	2,502	64.5	4.8	3.0
05-10	56	7,318	- 1,501	3,948	53.9	23.1	12.4
10-15	25	11,840	- 589	3,618	30.5	16.7	5.0
15-20	24	17,501	- 1,090	6,136	35.0	23.6	8.2
20-25	5	22,561	- 3,867	6,621	29.3	6.3	1.8
25-30	2	27,407	-11,775	16,672	60.8	3.1	1.8
30-up	10	35,186	- 6,230	11,964	34.0	19.8	6.7
TOTAL	169	10,516	- 1,550	4,846	46.0	100.0	40.6 (13)

(2) Summation of Ground Counts by Link
(3) Summation of Assignment Volumes by Link
(4) $\frac{1,515,252}{1,777,278}$ - 100=-14.7
(5) An Aggregation Level
(6) Number of Sections in Volume Group
(7) Average Ground Count in Aggregation Level.
(8) Amount Average Assigned Volume is greater than average Ground Count.
(9) The Standard deviation of the difference between the average Ground Count and the average assigned volume. For the volume group 0-500, the value 189 for the Standard deviation means that the average difference between the average ground count and the average assigned volume falls between 718± 189, two thirds of the time.
(10) Standard deviation divided by the average ground count.

(11) The percent the summation of ground counts within a row is of the total counts on all links. For example in volume group 10000-15000, this value is (25X11,840)/1,777,278=16.7%
(12) Percent standard deviation multiplied by the percent of total.
(13) Summation of individual weight of errors.

TABLE V-1

ERROR MEASURES USED FOR CHECKING ASSIGNMENT RESULTS. (51)

5. A graphic comparison of ground counts versus assigned volumes. The type of measures and checks made can be summarized to various levels of aggregation, including:
    - Total Area
    - Volume Groupings
    - Facility Types
    - Geographic Location
    - Specific routes
    - Geographic aggregations
    - Combinations of the above

VMT

Table V-2 shows an example of the comparisons that can be made between assignment VMT and counted VMT by functional type, within sectors of an urban area, and within ring. As shown, total vehicle miles of travel from the assignment is 98.8% of total VMT from counts, indicating that the travel data have been adjusted to represent close to 100% of all travel and that the assignment technique has been properly calibrated. The high type facilities indicate an overload. Sector VMT's appear to be within 10% except for sector 0. There is greater variation in comparisons by ring.

Table V-3 compares assigned VMT to actual VMT by ring and link type. This table shows that VMT across the entire area checks within 1%. Primary arterial VMT checks by ring are within a maximum error of 6.2%, secondary arterials check within a maximum difference of 31.3%, and ramps within a maximum error of 60.0%. Within rings, the largest difference is 5.2% (ring 4). Within facility type, the largest difference is 9.9%. This type of table is valuable for checking assignment results by area type and facility type combined. Similar tables can be prepared comparing assigned volume and counts by stratifying by jurisdiction and functional class, ring-sector and functional class, or area type and functional class.

cutlines

A more stringent check of assignment results is to compare actual volumes without conversion to VMT. The State of Ohio has developed a set of comparisons made for most of their studies. Table V-4 shows comparisons of link volumes across some of the cutlines used (corridors) in the Cleveland Area. The location of the corridors are shown in Figure V-2. As can be seen, the corridor comparisons vary from a value of 93.7% to 150.2%.

RMSE

Many studies compare assigned volumes to ground counts on a link by link basis utilizing the root-mean-square analysis for providing summary statistics (see Table V-5). Generally, this comparison is accomplished in volume ranges, but may be done by functional classification, area type, administrative class, or any other aggregation. The paper "Report on the Accuracy of Traffic Assignment When Using Capacity Restraint" provides excellent examples of checks that can be made (51). It also provides an indication of the accuracy of results that may be obtained from traffic assignment techniques.

The root mean square error analysis results may be plotted on the curves representing the O-D survey accuracy shown in Figure V-1. Comparison of the % RMS error from the assignment check with that inherent in the O-D survey will provide an indication of the assignment error caused by the travel survey data.

TABLE V-2

VMT ANALYSIS FROM FIRST RESTRAINED ASSIGNMENT (4 ITERATIONS)

Analysis Base	Assigned VMT	Count VMT	Percent of Control Total
Total	20,553,451*	20,811,723**	98.8
Functional Link Type***			
Freeway	2,888,517	2,530,271	114.1
Expressway	352,054	352,574	99.9
Major Arterial	11,168,722	11,325,109	98.6
Minor Arterial	4,736,582	6,024,145	78.6
Turnpike	786,120	498,019	157.8
TOTAL	19,931,995	20,730,568	96.1
Sectors			
0	510,393	661,211	77.2
1	3,148,349	2,870,654	109.7
2	2,473,738	2,296,925	107.7
3	1,572,544	1,494,307	105.2
4	1,239,061	1,116,836	110.9
5	1,207,450	1,308,517	92.3
6	2,425,138	2,674,391	90.7
7	2,299,521	2,369,412	97.1
8	2,868,561	2,951,384	97.2
9	3,747,262	3,484,310	107.5
Ring			
0	510,393	661,221	77.2
1	879,348	999,434	88.0
2	2,036,491	1,946,666	104.6
3	3,953,780	3,527,085	112.1
4	5,090,091	4,211,411	120.9
5	4,016,004	4,014,294	100.0
6	4,329,138	5,004,303	86.5
7	676,772	863,543	78.4

*Without local streets.

**Without through turnpike volumes.

***Ramps and special facilities are not included. Differences in percentage figures are related to inclusion of only those ramps with actual traffic counts in count total and all ramps in assigned totals.

SOURCE: Ohio Department of Highways

TABLE V-3

TRAFFIC ASSIGNMENT COMPARISONS BY RING

	Primary Arterial			Secondary Arterial			Ramps			Total		
Ring	Counts	Assign.	% Diff.	Counts	Assign.	% Diff.	Counts	Assign.	% Diff.	Counts	Assign.	% Diff.
0	1136	1119	1.5	166	159	4.2	80	85	-6.2	1382	1363	1.4
1	3367	3159	6.2	740	860	-16.2	85	136	-60.0	4192	4155	0.9
2	4215	4127	2.1	1327	911	31.3	501	752	-50.1	6043	5790	4.2
3	15761	15359	2.6	3407	3577	-5.0	4365	4365	10.2	23533	23746	-0.9
4	6895	7265	-5.4	1552	1797	-15.8	1787	1708	4.4	10234	10770	-5.2
TOTAL	31374	31029	1.1	7192	7304	-1.6	6818	7491	-9.9	45384	45824	-1.2

All VMT's divided by 100

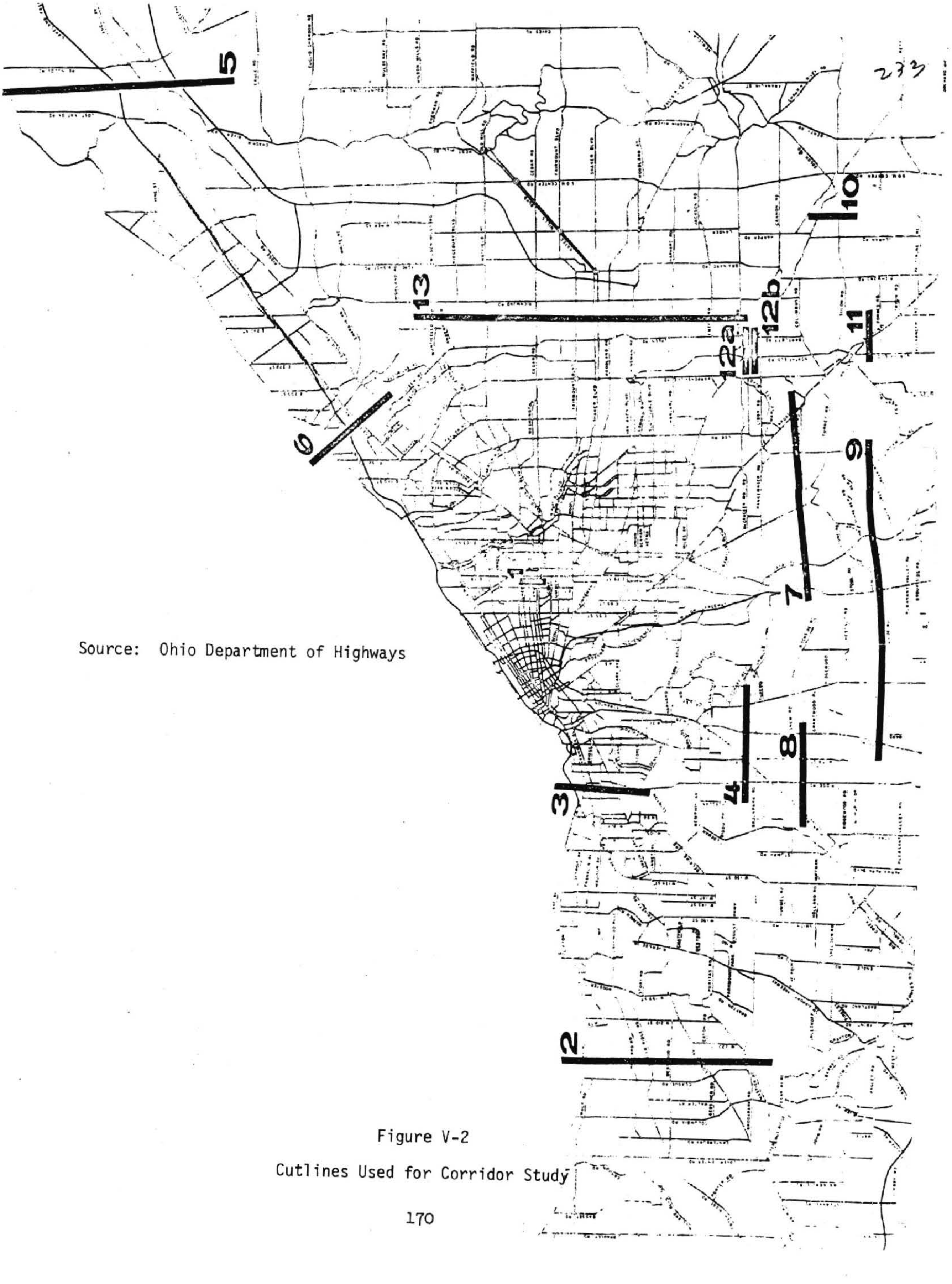
Source: Ohio Department of Highways

TABLE V-4

CORRIDOR CHECKS

Source: Ohio Department of Highways

Corridor Number	Street	Assigned Volume	Ground Count	Percent of Control Total
1	Chester	29,533	32,900	
	Euclid	11,924	19,200	
	Carnegie	16,550	13,400	
	Cedar	17,675	13,400	
	Total	75,682	78,900	95.9
2	Lake Avenue	21,335	17,800	
	Detroit	15,683	12,050	
	Hilliard	11,016	11,500	
	Center Ridge	9,278	11,600	
	West Wood	5,270	3,800	
	Lorain	20,792	19,900	
	Brookpark	17,763	16,100	
	Mastick	6,077	5,200	
	Total	107,214	97,950	109.5
3	Shoreway EB	39,302	35,600	
	Shoreway WB	50,188	35,600	
	Detroit	21,066	21,400	
	Franklin	10,941	9,000	
	Madison	13,492	9,600	
	Lorain	26,139	17,300	
	Clark	12,911	17,250	
	Denison	28,165	26,000	
	Total	202,204	171,750	117.7
4	Ridge	22,537	23,000	
	Pearl	19,835	32,500	
	State	23,488	18,700	
	Broadview	20,509	18,000	
	Total	86,369	92,200	93.7
12A	Warrensville	22,759	16,000	
	Northfield	33,898	21,100	
	Aurora Road	24,466	16,900	
	Total	81,123	54,000	150.2



Source: Ohio Department of Highways

Figure V-2

Cutlines Used for Corridor Study

TABLE V-5

R. M. S. Analysis: O/D Assigned Volumes Versus Observed Volumes

No. of Links	Link Volume (OBS.)	V_O	$\Sigma(V_O-V)^2$	Absolute R.M.S.	Percent R.M.S.
17	$<$ 5,000	46,756	51,745,241	1740	63.2
17	5,000-9,999	124,285	255,967,617	3885	53.0
5	10,000-14,999	60,580	54,934,380	3310	27.3
4	15,000-19,999	64,951	63,403,749	3980	24.3
5	20,000	130,508	156,097,920	5590	21.4
48	Totals	427,080	582,148,907	3485	39.2

V_O = observed volume
V = assign volume

Source: Ohio Department of Highways

The experience of another State has shown that a simple but effective check for network assignments using ground counts can be made by tabulating the number of links by facility type, ADT range and assignment volume-to-ground-count ratio group. For example, the tabulation would indicate the number of expressway links with ADT's greater than 30,000 that have assignment-to-ground-count ratios between 0.75 and 1.25. This same approach could be used in judging the effectiveness of network calibration.

PRECISION OF ESTIMATES

It is difficult to establish desired levels of precision to be obtained in the traffic assignment process. There are differences in accuracy of trips assigned, network parameters used, techniques applied, size and level of network coded, and geographic area covered.

levels of precision

In developing levels of precision by comparing existing traffic volume counts and assignment volume results, one should keep in mind that errors found are based upon assignments made where ground counts are available as a base toward which one works in calibrating the assignment model. In this calibration, the assignment model is adjusted so that it can reproduce the vehicular traffic that is taking place as accurately as possible. It is then assumed that the same type of assignment procedure may be used to allocate future trip interchanges to a future transportation system in a reasonable manner. The ground count base, however, is not available for future year assignments. One hopes that the accuracy of future year assignment, barring variations in trip forecasts, is similar in accuracy to that developed for the base year.

A number of cities have been examined where statistics comparing ground counts and assigned volumes have been developed (51). This was accomplished to compare changes in accuracy due to application of the capacity restraint technique. Considering that capacity restraint is a useful tool in providing accurate assignment results, the work provides insight into accuracies of traffic assignment. The results of the work indicates that the best way to determine the accuracy of the assignment process is a graphic presentation of the results on a link-by-link basis on a network map. However, the root mean square (RMS) error computed by volume range is a good method of summarizing assignment error since it provides an indication of errors in individual link sections. In addition, the "percent standard deviation" is approximately equal to the % RMS error and was used to report results for ten cities. The percent standard deviation for a volume group represents, for all practical purposes, the standard deviation of the differences between the average ground counts and average assigned volumes in that group, divided by the average ground count. For example, if a volume range 1-500 has a standard deviation of 189 (referring to Table V-1) and the average difference between the average ground count and assigned volume was + 718, then the average difference between the average ground count and the average assigned volume falls between 718 ± 189, two thirds of the time. The percent standard deviation would be 189/$43\overline{6}$ or 43.3% (where 436 equals the average count). Table V-6 presents the percent standard deviation by volume group for ten cities.

Table V-6 shows that assignment accuracy is best (in terms of percent standard deviation) at the high volume ranges where errors in the 12-15 percent range are achievable. Presumably at the much higher volumes (i.e., 60,000-100,000 VPD) errors less than 10% can be achieved. At the low volume end very high errors appear to be the rule, generally running over 100 percent. Fortunately, not too much design or major traffic improvement work are done at these low volumes using assignment results. Generally, it can be seen that the error in assignment is quite large for volume groups up to about 5000 vehicles per day; the error obtained for volumes greater than 10,000 is considerably less. For additional indications of the accuracy of traffic assignment the reader is referred to Figure and Tables in the previous section, "statistical measures".

Although it is difficult to establish desired levels of accuracy which all practitioners should strive for, it is important that desirable accuracy levels be established by each practitioner relative to the use to be made of the assignment results. For design purposes, for example, an accuracy should be achieved which would not cause a difference of one lane in the design due to inaccuracies of the assignment results. Work done for the NCHRP by Creighton, Hamburg Planning Consultants (34) provides insight into the effect of assignment inaccuracy on the design process. Figure V-3 shows the one direction design hour volume ranges within which four, six, and eight lane urban freeways are required for design levels of service C and D. Each plateau on the curves can be separated into zones where the number of lanes is either sensitive or insensitive to the design hour volume. As an example, there is little problem in specifying six lanes providing level of service C when the estimated DHV is 4000 (the midpoint of the plateau) since the DHV could be in error by ± 25% without changing the lane requirement. However, if the DHV were near the extremes of the range (3200 or 4800) a very small error could result in under or over design by one lane in each direction.

assignment
accuracy
& design
volumes

Figure V-4 further strengthens this idea. It shows zones of sensitivity and insensitivity at level of service B for 10 percent, 20 percent, and 50 percent estimation errors. These areas of insensivity are determined by finding the segment of each line shown in Figure V-4 where an error in traffic volume would not cause a selection of either one lane less or more than required. In the sensitive areas the wrong number of lanes might be selected. By summing the lengths of the insensitive and sensitive sections along each estimation error line, one can find the proportion of cases where the number of lanes is either sensitive or insensitive to the estimation errors. If one assumes that traffic estimates are likely to occur all along the volume level shown (0-5000 VPH), it could be inferred that for a 10% estimation error the number of lanes is sensitive in 35% of the cases and insensitive in 65% of the cases; at a 20% error the lane numbers are sensitive in 67% of the cases; and at a 50% error the number of lanes is sensitive in 87% of the cases. It is desirable to keep error low, since this decreases the number of decisions that must be made in sensitive areas.

An approach that might be used to establish desired accuracy would insure that the design would not be off by more than one lane due to the errors in the traffic estimates. Table III-3 shows an example of urban design criteria and standards calculated on the basis of some assumed values of directional factors, peak hour factors, etc. Assuming the decision is made to build the

TABLE V-6-PERCENT STANDARD DEVIATION BASED ON THE RESULTS OF AVERAGING FOUR LOADINGS (51)

	Percent Standard Deviation by Volume Group											
	00-1/2	1/2-01	01-02	02-03	03-05	05-10	10-15	15-20	20-25	25-30	30-UP	Total
Salem	76.2	49.5	41.9	31.3	37.6	33.8	32.8	21.7	59.7	-	-	41.8
Sioux Falls*	132.8	156.8	107.5	56.4	54.6	38.7	36.6	-	-	-	-	49.1
Green Bay	62.9	55.4	62.2	71.6	58.8	46.7	38.9	29.3	15.2	-	-	49.4
Madison	199.6	99.4	61.1	42.7	36.4	30.9	25.6	18.1	12.7	7.0	14.8	30.9
Tucson*	138.0	91.6	124.3	79.1	44.3	36.6	34.2	39.6	21.3	21.7	-	47.7
Salt Lake**	485.4	212.9	88.0	50.7	43.6	34.0	20.8	32.0	30.3	15.9	12.2	38.0
Honolulu	141.4	120.0	98.6	51.1	63.1	54.4	52.1	25.0	35.1	34.0	36.7	53.5
Portland*	256.4	152.7	126.8	68.6	61.5	48.8	39.7	32.5	31.3	29.1	53.1	55.3
Atlanta	63.3	68.8	77.3	59.0	45.4	40.5	27.0	26.5	27.5	42.4	36.1	39.0
Denver*	817.4	315.4	174.9	97.5	75.6	53.1	31.8	23.3	26.3	25.5	16.0	44.4

*Average of 3 loadings

**Average of 5 loadings

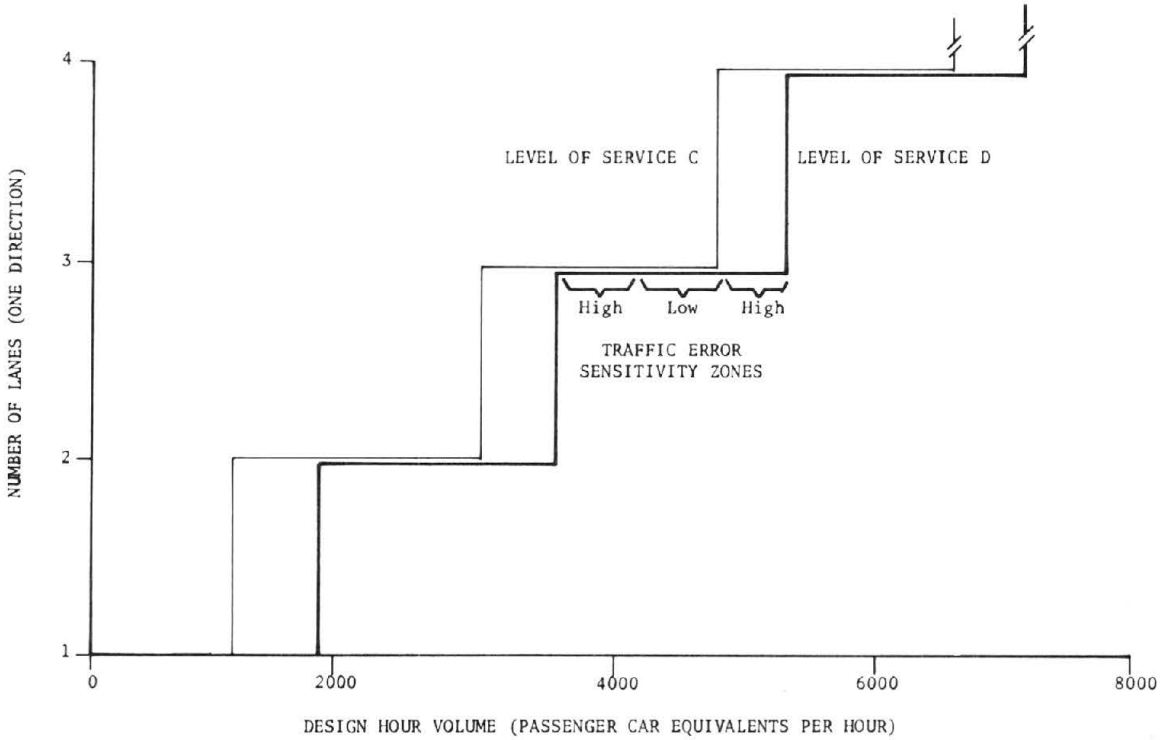


FIGURE V-3

Traffic lane requirements for given design-hour volumes on urban freeways. (34)

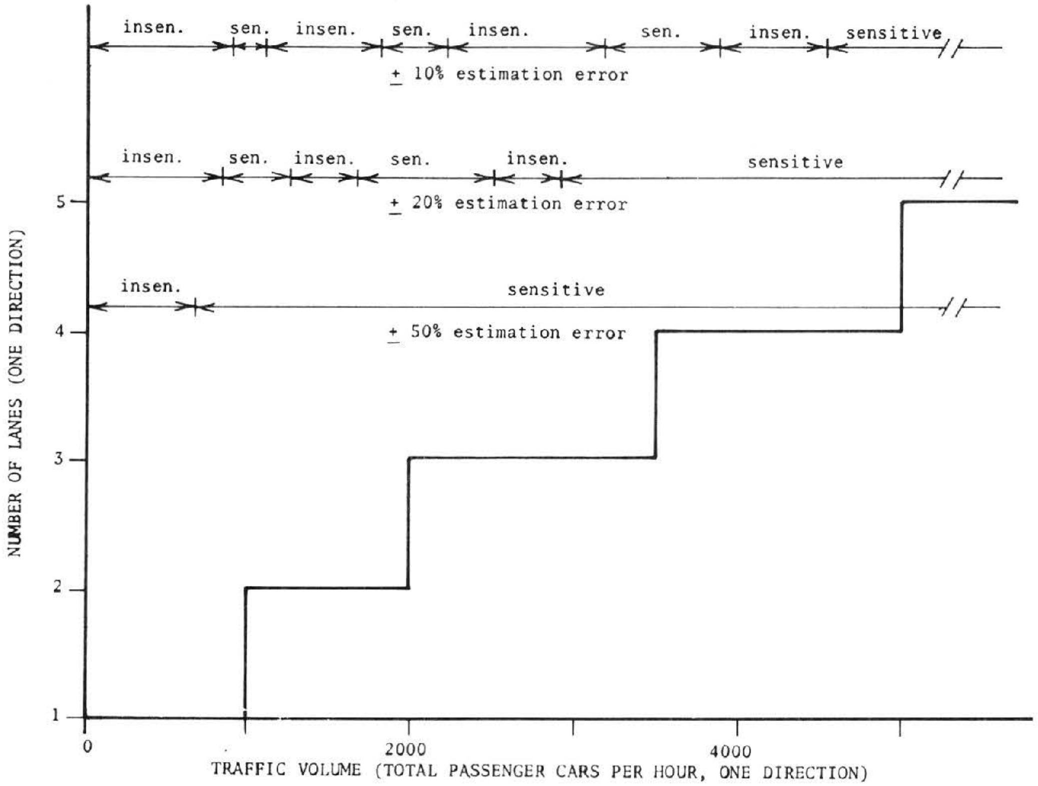


FIGURE V-4

Number of lanes versus traffic volume for level of service B. showing sensitive and insensitive zones. (34)

TABLE V-7

Percent Error in Assignment Results Related to ADT

Functional Class	Number of Lanes	ADT Range (000's)	± % from ADT	ADT
13	8	80-105	13	92800
12	6	55-80	18	67600
11	4	30-55	29	42600
10	6	33-43	13	38300
9	4	23-33	28	28300
8	6	27-36	17	31800
7	4	16-27	25	21200
6	6	20-28	17	24800
5	4	12-20	27	15700
4	6	------	--	-----
3	4	9-18	34	13600
2	4	8-13	27	10250
1	2	2-8	56	4850

the number of lanes indicated by a range on either side of each ADT, equal to one-half the difference from the next ADT, the values shown in Table V-7 can be derived and are also plotted in Figure V-5. This result would indicate that to be no more than one lane off in a design, the following average errors would apply:

Volume Range (000's) (ADT)	Error in Volume - %
5-10	35-45
10-20	27-35
20-30	24-27
30-40	22-24
40-50	20-22
50-60	18-20
60-70	17-18
70-80	15-16
80-90	14-15

Referring to Table V-6 showing results from ten studies, it can be seen that many studies achieve the accuracy shown above and in some cases do considerably better.

PRESENTATION OF RESULTS

The traffic assignment process results in large amounts of output data in the form of system loads. These system loads must be reviewed in relation to the system established, input variables, such as, speed and capacity and in relation to loads obtained from alternate systems. Assimilation of assignment results varies with the type of output media (i.e., tabulations, graphical plots, system plots on a link by link basis) as well as with users of the data.

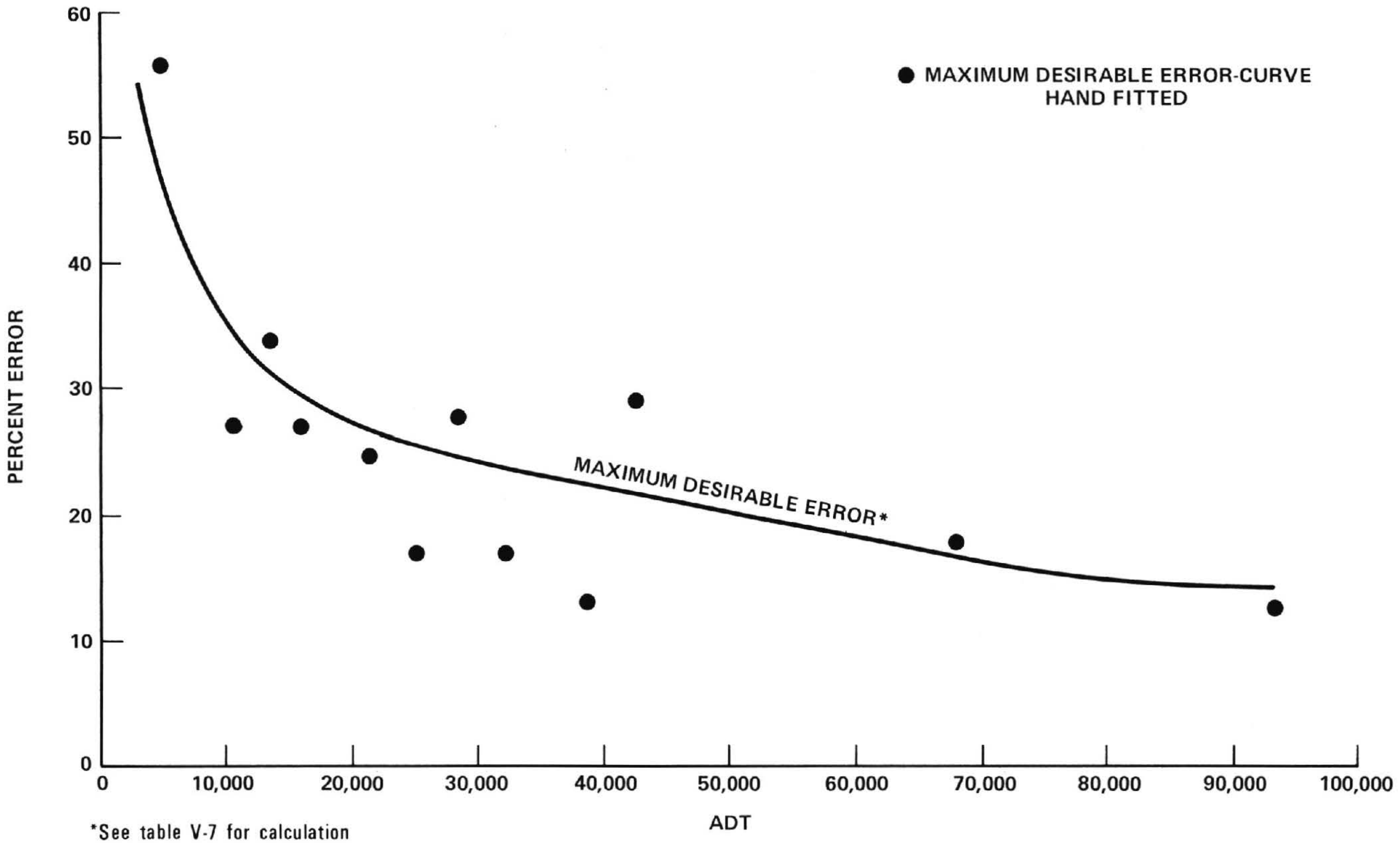
Users of Results

users of O/P

The users of traffic assignment results include urban transportation planning and operating agencies, other public planning and operating agencies, decision makers in government, the public and private business firms. These users generally require differing forms and levels of output media. The output may be used for:

- Reporting and presentation
- Analysis
- Supplying modified input to modeling procedures

Decision makers require information which is in highly summarized form, and can be used by the decision maker in presentations to others such as at public hearings. In addition, the output should be available to meet quick reaction type of requests. The output medium must provide concise summary information amenable to quick visual interpretation. The types of output generally desired



*See table V-7 for calculation

FIGURE V-5

PERCENT ERROR IN ASSIGNMENT RESULTS RELATED TO ADT include: geographic data displays (i.e., map presentation of data based upon coordinates associated with the data); histograms; bar charts; and other visual aids for presenting relationships between data.

The analyst generally requires more detailed output. He must be able to evaluate detailed results. He requires well organized tabulations as well as detailed network geographic display. He should be able to obtain a wide variety of data organizations, whether in tabular or geographic form.

In this report, little discussion will be presented relative to tabular reports. Generally tabular reports must be tailored to the needs of the user. The various computer systems available generally provide information for the analyst on both a detail link by link basis and in summary statistics, such as, average network speeds, vehicle miles of travel, etc., summarized either for the entire area or in accordance with user specifications for area types, functional or other classifications, volume ranges, etc. Most computer systems provide well designed tabular reports which are most useful for the analyst. Tabulations or summary reports for others, such as, administrators, reports to the public, etc., generally are made from the detail information. Most are done manually from the more detailed computer output. Some users of traffic assignment procedures have produced their own programs for summarizing assignment results for use by others.

computer O/P

Display of Assignment Results

Traffic assignment results basically consist of computer generated traffic volumes on the various sections of facility on a network. These traffic volumes can be analyzed on a link by link basis, as well as by reviewing summary statistics by facility type and/or area. In addition, other values, such as capacity, are compared with the resultant assignment volumes and these comparisons viewed on a link by link basis or on a summary basis. Graphical display may include the following:

- Geographic data display on a link basis; i.e., map presentation of data.
- Histograms, bar charts, and other visual aid for presenting relationships between data; i.e., the changes in speed by facility type due to capacity restraint application.
- Geographically and relationship coordinated displays such as stick diagrams which, due to recent developments in plotting software, may now be visually represented by "three-dimensional" perspective views; i.e. presentation of vehicle miles of travel by geographic location (ring, sector, etc.). An example of such a diagram is shown in Figure V-6.

graphical display

Many types of geographic data display on a link by link basis have been produced. Examples are:

- Links annotated with directional volumes
- Links annotated with non-directional volumes
- Links annotated with volumes and with capacities
- Links annotated with volumes from two sources (e.g., O-D volumes as well as Gravity Model Volumes).
- Links annotated with or plotted with color representing the ratio of two values, such as, volume/capacity.

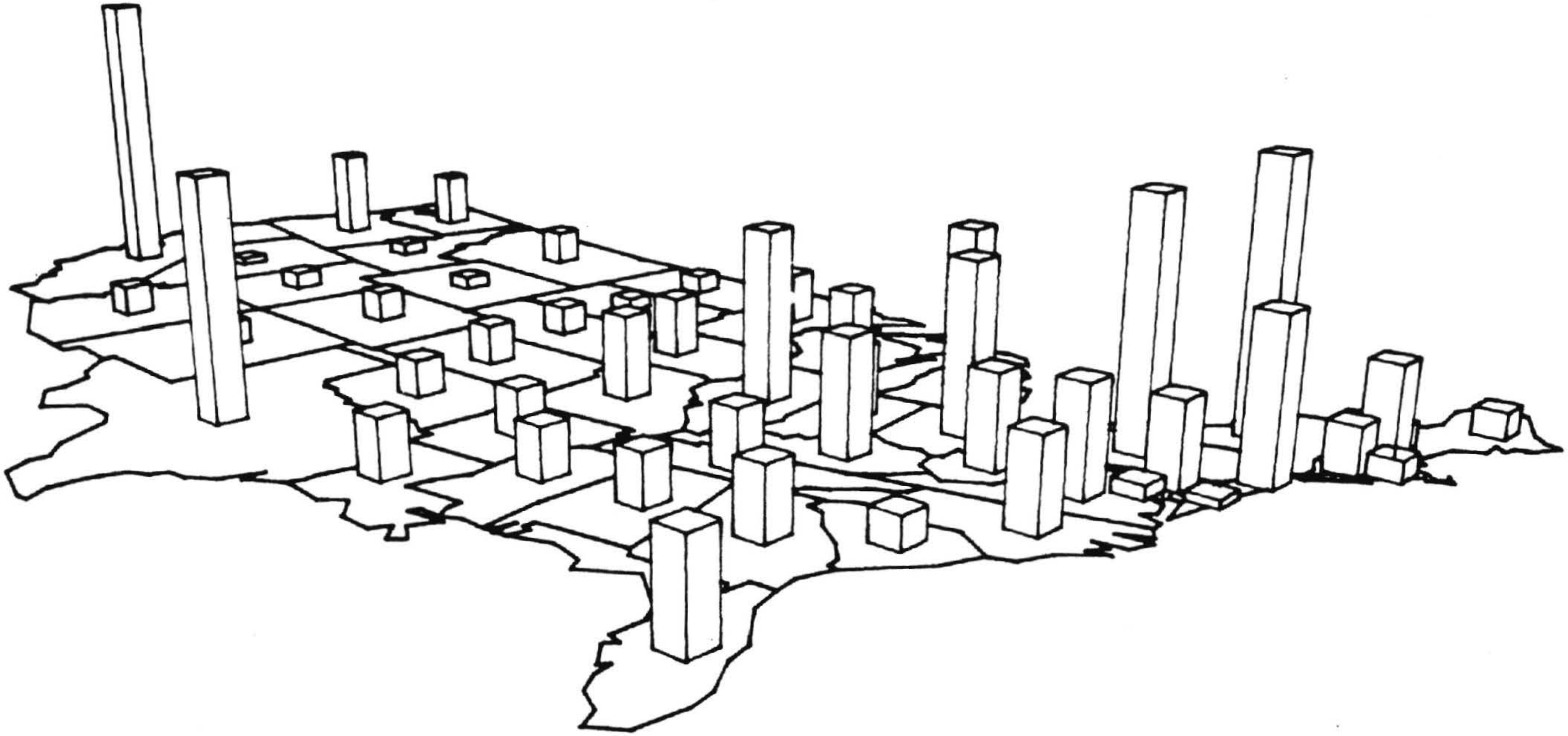


FIGURE V-6

PLOTTER PRODUCED STICK DIAGRAM

Source: Creighton, Hamburg, Inc.

graphical display

- Volumes shown in bandwidth form (width of band proportional to volume, either "open" or filled in solid).
- Bandwidth plots showing (say) capacity on one side of the link, assigned volume on the other.
- Links shown in up to six or eight different colors where each color represents a range of volumes.
- Color groupings combined with bandwidth.

The above types of graphical representation might be produced for an entire system or only for some portion of the system. Selected criteria might include plotting only those links that are over capacity or resultant speeds after capacity restraint below some set value. Perhaps only volumes are desired for certain classifications of facility; i.e., freeways, or in selected geographic locations throughout an area.

The above list certainly is not exhaustive, but should suggest the types of displays produced from detailed computer output. The above types of display might be produced for entire networks or only some portion for special study. Likewise, these types of display are not produced from all traffic assignment runs but only when detailed analysis or presentation to others is required. In testing of alternatives, for example, some practitioners only review summary output statistics and do not plot detail link values until an alternative is chosen for detailed study.

Some examples of link plots are shown in Figures V-7 through V-17 (these may be produced manually or by automatic plotting methods as described in the next section; examples of both are presented here). Figure V-7 shows an example of a section of a network annotated with link volumes (non-directional) as produced by an automatic plotter.

Figure V-8 shows volumes assigned to individual links by bandwidth produced by a plotter. Figure V-9 shows volume/capacity ratios by bandwidth (the original of this plot was in color with different colors used for different V/C ratio ranges). Figure V-10 shows a comparison of assigned volumes and ground counts on an existing freeway system. Figure V-11 is a similar comparison, accomplished by using an automatic plotter. Figure V-12 is a manually produced display of needs on a corridor basis. Figure V-13 is an automatically plotted network with one tree also shown. Link times are annotated for each link. The original was plotted with the base network in pale red and the tree in blue.

Summary statistics and comparative results from alternate traffic assignments can be shown by histograms, bar charts, graphs, etc., either produced manually or through the use of automatic plotting devices. These automatic plot devices are generally capable of producing most of the types of display discussed below. The types of assignment results which can be displayed by summary statistics are listed below with reference to example displays:

- Trip length distributions from various capacity restraint runs, comparing alternate systems, or comparing O-D versus model trips (see Figure V-14 for example).
- Comparison of summary statistics for alternate route locations, such as, average speeds, vehicle miles of travel, or derivatives from the assignment process, such as, costs. Figure V-15 presents costs plotted for alternate locations of a proposed facility.

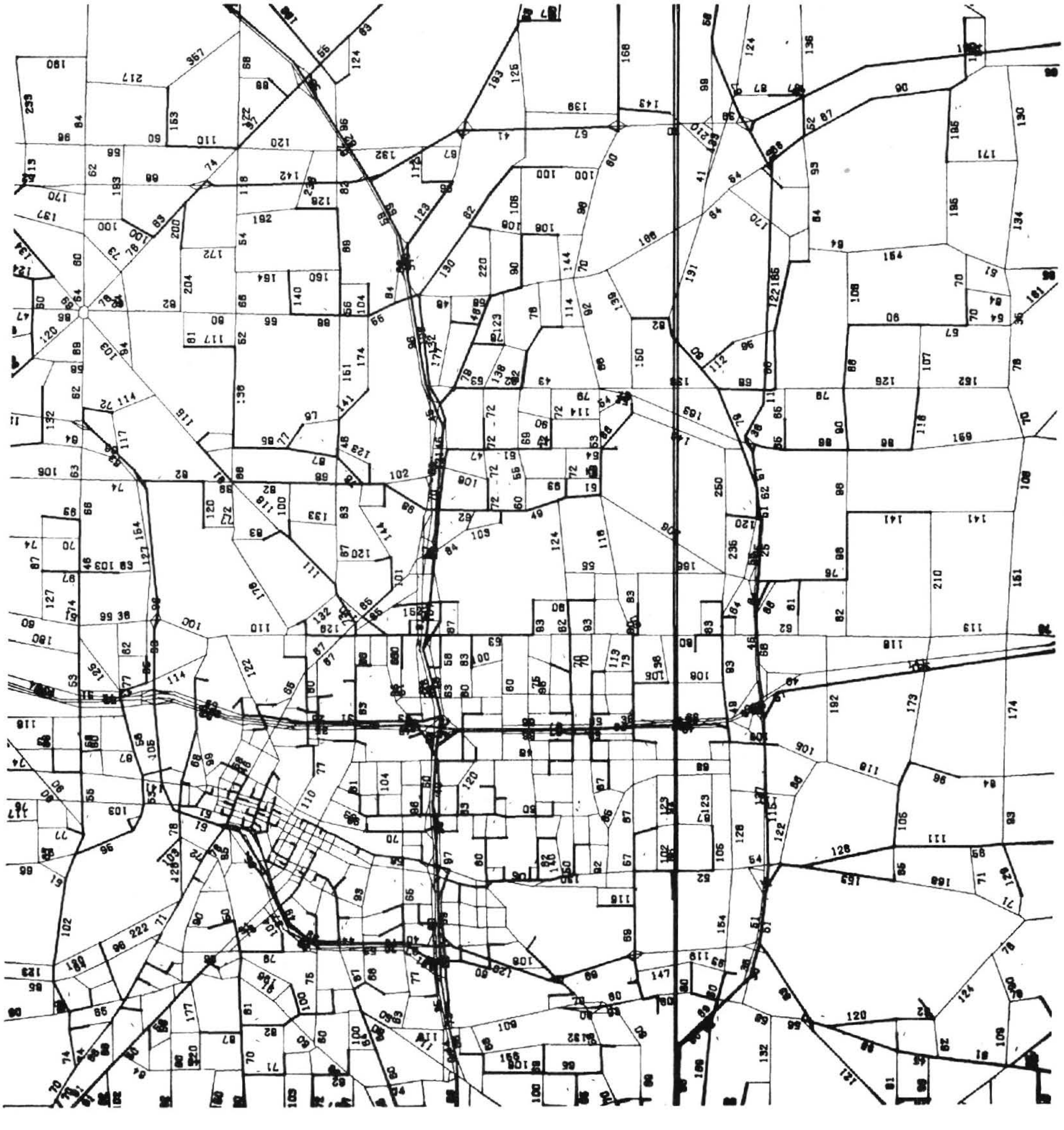
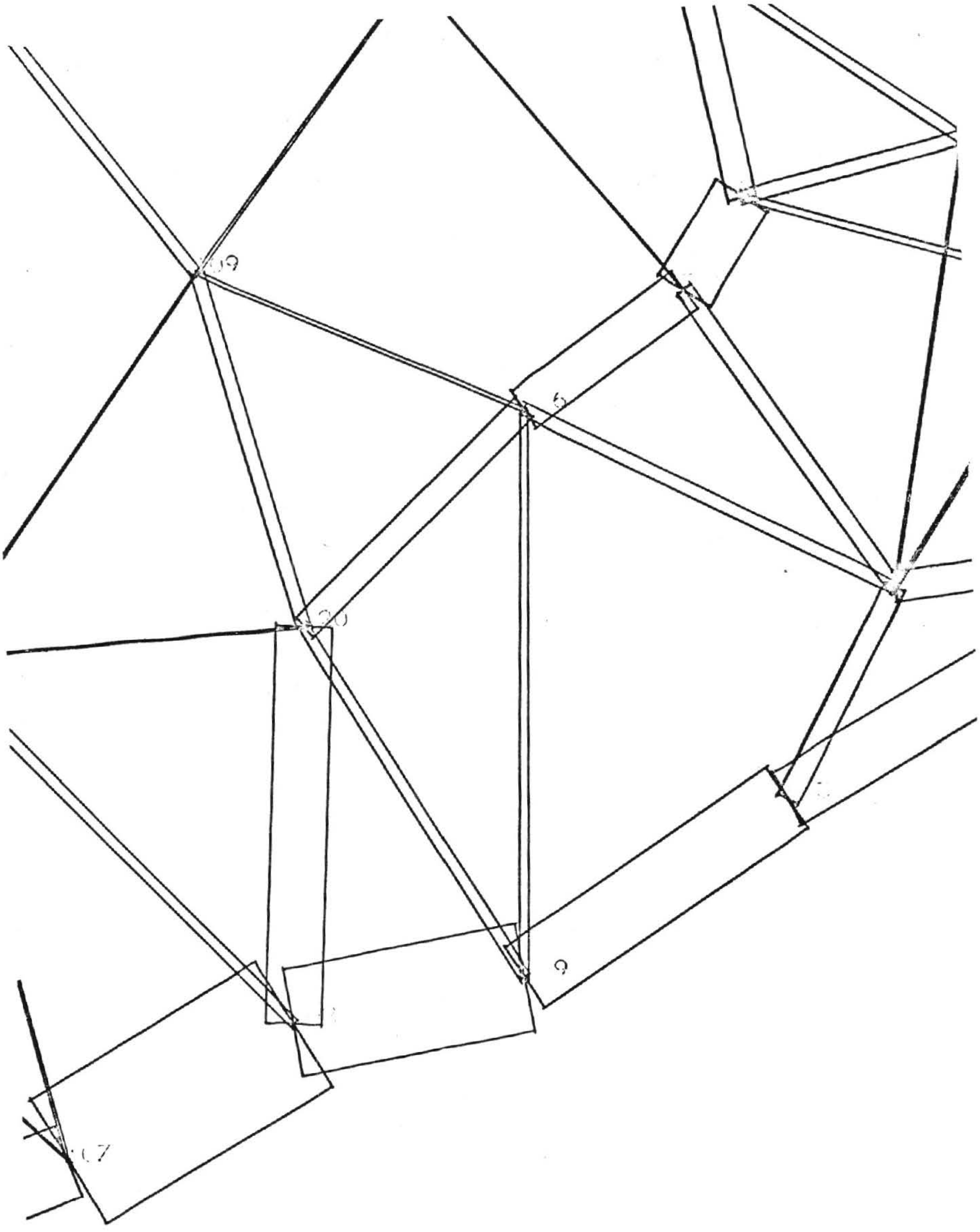


FIGURE V-7
NETWORK PLOT WITH ASSIGNMENT

Source: Ohio Department of Highways



Source: Connecticut Highway Department

Figure V-8

Network Band Plot

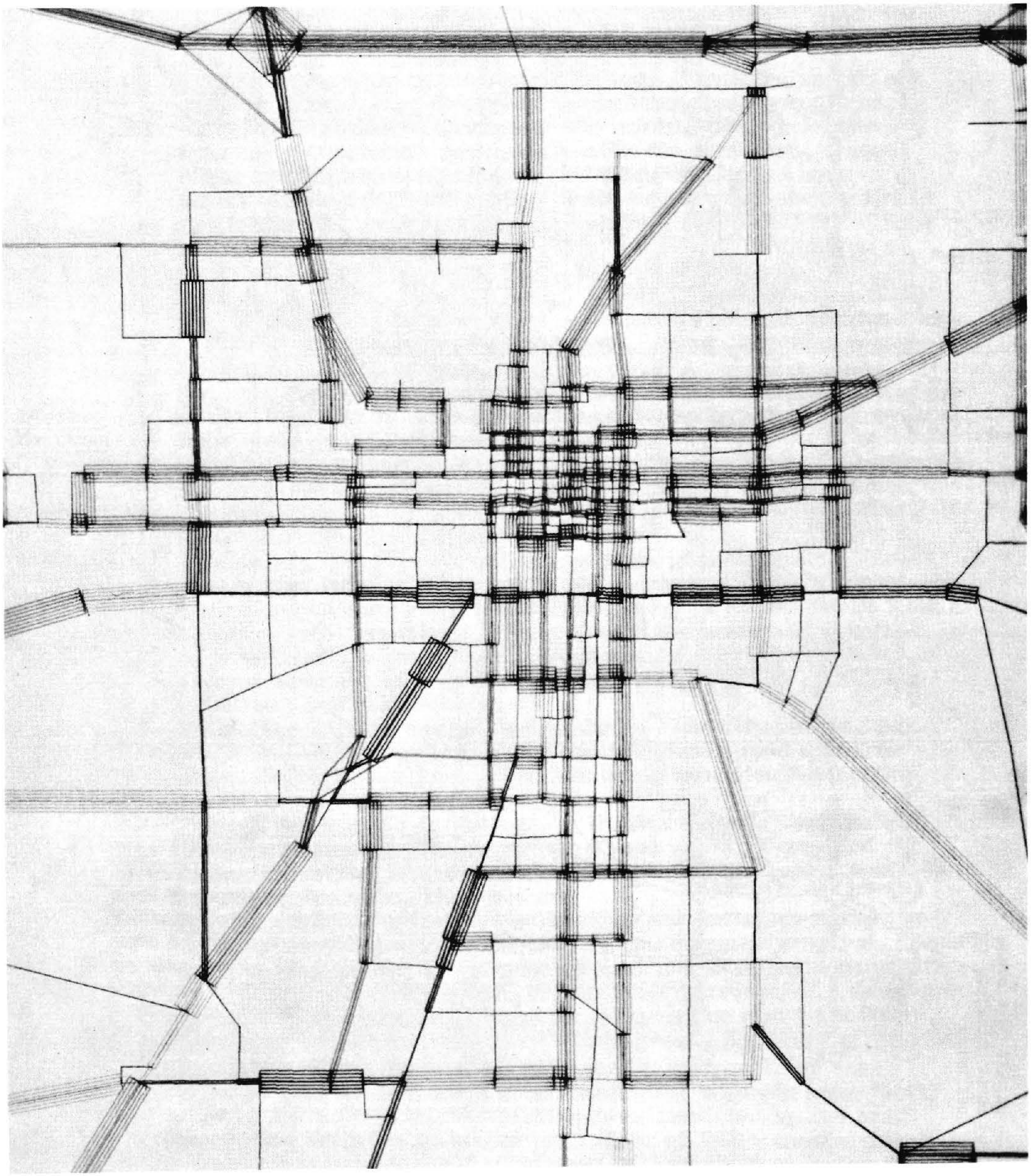
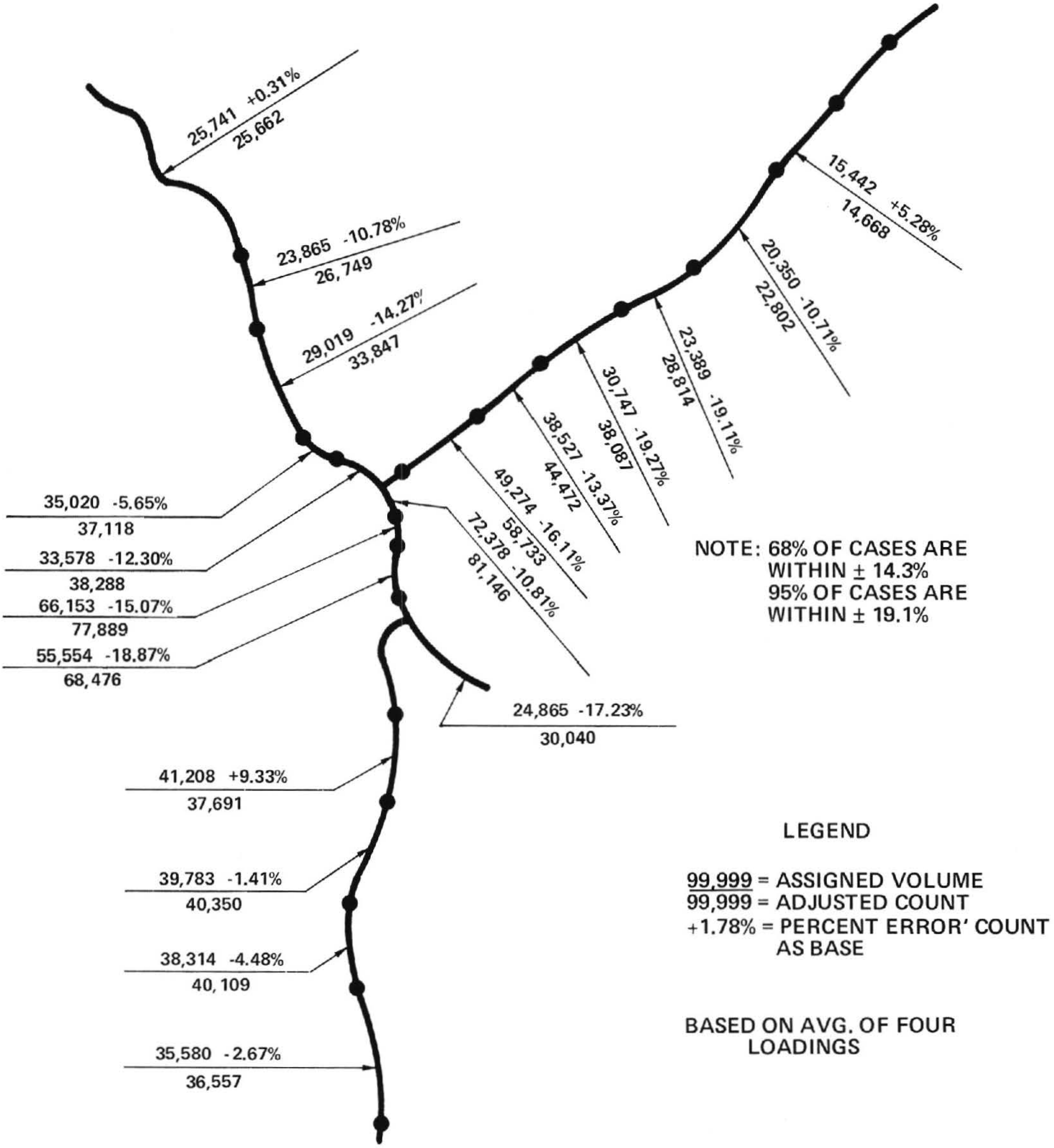


FIGURE V-9 VOLUME/CAPACITY RATIOS BY BAND WIDTH

SOURCE: OHIO DEPT. OF HIGHWAYS



NOTE: 68% OF CASES ARE
WITHIN ± 14.3%
95% OF CASES ARE
WITHIN ± 19.1%

LEGEND

99,999 = ASSIGNED VOLUME
99,999 = ADJUSTED COUNT
+1.78% = PERCENT ERROR' COUNT AS BASE

BASED ON AVG. OF FOUR LOADINGS

FIGURE V-10

COMPARISON OF ASSIGNED VOLUME-TO-GROUND COUNTS ON EXISTING FREEWAY SYSTEM IN ATLANTA(51)

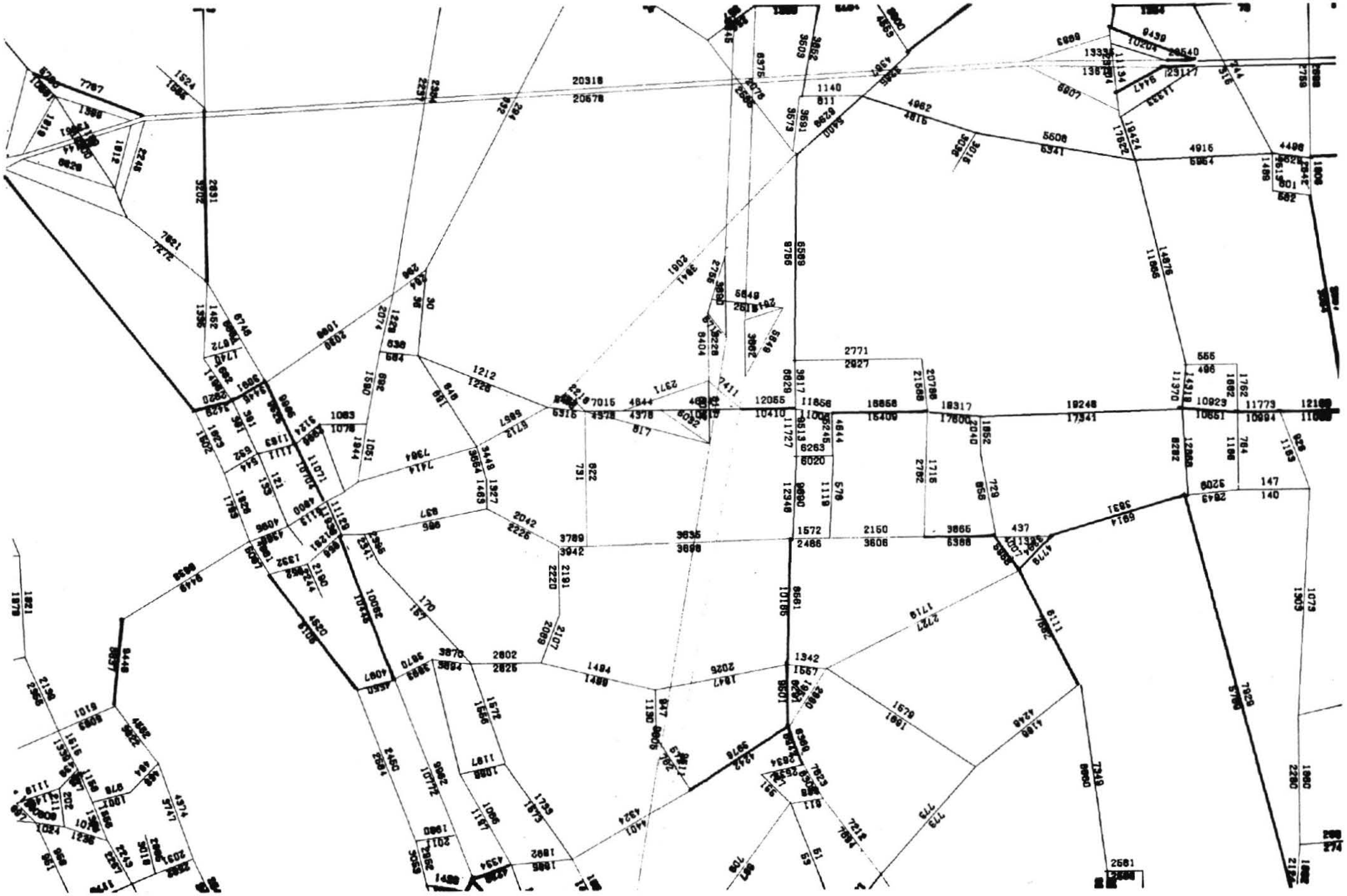
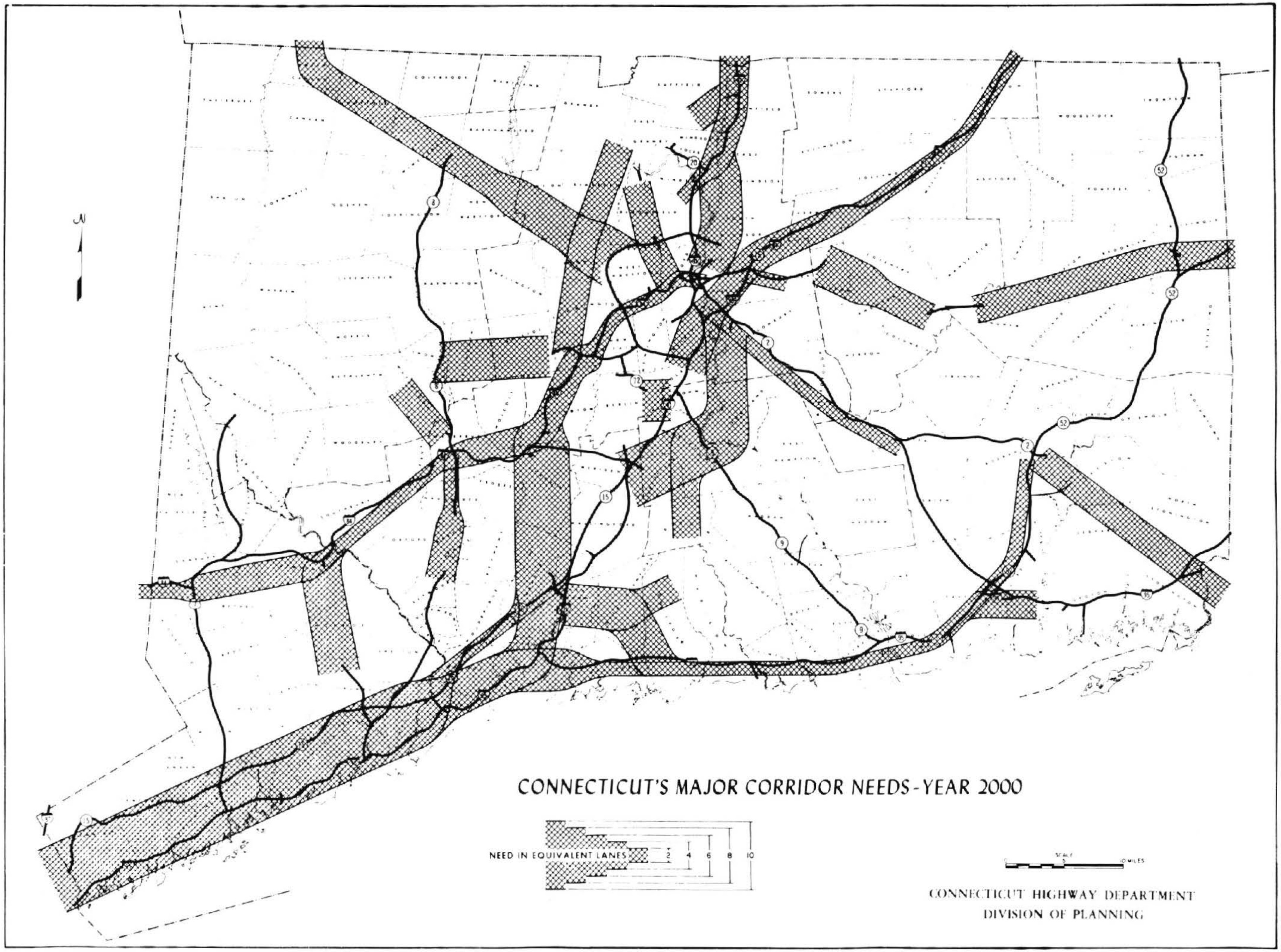


FIGURE V-11

Source: Ohio Department of Highways

COMPARISON OF ASSIGNED VOLUMES AND GROUND COUNTS



CONNECTICUT'S MAJOR CORRIDOR NEEDS - YEAR 2000

FIGURE V-12

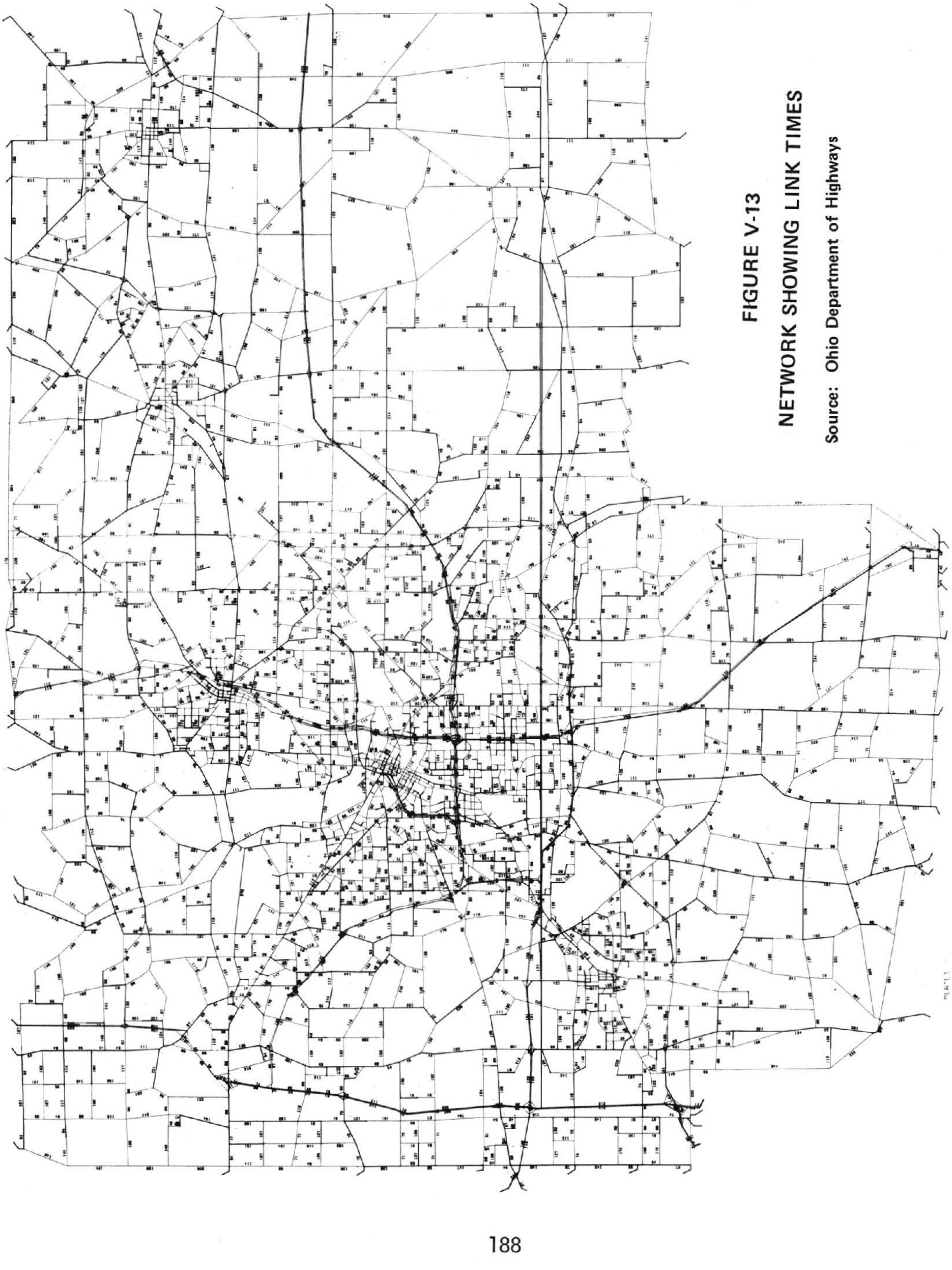
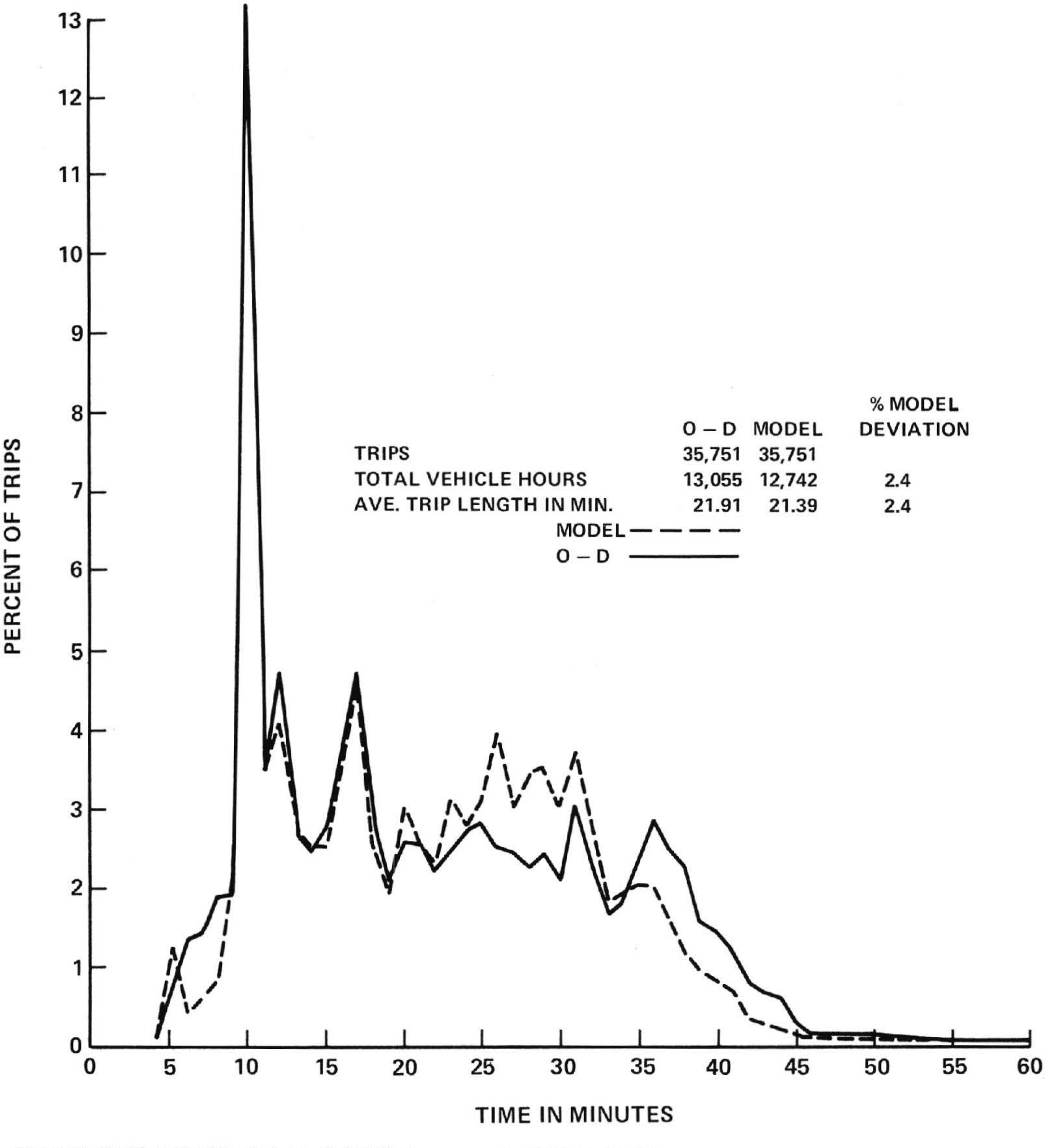


FIGURE V-13

NETWORK SHOWING LINK TIMES

Source: Ohio Department of Highways

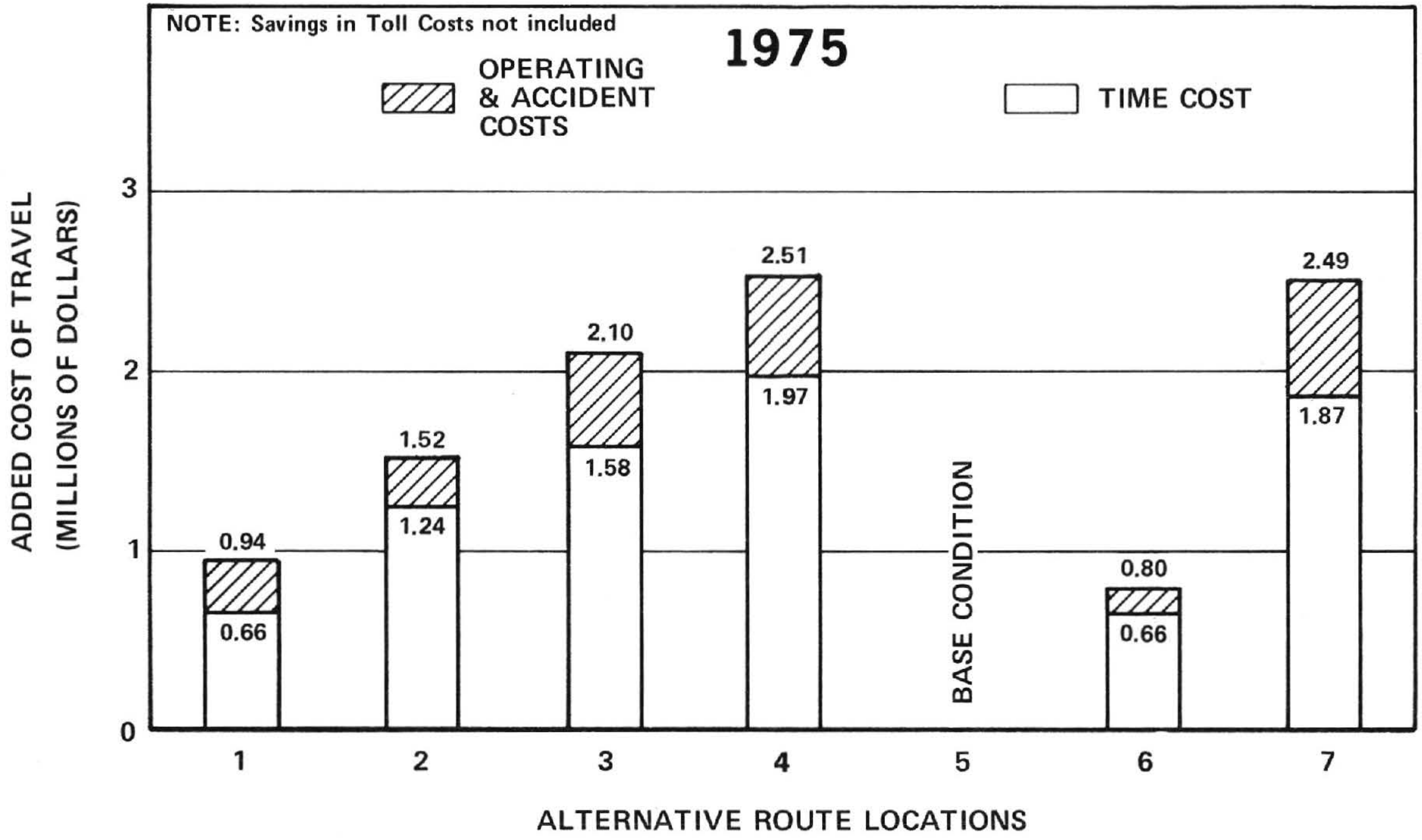


	O – D	MODEL	% MODEL DEVIATION
TRIPS	35,751	35,751	
TOTAL VEHICLE HOURS	13,055	12,742	2.4
AVE. TRIP LENGTH IN MIN.	21.91	21.39	2.4

SOURCE: MATS, Harland Bartholomew & Associates

FIGURE V-14

DISPLAY OF TRIP LENGTH FREQUENCY DISTRIBUTION



Source: Delaware Valley Reg. Pl. Comm.

FIGURE V-15

COSTS FOR ALTERNATE LOCATIONS OF A PROPOSED FACILITY

- Number or percentage of links in some stratified grouping, such as, volume, speed, volume/capacity, etc. An example of such a display for volumes is shown in Figure V-16 .
- Comparisons of traffic volume with capacity across some corridor as shown in Figure V-17 .

Automatic Plotting

The voluminous output of computer programs used for transportation planning requires that efficient means be utilized for assimilating the data. Automatic plotting methods offer the means for a faster assimilation of planning information than can be accomplished from printed output. Most state highway departments either currently have plotting equipment, are planning to acquire such equipment, or are updating already available equipment. The three types of equipment to be considered are:

- Digitizers
- Electro-Mechanical Plotters
- CRT Display Units

automatic plotting

There have been dramatic improvements in computer graphics since 1955 when maps of travel desire lines were printed directly by IBM accounting equipment for the Detroit Metropolitan Area Traffic Study. This use of printing values in a coordinate format to map data has been elaborated to include isolining, symbolic representation, and shading, all using high speed printers. Line plotters have been used to prepare line drawings of networks, traffic flow maps, charts and graphs, maps of boundaries, such as, census tracts, counties, etc., and perspective drawings of three dimensional arrays, such as, the population density of a region. Finally, the development and use of the cathode ray tube as a direct graphic display device has come into its own in many fields, and eventually may become part of any plotting system. A recent report was prepared on digitizing, plotting, and display equipment and methods from the viewpoint of the transportation planner. Much of the material contained herein has been extracted from the report "From Numbers to Pictures" prepared for the Federal Highway Administration by Mr. Ernest Nussbaum of the General Electric Technical and Operations Services Department (54).

Automatic plotting requires that coordinates be associated with the points to be represented. Digitizing is the process of determining coordinates for points and identifying them.

digitizing

Most plotting work useful to transportation planners must be preceded by extensive digitizing. The latter cannot be performed too carefully, as errors in the digitized data are apt to cause considerable expense in wasted computer and plotter runs. The cost of such careful digitizing is fairly high and justified only if it is spread over a number of plots making use of the data. For assignment purposes, this generally consists of determining the coordinates of nodes and centroids for the transportation network and identifying the coordinates with their node numbers. This can be done either manually by measuring each point off a map, or by machine digitizing where an operator moves a cursor from point to point, activates a switch to automatically record the point's coordinates, and keys in necessary identifying data. If area boundaries (zones, blocks, etc.) must be digitized and most of the shapes are irregular, machine digitizing is generally less expensive than manual efforts. Where networks are to be digitized, the choice is usually dependent upon

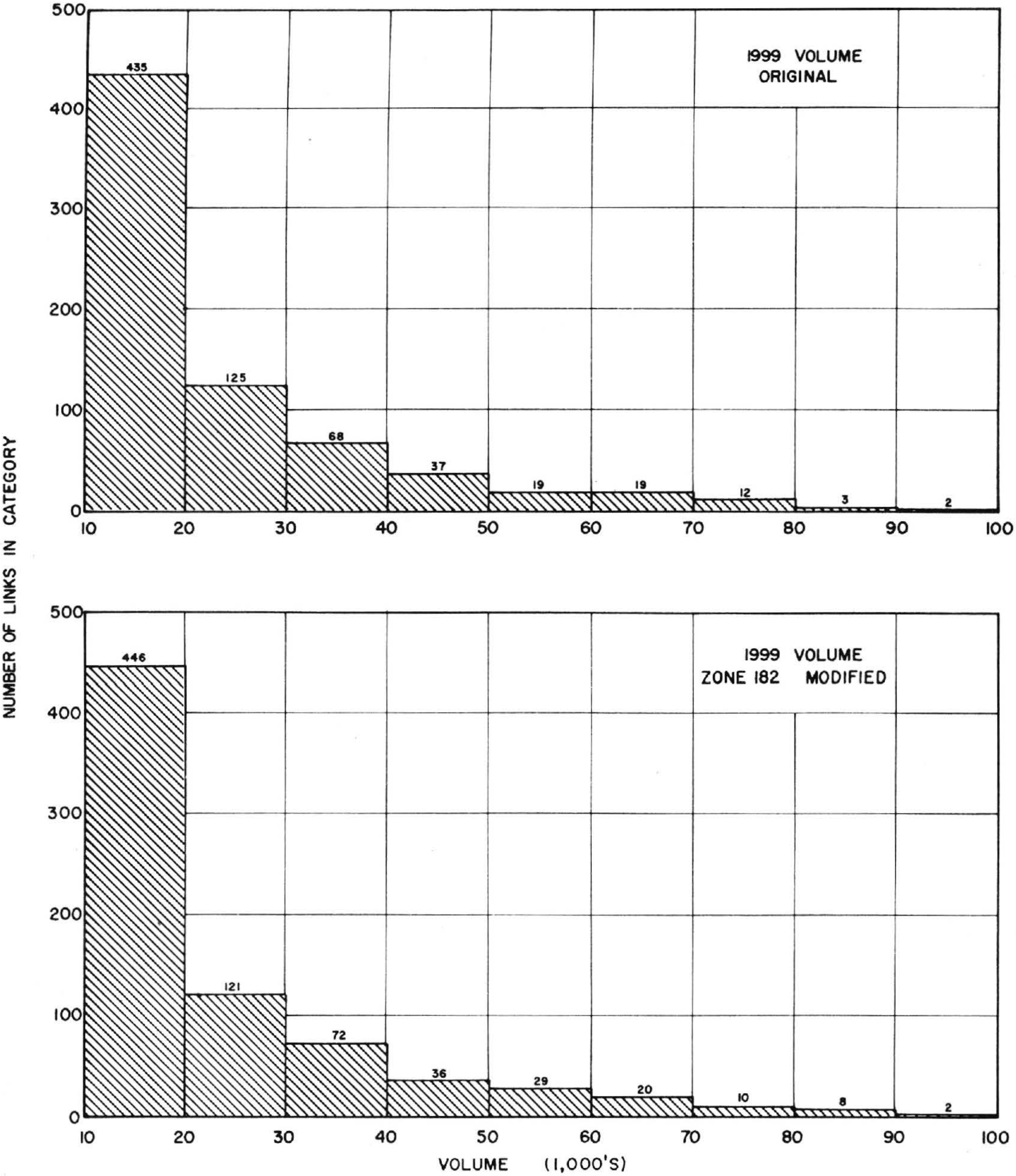
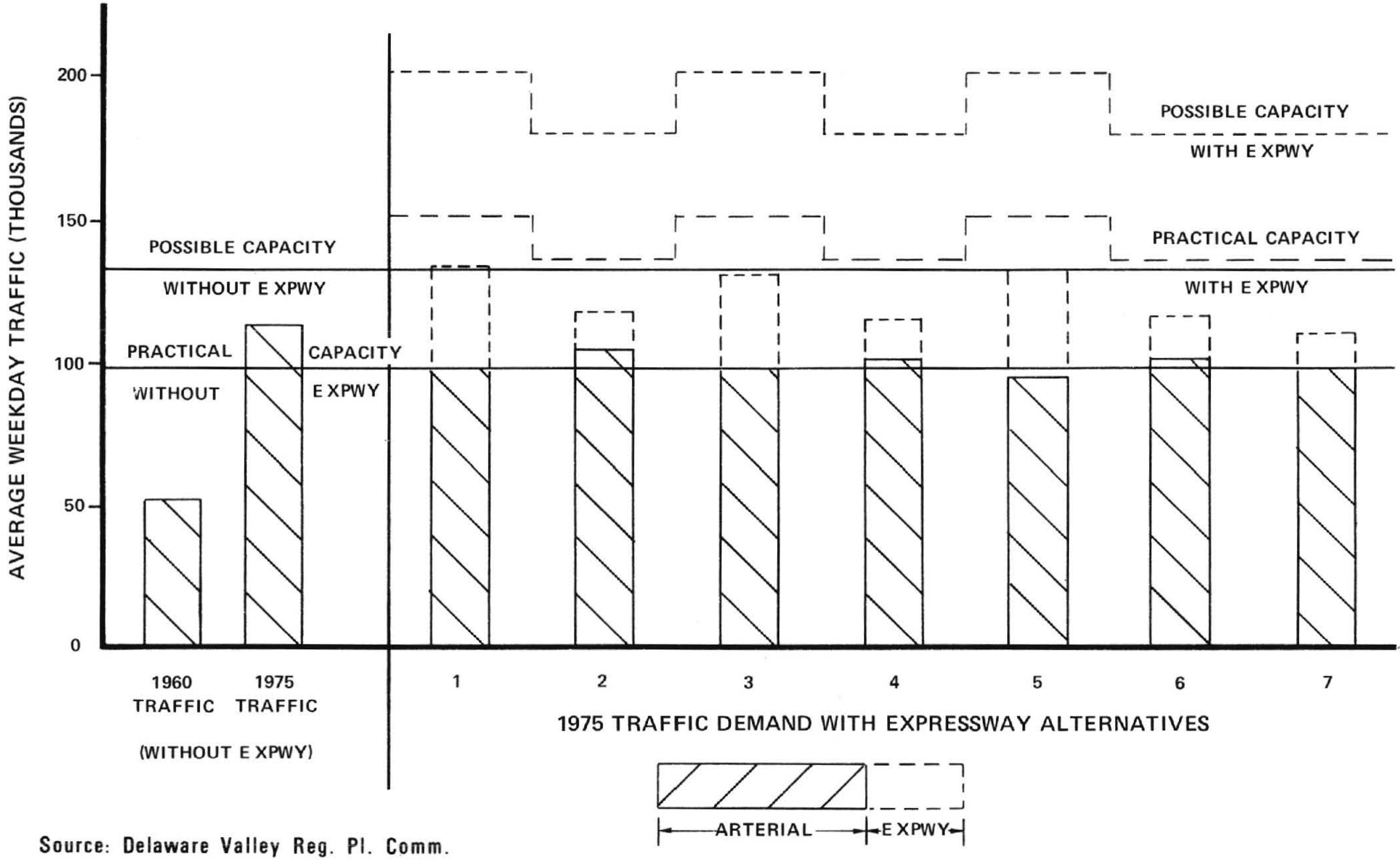
1999 VOLUME
ORIGINAL
435
125
68
37
19
19
12
3
2
1999 VOLUME
ZONE 182 MODIFIED
446
121
72
36
29
20
10
8
2
0
100
200
300
400
500
10
20
30
40
50
60
70
80
90
100
NUMBER OF LINKS IN CATEGORY
VOLUME (1,000'S)

FIGURE V-16



Source: Delaware Valley Reg. Pl. Comm.

FIGURE V-17

COMPARISON OF TRAFFIC VOLUMES AND CAPACITY FOR SEVERAL ALTERNATIVES WITHIN A CORRIDOR

the street pattern. Where most of the system is a grid pattern, the labor of manual digitizing is greatly reduced since for all nodes on a particular E-W or N-S line, one of the coordinates has to be determined only once. In addition, there is generally a problem with digitizers to obtain exactly the same coordinate value along a facility for one of the directions on all nodes to avoid wiggles in the automatic plots made from these.

When only one or two map sheets with relatively few data points are to be digitized, it is generally quicker to do the work manually. Digitizers are most useful where there are thousands of points to be digitized. Also, if maps are of small scale or if digitizing must be done from prints of poor quality, better results will be obtained if the job is accomplished manually.

Once the necessary points have been digitized, automatic plotting is generally cost effective relative to manual plotting of assignment results. The choice of whether to use automatic plotting should be based on the number and types of displays to be produced as well as the relative costs of manual to automatic plotting. Basically, automatic data plotting can be justified for the following reasons.

- Decrease errors since plot is made directly from output of a computer program.
- Decrease the time span from the raw data state to the useful information state.
- Free personnel for other work.
- Increase information accuracy and reliability.
- Eliminate tedious and boring jobs.

The automatic plotters that are useful for transportation planning applications should have a surface on which plots at least 2 1/2 X 3 feet can be made. These plotters can be driven with input provided by a computer (on-line) or magnetic tape or cards (off-line).

The majority of state highway departments and other transportation planning agencies have access to a plotter. A considerable number are now producing traffic assignment results automatically plotted.

When considering acquisition of a plotter, consideration should be given to the following items:

- Flatbed versus drum
- Size of plotting area
- Physical size and weight
- Off-line versus on-line operation
- Hardware Versus Software Features
- Annotation Capability
- Multi-pen capability
- Paper Advance Mechanism
- Speed
- Noise Level
- Software Availability and Cost
- Service Costs and Availability
- Cost and Availability of Supplies
- Cost of Lease or Purchase

In addition, consideration can be given to the use of plotters available through service bureau operations. The decision to buy or lease versus use of a service bureau will depend on the quantity of plots to be made, the size of the system(s) to be plotted, as well as, the source of other computer related services. Figure V-18 shows an example of an automatic plotter.

CRT

An automatic display device which has not yet found widespread use in transportation planning is the cathode ray tube (CRT) on which lines and alphanumeric characters can be "drawn" by a computer for rapid visual examination. A picture can be created within a few seconds. There appears to be possibilities for future use of such equipment.

Currently, screen sizes vary from about 5 X 7 inches to 12 X 12 inches. Some display units have an optional hard copy attachment with which a permanent record of a picture can be made if desired.

Most use of CRT units stresses "interactive" capability where the user is on-line with the computer and uses some device to make changes in the data stored. These devices include light pens, joysticks, keyboards, etc.

For displaying graphs, very small networks, small portions of large networks, or any other relatively uncomplicated picture, CRT's are feasible solutions. Large area displays (entire networks) can not be readily handled. The advantage of CRT display is that output is available immediately after being produced by the computer. A number of different plots can be shown in rapid succession. In addition, the analyst can make changes to the picture (i.e., add or delete links, link speeds, etc.) and see the results visually soon after.

This Chapter provides the reader with a set of evaluation procedures and measures for evaluating traffic assignment results. Assignment results obtained in the application of techniques by field personnel are shown to allow comparisons in traffic assignment application.

FIGURE V-18
AUTOMATIC PLOTTER

Source: California Computer Products, Inc.

CHAPTER VI
SUMMARY

Traffic assignment is a much used method and important part of the Transportation Planning process. The technique has progressed from manual applications through use of large - high speed electronic computers. Through the years methods have been developed which offer advantages over what might be classified as the "traditional approach" for specific applicational needs. However, the traditional approach, which may be typified by the Federal Highway Administration Urban Planning System is still the most utilized approach to traffic assignment. Likewise, applications of assignment methods have evolved over the years and there is a wealth of background experience to draw from in utilizing assignment techniques which, it is hoped, is reflected in this document. The products of the assignment process are varied and in some cases voluminous. Precision of results vary by the care taken and applicational methods utilized. The utility of results is greatly enhanced by the presentation techniques utilized and summaries produced. This document presents background information in these products.

The utilization of a specific applicational technique should be based upon specific needs, such as: overall system testing and evaluation, small area detailed analysis, sketch planning and development of design volumes. Techniques should be chosen carefully in relation to the problem at hand and overall considerations of accuracy and cost. Available techniques include the traditional highway assignment techniques, the transit planning system, micro-assignment, the direct traffic estimation method and the numerous variations on these.

Traffic assignment techniques are utilized for many purposes as well as special applications. They are used for: testing and developing alternate transportation systems; establishing short range priority programs; detailed studies of traffic generators, corridor location studies; developing design volumes; and providing input to other planning tools. Subsidiary special applications may include studying the air pollution and noise effects of a system, evaluating traffic effects of shopping centers and filling stations, determining locations for public services such as fire stations and ambulances and scheduling routings for trucking systems for solid waste pick-up and disposal.

Traffic assignment techniques have found most application in urban study, but have successfully been utilized for statewide and nationwide study.

Analysis of traffic assignment results, while not considered as part of the process by some, is extremely important. Traffic assignment analysis should include:

- establishing the validity of assignment results
- systematically producing workable data for evaluation including economic evaluations, further general planning and design volumes.
- permitting evaluation of internal system performance (identifying good and weak points in the system, delineating deficiencies, etc.)
- establishing comparative evaluations with other parameters to aid in the planning and design
- permitting the evaluation and interpretation of results for use by engineers.

Most users of traffic assignment techniques for basic system planning consider a minimum of three assignments:

- existing trips to the existing system
- future trips to the existing plus committed network
- future trips to the existing plus committed plus proposed network

A good deal of analytical and comparative analysis is never accomplished due to poor documentation of decisions made during the traffic assignment process as well as poor documentation and notation of input data, maps, printouts, tapes, cards, etc. Additionally, funds are often wasted in re-doing work already accomplished and in trying to track down the work accomplished sometime earlier. It is extremely important that good records be maintained on the status of data, runs, output, decisions made and other factors related to the process. One scheme used (14) is based upon an identification number being given to each traffic assignment. Some have used a two digit system where the first digit refers to the year which the network represents and the second digit represents the individual assignment or revision thereof. For example, the number "1-5" would represent the existing system, revision of assignment number 5; the number "3-7" would represent a 1985 network, trial number 7. All maps and tabulations pertaining to the individual assignment are given this number. All material such as tracings, prints, notes, decisions made and analysis should be kept together or cross-referenced by some filing system. Copies of the following basic tabulations should be bound together, labeled and preserved for reference:

- tabulation of link data cards
- printed historical record
- assigned volumes
- tabulation of zone-to-zone trips
- tabulation of selected trees

It is most important that magnetic tapes with output data be well labeled. A suggested method is to maintain a card file containing detailed information relative to a tape and referenced to the tape by a number. The number would be placed on the tape along with a short description of the tape contents. The cards of the file should be organized to allow easy access to the tape. Some organizational schemes include:

- by data type; i.e. historical records, trees, trips.
- by system; i.e., 1990 transit system, 1980 highway system, 1970 current plus committed.
- by project type; i.e., long range study, corridor study, special generator studies, etc.

The selection and use of an assignment process should logically proceed from the specification of the problem(s) to be solved through the procedures to be used to the analysis of results. A summary of the major steps that should be considered is presented below:

- define problem
- establish goals and objectives
- develop analytical approach
- select methods including those for traffic assignment
- review inventories and summaries available
- prepare base maps
- lay-out network to be utilized
- obtain system parameters - speeds, volume, capacity, etc. - required

- code the network for processing
    - . locate and number centroids
    - . connect centroids to system
    - . locate and define nodes
    - . prepare a node numbering table
    - . assign node numbers
    - . code system parameters including turn penalties and prohibitors
    - . treat special situations such as external stations
- evaluate zone-network relationships
- adjust and calibrate network
- check results of calibration versus measurable characteristics
- utilize process for solving problem(s) defined
- summarize results for presentation

Again, the traffic assignment methods provide a useful tool for transportation planning applications. The method to be used should be selected carefully, applied carefully and the results analyzed and used with a knowledge of the limitations as well as the benefits to be derived. This document has attempted to provide information on the methods, applications and products of traffic assignment.

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