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DEVELOPMENT, TESTING, AND EVALUATION OF A
NODAL RESTRAINT ASSIGNMENT PROCEDURE

by

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Research Report 1153-4
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The Texas A&M University System
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June 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA				
in ²	square inches	645.2	centimetres squared	cm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
ac	acres	0.395	hectares	ha

MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

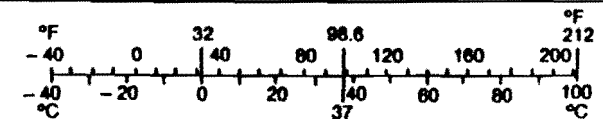
AREA				
mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	2.53	acres	ac

MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

This research developed and evaluated a traffic assignment procedure in which capacity restraint was applied to nodes instead of links. The conventional traffic assignment techniques consider alternative paths through a successive impedance adjustment process in which link impedances (travel times) are adjusted based upon the ratios of the assigned link volume to a coded link capacity. In reality, the capacity of an urban street system is constrained by intersections (nodes) instead of links. The nodal restraint assignment procedure was, therefore, expected to be more responsive than the conventional capacity restraint assignment procedures.

The procedure was developed by utilizing the concept of the intersection sum of critical lane volumes in the **Highway Capacity Manual 1985**. A nodal impedance adjustment subroutine was incorporated in the assignment process to account for intersection delays where link impedances were held constant and nodal impedances were updated from iteration to iteration. The impedance for each turning movement at a node is determined by the association of all the movements encountered at the node.

The proposed nodal restraint assignment procedure then was applied to a test network (the Preston Road in North Dallas). In the application, various assignment procedures and different impedance adjustment function parameters were used to test the robustness of the proposed procedure.

The nodal restraint assignment was evaluated through comparison with the selected "best" of the available conventional capacity restraint assignments based upon traffic counts at major intersections along Preston Road. The evaluation was based on various micro-level analyses which included analyses of mean difference and root mean square errors of approach volumes and turning movements, analysis of turning movements as a percentage of approach volume, and paired t-tests of approach volumes and turning movements.

These analyses show that the nodal restraint assignment generally produced better turning movement replications than the available capacity restraint assignments.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation. Additionally, this report is not intended for construction, bidding, or permit purposes. Jimmie D. Benson, P.E., was the Principal Investigator for the project.

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CHAPTER I

INTRODUCTION

PROBLEM STATEMENT

In transportation planning, two different levels of travel demand forecasting are generally conducted: system-level analysis and project-level analysis. The system-level analysis aims to evaluate the future land-use/transportation alternatives for a large urban region. The project-level analysis, on the other hand, is usually site-specific and focused on an individual project.

The traditional urban transportation modeling process (trip generation, trip distribution, mode choice, and traffic assignment) has been found to be an effective tool for system-level analysis. However, the traffic assignment results, especially turning movement forecasts, from the process are usually not directly suitable for project-level planning. In practice, intensive manpower is needed to modify turning movement forecasts from current traffic assignment models. This is usually time-consuming and expensive, and often requires the judgment of experienced individuals.

Existing traffic assignment techniques may be classified into one of three groups: all-or-nothing assignment, capacity restraint (iterative, equilibrium, and incremental) assignments, and multipath (stochastic and random impedance error) assignments. Capacity restraint assignment techniques consider alternate paths through a successive adjustment process in which link speeds (or impedances) are adjusted based upon the ratio of the assigned link volume to a coded link capacity. In reality, the capacity of an urban street system is constrained by the arterial-to-arterial intersections. Consequently, the application of the capacity restraint adjustment to node, instead of link, impedances might be more responsive than the current capacity restraint procedures.

This research proposed a nodal capacity restraint procedure which incorporates a dynamic nodal impedance subroutine to account for intersection delay in the assignment process. Here, "dynamic" means that (1) the impedance for each turning movement at an intersection (node) is adjusted according to the interactions among all the assigned turning movements encountered at the node and (2) the cycle length of a node is variable and is

determined by the sum of evaluated critical turning movements. The delay for each movement at a node is calculated based on the **Highway Capacity Manual 1985** delay equation (1). The capacity for each movement is computed by using the green time assigned to the movement and a specified saturation flow rate.

It should be noted that computation of the nodal impedance aims to acquire a more responsive traffic pattern replication (mainly turning movements), not to precisely estimate delay for a single intersection or a series of intersections. In addition to the conventional link data, the proposed procedure requires only the identification of the nodes at which the nodal restraint is to be applied and the number of lanes for each movement at each of those nodes. The procedure is suitable for saturated peak-hour/peak-period networks where the volume/capacity (V/C) ratio at most intersections is 1.2 or less. The study area, Preston Road Corridor in the North Dallas area, is a typical arterial where the V/C ratios range from about 0.8 to 1.2.

RESEARCH OBJECTIVE

The application of V/C restraint at network nodes is expected to improve the quality of traffic assignments for project-level applications. The proposed procedure should also be more appropriate for peak-hour/peak-period assignments than the existing capacity restraint assignments. Thus, the principal objective of this research was to develop a nodal restraint assignment procedure which can improve the effectiveness of traffic assignment (i.e., to produce more accurate replications of traffic volumes, especially turning movements, than the existing assignment procedures).

This research examines whether the nodal restraint assignment generates better traffic replication than the conventional capacity restraint assignments. The research hypothesis was as follows:

H_0 : The proposed nodal restraint assignment and the conventional capacity restraint assignments produce similar traffic estimates when compared to counted turn volumes.

versus

H_1 : The nodal capacity restraint assignment produces more accurate assigned turning

movements than the conventional capacity restraint assignments when compared to counted turn volumes.

ORGANIZATION OF THE REPORT

The report is organized in six chapters including an introduction, literature review, methodologies, development of the procedure, testing and evaluation of the application of the procedure to a test network, and conclusions and recommendations.

The research background and purpose are introduced in Chapter I. The literature related to the study is reviewed in Chapter II. The proposed assignment procedure and methodologies used to develop the procedure are discussed in Chapter III.

Various tests were conducted to determine if the proposed assignment procedure performed as expected. These tests are described and analyzed in Chapter IV. The results from the proposed assignment procedure were compared with results from the conventional capacity restraint assignments based upon the available ground counts. They are described in Chapter V. In Chapter VI the research findings are summarized and future research directions are proposed.

CHAPTER II

LITERATURE REVIEW

The literature related to this research is organized into the following three sections: (1) conventional link capacity restraint assignment techniques, (2) peak-hour/peak-period assignment techniques, and (3) transportation planning models that consider intersection delays in the traffic assignment process.

CONVENTIONAL CAPACITY RESTRAINT ASSIGNMENT TECHNIQUES

Conventional capacity restraint assignment models generally utilize two procedures, iterative and incremental. The iterative assignment technique involves a number of successive network buildings, minimum paths searches, network loadings, and impedance adjustments to obtain the assigned link volumes on a coded transportation network. The adjustment of link impedances to reflect operating conditions (congestion effects) usually uses the last assigned link volumes to calculate the adjusted impedance for the next iteration. However, in some cases, a weighted mean of the impedance from previous iterations is used.

There are various views as to the appropriate number of iterations that should be used. Four iterations are generally considered to be sufficient. Research by Humphrey (2) found that at least three to four iterations are desirable to apply capacity restraint procedures, and reasonable assignment results are obtained by using an average of four loadings. Unpublished research by Stover, et al, (3) produced similar conclusions. Benson (4) suggests that an even number of iterations should be used; this is especially critical when oscillations in link impedances and assigned volumes occur on successive iterations.

The equilibrium assignment procedure is a variation of the iterative capacity restraint technique using successive all-or-nothing assignments which are weighted so as to achieve a stated objective function. In 1952, Wardrop proposed the use of two criteria based on journey times to determine the distribution on travel routes (5); these are (1) the journey times on all the routes actually used are less than or equal to journey times by a single vehicle on any unused route, and (2) the average journey time is a minimum. The first

criterion is known as the principle of equal travel times. This principle implies that traffic will tend toward an equilibrium situation in which no driver can reduce his or her journey time by choosing a new route. The second criterion is equivalent to the principle of minimizing total travel time. A network system is considered the most efficient when the second criterion is satisfied, i.e., the total vehicle-hours are minimized.

Two types of incremental capacity restraint procedures are generally used in practice. In the first procedure, an individual tree is built for a centroid which is selected at random, and trips from this centroid to all other centroids are loaded. The base travel times on the individual links are then adjusted according to the link capacity function. Then, a tree is built for another randomly selected centroid, and the corresponding trips are assigned. This procedure is sometimes referred to as a one-pass incremental process which was first developed by Schneider for the Chicago Area Transportation Study (6). It is found in practice that only one tree loading has very little impact on impedance adjustments. In most cases, travel times on the individual links are adjusted after trips from a number of centroids have been loaded.

In the second type of procedure, increments (fractions) of the total origin-destination (O-D) table are loaded successively to the minimum path trees built for all centroids. A portion of the O-D table is first assigned to the minimum path trees for all origin centroids using the initial coded travel cost (travel time). The assigned volumes are then factored to present a 100 percent loading, and the link impedances are adjusted according to the link capacity functions. A new network is then built, new minimum paths are built using the updated link impedances, and another increment of the trip table is loaded. The process is repeated until 100 percent of the trip table has been assigned. The D-FW (Dallas-Fort Worth) Joint Model, an incremental traffic assignment model developed by the Texas Department of Transportation (TxDOT) and the North Central Texas Council of Governments (NCTCOG) uses an approach which combines these two procedures (7).

PEAK-HOUR/PEAK-PERIOD ASSIGNMENT TECHNIQUES

Traffic in major United States urban areas has substantially increased over the past two decades. As a consequence, project-level traffic assignments, mainly peak-hour/peak-

period assignments, are becoming more essential for urban traffic management and improvement projects. Generally, there are three approaches in practice to developing peak-hour/peak-period traffic volumes used for management or design purposes:

1. **Factoring 24-hour assignment:** Assign total daily (24-hour) travel to a 24-hour network (e.g., network links are coded in 24-hour capacities), and factor the resultant link loads to peak-hour directional volumes,
2. **Peak-period assignment:** Factor the 24-hour trip table to produce a peak-period (from one to four hours) trip table, and assign it to a peak-period network. If the peak-period exceeds one hour, the assigned volumes are then factored to obtain the peak-hour directional volumes.
3. **Fully modeled peak-hour assignment:** Perform the entire modeling process (trip generation, trip distribution, mode choice, and traffic assignment) for the peak 60-minute period.

The first approach (factoring 24-hour traffic assignment) is the most typical practice. The approach may be suitable for cities which experience minor traffic congestion; however, it is generally not sensitive to the composition of traffic by trip purpose or to the upstream impacts of a peak-period "bottleneck" in capacity. For large urban areas where highly saturated traffic conditions are being experienced, the peak-period modeling technique is preferred over the first approach. Benson, Bell, and Stover have developed such a peak-period modeling capability for large urban areas (8).

The third method (fully modeled peak-hour assignment) is not practical in view of the extensive data required to perform the trip generation, distribution, and mode choice for a 60-minute period. Furthermore, the peak 60-minute traffic volume occurs at different times in different locations in a large urban area. Benson, Bell, and Stover found that the peak 60-minute volume is a constant percentage of the peak-period volume even though the highest hourly volume occurs at different times throughout a large network. Therefore, they suggested that the peak-period be modeled if a fully modeled peak-hour assignment were to be used and the peak 60-minute volume be obtained by factoring the fully modeled period.

MODELS CONSIDERING INTERSECTION DELAY

The technique of considering nodal (intersection) capacities and delays in the traffic assignment process was first attempted by Creighton, Hamburg, Inc. (9, 10). This traffic assignment model, micro-assignment, was developed for simulating detailed vehicular movement in small areas (subareas). The model was required to give an explicit treatment of all traffic movements in an area equivalent to approximately 200 city blocks and to provide data on link volumes, congestion delay, and travel costs for given time periods throughout the day. The model was implemented by a set of computer programs for the IBM System 360 (at that time a part of the Bureau of Public Roads Urban Transportation Program System). A modified version of the model with more intersection analysis capability was developed in 1984 (11). The Intersection Analysis Model was incorporated in the Urban Transportation Planning System (UTPS) and operated as a submodel within the traffic assignment program UROAD. The model can be operated either in an area of interest (i.e., the micro area) limited to 200 to 300 intersections or in a region-wide assignment in which detailed delay calculations for selected intersections are made. The application requires an intensive coding effort including detailed intersection geometrics, traffic control operation, and link characteristics. No testing or evaluation of the model has been reported in the literature.

CORFLO is a transportation modeling system which has been supported by the Federal Highway Administration, U.S. Department of Transportation (12). The system was developed as a tool for use in traffic engineering and transportation planning to test transportation management strategies. This software system consists of three component models that interface to form an integrated system. Two of the models (FREFLO and NETFLO) simulate traffic operations, and the third (TRAFFIC) is an equilibrium traffic assignment model. Major features in TRAFFIC related to nodal delay consideration include (1) the transformation of the common geometric network into a "path network" which contains mainly movements (not links) and nodes, (2) the movement impedance in the path network implicitly encompassing link travel impedance and turning impedance, and (3) the movement impedance, for both the freeway and arterial movements, adjusted based on the conventional BPR impedance adjustment function. The capacity of an arterial movement

passing a signalized node is determined by the signal interval (phase), green time, and saturated flow rate specified by the user.

As part of an on-going research (Project 02340, "Fuel Saving from Surveillance, Signing, and Signal Control Systems for Freeway Congestion Reduction") being conducted by the Texas Transportation Institute, some modifications have been made to the TRAFFIC program in order to enhance the dynamic assignment capacity. First, the impedance adjustment function (BPR delay function) applied to an arterial movement was replaced by the **Highway Capacity Manual 1985 (1)** delay function. In addition, a nodal capacity "restricted" assignment capability was developed to reflect lane closure activities. Other features such as queue estimation, queue storage capacity, and expandable sequential trip tables to include uncompleted trips (those having a trip length longer than the assignment time interval) are also considered in the dynamic assignment capacity.

CONTRAM5 (CONTinuous TRAffic Assignment Model), developed by Transport and Road Research Laboratory (TRRL) in the United Kingdom, is a computer-based traffic assignment model for use in the design of traffic management schemes (13, 14). It is fairly sophisticated due to a detailed simulation of delays at intersections. The model predicts vehicle routes, flows, and queues in a network of streets and intersections. Intersections may be controlled by traffic signals or "give-way" (stop and yield operations) rules. Major features of the model include (1) representing variation in traffic conditions with time, particularly where demands temporarily exceed capacity (e.g., during peak periods); (2) allowing for blocking-back effects where a queue from one intersection fills a street and restricts the capacity at an upstream intersection; and (3) subdividing results into three vehicle classes such as cars, buses, and lorries (heavy goods vehicles).

SATURN (Simulation and Assignment of Traffic to Urban Road Network) developed by the Institute of Transport Studies, University of Leeds in the United Kingdom, is a computer model developed for analyzing and evaluating traffic management schemes in relatively localized networks (15, 16). The model performs a sophisticated simulation of delays at intersections resulting from a given pattern of traffic. In the assignment stage, this delay information is used to select the minimum time routes for each element in the trip table. Like most of the sophisticated traffic operation models, the model requires intensive

intersection operation information input.

In addition to the models supported by or developed by the public sectors, some proprietary transportation planning packages, such as MINUTP, TMODEL2, System II, and TRIPS have attempted to take the intersection delays (or capacities) into account in their assignment procedure. MINUTP developed by COMSIS (17) has a two-level option of capacity restraint assignment modeling: link restraint and nodal restraint. The nodal restraint is determined by the form of delay at turning movements. The turning movement delay is specified by a corresponding value from a curve of turn penalty vs. V/C ratio (seven different delay function curves are available). After an iteration in the assignment process, any intersection movement with a valid turn penalty value (coded on an intersection data file) is considered for delay in the next iteration.

TMODEL2 is another transportation planning model that utilizes the turn penalty to account for nodal delay. The model supports both user-specified incremental and iterative loading techniques and dynamically models node and link delay (18). Node delays are calculated by examining the total entering volumes. If the node delay parameters are not specified by the user, a node delay is computed using a default equation derived through regression analysis which compares average delay to V/C ratios. The resultant node delay is then assigned to all the links terminating in the node.

System II, developed by JHK and Associates, was designed as a transportation analysis tool to address the land-use and transportation issues in urban area. The model basically has an option of "intersection capacity constraints;" and thus, three levels of traffic assignment can be analyzed: (1) a normal regional assignment capability (without intersection capacity constraints), (2) a moderate level of detail, and (3) a detailed level which takes intersection delays into account. Intersection delays are calculated by the **Highway Capacity Manual 1985** procedure. One of the major purposes of the model is to perform traffic impact analyses. The model generates reports for determining where improvements will be necessary to maintain acceptable levels of service (19).

TRIPS, a comprehensive transportation modeling package for both mainframe and microcomputers parallels UTPS/PLANPAC in function capability and has a new feature of modeling highway assignment with dynamic intersection delay (20). The model handles the

intersection delay by using the "arc" concept. An arc is the segment between the mid-point of a link and the mid-point of an adjacent link and, thus, implies a turning movement through an intersection. This concept is presumably similar to the "path network" of CORFLO. Within an iteration, new paths are built according to the current arc impedance. The travel time along an arc is then a composite of actual link travel time and the turning movement delay. Link travel times are calculated using speed-flow curves, and turning movement delays are calculated as a function of the flow and traffic controls at the intersection. These new arc times are subsequently used to build new paths that form the basis for a revised assignment. According to the vendor, the approach to intersection modeling is based on research and models developed by the U.K. Transportation and Road Research Laboratory.

Recently, research related to the concept of nodal restraint assignment has been reported in the literature. William G. Allen, Jr. proposed an approach for simulating traffic control devices in a sub-area network (21). The travel demand model was implemented using MINUTP. The control device simulation method was applied using a FORTRAN program which modifies the speed and capacity values of controlled links. The program reads a MINUTP binary network file and identifies the free-flow speed, capacity class, and the type of control device at the B node. The link speed is then recalculated to include the average zero-volume (intersection operation) delay encountered by a single vehicle, and the capacity class is reduced to account for the lower capacity of controlled approaches. The binary file is then output. In the MINUTP assignment program, the sensitivity of the BPR restraint formula is increased for controlled links. As a result, the delay at a controlled link can be simulated by a modified BPR delay curve. Three types of controlled links are simulated: (1) the major approach to a signalized intersection, (2) the minor approach to a signalized intersection, and (3) the approach to a stop sign. A common cycle length is assumed for all signals, but the major approaches all have a common green time which is greater than the common green time of the minor approaches.

D.E. Boyce, H.K. Chen, N. Roupail, and A. Sen developed a subregional route choice model in which link travel times reflect intersection flows (22). In the assignment process, the intersection traffic signals and corresponding approach service levels are

adjusted in relation to the predicted approach flows; an equilibrium between traffic signal settings that minimizes total network travel time and route choices that are optimal from each user's point of view is sought. They formulated the problem as a bi-level nonlinear programming problem and termed it the Traffic-Responsive Signal Control (TRSC) scheme. The TRSC scheme considers the effect of signal controls on traffic flows in the standard traffic assignment problem through the integration of traffic control and traffic assignment submodels.

The intersection delays were computed according to either the delay minimization or the equal degree of saturation formulations. The nodal impedances were presented in the form of additional weights (penalties). Thus, the network is believed to be coded in a traditional way and is not represented by movements (arcs) and nodes. The scheme was applied to the Chicago Area Transportation Study North Shore regional network. As shown in Table 2-1, eight models based on two traffic signal timing policies (delay minimization or equal degree of saturation), two different treatments of two-way stop intersections (the same as a signal or Highway Capacity Manual 1985 non-signalized intersection method), and two different weights for turning movements (equal weights for turns or different weights for turns) were tested. Among them, four models (Models I, II, III and V) were

**Table 2-1
Test Models of the Traffic-Responsive Signal Control (TRSC) Scheme**

Treatment of Two-Way Stop	Signal		Highway Capacity Manual 1985 Method	
	Delay Minimization	Equal Degree of Saturation	Delay Minimization	Equal Degree of Saturation
Equal Weights for Turns	Model I	Model III	Model V	Model VII
Different Weights for Turns	Model II	Model IV	Model VI	Model VIII

Source: (22)

illustrated and compared. It was found that, given the low V/C of the test network and insensitivity for signal timing policy and other factors, Model III might be the best choice for practical use.

It is noted from the discussions above that some transportation planning models have already taken intersection delays into account. There are, nevertheless, a few reasons to support the development, testing, and evaluation of a nodal restraint procedure. First, the objective of most models was to estimate intersection delays rather than to improve turn volume estimates. Second, the concept of dynamic nodal impedance (variable cycle length according to interaction among turning movements) in the traffic assignment process was rarely found in the literature. Some of the models, such as MINUTP and TMODEL2, estimated intersection delays by regarding the nodal impedances as turn penalties which were adjusted according to a penalty vs. V/C ratio curve. The interaction of all the movements encountered at an intersection is presumably not taken into account. Some of them, such as Intersection Analysis and TRAFFIC in CORFLO, calculate nodal delay by simulating the intersection traffic operation but are based on constant cycle length and fixed green time for each movement. Third, the sophisticated traffic simulation type of local area assignment models such as Intersection Analysis Model, CORFLO and CONTRAM, commonly require intensive intersection operation and geometric information which are usually not readily available in planning analyses.

The literature does not contain information where the modeled results were compared to actual field data. The absence of such material in the literature suggests that the various models have not been validated by comparing their results with observed intersection counted movements. Conversations with vendor representatives of various proprietary software indicated that such evaluations have not been performed.

CHAPTER III

NODAL RESTRAINT ASSIGNMENT PROCEDURE

This chapter describes the process of the proposed procedure and discusses the methodologies used to develop the procedure. The first section, Conceptual Development of the Procedure, discusses how the idea is different from conventional capacity restraint assignments and the problems encountered in the initial stage of the development. The second section, Network Configuration, describes how the conventional coded network was modified in order to include turning movement attributes. The third section, Calculation of Nodal Impedances, discusses the methodologies used to compute nodal impedances in the nodal impedance adjustment subroutine. The last section, Nodal Restraint Assignment Procedure, describes interfacing the nodal impedance subroutine with a traffic assignment main routine and summarizes the entire process of the proposed procedure.

CONCEPTUAL DEVELOPMENT OF THE PROCEDURE

Two problems were encountered in the initial stage of developing the proposed assignment procedure. When nodal impedances were taken into account in addition to the link impedance (1) what travel impedance should be used as the basis for path searching and (2) how should the impedance in the assignment process be adjusted. The common tactic used in most of the models that were reviewed in the previous chapter was to include both the link and the nodal impedances as the total travel impedance and to adjust both of them by a common delay adjustment function or by two different functions.

In this research, the proposed nodal restraint procedure was to incorporate both the link and the nodal impedances as the travel impedance but with adjustments made only to the nodal impedances. Thus, the link impedances are regarded as fixed values which represent roadway travel times; and the nodal impedances are considered as variables which account for the intersection congestion delays. The presumptions behind this are twofold. First, capacities of urban streets are mainly constrained by intersection traffic conditions and operations; and delays occur as a consequence. Second, the capacity of a link (roadway) is, in a sense, fixed; while the capacity of a movement at a node (intersection) is variable

depending upon its association with other movements at that node.

The conventional capacity restraint assignment process, shown in Figure 3-1, involves a number of successive network buildups, minimum path searches, network loadings, and impedance adjustments to obtain the assigned link volumes. The nodal restraint assignment process appears to be quite similar to the conventional capacity restraint assignment process except that the V/C adjustment is applied to nodal impedance instead of link impedance. As shown in Figure 3-2, after each iteration or incremental loading, the nodal impedances are updated based upon the V/C for each movement. The updated nodal impedances, together with the constant link impedances, are then used to build a new network for the next assignment.

The proposed nodal restraint assignment procedure is more complicated than conventional turn penalties. First, the network configuration for the application of nodal impedance is different from the configuration of the conventional link impedance applications. Second, nodal restraint requires an adjustment procedure whereby the impedance for each movement at a node is determined by an association of all the movements encountered at the node (i.e., the capacity and the impedance of a turning movement at a node are variables which are a function of all the other movements entering the node). More details about the dynamic nature of this adjustment procedure are discussed in the section, Calculation of Nodal Impedances.

The revised nodal restraint assignment consists of the following steps:

1. Coding the transportation network in a new way to include turning movement attributes.
2. Computing link impedances by coded link speed and distance.
3. Building a network with the constant link impedances and the updated nodal impedances. The nodal impedance for each movement is set to zero in the first iteration. This implies that the network is assumed uncongested in the initial iteration.
4. Searching minimum paths and loading trips to the network.
5. Accumulating turn volumes (turning movements) at each selected node.

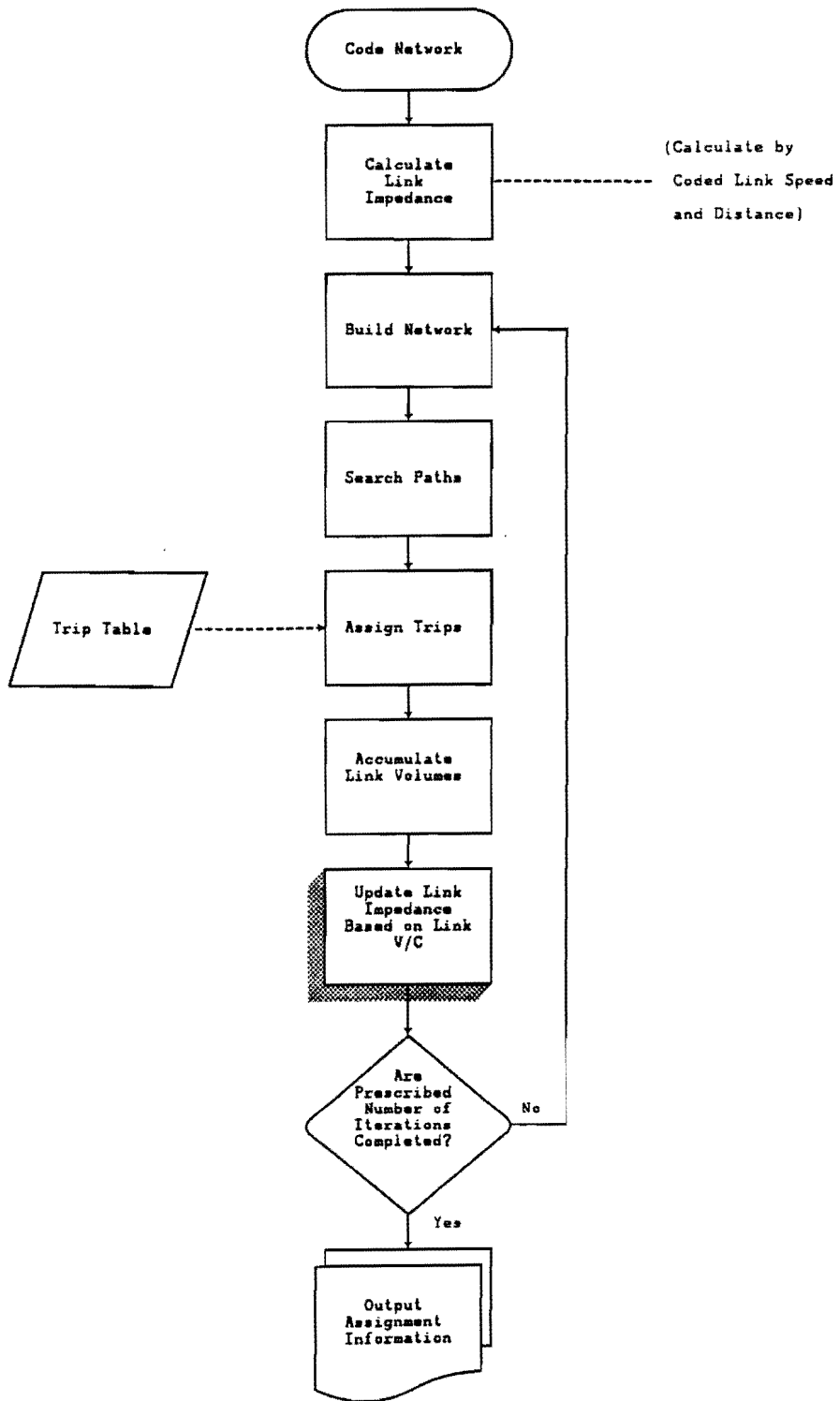


Figure 3-1 Conventional Capacity Restraint Assignment Process

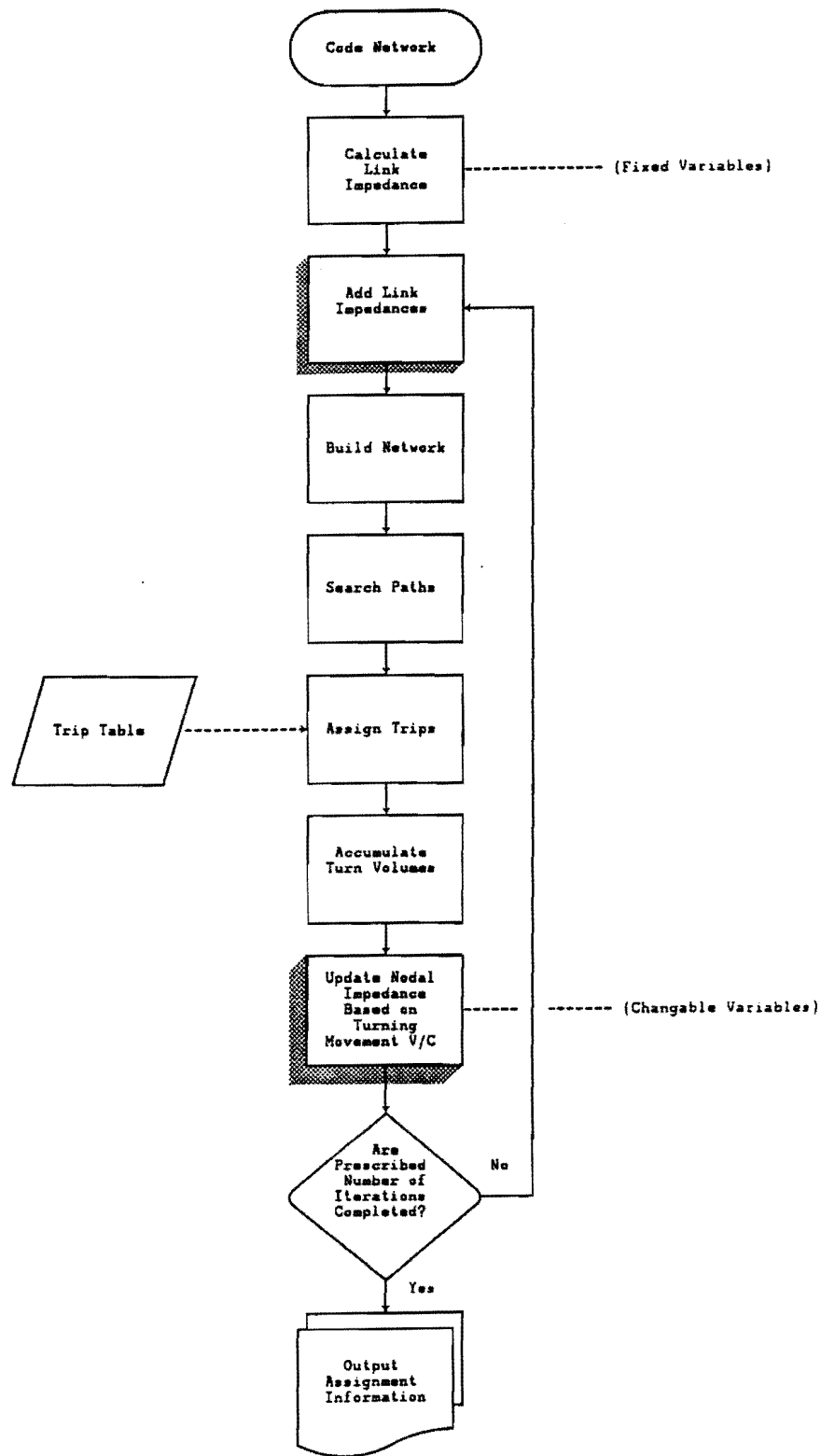


Figure 3-2 Simplified Nodal Restraint Assignment Process

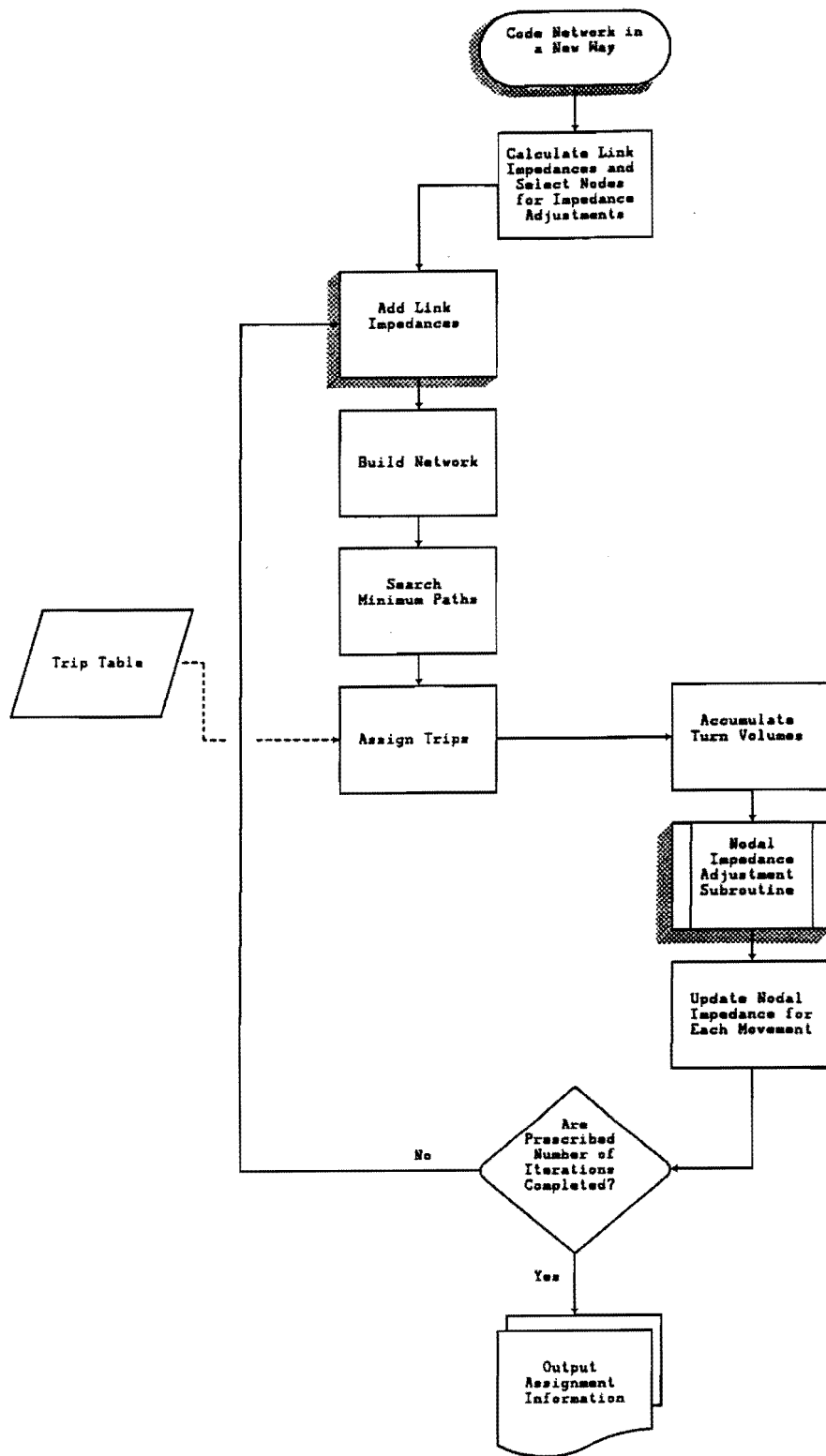


Figure 3-3 Proposed Nodal Restraint Assignment Process

6. Proceeding with the nodal impedance adjustment subroutine to calculate the nodal impedance for each movement at each selected node.
7. Updating nodal impedances for each movement.
8. Repeating Steps 3-7 until the prescribed number of iterations are completed.

This process describes a general concept of the proposed procedure. Details, such as how to reiterate the assignment process and how to accumulate the assigned turn volumes for the impedance adjustment, are discussed in the last section of this chapter.

NETWORK CONFIGURATION

The network for implementing the nodal restraint assignment procedure is different from that used in conventional capacity restraint assignment procedures. The network consists of turning movements in addition to other transportation network units such as links, nodes, and centroids. The addition of turning movements is executed by a FORTRAN program TRNFORM (TRaNsFORMAtion, see Appendix A). The program is designed in an interacting style which requires the planner to select nodes for applying nodal impedances and to input nodal information (basically the number of lanes for each turning movement) through a series of simple questions. After a node is selected, the program appends the associated new turning movement units to the original network data set.

The transformation of the network configuration can be explained by using a simple example. Figure 3-4 shows that the network is coded originally as a conventional network which consists of six zones, eight nodes, six two-way centroid connectors, and seven two-way links. In the network each two-way link (or centroid connector) is actually composed by two one-way links (or centroid connectors). The network, thus, can be regarded as six zones, seven nodes, 12 one-way centroid connectors, and 14 one-way links as shown in Figure 3-5.

The network configuration used to implement the proposed nodal restraint assignment procedure is shown in Figure 3-6. To implement the procedure, each selected node in the conventional network configuration is disaggregated into four nodes and 12 turning movements. As shown in Figure 3-6, the original node 100 (see Figure 3-5) is disaggregated into four new nodes (101, 102, 103, and 104) and 12 turning movements (101-

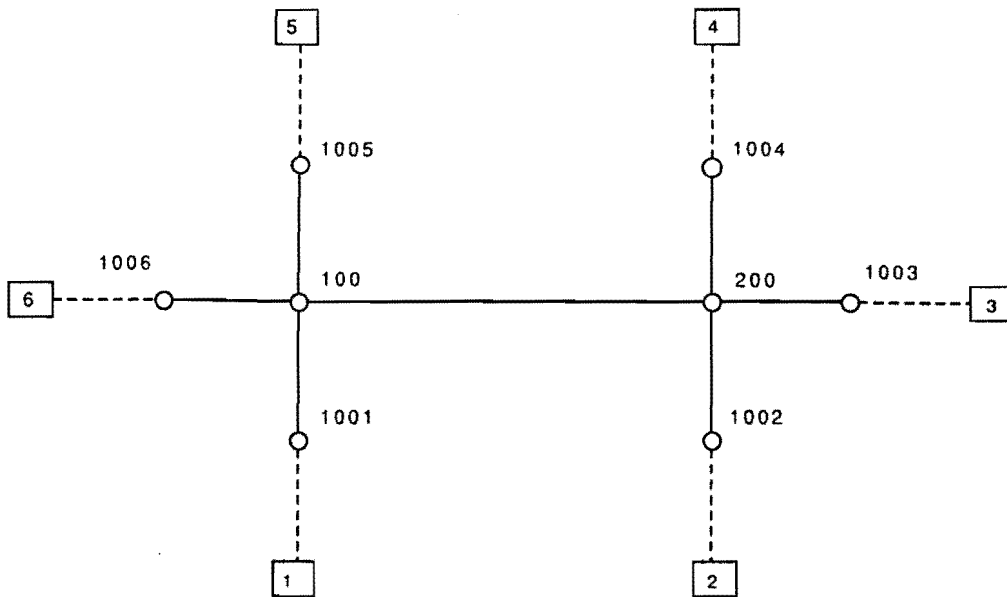


Figure 3-4 Conventional Network Configuration of a Simple Example (Network Presented in Two-Way Links and Nodes)

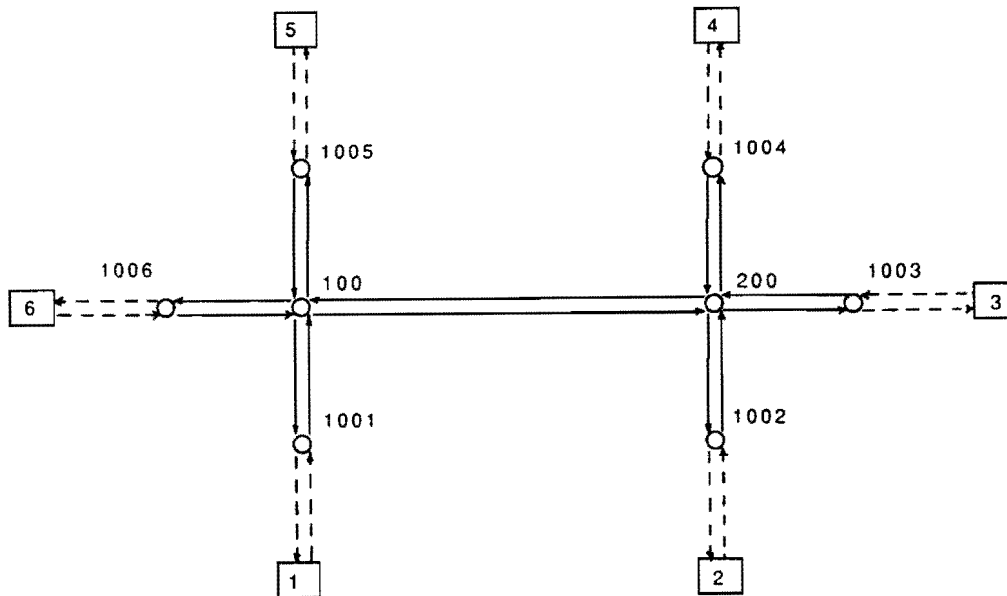


Figure 3-5 Conventional Network Configuration of a Simple Example (Network Presented in One-Way Links and Nodes)

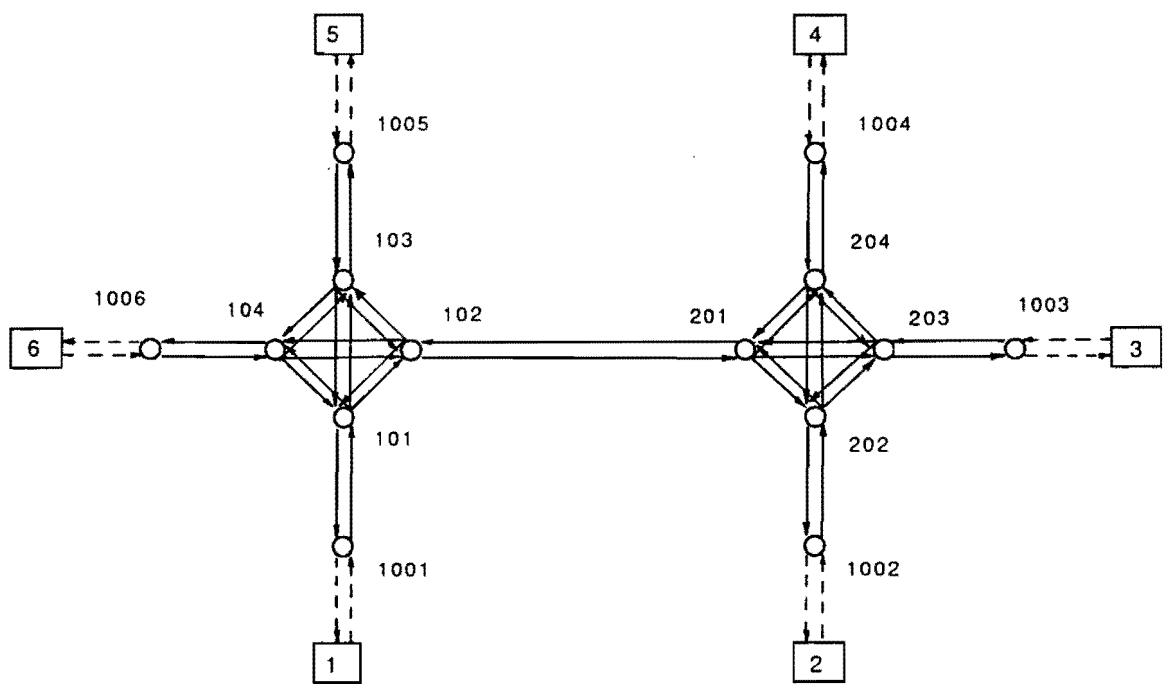


Figure 3-6 Network Configuration Used to Implement the Proposed Procedure Which Consists of Links, Turning Movements, and Nodes

102, 101-103, 101-104, 102-103, 102-104 . . . 104-103). The original node 200 is disaggregated in the same fashion as well. The remaining nodes which are connected to centroid connectors are not selected for implementing the nodal impedances.

This method actually appends the new nodes and their associated turning movements to the original network. Turning movements have the attribute of time (impedance) but no "length." In this way, most of the attributes originally coded in the network do not require a change. For example, all the attributes of the original link 1001-100 (see Figure 3-5) are then transferred to the new link 1001-101 (see Figure 3-6). However, there is one problem with this network configuration. Illogical paths, such as 101-102-103, or 101-104-103, may replace the logical path 101-103 in the assignment process. The problem is avoided by automatically appending turn prohibitors to these illogical paths.

A more efficient network configuration to implement nodal restraints is to replace all the link units by movement units. Figure 3-7 shows that the network configuration consists of fewer nodes and fewer links than the network discussed above (see Figure 3-6). The basic concept for this configuration is that three elements can be represented by a single movement: (1) the travel along one-half the length of an approach link, (2) the turning movement, and (3) the travel along one-half the length of a departure link. In this recoded network configuration, each movement is connected from the mid-point of a link to the mid-point of another link. For example, the movement 101-120 (see Figure 3-7) is recoded from the mid-point of the original link 1001-100 (see Figure 3-5) to the mid-point of the original link 100-200. This movement (101-120) actually consists of three elements from the conventional network (see Figure 3-5): (1) half of the link 1001-100, (2) the turning movement from link 1001-100 to link 100-200, and (3) half of the link 100-200.

This network configuration can be further modified in order to eliminate the illogical path problem. As shown in Figure 3-8, each node connected to movements is disaggregated into two nodes so as to maintain the directional consistence for movement connections. For example, when node 101 (see Figure 3-7) is disaggregated into nodes 101a and 101b (see Figure 3-8), the illogical path 101-120-105 (replacing logical path 101-105) is very unlikely to be formed.

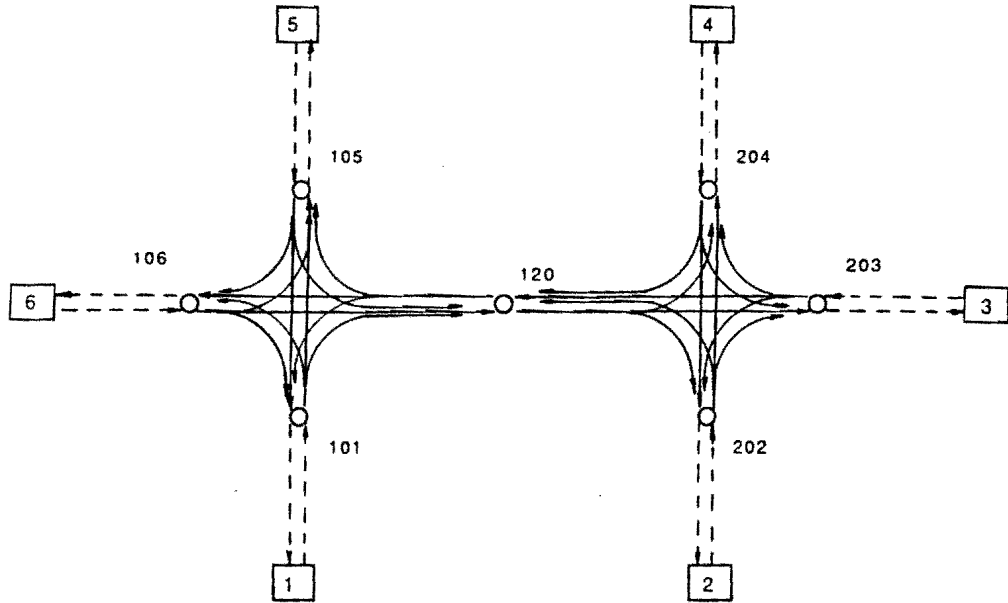


Figure 3-7 Network Configuration Consists of Only Movements and Nodes

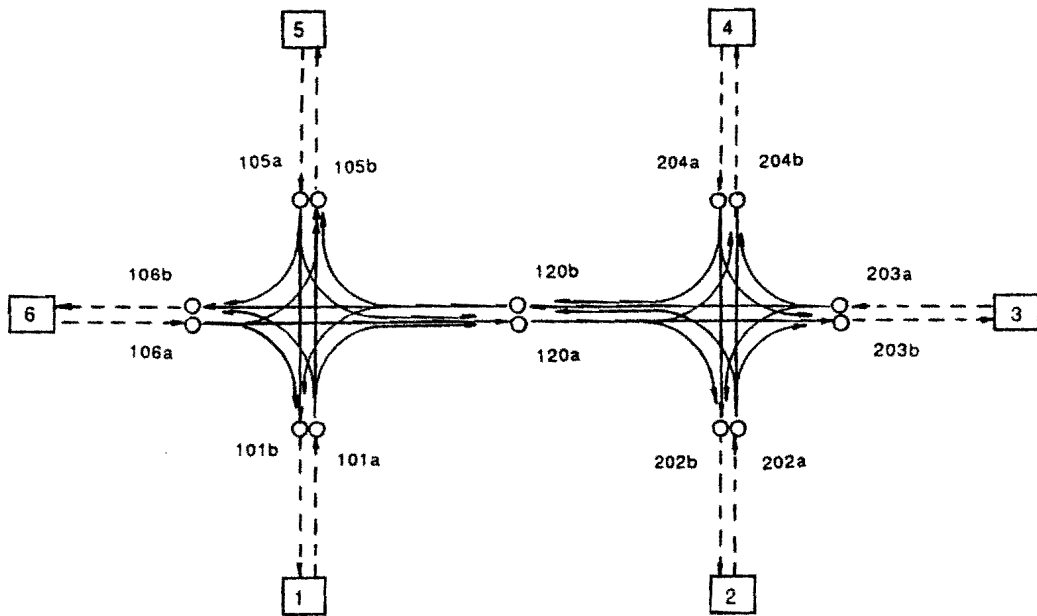


Figure 3-8 Network Configuration Recommended for Future Implementation of Nodal Restraints

The technique of transforming the conventional network into the last network configuration (as shown in Figure 3-8) has already been developed. The federally supported intersection simulation system CORFLO (18) has included the capability of internally transforming a conventionally coded network into such a configuration ("path network"). In this research the network configuration of appending new nodes and turning movements with turn prohibitors at each selected node did provide a basis for implementing the proposed procedure. However, the network consisting of directional movements and mid-block nodes (see Figure 3-8) is the configuration that should be adopted in future automated implementations.

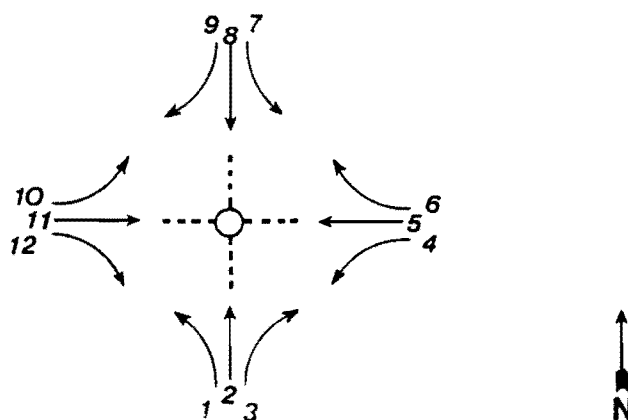
CALCULATION OF NODAL IMPEDANCES

In the proposed nodal restraint procedure, the link impedances are held constant, whereas nodal (turning movement) impedances are updated from iteration to iteration. The nodal impedance for each movement is updated through the nodal impedance adjustment subroutine. The subroutine is executed by a FORTRAN program, NODIMP (NODal IMPedance, see Appendix B), which calculates the nodal impedance for each movement at a selected node and updates the network data set for network building in the next iteration. This section describes how nodal impedances are computed in the program, and discusses major points of the proposed calculation process.

The algorithm for calculating nodal impedances at a node (intersection) was primarily derived from the planning analysis and operational analysis in Chapter 9 of the **Highway Capacity Manual 1985 (1)**. At each selected node, assigned turn volumes are decomposed into assigned lane volumes; and the sum of critical lane volumes at the node is computed based on the planning analysis. These values then are used to derive the cycle length, the ratio of green time to cycle length, degree of saturation V/C , and nodal impedance (delay per vehicle) for each movement in a procedure similar to the operation analysis. The cycle length of a node is variable from 60 seconds to 120 seconds and is determined by the sum of evaluated critical turning movements. The share of green time (g/C) for a movement is determined by the ratio of its assigned lane volume to the sum of critical lane volumes. In short, the impedance for each movement at a node is adjusted according to the

interaction among all assigned turning movements encountered at the node.

In the calculation process, turning movements must be discerned by their relative locations so that the program can emulate the interaction among the turning movements at each selected node. For convenience, a notation scheme is set up to describe the calculation process in a step-by-step algorithm. As shown in the diagram below, there are 12 turning movements at a four-leg intersection. The location of each movement is denoted by a subscript i where $i = 1 \dots 12$; and thus, the attributes associated with each movement can be denoted in the same way. Each subscript actually implies two properties: (1) approaching direction (north-bound, south-bound, east-bound, or west-bound), and (2) moving direction (left-turn, through, or right-turn). For example, V_1 denotes the lane volume of the north-bound left-turn movement, and V_2 denotes the lane volume of the north-bound through movement, and so on. The labeling of these subscripts begins at the north-bound left-turning approach in a counterclockwise order.



Using this notation scheme, the geometric attributes of a left-turn (LT) or a right-turn (RT) movement is implied by the number of lanes (l_i) associated with the movement. Examples of associating subscript numbers, lane numbers, and lane geometrics are shown as below:

- (1) If LT is a shared lane, $l_i = 0$ for $i = 1, \text{ or } 4, \text{ or } 7, \text{ or } 10$.
- (2) If LT is not a shared lane, $l_i > 0$ for $i = 1, \text{ or } 4, \text{ or } 7, \text{ or } 10$.
- (3) If RT is a shared lane, $l_i = 0$ for $i = 3, \text{ or } 6, \text{ or } 9, \text{ or } 12$.

- (4) If RT is not a shared lane, $l_i > 0$ for $i = 3, \text{ or } 6, \text{ or } 9, \text{ or } 12$.

The calculation of nodal impedances for turning movements at a selected node consists of seven steps (see Figure 3-9). These steps are described below:

1. Read Assigned Turn Volumes and Calculate Lane Volume for Each Movement

The lane volumes (assigned volumes per lane for all the turning movements at an intersection) are the basis of the whole calculation process. In general, either the left-turn shared lane analysis or the general intersection analysis is used to compute lane volumes (1). The selection between the two analysis methods is based upon the geometric layout of left turns at the intersection. For both methods, lane volume calculation can be expressed in a general form:

$$\text{For all } i=1,2, \dots, 12, \quad V_i = \frac{V_i^a}{l_i} \quad (3.1)$$

where: V_i = lane volume (assigned volume per lane) for movement i
 V_i^a = assigned volume for movement i
 l_i = number of lanes for movement i

It should be noted that Equation (3.1) is a general expression. The computation of lane volume for a turning movement sharing a lane with another movement actually is more complicated. The algorithm was designed to first inspect the left-turn movement of each approach. As shown in Figure 3-9, if the left-turn movement shares a lane with its neighboring through movement, the calculation branches to the left-turn shared lane analysis. If the left-turn movement does not share any lane with other movements, the calculation branches to the general analysis. In the left-turn shared lane analysis, two types of geometrics for the approach are considered: 1) single-lane approach, and 2) multiple-lane approach.

Left-turn Shared Lane Analysis

The algorithm first notes if there are shared left-turn movements at the intersection. It searches $l_i = 0$ for $i = 1, \text{ or } 4, \text{ or } 7, \text{ or } 10$. In the case of $l_i = 0$, i.e., if the north-bound (NB) left-turn movement is shared, it then decides to proceed with the single-lane analysis or the multiple lane analysis.

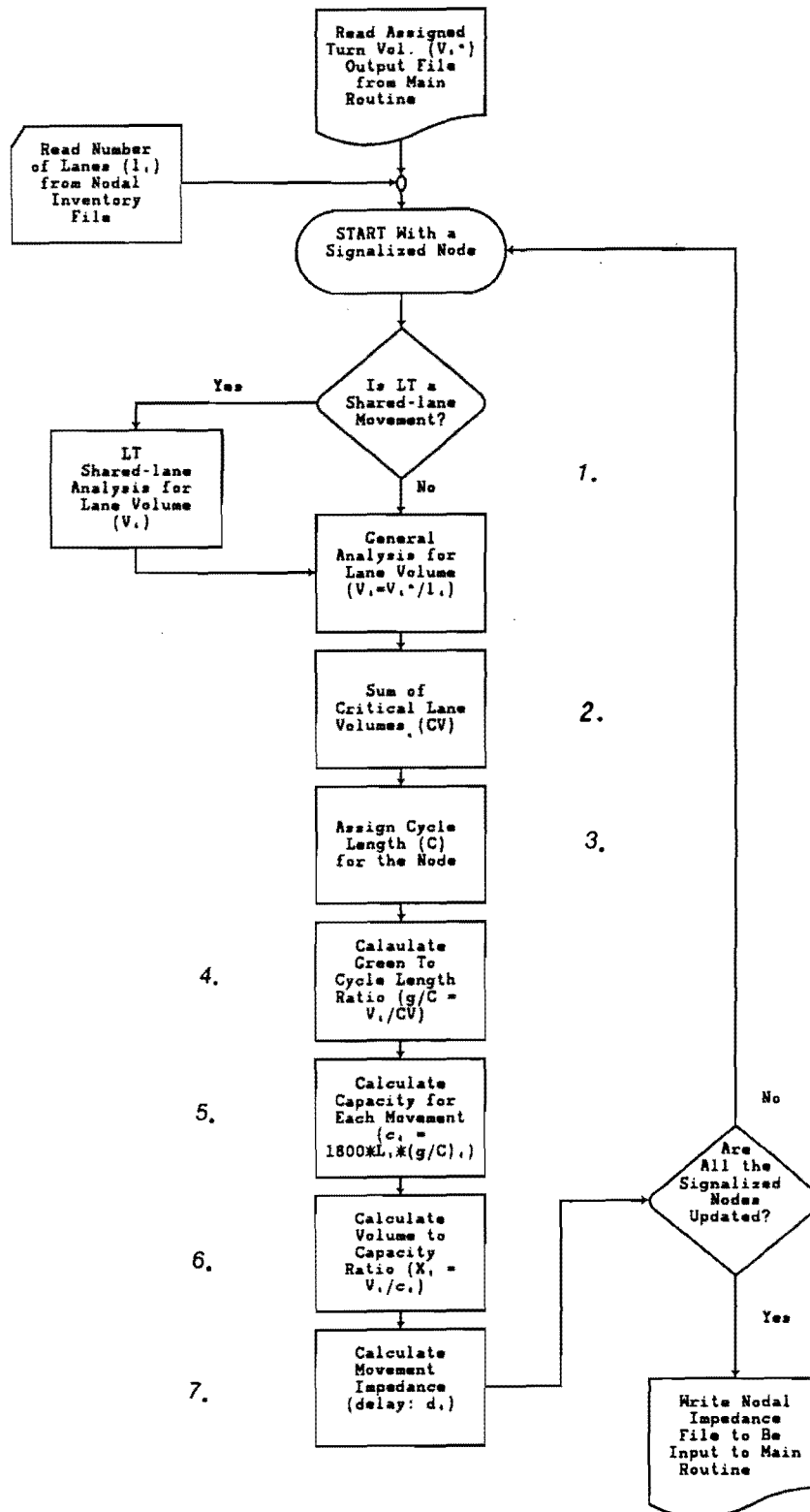


Figure 3-9 Flow Chart of the Nodal Impedance Adjustment Subroutine

- 1) **Single-lane Analysis:** The algorithm branches to the single-lane analysis if there is only one lane on the NB approach, i.e., $l_2 = 1, l_3 = 0$.

$$V_1 = V_1^a - V_7^a, \text{ if } V_1^a > V_7^a$$

$$V_1 = 0, \text{ if } V_1^a < V_7^a$$

$$V_2 = V_1^a * PCE + V_2^a + V_3^a$$

$$V_3 = 0$$

where:

$$PCE = 1.1, \text{ if } V_8^a + V_9^a < 200$$

$$PCE = 2.0, \text{ if } 200 \leq V_8^a + V_9^a < 600$$

$$PCE = 3.0, \text{ if } 600 \leq V_8^a + V_9^a < 800$$

$$PCE = 4.0, \text{ if } 800 \leq V_8^a + V_9^a < 1000$$

$$PCE = 5.0, \text{ if } V_8^a + V_9^a \geq 1000$$

- 2) **Multiple-lane Analysis:** The algorithm branches to the multiple-lane analysis if there is more than one lane on the NB approach, i.e., $l_2 + l_3 > 1$.

$$V_1 = V_1^a$$

If $l_3 = 0$, then

$$V_2 = \min \{(V_1^a * PCE + V_2^a + V_3^a) / l_2, (V_2^a + V_3^a) / (l_2 - 1)\}$$

$$V_3 = 0$$

If $l_3 > 0$, then

$$V_2 = \min \{(V_1^a * PCE + V_2^a) / l_2, V_2^a / (l_2 - 1)\}$$

$$V_3 = V_3^a / l_3$$

where:

$$PCE = 1.1, \text{ if } V_8^a + V_9^a < 200$$

$$PCE = 2.0, \text{ if } 200 \leq V_8^a + V_9^a < 600$$

$$PCE = 3.0, \text{ if } 600 \leq V_8^a + V_9^a < 800$$

$$PCE = 4.0, \text{ if } 800 \leq V_8^a + V_9^a < 1000$$

$$PCE = 5.0, \text{ if } V_8^a + V_9^a \geq 1000$$

The algorithm then proceeds to examine the other approaches sequentially. In cases where the left-turn movement on any other approach is shared, i.e., $l_4 = 0$, $l_7 = 0$, or $l_{10} = 0$, the same analysis process described above is followed.

General Analysis

The following analyses generally are applied to approaches having one or more exclusive lanes.

1) The lane volume of a left-turn lane volume:

For all $i = 1, 4, 7, 10$

$$V_i = V_i^a / l_i$$

2) The lane volume of a through movement:

For all $i = 2, 5, 8, 11$

$$V_i = V_i^a / l_i, \text{ if } l_{i+1} > 0$$

$$V_i = (V_i^a + V_{i+1}^a) / l_i, \text{ if } l_{i+1} = 0$$

3) The lane volume of a right-turn movement:

For all $i = 3, 6, 9, 12$

$$V_i = V_i^a / l_i, \text{ if } l_i > 0$$

$$V_i = 0, \text{ if } l_i = 0$$

2. Calculate the Sum of Critical Lane Volumes

The sum of critical lane volumes is composed of two parts, the critical lane volumes of the north-south direction and of the east-west direction.

$$CV = CV_{(N-S)} + CV_{(E-W)} \quad (3.2)$$

where:

CV	=	the sum of critical lane volumes for the intersection
$CV_{(N-S)}$	=	the sum of critical lane volumes for the north-south direction
	=	$\max \{ V_1 + V_8, V_2 + V_7 \}$
$CV_{(E-W)}$	=	the sum of critical lane volumes for the east-west direction
	=	$\max \{ V_4 + V_{11}, V_5 + V_{10} \}$

3. Estimate Cycle Length for the Intersection

The signal cycle length for an intersection is approximated by the sum of the critical volumes based on the assumption of 16 seconds lost time for each cycle. All the intersections are assumed to be operated in a two-phase and lead-leg operation which is believed to be in accordance with the operation implied by the **Highway Capacity Manual 1985** planning analysis. Eight seconds are assumed to be lost in each phase, including 4 seconds of starting delay (23) and four seconds of yellow interval.

The cycle length is varies from 60 seconds to 120 seconds and is determined by the sum of evaluated critical turning movements. The calculation of the length of a cycle is based on the maximum utilization of a cycle. As such, the length of a cycle is decided by the lost time and the time required to progress through the critical movements (2 seconds headway per vehicle) in a cycle. For example, for 16 seconds lost time per cycle and a saturation flow of 1,800 vehicles per hour, if the sum of critical lane volumes is 1,480 in a hour, the cycle length assigned for this case is 90 seconds. The formulas used in the estimation are:

$$C = 60, \text{ if } CV \leq (S*(1-L/60)) \quad (3.3a)$$

$$C = (S*L)/(S-CV) , \text{ if } (S*(1-L/60)) < CV \leq (S*(1-L/120)) \quad (3.3b)$$

$$C = 120, \text{ if } CV > (S*(1-L/120)) \quad (3.3c)$$

where:

- C = cycle length
- CV = sum of critical lane volumes
- S = saturation flow rate
= 1,800 vehicles/hour
- L = lost time per cycle
= 12 seconds/cycle

4. Calculate the Ratio of Green Time to Cycle Length (g/C) for Each Movement

The algorithm assumes that green time for a movement at an intersection is not fixed but is a variable which is a function of its assigned volume. In this application, the ratio of green time to cycle length (g/C, or more precisely the ratio of green time to cycle length excluding the lost time, $g/(C-L)$) for each movement, is considered to be proportional to the ratio of assigned lane volume to the sum of critical lane volumes. Within each phase of a cycle, the green time of the phase is used by the critical movements and is parallel to the non-critical movements in the same phase. The distribution of g/C of a cycle is decided, for the most part, by the critical movements.

- a. Calculation of g/C for critical movements: The ratio of green time to cycle length of a critical movement is approximated by proportioning its lane volume to the sum of critical lane volumes.

$$\text{For all } i = i^* \quad (g/C)_i = \frac{V_i}{CV} \quad (3.4)$$

where:

- $(g/C)_i$ = green split for critical movement i
- V_i = lane volume for critical movement i
- CV = the sum of critical lane volumes for the intersection
- i^* = critical movement i

- b. Calculation of g/C for non-critical movements: For movements operated in the same approaching phase (north-south or east-west), the non-critical movements are given the same length of green time as that provided for the critical movements. This time period then is redistributed between the two non-critical movements based on the proportion of the lane volume of each movement to the sum of these two paired non-critical lane volumes.

- (1) For the N-S approaching phase, i.e., for all $i = 1, \text{ or } 2, \text{ or } 7, \text{ or } 8$, and $i \neq i^*$

$$(g/C)_i = \frac{V_i}{NCV_{(N-S)}} * \frac{CV_{(N-S)}}{CV} \quad (3.5a)$$

where:

- $CV_{(N-S)}$ = the sum of critical lane volumes for north-south direction
- = $\max \{ V_1 + V_8, V_2 + V_7 \}$
- $NCV_{(N-S)}$ = the sum of non-critical lane volumes for north-south direction
- = $\min \{ V_1 + V_8, V_2 + V_7 \}$

- (2) For the E-W approaching phase, i.e., for all $i = 4, \text{ or } 5, \text{ or } 10, \text{ or } 11$, and $i \neq i^*$

$$(g/C)_i = \frac{V_i}{NCV_{(E-W)}} * \frac{CV_{(E-W)}}{CV} \quad (3.5b)$$

where:

- $CV_{(E-W)}$ = the sum of critical lane volumes for east-west direction
- = $\max \{ V_4 + V_{11}, V_5 + V_{10} \}$
- $NCV_{(E-W)}$ = the sum of non-critical lane volumes for east-west direction
- = $\min \{ V_4 + V_{11}, V_5 + V_{10} \}$

(3) Calculation of g/C for right-turn exclusive movements: The algorithm assumes that all the exclusive right-turns are operated in the mode of right-turn-on-red. The green time available for an exclusive right-turn is then a function of its conflicting left-turn and through movements.

$$\text{a. For } i = 3, \text{ if } l_3 > 0, (g/C)_3 = 1 - (V_7 + V_{11})/CV \quad (3.6a)$$

$$\text{b. For } i = 6, \text{ if } l_6 > 0, (g/C)_6 = 1 - (V_{10} + V_2)/CV \quad (3.6b)$$

$$\text{c. For } i = 9, \text{ if } l_9 > 0, (g/C)_9 = 1 - (V_1 + V_5)/CV \quad (3.6c)$$

$$\text{d. For } i = 12, \text{ if } l_{12} > 0, (g/C)_{12} = 1 - (V_4 + V_8)/CV \quad (3.6d)$$

In the case where $l_i = 0$, for all $i = 3, 6, 9, 12$ (i.e., i is a right-turn shared movement), $(g/C)_i = 0$ is assigned. It is assumed that the right-turn shared movements will experience the same delay as the through movement with which its lane is shared.

5. Calculate Lane Capacity for Each Movement

The lane capacity for each movement at an intersection is determined by its green time to cycle length ratio and the saturation flow rate.

$$c_i = S_i * (g/C)_i \quad \forall i=1, 2, \dots, 12 \quad (3.7)$$

where:

- c_i = lane capacity for movement i
- S_i = saturation flow rate
= 1,800 pcphpl (passenger cars per hour per lane)

6. Calculate X (V/C Ratio) for Each Movement

The V/C ratio, X , which is also called the degree of saturation, is determined by the ratio of the lane volume to the lane capacity for each movement.

$$X_i = \frac{V_i}{c_i} \quad \forall i=1, 2, \dots, 12 \quad (3.8)$$

where:

- X_i = degree of saturation
= V/C ratio of the movement at the intersection
- V_i = lane volume for movement i

In the case of $c_i = 0$, then $X_i = 0$.

7. Calculate Nodal Impedance for Each Movement

The calculation of nodal impedance (delay) for each movement is based on the delay function described in Chapter 9 of **Highway Capacity Manual 1985**. It is assumed that the traffic condition is composed of arrivals that are widely dispersed throughout the red and green phases and where the signal system is uncoordinated. Such an assumption suggests an average traffic condition. A progression adjustment factor of 0.85 was used in the delay function since the variable cycle length is, in a sense, parallel to the actuated signal operation.

For all $i = 1, 2, \dots, 12$, if $X_i > 0$, then

$$d_i = 0.85 * (0.38C \frac{[1-(g/C)_i]^2}{[1-(g/C)_i * X_i]} + 173X_i^2 [(X_i-1) + \sqrt{(X_i-1)^2 + (16X_i/c_i)}]) \quad (3.9)$$

where:

- d_i = average stop delay per vehicle for movement i
- C = cycle length of the intersection
- $(g/C)_i$ = green time to cycle length ratio for movement i
- X_i = volume to capacity ratio of movement i
- c = capacity of movement i

Equation (3.9) is used for all movements (both critical and non-critical) except for left-turn shared-lane movements whose X_i is equal to zero and for right-turn shared-lane movements. The shared-lane right-turn or shared-lane left-turn movement is assumed to experience the same delay as the through movement with which its lane is shared.

- a. For left-turn shared-lane movement, i.e., for $i = 1, 4, 7, 10$, if $X_i = 0$, $d_i = d_{i+1}$.
- b. For right-turn shared-lane movement, i.e., for $i = 3, 6, 9, 12$, if $X_i = 0$, $d_i = d_{i-1}$.

The same delay is also assumed for all three movements on a single-lane approach.

For all $i = 2, 5, 8, 11$, if $l_i = 1$, and $l_{i-1} = l_{i+1} = 0$,

$$\text{then } d_i = d_{i-1} = d_{i+1} = \max \{ d_i, d_{i-1}, d_{i+1} \} .$$

According to the **Highway Capacity Manual 1985**, the delay function predicts the average delay per vehicle for an assumed random arrival pattern for approaching vehicles. The first term of the equation accounts for uniform delay, i.e., the delay that occurs if arrivals are uniformly distributed over time. The second term of the equation accounts for incremental delay of random arrivals over uniform arrivals and for the additional delay due to cycle failures. The equation yields reasonable results for values of X between 0.0 and 1.0 . Oversaturation (i.e., $X > 1.0$) is not desirable. The **Highway Capacity Manual 1985** also recommended that the equation be used with caution for values of X up to 1.2 .

It should be noted that the calculation of nodal impedances discussed above is primarily for planning applications, not for precise delay estimation of an individual or a few coordinated intersections along an arterial for engineering purposes. All the assumptions made in the computation process aim to provide an average condition for a network-wide traffic evaluation. These assumptions generally are considered appropriate in terms of the stability and flexibility of the assignment model.

NODAL RESTRAINT ASSIGNMENT PROCEDURE

As mentioned previously, the application of the proposed procedure required (1) a new network configuration to include turning movement attributes, (2) a new impedance adjustment subroutine to compute nodal impedances, and (3) a traffic assignment main routine to be combined with the subroutine. The network configuration was modified by using the program TRNFORM (see Appendix A). The nodal impedances were computed by using the program NODIMP (see Appendix B). The build network and load highway network functions in TRANPLAN (24) were used as the traffic assignment main routine and combined with the nodal impedance adjustment subroutine.

The major portion of the nodal restraint assignment procedure is a reiterate process of updating nodal impedances, building networks, and loading trips. As shown in Figure 3-10, at each iteration, nodal impedances are computed and updated in the nodal impedance adjustment subroutine (at the initial iteration, nodal impedances are overlooked). After the nodal impedances in the current network data set are updated, a new network is built by using the build highway network function (HWYNET.EXE), and trips are loaded

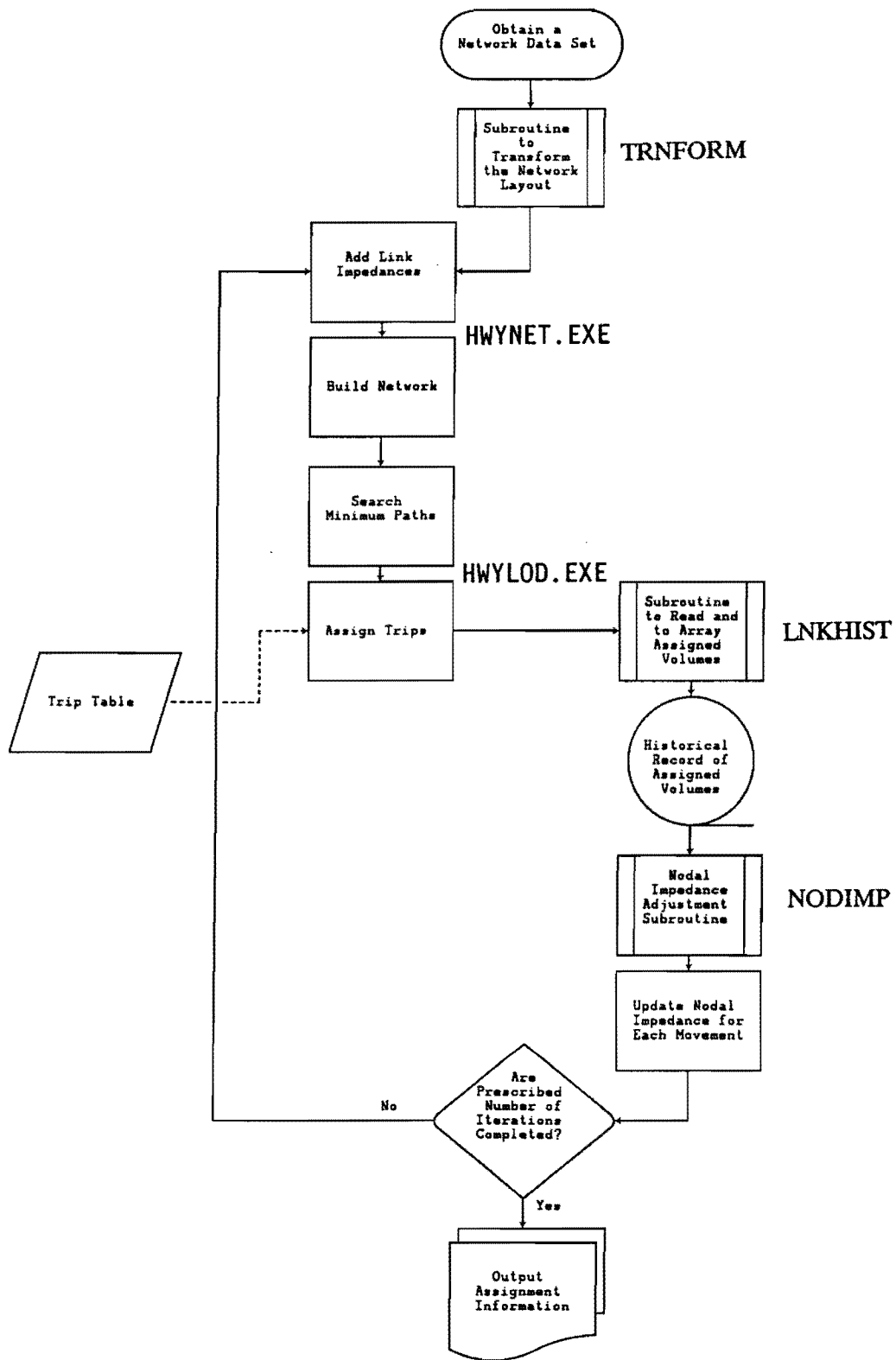


Figure 3-10 Nodal Restraint Assignment Procedure Applied in the Research

to the network by using the all-or-nothing assignment option of the load highway network function (HWYLOD.EXE) in TRANPLAN. The assigned turn volumes are then used as a basis for adjusting nodal impedances in the nodal impedance adjustment subroutine.

However, the assigned volumes from TRANPLAN's load highway network function are unformatted data which cannot be read directly by the program NODIMP. Another FORTRAN program, LNKHIST (LiNK HISTory, see Appendix C), was written to provide interface between the traffic assignment main routine and the nodal impedance adjustment subroutine. The program LNKHIST reads the unformatted assignment data and arrays the assigned turn volumes (and nodal impedances) after each iteration. Thus, the historical record of assigned volume arrays by iterations provides the means for accumulating the assigned volumes necessary to update the nodal impedances based on the procedure chosen to reiterate the assignment process.

The reiterative procedures considered for applying the nodal restraint assignments include four incremental procedures; they are (1) equal weighting incremental procedure with the accumulated volumes expanded to 100 percent, (2) equal weighting incremental procedure without expanding the accumulated volumes, (3) weighted average incremental procedure with the accumulated volumes expanded to 100 percent, and (4) weighted average incremental procedure without expanding the accumulated volumes. The "equal weighting" means that a uniform increment was used at each iteration. For example, 25 percent of the assigned volumes from each iteration is used for a four-iteration incremental assignment. The "weighted average" means that unequal increments which total 100 percent are used. For example, 35 percent, 25 percent, 25 percent, 15 percent may be used by analysts in a four-iteration incremental assignment. In this application, the assignment procedure is selected through specifying parameters in the program NODIMP.

In summary, the entire process of the nodal restraint assignment procedure applied in this research included the following steps:

1. Obtain the network data set of a study area.
2. Transform the network data set to include turning movement attributes by using the program TRNFORM.
3. Build the network with the constant link impedances and the updated nodal impedances

by using TRANPLAN's build network function. The nodal impedances are zero in the initial iteration.

4. Search minimum paths and load trips to the network by using TRANPLAN's load highway network function.
5. Array the assigned turn volumes (turning movements) by using the program LNKHIST.
6. Proceed with the nodal impedance adjustment subroutine by using the program NODIMP to calculate the nodal impedance for each movement at selected nodes and to update the nodal impedance (in the network data set) for the next assignment.
7. Repeat Steps 3-6 until the prescribed number of iterations are completed.

It should be noted that the process described above is a prototype procedure which aims to test the new assignment procedure and still needs to be refined. However, subroutines can be developed to eliminate the awkward and time-consuming procedures used in testing the prototype procedure.

CHAPTER IV

NODAL RESTRAINT ASSIGNMENT PROCEDURE TESTING

INTRODUCTION

Testing and evaluating newly developed assignment procedures are essential. This chapter examines the robustness (i.e., the stability and flexibility) of the proposed nodal restraint procedure through a series of tests. Evaluation of the proposed procedure is presented in Chapter VI. The procedure is compared with the selected "best" capacity restraint assignment (selection is detailed in Appendix D) based on the available ground count data. This chapter focuses on the proposed assignment procedure itself, i.e., how the proposed assignment procedure performed and whether it performed as expected.

This chapter commences with descriptions of the test network and the available ground count data. The impedance values produced by the nodal impedance subroutine were examined to see if they were computed correctly. The nodal impedance function used to compute the nodal impedances was examined through comparison with the delay equation used in the D-FW Joint Model (7) and the widely used BPR delay equation. The efficiency of the proposed model was examined by analyzing the rate of convergence. The stability of the model was examined through network performance measures such as vehicle-miles of travel, average V/C ratio, and distribution of directional link V/C in the network.

Four different procedures for the nodal restraint assignment were considered in the initial stage of testing. All were executed using 10 iterations. These procedures include:

1. Equal weighting incremental procedure without expanding the accumulated assigned volumes to 100 percent: At each iteration, all the trips from each O-D pair are loaded to the network, and nodal impedances are adjusted according to accumulated weighted turn volumes from the previous and the current iterations. The weight of the assigned turn volumes for each iteration is 10 percent uniformly.
2. Equal weighting incremental procedure with the accumulated assigned volumes expanded to 100 percent: At each iteration, all the trips from each O-D pair are loaded to the network, and nodal impedances are adjusted according to the projected turn volumes which are expanded from the accumulated weighted turn volumes (from the

previous and the current iterations) to 100 percent. The weight of the assigned volumes for each iteration is a uniform 10 percent when 10 iterations are used.

3. Weighted average incremental assignment without expanding the accumulated assigned volumes to 100 percent: At each iteration, all the trips from each O-D pair are loaded to the network, and nodal impedances are adjusted according to accumulated weighted turn volumes from the previous and the current iterations. The weight of the assigned turn volumes for each iteration is 20, 15, 10, 10, 10, 10, 10, 5, 5, 5 percent, sequentially.
4. Weighted average incremental procedure with the accumulated assigned volumes expanded to 100 percent: At each iteration, all the trips from each O-D pair are loaded to the network, and nodal impedances are adjusted according to the projected turn volumes which are expended from the accumulated weighted turn volumes (from the previous and current iterations) to 100 percent. The weight of the assigned turn volumes for each iteration is 20, 15, 10, 10, 10, 10, 10, 5, 5, 5 percent, sequentially.

It should be noted that the process of loading trips and accumulating volumes in these procedures is contrary to that usually conducted in the capacity restraint assignments, such as those assignments conducted in Appendix D. In these procedures, all the trips in the O-D table are assigned to the network; and then the loaded turn (link) volumes are weighted according to a specified percentage. In the capacity restraint assignments, the trips in the O-D table are weighted according to a specified percentage before they are loaded to the network; and then the link volumes are accumulated.

The first and third procedures (i.e., the incremental procedures adjusting nodal impedances without expanding the accumulated volumes to 100 percent) were eliminated early in the analysis because of their limited effectiveness. These procedures diverted very few trips until 80 percent of the trips were loaded to the network. The possible reason for this is discussed in the second section of this chapter. The following discussions are generally focused on the performance of the second and fourth procedures, which were selected as the two final models for study.

TEST NETWORK AND GROUND COUNT DATA

The Preston Road Corridor in North Dallas was selected as the study area. As shown in Figure 4-1, Preston Road is one of the principal arterials linking central Dallas and North Dallas (especially the Plano area). Most intersections along the arterial are fully saturated during the PM peak hour (17:00 - 18:00). The study area is about six miles long and three miles wide and includes (1) Preston Road and its parallel arterials Hillcrest and North Tollway running in the north-south direction, and (2) Belt Line, Arapaho, Frankford, Plano Parkway, and other arterials running in the east-west direction.

The test network is a small area network extracted from the North Dallas PM peak-hour regional network. The regional network data were provided by NCTCOG in a format ready to run TRANPLAN. These data, constituting a PM peak-hour traffic assignment, include (1) PM peak-hour (17:00 - 18:00) network with details focused on the North Dallas area, (2) PM peak-hour (17:00 - 18:00) vehicular trip table, and (3) traffic assignment execution file. The traffic assignment was a product of the NCTCOG travel demand forecasting model (7) (presently called the D-FW Joint Model to represent the joint effort of TxDOT and NCTCOG). Observed historical traffic counts on scattered locations along Preston Road were also provided by NCTCOG.

The test network and the affiliated trip table were extracted from the regional network and trip table by using subarea windowing functions in TRANPLAN (24). The procedure of extracting the small network and trip table includes three steps: (1) using the extract subarea network function (EXNET.EXE) to obtain the small area network, (2) using the load highway selected links function (HWYLOD.EXE) to accumulate trips entering and exiting external stations, and (3) using the extract subarea trip table function to obtain the small area trip table. As shown in Figure 4-2, the windowed small area network encompasses 47 internal traffic zones and 40 external stations.

The ground count data used to evaluate the proposed assignment procedure and the capacity restraint assignments were provided by TTI. Turning movement counts conducted by TTI's Arlington office in 1989 and 1990 were available for 14 locations (eight of them in the study area) along Preston Road (State Highway 289) from LBJ Freeway (I-635) to State Highway 121. These turning movements are nine-hour counts including: (1) AM counts:

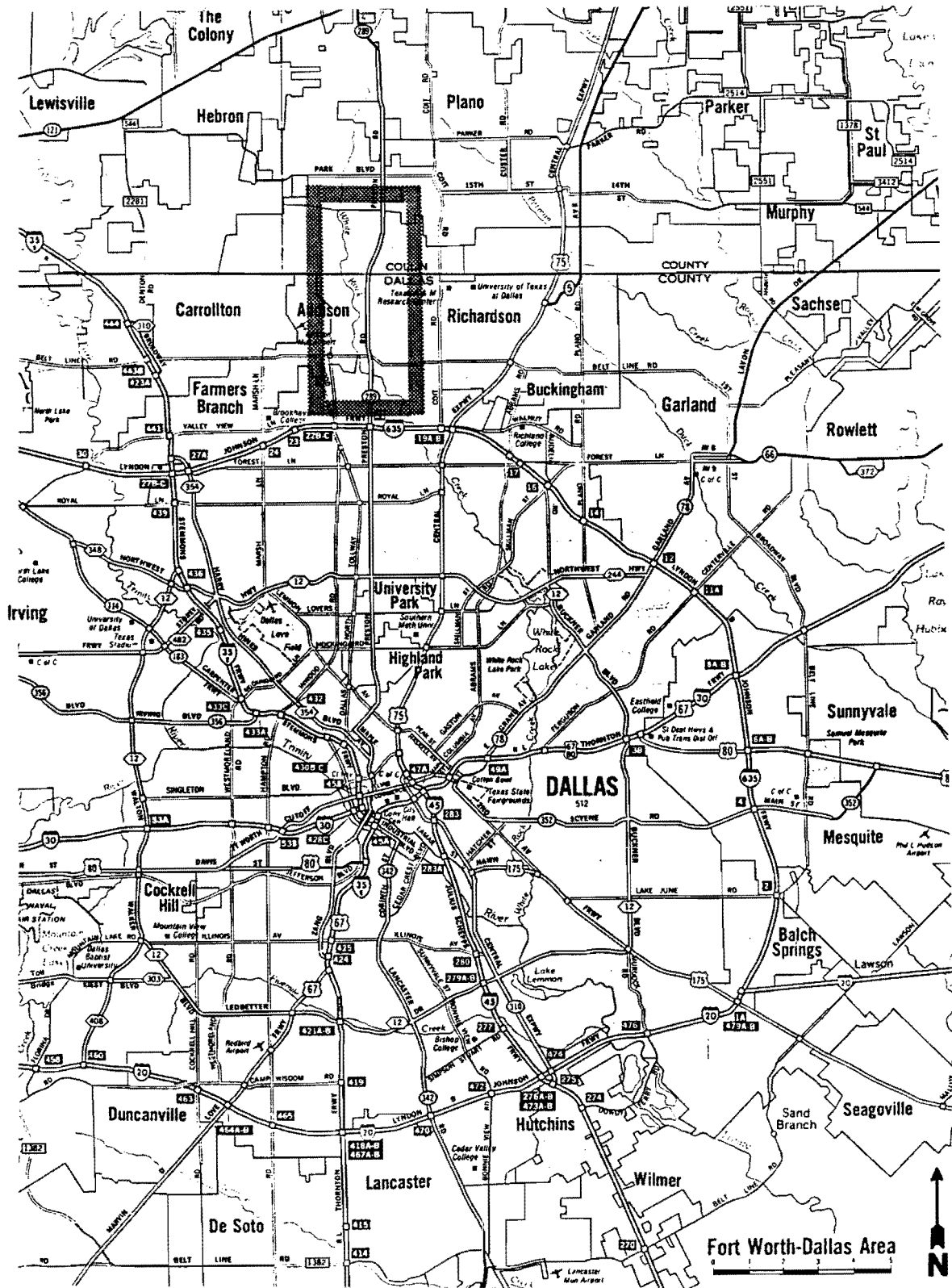


Figure 4-1 The Study Area: Preston Road Corridor in North Dallas

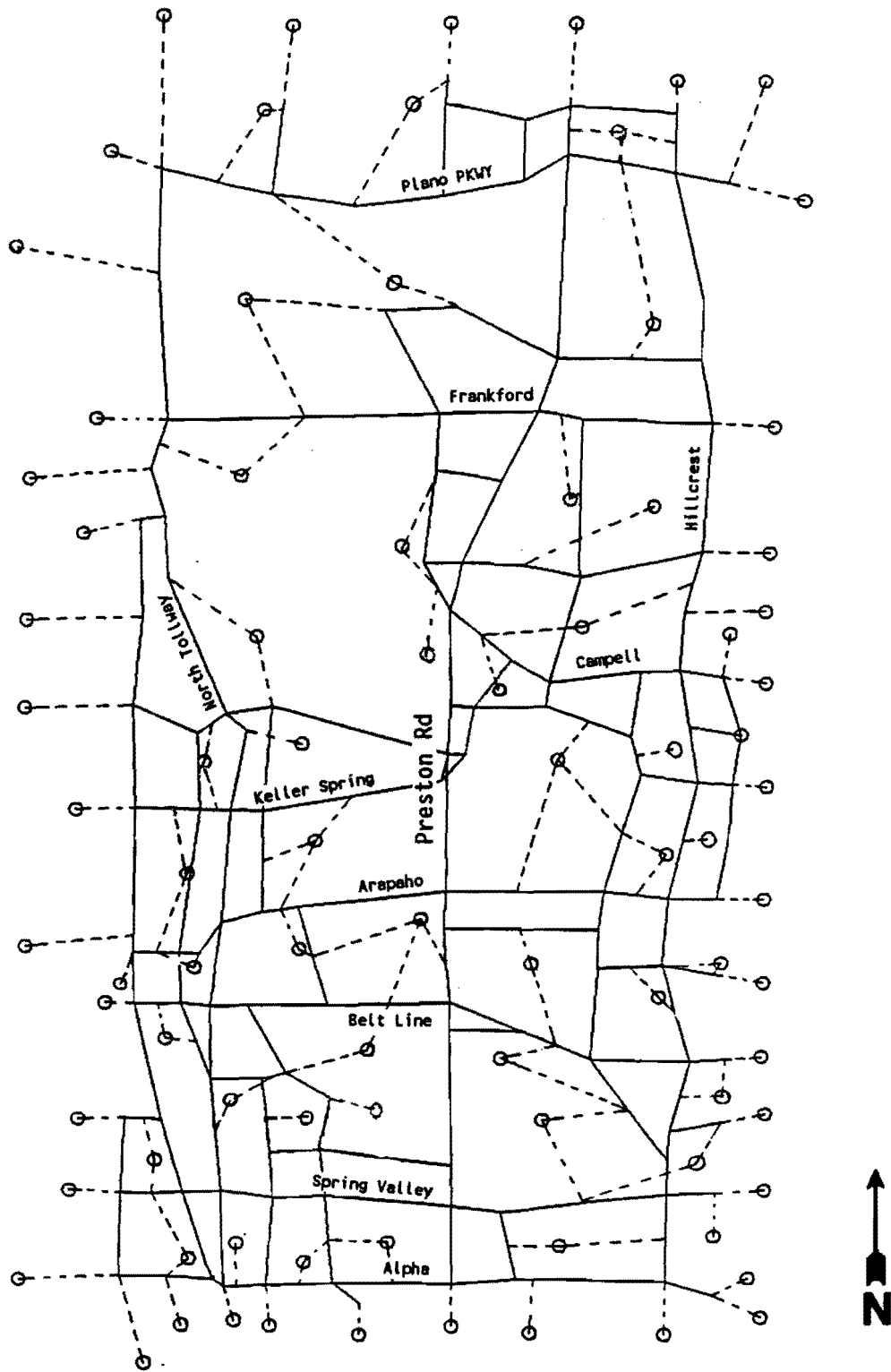


Figure 4-2 The Test Network

6:00 - 9:30, (2) PM counts: 15:30 - 19:00, and (3) off peak: 11:00 -13:00. PM counts from 17:00 to 18:00 were used to evaluate assignment results. In addition to the turning movements, approach volume machine counts at each location were collected during the same period.

These data were found to be acceptable for this research. The traffic counts collected by TTI were first examined. The approach volume counts at scattered locations along Preston Road were found to be generally in compliance with the historical growth trend. The assignment results from the D-FW Joint Model were also evaluated. When compared to the available TTI ground count data, the assigned link volumes from the model were found to be moderately acceptable, but the assigned turning movements were not acceptable. It was found that the percent root mean square errors (PRMSE) of the approach volumes at the eight intersections was about 50 percent, but the PRMSE the assigned turning movements at these intersections was about 90 percent. Apparently, the turning movement replications require improvement for project-level purposes.

EXAMINATION OF THE NODAL IMPEDANCE CALCULATION

Before different assignment procedures were tested, the nodal impedance subroutine (NODIMP) was examined as to whether it generated proper impedance estimates. The computation of the sum of critical lane volumes was inspected first since it is the basis for deriving nodal impedances. Next, the computation of nodal impedance for signalized nodes was examined. In this research, the nodal restraint was applied to all the nodes in the test network except those linked to one or more centroid connectors. As a result, the selected nodes for applications of nodal restraint include signalized intersections and non-signalized intersections. It is, thus, necessary to examine whether the application of the critical lane volumes approach and the accordingly nodal impedance computation process to non-signalized nodes produced appropriate figures for the assignment procedure.

Computation of the Sum of Critical Lane Volumes

Two conditions presented in Chapter 9 (pages 9-59 and 9-60) of the **Highway Capacity Manual 1985** were employed to validate the computation of the sum of critical

lane volumes. The first case involves the calculation of an intersection with an exclusive left-turn lane(s). In the second, more complicated case, the left-turn shared lane analysis must be used to obtain proper lane volume estimates.

The computation of the sum of critical lane volumes for the first example is illustrated in Table 4-1. As shown, the NB-TH, SB-LT, WB-TH, and EB-LT movements are the critical movements and result in a critical lane volume sum of 1,193. The result concurs with that shown in the **Highway Capacity Manual 1985**.

The computation of the sum of critical lane volumes for the second example is illustrated in Table 4-2. As mentioned in Chapter III, lane volume calculation for left-turn shared movements can further be classified into single-lane analysis and multiple-lane analysis. In this example, the computation of lane volume for the NB and SB approaches requires single-lane analysis and that for the WB and EB approaches require multiple-lane analysis. These computations are:

1. Computation of lane volumes for movements in the NB and SB approaches:

$$\begin{aligned}
 V(1) &= 0 \\
 V(2) &= VA(1)*PCE + VA(2) + VA(3) \\
 &= 80*2 + 150 + 60 \\
 &= 370 \\
 V(3) &= 0 \\
 \\
 V(7) &= VA(7) - VA(1) \\
 &= 120 - 80 \\
 &= 40 \\
 V(8) &= VA(7)*PCE + VA(8) + VA(9) \\
 &= 120*2 + 230 + 170 \\
 &= 640 \\
 V(9) &= 0
 \end{aligned}$$

2. Computation of lane volumes for movements in the WB and EB approaches:

$$\begin{aligned}
 V(4) &= VA(4) \\
 &= 170 \\
 V(5) &= \min \{ (VA(4)*PCE + VA(5) + VA(6))/Ln(5), (VA(5) + VA(6))/(Ln(5)-1) \} \\
 &= \min \{ (170*4 + 360 + 110)/2, (360 + 110)/(2-1) \} \\
 &= 470 \\
 V(6) &= 0
 \end{aligned}$$

Table 4-1
Computation of the Sum of Critical Lane Volumes,
Example from the Highway Capacity Manual 1985

Turning Movement i	Assigned Turn Vol. VA(i)	Lane Number Ln(i)	Assigned Lane Vol. V(i)	Sum of Critical Lane Volume CV	
1 (NB-LT)	260	1	260		
2 (NB-TH)	700	3	440 *	CV(n-s)	640
3 (NB-RT)	180	0	0		
4 (WB-LT)	80	1	80		
5 (WB-TH)	1200	3	433.3 *		
6 (WB-RT)	100	0	0		
7 (SB-LT)	200	1	200 *	CV(e-w)	553.3
8 (SB-TH)	550	3	325		
9 (SB-RT)	100	0	0		
10 (EB-LT)	120	1	120 *		
11 (EB-TH)	1300	3	433.3		
12 (EB-RT)	460	1	460	CV = CV(n-s)+CV(e-w) =	1193.3

* Critical Movement

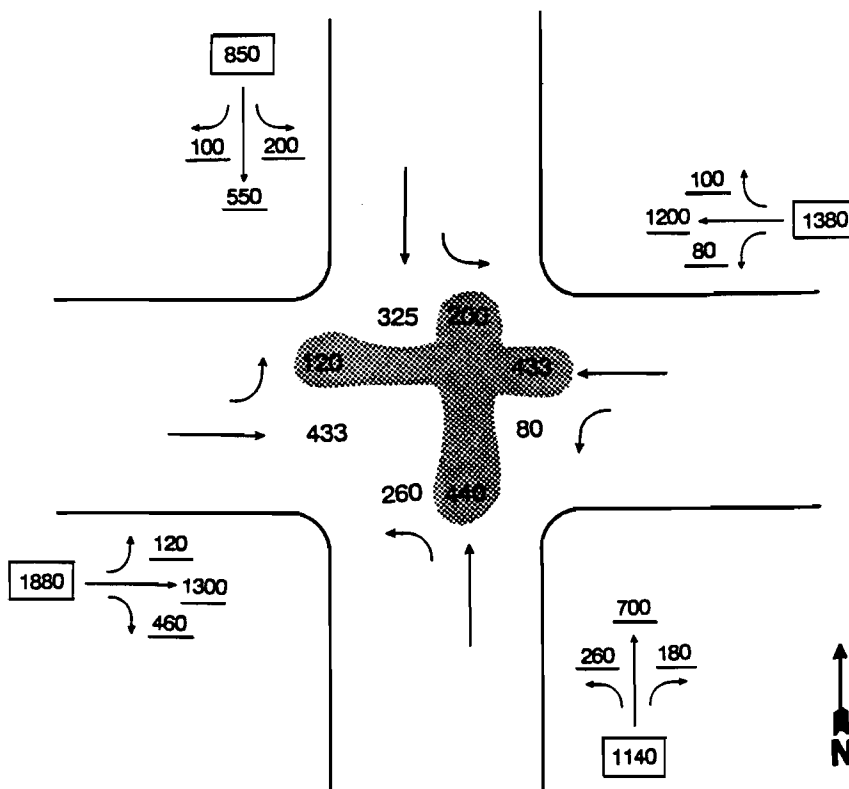
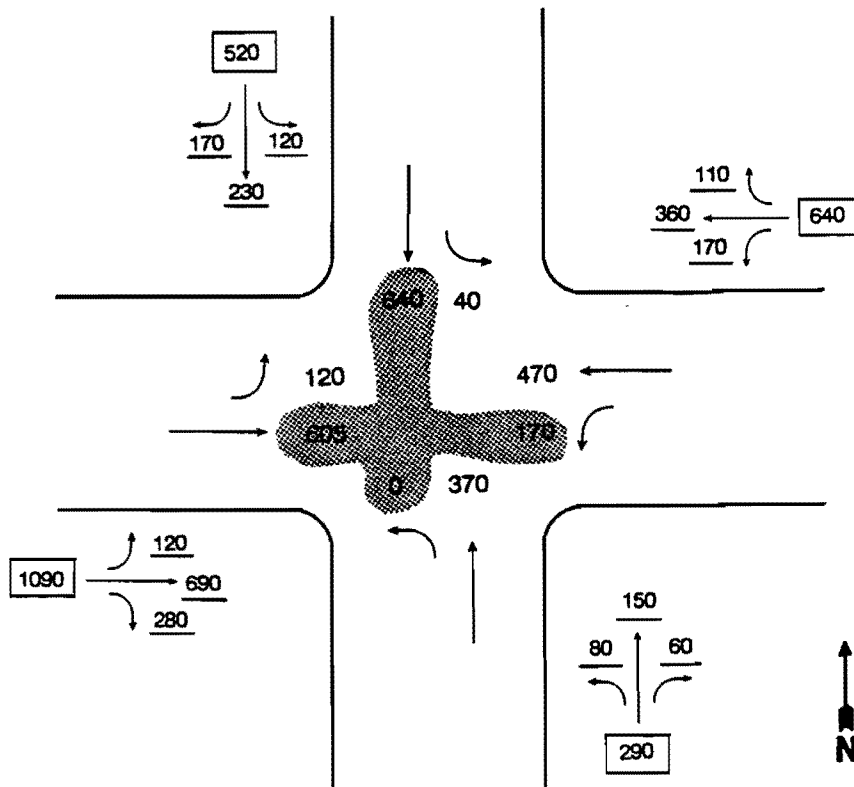


Table 4-2
Computation of the Sum of Critical Lane Volumes,
Example from the Highway Capacity Manual 1985

Turning Movement i	Assigned Turn Vol. VA(i)	Lane Number Ln(i)	PCE ^a	Assigned Lane Vol. V(i)	Sum of Critical Lane Volumes CV
1 (NB-LT)	80	0	2.0	0 *	V(1)+V(8) = 640 or CV(n-s) = 640
2 (NB-TH)	150	1		370	
3 (NB-RT)	60	0		0	V(2)+V(7) = 410
4 (WB-LT)	170	0	4.0	170 *	
5 (WB-TH)	360	2		470	V(4)+V(11) = 775 or CV(e-w) = 775
6 (WB-RT)	110	0		0	
7 (SB-LT)	120	0	2.0	40	V(5)+V(10) = 590
8 (SB-TH)	230	1		640 *	
9 (SB-RT)	170	0		0	CV = CV(n-s)+CV(e-w) = 1415
10 (EB-LT)	120	0	2.0	120	
11 (EB-TH)	690	2		605 *	
12 (EB-RT)	280	0		0	

* Critical Movement

^a Passenger Car Equivalent Factor



$$\begin{aligned}
V(10) &= VA(10) \\
&= 120 \\
V(11) &= \min \{ (VA(10)*PCE + VA(11) + VA(12))/Ln(11), \\
&\quad (VA(11) + VA(12))/(Ln(11)-1) \} \\
&= \min \{ (120*2 + 690 + 280)/2, (690 + 280)/(2-1) \} \\
&= 605 \\
V(12) &= 0
\end{aligned}$$

3. Computation of the sum of critical lane volumes:

$$\begin{aligned}
CV(n-s) &= V(1) + V(8) \\
&= 640 \\
CV(w-e) &= V(4) + V(11) \\
&= 775 \\
CV &= CV(n-s) + CV(w-e) \\
&= 1415
\end{aligned}$$

Again, the result from the NODIMP program coincides with that shown in the **Highway Capacity Manual 1985**.

Computation of Nodal Impedance for Signalized Nodes

The computation of nodal impedance for signalized nodes was derived from the operation analysis in Chapter 9 of the **Highway Capacity Manual 1985**. However, the computation procedure has been modified because some operation characteristics were not used in planning applications. One major element in the computation procedure is the distribution of green time to cycle length ratio (g/C) among various movements at an intersection. In brief, a cycle consists of two phases (north-south direction and east-west direction), and the green time for each phase is decided by the associated critical movements. This green time is then parallel and used by the non-critical movements operated in the same phase. Such a design allows non-critical movements to fully utilize the entire green time period in the phase. This point is further explained by the following example.

As shown in Table 4-3, a typical signalized node in the test network was selected to demonstrate the computation of nodal impedance. The values shown in the table are abstracted from the tenth iteration of an equal weighting incremental nodal restraint

assignment. The intersection was ascribed a cycle length of 120 seconds because its sum of critical lane volumes (=1645) was greater than 1560 (=1800*(1-16/120), see Equation 3.3c).

The computation is summarized as follows:

1. Calculation of g/C for critical movements: The g/C of a critical movement is approximated by proportioning its lane volume to the sum of critical lane volumes.

- (a) For the N-S approaching phase:

$$(g/C)_2 = 729/1645 = 0.44$$

$$(g/C)_7 = 241/1645 = 0.15$$

- (b) For the E-W approaching phase:

$$(g/C)_4 = 171/1645 = 0.10$$

$$(g/C)_{11} = 505/1645 = 0.31$$

2. Calculation of g/C for non-critical movements: For movements operated in the same approaching phase, the non-critical movements obtain the same the green time provided for the critical movements. This green time period then can be distributed according to the proportion of the lane volume of each non-critical movement to the sum of these non-critical movements.

- (a) For the N-S approaching phase:

$$(g/C)_1 = \frac{V_1}{NCV_{(N-S)}} * \frac{CV_{(N-S)}}{CV} = \frac{281}{(281+580)} * \frac{(729+241)}{1645} = 0.19$$

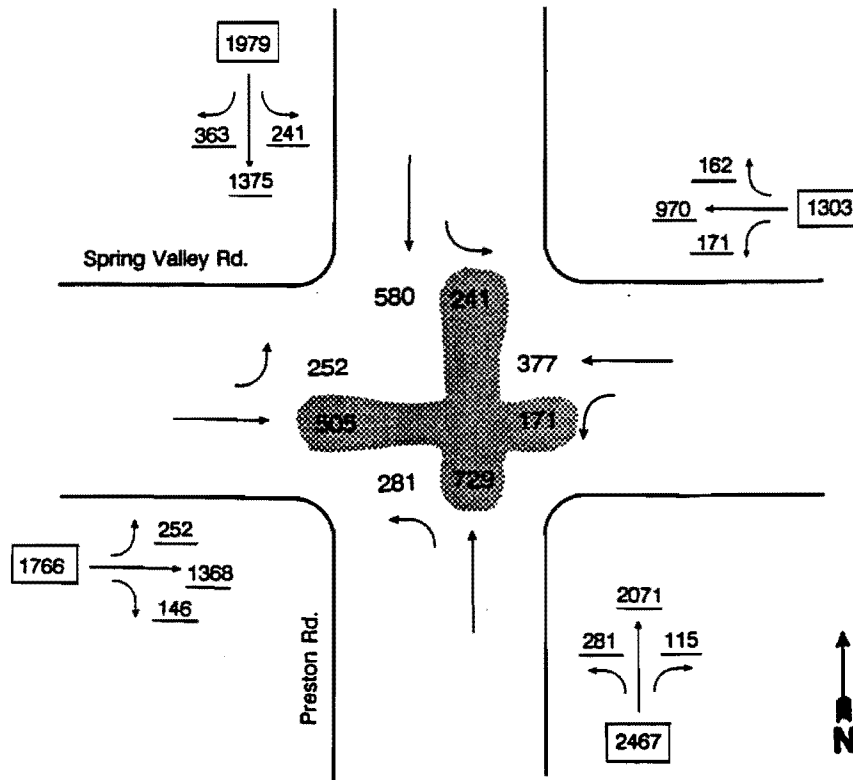
$$(g/C)_8 = \frac{V_8}{NCV_{(N-S)}} * \frac{CV_{(N-S)}}{CV} = \frac{580}{(281+580)} * \frac{(729+241)}{1645} = 0.40$$

Table 4-3
Summary of the Nodal Impedance Calculation for
a Selected Node in the Test Network

Turning Movement	Assigned Turn Vol. VA(i)	Lane Number Ln(i)	Assigned Lane Vol. V(i)	g/C Ratio g(i)/C	Lane Capacity c(i)	Degree of Saturation X(i)	Delay per Vehicle D(i) in Min.
1 (NB-LT)	281	1	281	0.19	300	0.94	1.63
2 (NB-TH)	2071	3	729 *	0.44	691	1.05	0.72
3 (NB-RT)	115	0	0				0.72
4 (WB-LT)	171	1	171 *	0.1	162	1.05	1.46
5 (WB-TH)	970	3	377	0.25	384	0.98	0.47
6 (WB-RT)	162	0	0				0.47
7 (SB-LT)	241	1	241 *	0.15	229	1.05	1.08
8 (SB-TH)	1375	3	580	0.4	619	0.94	0.94
9 (SB-RT)	363	0	0				0.94
10 (EB-LT)	252	1	252	0.16	256	0.98	0.87
11 (EB-TH)	1368	3	505 *	0.31	478	1.05	0.81
12 (EB-RT)	146	0	0				0.81

Sum of Critical Lane Volumes = 1645
 Cycle Length = 120 sec.
 Lost Time = 16 sec. per cycle
 Average Nodal Impedance for the node = 0.82 minute per vehicle

* Critical Movement



(b) For the E-W approaching phase:

$$(g/C)_5 = \frac{V_5}{NCV_{(E-W)}} * \frac{CV_{(E-W)}}{CV} = \frac{377}{(377+252)} * \frac{(171+505)}{1645} = 0.25$$

$$(g/C)_{10} = \frac{V_{10}}{NCV_{(E-W)}} * \frac{CV_{(E-W)}}{CV} = \frac{252}{(377+252)} * \frac{(171+505)}{1645} = 0.16$$

3. Computation of the Nodal Impedances: Once the g/C ratio for each movement was determined, the lane capacity, volume to capacity ratio, and the nodal impedance for each movement were computed sequentially (see Chapter III). The maximum nodal impedance for each movement was constrained by specifying maximum X (V/C Ratio) = 1.2. As shown in Table 4-3, the nodal impedances for the movements at this node ranged from 0.72 to 1.63 minutes. The average nodal impedance for the intersection was 0.82 minute per vehicle.

Computation of Nodal Impedance for Unsignalized Nodes

The nodal restraint was applied to all the nodes in the test network except those linked with one or more centroid connectors. In other words, the same computation process (described in Chapter III and the previous section) for signalized nodes was applied to all nodes in the test network. The application was considered viable for planning purposes since (1) the nodal impedance was calculated based upon the assigned volumes, not by the signal timings, and (2) the impedance of a movement was calculated with respect to other movements at the node. However, it is necessary to examine whether the application of the computation process to unsignalized nodes produced appropriate figures for the assignment procedure.

Among 89 nodes in the test network selected for nodal restraint application, 29 are unsignalized. Most of them represent intersections of a collector and an arterial (usually a minor arterial). In the computation process, "T" (three-leg) intersections were treated the same as a four-leg intersection by appending a dummy link with zero volume. A typical case

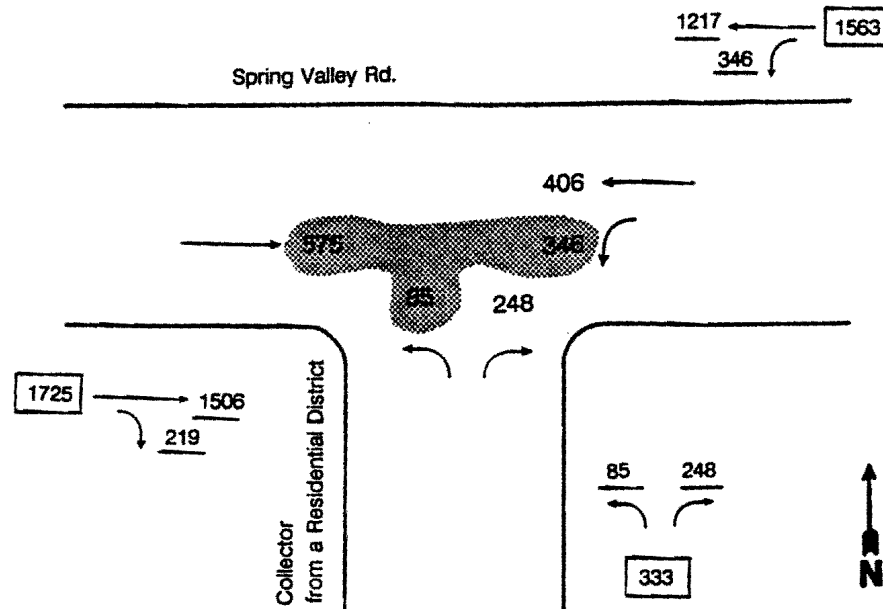
of the computation of nodal impedance for an unsignalized node in the test network is shown in Table 4-4. This case was abstracted from the same 10-iteration equal weighting incremental assignment as the example in the previous section. The critical movements at the node were identified to be the NB-LT ($V_l=85$), WB-LT ($V_4=346$), and EB-TH ($V_{II}=575$). The nodal impedances for the movements at the node ranged from 0.10 to 0.38 minute. The average nodal impedance for the node was 0.12 minute per vehicle. The average nodal impedances for most unsignalized nodes in the test network were less than 0.2 minutes.

Table 4-4
Summary of the Nodal Impedance Calculation for
a Selected Node in the Test Network

Turning Movement i	Assigned Turn Vol. VA(i)	Lane Number Ln(i)	Assigned Lane Vol. V(i)	g/C Ratio g(i)/C	Lane Capacity c(i)	Degree of Saturation X(i)	Delay per Vehicle D(i) in Min.
1 (NB-LT)	85	1	85 *	0.1	132	0.64	0.38
3 (NB-RT)	248	1	248	0.5	660	0.38	0.10
4 (WB-LT)	346	1	346 *	0.34	454	0.76	0.26
5 (WB-TH)	1217	3	406	0.6	792	0.51	0.08
11 (EB-TH)	1506	3	575 *	0.57	754	0.76	0.12
12 (EB-RT)	219	0	0				0.12

Sum of Critical Lane Volumes = 1007
 Simulated Cycle Length = 60 sec.
 Lost Time = 16 sec. per cycle
 Average Nodal Impedance for the Node = 0.12 minute

* Critical Movement



ANALYSIS OF THE IMPEDANCE ADJUSTMENT FUNCTION

In the nodal restraint assignment procedure, nodal impedances were adjusted after each iteration based upon their associated turning movement V/C 's at each node. The nodal impedances were adjusted by using the delay function in the **Highway Capacity Manual 1985**. This section compares this function with the delay equation used in the D-FW Joint Model and the BPR impedance adjustment function. The delay function in the D-FW Joint Model performed various capacity restraint assignments (see Appendix D). The BPR impedance adjustment function was selected because it is widely used by transportation planners.

As mentioned in Chapter III, the mathematical form of the impedance adjustment function used in the nodal restraint assignment is as follow:

$$d_i = 0.85 * \left[0.38C \frac{(1-(g/C)_i)^2}{(1-(g/C)_i * X_i)} + 173X_i^2 ((X_i-1) + \sqrt{(X_i-1)^2 + (16X_i/c_i)}) \right] \quad (4.1)$$

where: d_i = average stop delay per vehicle for movement i
 C = cycle length of the intersection
 $(g/C)_i$ = green time to cycle length ratio for movement i
 X_i = degree of saturation
 = $(V/c)_i$
 = volume to capacity ratio of movement i
 c = capacity of movement i

It should be noted that, unlike the common practice in conventional capacity restraint assignments, the capacity of each turning movement in this adjustment function is variable instead of fixed. The turning movement capacity varies according to its designated g/C , and the allocation of g/C for each movement is based on its assigned turn volume in association with other movements at the node.

The impedance adjustment function used in the D-FW Joint Model is an exponential linear-curve form. The delay impedance assigned to each link is calculated from the volume-delay equation below (7):

$$Delay(\text{min./mile}) = \text{Min} \left\{ A * \exp \left[B * \left(\frac{V}{c} \right) \right], C \right\} \quad (4.2)$$

where: V = hourly volume of the link
 c = hourly capacity of the link
 A, B, C = parameters calibrated to produce observed traffic volumes under various traffic conditions

The function parameters A , B , and C vary by time of day (daily vs. peak hour) and capacity type. The parameters selected for this study are $A=0.05$, $B=4.50$, $c=10.00$, because the assignment was applied to a peak-hour network where links are low-capacity facilities.

The BPR impedance adjustment function is frequently used for impedance adjustments in the existing traffic assignment practices. It can be expressed in a general form as below (25):

$$T = T_0 \left(1 + \alpha * \left(\frac{V}{C} \right)^\beta \right) \quad (4.3)$$

where: T = adjusted (balanced) travel time
 T_0 = free-flow travel time
 V = assigned volume
 C = capacity

In the function, α and β are function parameters; $\alpha = 0.15$ and $\beta = 4$ are commonly used.

A hypothetical case was employed to compare these three different impedance adjustment functions. The case, a five-mile major arterial with a 35 MPH speed limit and signals every 0.5 miles, was considered similar to the major arterial (Preston Road) in the test network.

Impedance adjustment analysis for the three impedance adjustment functions is summarized in Table 4-5. In the application of nodal impedance adjustment functions, only the impedance adjustments made to through movements approaching a signal node were displayed. The total travel time is a combination of link travel time (fixed) and nodal impedance (varied). In applications of the D-FW Joint Model and BPR impedance adjustment functions, the total travel time was accumulated from the link impedances. The

average impedance adjustment ratio was estimated by comparing the current travel time to the initial free-flow travel time.

Based on this case, the relationships between V/C and impedance adjustment (T/T_0) of the three functions were shown in Figure 4-3. The D-FW Joint Model delay function ascends much more rapidly than the nodal impedance function and the BPR function, especially for V/C ratios greater than 0.6. The BPR function has the least impact on impedance adjustment among the three functions. The nodal impedance adjustment function falls between the D-FW Joint Model and BPR functions and increasingly raises the impedance adjustment when V/C ratios are greater than 0.8.

Using the nodal impedance adjustment function, several different nodal restraint assignment procedures were tested. For both the equal weighting and the weighted average incremental procedures, the assignment process was found to be more effective when the accumulated volumes were expanded to 100 percent than when they were not expanded. The assignment process without expansion of the accumulated volumes did not divert many trips until 80 percent of the trips were loaded to the network. This reflects the nature of the nodal impedance function in that impedance does not significantly increase until the V/C is greater than 0.8.

In addition to evaluating the assignment procedures, different parameters were evaluated for the nodal impedance adjustment function. To avoid instability caused by very small or very large assigned turn volumes, the g/C ratio for the left-turn, through, and right-turn movements were confined within a range. It was assumed that (1) the minimum green time for through and right turns is 5 seconds and for left turns is 3.5 seconds, and (2) the maximum green time for through and right turns is 80 seconds and for left turns is 50 seconds. After several tests of different ranges, the g/C ratio for both through and right-turn movements was calibrated as a range between 0.1 and 0.75, and left-turn movement was between 0.08 and 0.5.

Different upper bounds of maximum delay for the adjustment function were tested. The scenarios include (1) maximum delay constrained by maximum $V/C = 1.2$, (2) maximum delay constrained by $V/C = 1.4$, and (3) no constraint on V/C but maximum delay = 6 minutes per vehicle. Using the 10-iteration equal weighting incremental procedure, the

Table 4-5
Analysis of Different Impedance Adjustment Functions
Based on a Hypothetical Case

The case:

A five-mile arterial with 35 MPH speed limit and signals every 0.5 miles.

V/C (X) Ratio	Nodal Impedance Adjustment Function						Delay Function Used in D-FW Joint Model			BPR Impedance Adjustment Function		
	Nodal Imped/ Node (min.)	Total Nodal Imped. (min.)	Total Link Time (min.)	Total Travel Time (min.)	Avg. Speed (MPH)	Avg. Imped. Adjust Ratio	Total Travel Time (min.)	Avg. Speed (MPH)	Avg. Imped. Adjust Ratio	Total Travel Time (min.)	Avg. Speed (MPH)	Avg. Imped. Adjust Ratio
0.0	0.23 ^a	2.33	8.57	10.90	27.53 ^b	1.0000	10.57	28.38 ^c	1.0000	10.57	28.38 ^c	1.0000
0.1	0.24	2.42	8.57	10.99	27.29	1.0089	10.96	27.36	1.0371	10.57	28.38	1.0000
0.2	0.25	2.53	8.57	11.10	27.03	1.0186	11.19	26.82	1.0582	10.57	28.37	1.0002
0.3	0.26	2.65	8.57	11.22	26.74	1.0294	11.54	26.01	1.0912	10.58	28.35	1.0012
0.4	0.28	2.78	8.57	11.35	26.43	1.0415	12.08	24.83	1.1431	10.61	28.27	1.0038
0.5	0.29	2.93	8.57	11.50	26.08	1.0554	12.94	23.18	1.2244	10.67	28.12	1.0094
0.6	0.31	3.11	8.57	11.68	25.68	1.0719	14.29	20.99	1.3519	10.78	27.84	1.0194
0.7	0.33	3.33	8.57	11.90	25.20	1.0924	16.41	18.29	1.5519	10.95	27.39	1.0360
0.8	0.36	3.64	8.57	12.22	24.56	1.1210	19.72	15.21	1.8656	11.22	26.74	1.0614
0.9	0.42	4.21	8.57	12.78	23.47	1.1731	24.92	12.04	2.3576	11.61	25.84	1.0984
1.0	0.60	5.99	8.57	14.56	20.61	1.3358	33.08	9.07	3.1291	12.16	24.68	1.1500
1.1	1.11	11.11	8.57	19.68	15.24	1.8064	45.87	6.54	4.3390	12.89	23.27	1.2196
1.2	1.93	19.33	8.57	27.91	10.75	2.5608	60.57	4.95	5.7303	13.86	21.65	1.3110
1.3	1.93	19.33	8.57	27.91	10.75	2.5608	60.57	4.95	5.7303	15.10	19.87	1.4284
1.4	1.93	19.33	8.57	27.91	10.75	2.5608	60.57	4.95	5.7303	16.66	18.01	1.5762

Note:

^aThe nodal impedance adjustments were made to through movements. A typical capacity (2160) for the through movements was assumed by (1) cycle length = 120 seconds, (2) g/C = 0.4, (3) number of lanes = 3, and (4) saturation flow rate = 1800 vehicles per hour.

^bThe initial impedance is a combination of nodal zero-volume (V/C=0) impedance and constant link travel time. An average speed of 27.53 MPH was derived from: $27.53 \text{ MPH} = 0.5 \text{ Mile} / ((0.233 \text{ min.} + 0.857 \text{ min.}) / 60 \text{ min. per hour})$.

^cThe initial speed for a link with a signal node and speed limit of 35 MPH was computed by the formula $\text{Free Speed} = \text{Length} / ((\text{Length}/\text{Speed Limit}) + \text{Delay})$. In this case, an average speed of 28.38 MPH was derived from: $28.38 \text{ MPH} = 0.5 \text{ Mile} / ((0.5 \text{ Mile} / 35 \text{ MPH}) + (12 \text{ sec.} / 3600 \text{ sec. per hour}))$. (See Z, p.33).

Average Impedance Adjustment (T/T_0)

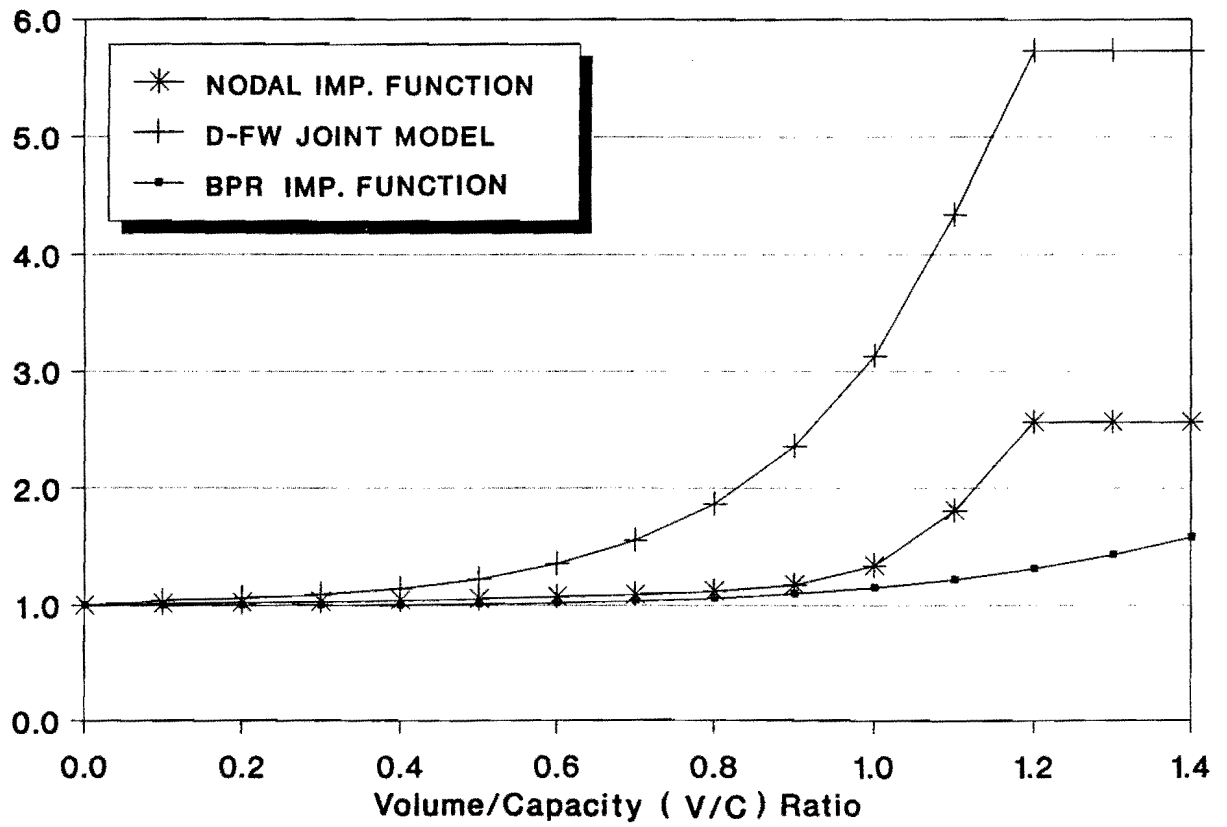


Figure 4-3 Impedance Adjustment Functions

three V/C constraint cases produced similar assignment results in which most V/C values were found under 1.2 at the tenth iteration. The first case (maximum delay constrained by V/C = 1.2) produced somewhat better turning movement replications than the other two cases. The upper bound of the function was defined therefore, as maximum X = 1.2 in this study.

CONVERGENCE RATE

The convergence rate was used to examine the assigned volume difference between the current iteration and the previous iteration. The fluctuation of convergence rate suggests how efficiently an assignment procedure performs. Two different assignment procedures were examined in this research: (1) the equal weighting incremental and (2) the weighted average incremental. In both procedures, the accumulated volume after each iteration was expanded to 100 percent. The convergence rate was examined in three different categories: (1) turn volumes, (2) link volumes, and (3) both link and turn volumes.

This research defines convergence rate as the assigned volume difference between the current and the previous iteration with respect to the previous iteration when both are expanded to represent 100 percent of the trips. In a percentage form, it is as follows:

$$\text{Convergence Rate} = \frac{(V_n - V_{n-1})}{V_{n-1}} * 100\% \quad (4.4)$$

where: V_n = accumulated volume of the current iteration (being expanded to 100%)
 V_{n-1} = accumulated volume of the previous iteration (being expanded to 100%)

The convergence rates of the equal weighting incremental procedure are summarized in Table 4-6. The plots of the convergence rate versus the number of iterations for (1) link volume, (2) turn volume, and (3) both link and turn volumes are illustrated in Figures 4-4a, 4-4b, and 4-4c, respectively. As shown, the link volume convergence rate decreases faster than the turn volume convergence rate. After the sixth iteration, the convergence rates for all three categories are less than or close to 10 percent.

Table 4-6
Convergence Rate of the Equal Weighting Incremental Procedure

Iteration Number	Convergence Rate Link Volume	Number of Links	Convergence Rate Turn Volume	Number of Turns	Convergence Rate Link & Turn Vol.	Total Number*
n = 2	360%	264	615%	804	509%	1068
n = 3	38%	264	98%	804	74%	1068
n = 4	19%	264	52%	804	39%	1068
n = 5	8%	264	64%	804	42%	1068
n = 6	6%	264	11%	804	9%	1068
n = 7	5%	264	9%	804	7%	1068
n = 8	3%	264	8%	804	6%	1068
n = 9	3%	264	6%	804	5%	1068
n = 10	3%	264	5%	804	4%	1068

* Total Number of links plus turns

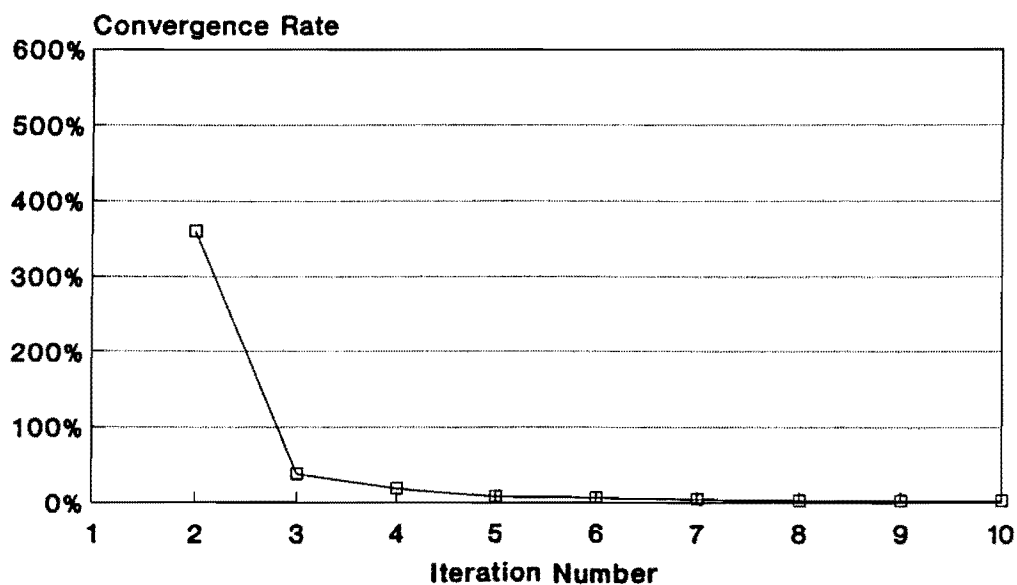


Figure 4-4a Link Volume Convergence Rate (Equal Weighting Incremental Procedure)

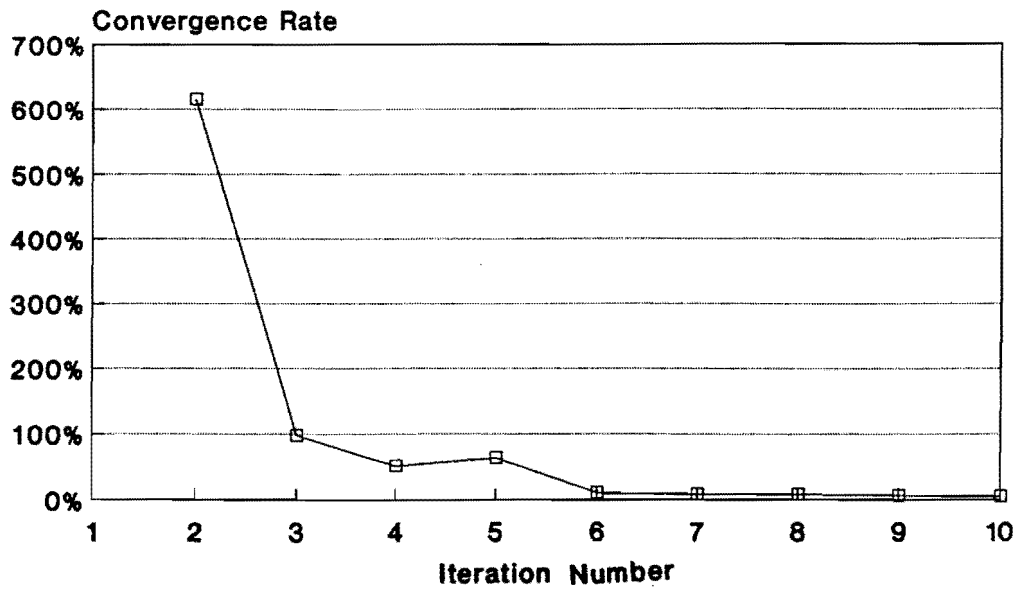


Figure 4-4b Turn Volume Convergence Rate (Equal Weighting Incremental Procedure)

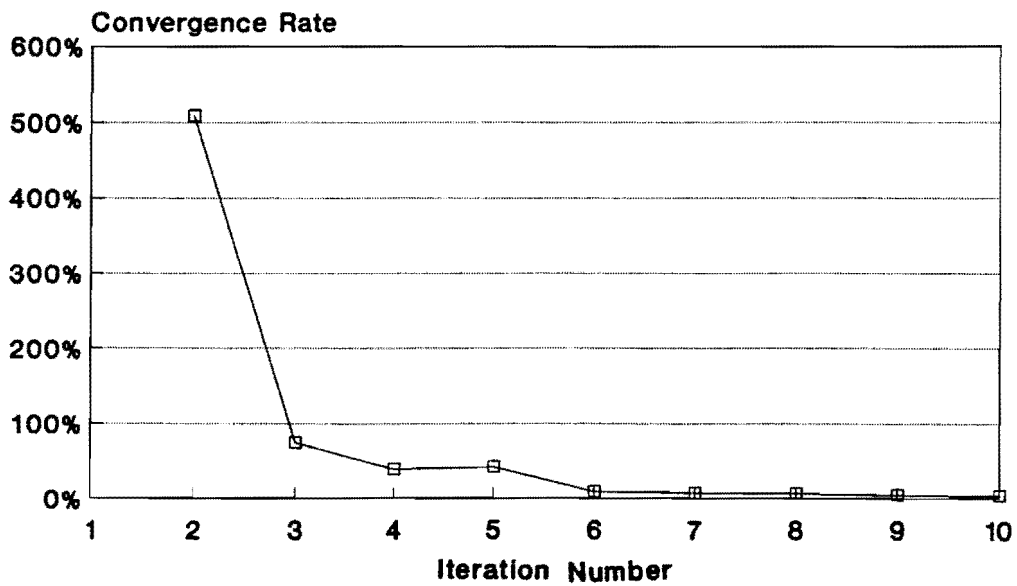


Figure 4-4c Link and Turn Volume Convergence Rate (Equal Weighting Incremental Procedure)

The convergence rates of the weighted average incremental procedure are summarized in Table 4-7. The plots of convergence rate versus the numbers of iterations for (1) link volume, (2) turn volume, and (3) both link and turn volumes are illustrated in Figures 4-5a, 4-5b, and 4-5c, respectively. As with the equal weighting procedure, the link volume convergence rate decreases faster than the turn volume convergence rate. After the sixth iteration, the convergence rates for all three categories are less than 10 percent.

For both the equal weighting and weighted average incremental procedures, the nodal restraint assignment appeared to converge by the sixth iteration. However, there was a prominent fluctuation between the second and the third iterations. This may be related to the setting of zero nodal impedances for the first iteration. A smoother convergence curve might occur if certain values were used as the initial nodal impedances. As indicated in the final chapter of this research, it may be a topic for further research.

Table 4-7
Convergence Rate of the Weighted Average Incremental Procedure

Iteration Number	Convergence Rate Link Volumes	Number of Links	Convergence Rate Turn Volumes	Number of Turns	Convergence Rate Link & Turn Vol.	Total Number*
n = 2	309%	264	527%	804	437%	1068
n = 3	39%	264	78%	804	62%	1068
n = 4	9%	264	30%	804	22%	1068
n = 5	5%	264	38%	804	25%	1068
n = 6	5%	264	10%	804	8%	1068
n = 7	4%	264	7%	804	6%	1068
n = 8	2%	264	3%	804	3%	1068
n = 9	1%	264	3%	804	2%	1068
n = 10	1%	264	3%	804	2%	1068

* Total number of links plus turns

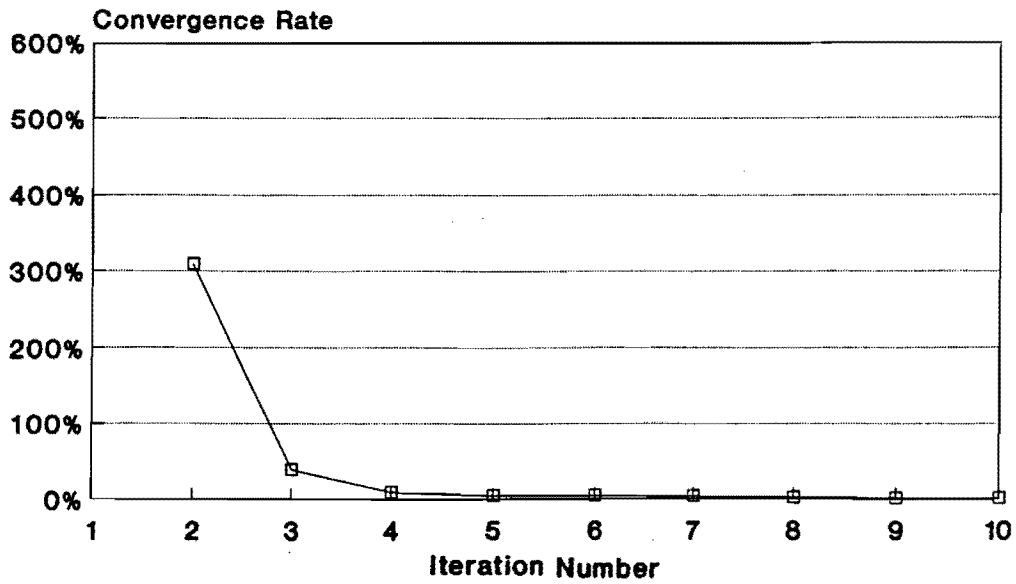


Figure 4-5a Link Volume Convergence Rate (Weighted Average Incremental Procedure)

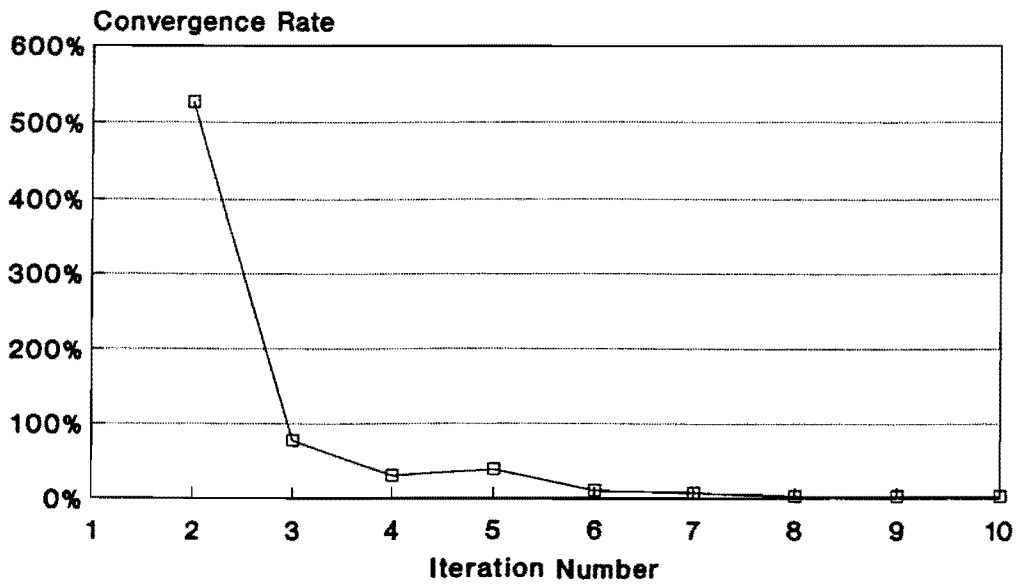


Figure 4-5b Turn Volume Convergence Rate (Weighted Average Incremental Procedure)

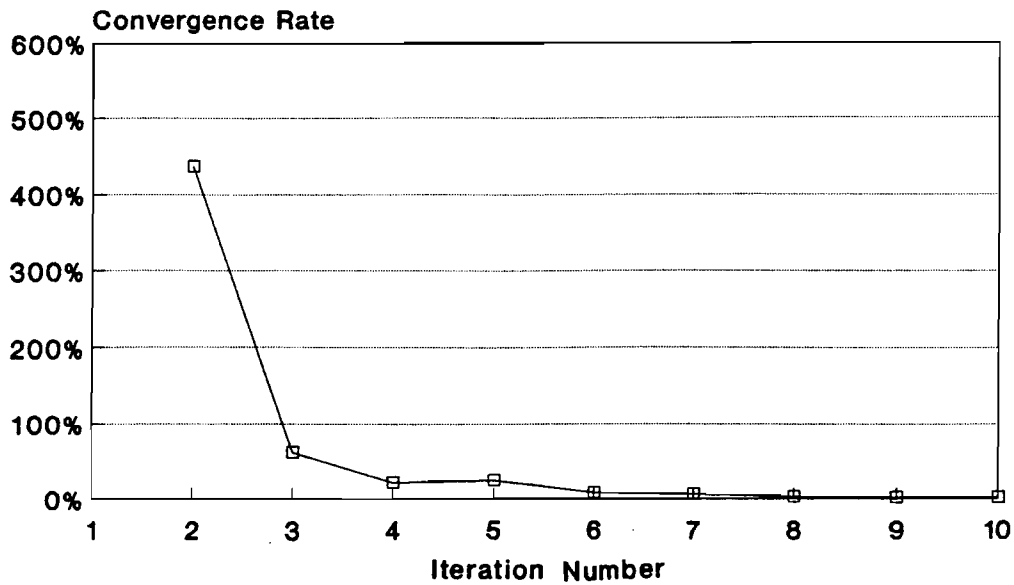


Figure 4-5c Link and Turn Volume Convergence Rate (Weighted Average Incremental Procedure)

ANALYSIS OF NETWORK PERFORMANCE MEASURES

Several macro-level measures were applied to the nodal restraint model in order to evaluate the network performance of different assignment procedures. These measures include total VMT, average V/C ratio, and the analysis of network V/C distribution. Details of the analysis are included in Appendix E. The analysis was conducted by comparing the results from the nodal restraint assignment with traditional capacity restraint assignments.

The total VMT and the average V/C of the proposed nodal restraint assignments, for both the equal weighting and weighted average incremental procedures, are comparable to parallel capacity restraint assignments. The analysis of network V/C distribution indicates that the nodal restraint assignment generated an overall comparable traffic pattern to capacity restraint assignments. Compared to the capacity restraint assignment without the accumulated volumes being expanded to 100 percent, the nodal restraint assignment

yielded higher directional link V/C 's on some major arterials. Compared to the capacity restraint assignment with the accumulated volumes expanded to 100 percent, the nodal restraint assignment yielded a similar portion of high directional link V/C 's on major arterials. It was noted that the link V/C 's were measured based on the coded link capacities.

The network performance measures of the nodal restraint assignment, for both the equal weighting and the weighted average incremental procedure, range between the capacity restraint assignments with and without the accumulated volumes expanded to 100 percent. This indicates that the network performance of proposed nodal restraint assignments in this application is reasonably stable. Overall, the tests in this chapter show that the proposed assignment procedure was robust and performed as expected.

CHAPTER V

EVALUATION OF NODAL RESTRAINT ASSIGNMENT RESULTS

INTRODUCTION

The evaluation methods applied in transportation planning usually include the macro-level and micro-level analyses. Macro-level analyses (Chapter IV) measure the entire network (or a major portion of the network) performance, while micro-level analyses evaluate the assignment accuracy on a link-by-link or a movement-by-movement basis. This chapter focuses on the micro-level analyses since the objective of this research was to develop a nodal restraint assignment which was expected to produce better turning movement replications than the conventional capacity restraint assignment techniques. The principal micro-level evaluation was the comparison of the assigned turn volumes with the available ground counts (i.e, the turning movement counts at the major intersections along Preston Road).

Prior to evaluating the nodal restraint assignment results, a capacity restraint assignment which provided the most accurate result was selected as the best of the various conventional capacity restraint assignments. As indicated in Appendix D, the iterative assignment generated the best results among the available capacity restraint assignments. However, the weighted average incremental assignment (without the accumulated volumes being expanded to 100 percent) produced a closely comparable assignment result to the iterative assignment. Thus, both of these assignments were included in this chapter for comparison with the nodal restraint assignment.

The nodal restraint assignment, as discussed in Chapters III and IV, was implemented using both equal weighting and weighted average incremental procedures. Although the equal weighting incremental procedure performed somewhat better than the weighted average procedure in terms of the various micro-level analyses, the two different assignment procedures actually produced comparable results. Thus, the results of both nodal restraint assignment procedures are included in this chapter.

Consequently, this chapter consists of two sets of evaluations. The first set includes the following three steps: (1) compare the results of the nodal restraint assignment using an

equal weighting incremental procedure to the ground counts, (2) compare the results from the iterative assignment to ground counts, and (3) evaluate the nodal restraint assignment and the iterative assignment to determine which produced better ground count replications. The second set of evaluation includes the following three steps: (1) using a weighted average incremental procedure, compare the results from the nodal restraint assignment to the ground counts, (2) compare the results from the weighted average incremental assignment to the ground counts, and (3) evaluate the nodal restraint assignment and the incremental assignment to determine which produced better ground count replications.

EVALUATION I: EVALUATION OF THE NODAL RESTRAINT ASSIGNMENT (EQUAL WEIGHTING INCREMENTAL PROCEDURE)

This section evaluates the nodal restraint assignment (equal weighting incremental procedure) and the iterative assignment to determine which produced better ground count replications. Both the nodal restraint assignment and the iterative assignment were iterated 10 times. The mechanisms of the two assignments are described below:

1. Nodal restraint assignment: At each iteration, all the trips in the O-D table were loaded to the network; nodal impedances were adjusted according to the projected turn volumes which are expanded to 100 percent from the accumulated weighted turn volumes. The weight of the assigned volumes for each iteration was a uniform 10 percent.
2. Iterative assignment: At each iteration, all trips in the O-D table were loaded to the network, and link impedances were adjusted according to the assigned volumes from the previous iteration.

A series of micro-level analyses were conducted to determine if the nodal restraint assignment produced a better result than the conventional capacity restraint assignment. The analyses focused on eight intersections (Figure 6-1) along Preston Road where the ground count information was available. These analyses include:

1. Analysis of mean difference, percent mean difference, root mean square errors, and percent root mean square errors of approach volumes,

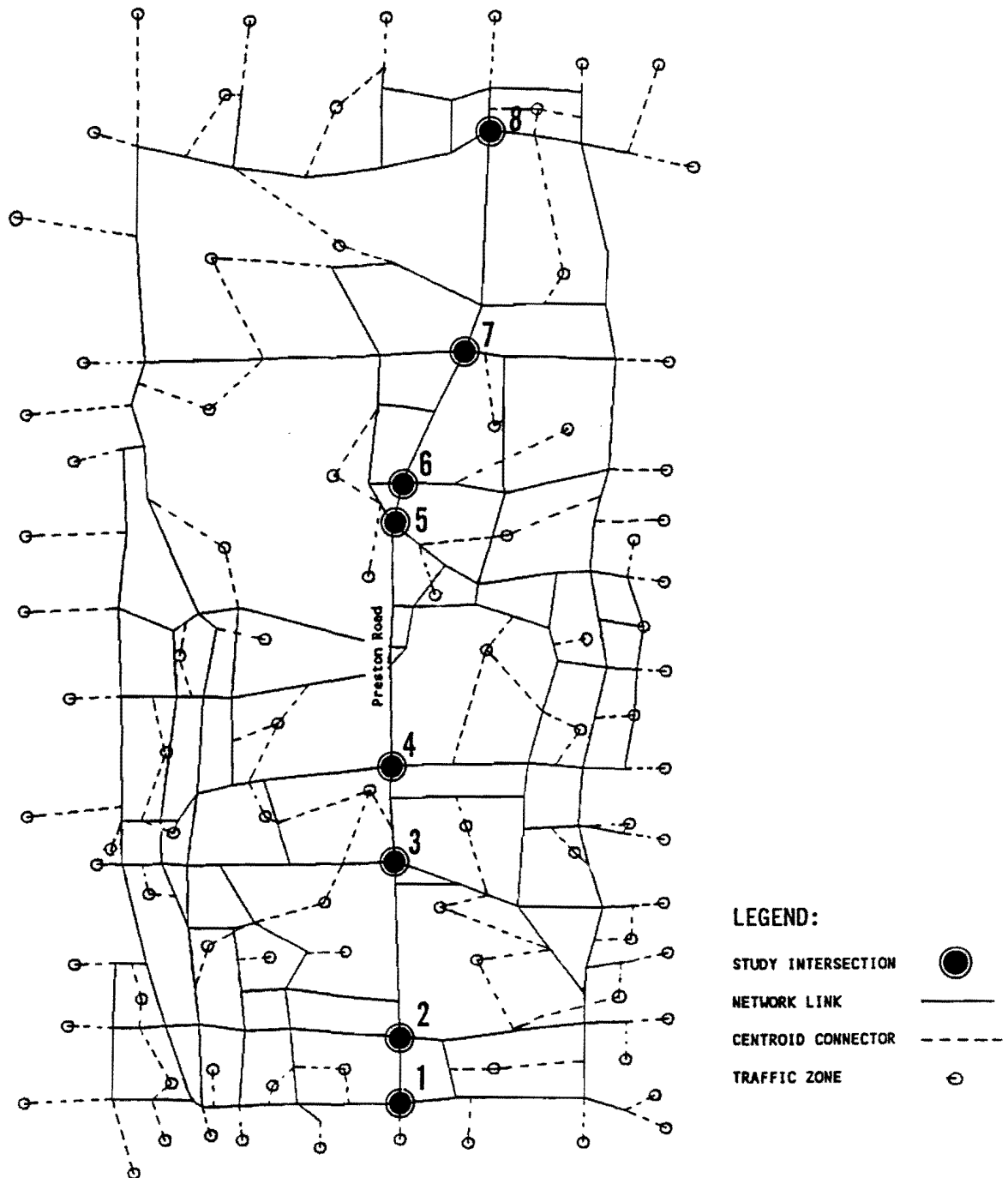


Figure 5-1 Locations of Intersections along Preston Road under Study

2. Analysis of mean difference, percent mean difference, root mean square errors, percent root mean square errors of turning movements,
3. Analysis of turning movements as a percentage of approach volume, and
4. Paired t-tests of both approach volumes and turning movements.

Analysis of Mean Difference, Percent Mean Difference, Root Mean Square Errors, and Percent Root Mean Square Errors of Approach Volumes

In transportation planning, various measures are commonly used to compare traffic assignment results with traffic counts for evaluation purposes. The measures employed in this research are mean difference, percent mean difference, root mean square errors, and percent root mean square error. The mean difference (and percent mean difference) is a measure of the average difference between the assigned and the counted volumes. The root mean square errors (and percent root mean square errors) measure the dispersion of these differences (errors). They were computed according to the following equations:

$$MD = \frac{\sum (A_i - C_i)}{N} \tag{5-1}$$

$$PMD = 100\% * \frac{MD}{(\sum C_i) / N} \tag{5-2}$$

$$RMSE = \sqrt{\frac{\sum (A_i - C_i)^2}{N-1}} \tag{5-3}$$

$$PRMSE = 100\% * \frac{RMSE}{(\sum C_i) / N} \tag{5-4}$$

where:

<i>MD</i>	=	mean difference
<i>PMD</i>	=	percent mean difference
<i>RMSE</i>	=	root mean square errors
<i>PRMSE</i>	=	percent root mean square errors
<i>A_i</i>	=	assigned volume for link (or movement) <i>i</i>

$$C_i = \text{counted volume for link (or movement) } i$$

$$N = \text{total number of links (movements)}$$

It is essential to evaluate assignment results based not only on the mean difference (MD) but also on the root mean square error (RMSE). The MD describes an average amplitude of the errors with respect to zero difference, and the RMSE characterizes the dispersion of these errors. For example, within a range of counted volumes (say 1,500 to 2,000 vehicles per hour), a group of links with many highly over-assigned volumes and under-assigned volumes may have a relatively small MD in which the positive and negative effects diminish the dimension of MD. In such a case, the measure of RMSE is useful in describing the wide dispersion of these errors.

The statistic measures of the approach volumes were computed in two ways. As shown in Table 5-1, the approach volumes were first classified into four groups based on their approaching directions, i.e., NB (north-bound), WB (west-bound), SB (south-bound), and EB (east-bound). Second, the approach volumes were grouped together regardless of their approaching directions.

Table 5-1
Summary of Approach Volume Measures from the Nodal Restraint Assignment (Equal Weighting Incremental Procedure) and the Iterative Assignment

Approach Direction	Sum of Counts	Number of Approaches	Nodal Restraint Assignment				Iterative Assignment			
			MD	PMD	RMSE	PRMSE	MD	PMD	RMSE	PRMSE
NB	20614	8	-98	-3.8	392	15.2	208	8.1	574	22.3
WB	7915	8	-41	-4.2	441	44.5	47	4.8	455	46.0
SB	13378	8	22	1.3	149	8.9	-466	-27.8	539	32.3
EB	10349	8	114	8.7	434	33.5	58	4.5	280	21.7
AVERAGE TOTAL	1633 52256	32	-1	-0.1	355	21.8	-38	-2.3	452	27.7

Statistic Measures:
MD = Mean Difference
PMD = Percent Mean Difference
RMSE = Root Mean Square Error
PRMSE = Percent Root Mean Square Error

At the first level of aggregation (i.e., turning movements clustered according to their approach directions), the nodal restraint assignment generated a smaller MD than the iterative assignment for all groups except the EB approach. The nodal restraint assignment also demonstrated less dispersion of differences (RMSE) than the iterative assignment for all groups except the EB approach. Overall, the nodal restraint assignment produced a smaller percent MD (-0.1 percent vs. -2.3 percent) and a more confined dispersion of differences (21.8 percent vs. 27.7 percent) than the capacity restraint assignment.

Analysis of Mean Difference, Percent Mean Difference, Root Mean Square Errors, and Percent Root Mean Square Errors of Turning Movements

These measures were next applied to the turning movements generated from the nodal restraint assignment and the iterative assignment. The turning movements under inspection were classified at three different levels. First, they were classified into 12 groups according to their approaching directions, i.e., NB, EB, SB, and WB, and turning directions, i.e., LT (left-turn), TH (through), and RT (right-turn). Second, they were classified into three groups according to their turning directions, i.e., RT, TH, and LT. Third, they were aggregated, regardless of their approaching and turning directions, to present an average measurement.

As shown in Table 5-2, the analysis at the first level of aggregation did not notably indicate which assignment model yielded a better result. Through simple better-or-worse comparisons, however, the nodal restraint assignment was found to perform generally better than the capacity restraint assignment for most of the groups except the NB-LT movements. The nodal restraint assignment acquired eight better scores out of the 12 groups of data under inspection. At the second level of aggregation, the nodal restraint assignment produced better MD's (and PMD's) than the iterative assignment in general. The nodal restraint assignment produced better RMSE (and PRMSE) than the iterative assignment in the TH group, but it generated similar results in the RT and LT groups to the iterative assignment. At the last level of aggregation, the nodal restraint assignment obviously performed better than the capacity restraint assignment in terms of PMD (-0.1 percent vs. -5.1 percent) and PRMSE (35.3 percent vs. 45.3 percent).

Table 5-2
Summary of Turning Movement Measures from the Nodal Restraint Assignment
(Equal Weighting Incremental Procedure) and the Iterative Assignment

Approach & Turning Direction	Sum of Counts	Number of Movements	Nodal Restraint Assignment				Iterative Assignment				Better- or-Worse Comparison	
			MD	PMD	RMSE	PRMSE	MD	PMD	RMSE	PRMSE		
NB	LT	1428	8	54	30.3	187	104.7	33	18.4	223	125.2	-
	TH	17226	8	-114	-5.3	210	9.8	218	10.1	350	16.3	+
	RT	1960	8	-38	-15.4	206	84.2	-43	-17.6	174	71.2	o
WB	LT	1812	8	-41	-18.2	242	106.9	-89	-39.3	279	123.0	+
	TH	4737	8	-15	-2.6	294	49.6	67	11.3	310	52.4	o
	RT	1366	8	15	8.9	69	40.6	69	40.4	182	106.5	+
SB	LT	1285	8	21	12.9	78	48.6	-47	-29.3	118	73.2	+
	TH	10761	8	-10	-0.8	110	8.2	-365	-27.1	423	31.4	+
	RT	1332	8	11	6.5	93	56.1	-54	-32.4	126	75.5	+
EB	LT	2852	8	-27	-7.5	160	44.8	-110	-30.9	184	51.7	+
	TH	5633	8	168	23.9	383	54.4	223	31.7	363	51.6	o
	RT	1864	8	-27	-11.7	172	73.7	-54	-23.2	269	115.3	+
ALL	LT	7377	32	2	0.7	43	18.5	-53	-23.0	41	17.7	
	TH	38357	32	7	0.6	32	2.6	36	3.0	130	10.8	
	RT	6522	32	-10	-4.8	52	25.4	-21	-10.3	44	21.7	
AVERAGE	544											
TOTAL	52256	96										

Notations for Better-or-Worse Comparison:

- + The nodal restraint assignment is better than the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences must be larger than 5 percent).
- The nodal restraint assignment is worse than the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences must be larger than 5 percent).
- o The nodal restraint assignment is close to the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences are less than 5 percent).

Analysis of Turning Movements as a Percentage of Approach Volumes

Another way to examine turning movements is to consider each turning movement as a percentage of its associated approach volume. Such a percentage, however, is correlated to the functional class of the approach street from which a movement is made as well as to the functional class of the cross street. For example, the percentage of a movement made from a major arterial turning to a minor arterial and the percentage of a movement made from a major arterial turning to a collector are usually dissimilar (the former usually higher than the latter). Therefore, the functional classifications of the intersected streets should be taken into consideration in the analysis of turning movements as a percentage of approach volumes.

According to the functional classification coded in the link data, the intersections under study were classified into three types: (1) a major arterial intersecting with a major arterial, (2) a major arterial intersecting with a minor arterial, and (3) a major arterial intersecting with a collector street. The turning movement data then were grouped according to the associated intersection types. Most of the intersections on Preston Road belong to the second type. The first type (major arterial to major arterial) consists of only one intersection (Preston Road at Belt Line). The third type (major arterial to collector) also includes only one intersection (Preston at McCallum). The results from the first and third types of intersections were not compared with the ground counts because of insufficient data. The turning movements at the intersections of the first and third types were displayed as a percentage of approach volumes for reference purposes.

In the second type (major arterial to minor arterial) of intersections, the turning movements were divided into six subgroups according to the functional classification of the approach, the cross streets, and the turning directions (LT, TH, or RT), and then were compared to ground counts. As shown in Table 5-3, both the nodal restraint assignment and the iterative assignment produced turning percentages which are comparable to the turning percentages of the counted data. For the turning movements from a major arterial turning to or crossing a minor arterial, the nodal restraint assignment performed slightly worse than the iterative assignment in the LT and TH groups (average error of LT movements: 2.6 percent vs. 0.6 percent; the average error of TH movements: -1.3 percent vs. 1.0 percent). For the movements from a minor arterial turning to or crossing a major arterial, however, the nodal restraint assignment performed better than the iterative assignment in all three direction groups (average error of LT movements: -5.0 percent vs. -9.8 percent; average error of TH movements: 2.4 percent vs. 5.4 percent; average error of RT movements: 2.5 percent vs. 4.4 percent). Overall, the nodal restraint assignment produced somewhat better turning movement replications than the iterative assignment when the movements were regarded as a percentage of approach volumes.

Table 5-3
Analysis of Turning Movements as a Percentage of Approach Volume
for the Nodal Restraint Assignment (Equal Weighting Incremental Procedure)
and the Iterative Assignment

Types of Inter.	Functional Classes			Number of Movements	Average Counted Turn Percent ^a	Nodal Restraint Assignment		Iterative Assignment	
	Approach Street	Cross Street	Turn Dir.			Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c
I.	MAJOR - MAJOR		LT	4	14.8	13.5	d	11.9	d
			TH	4	68.4	71.9		78.1	
			RT	4	16.7	14.5		10.0	
II.	MAJOR - MINOR		LT	12	7.9	10.5	2.6	8.5	0.6
			TH	12	81.6	80.3	-1.3	82.6	1.0
			RT	12	10.6	9.2	-1.3	8.9	-1.6
	MINOR - MAJOR		LT	12	24.7	19.7	-5.0	14.9	-9.8
			TH	12	59.8	62.2	2.4	65.2	5.4
			RT	12	15.6	18.1	2.5	20.0	4.4
III.	MAJOR - COLL.		LT	2	5.2	2.9	d	3.0	d
			TH	2	92.8	91.2		92.6	
			RT	2	2.0	5.9		4.4	
	COLL. - MAJOR		LT	2	31.6	70.0	d	26.8	d
			TH	2	21.8	16.7		33.4	
			RT	2	46.5	13.3		39.8	

Note:

^a Average Counted Turn Percentage = $\Sigma(\text{Counted Turn Volume} + \text{Counted Approach Volume}) \div (\text{Total Number of Data})$

^b Average Assigned Turn Percentage = $\Sigma(\text{Assigned Turn Volume} + \text{Assigned Approach Volume}) \div (\text{Total Number of Data})$

^c Average Error = Average Assigned Turn Percentage - Average Counted Turn Percentage

^d Not computed due to insufficient data (only one intersection)

Paired t-Tests of Approach Volumes and Turning Movements

The last micro-level analysis conducted was a series of paired t-tests. This statistical test was used to examine whether the mean of the assigned approach (or turn) volumes from each assignment model was significantly different from the mean of counted approach (or turn) volumes.

The paired t-test is an appropriate statistical procedure for analyzing turning movements. The assigned volumes from the selected locations are estimates from one assignment model. The corresponding counted volumes from the same locations can be regarded as estimates from another assignment model. The statistical test was used to determine whether the two assignments are significantly different in terms of the difference

between the paired estimates at the same location. It is well known that approach (or turn) volumes are correlated to their locations. If they are grouped together, instead of being paired by their distinctive locations, the difference between the two assignments may be canceled due to the variability among the estimates in each given assignment. By having each assignment provide an estimate at the same location, the difference between the two assignments for each location can be calculated; and, hence, the location-to-location variability is not canceled.

The research hypothesis for the test was as follows:

H_0 : Assigned approach (or turn) volumes are distributed with the same mean as the ground counts.

H_a : Assigned approach (or turn) volumes are not distributed with the same mean as the ground counts.

The test statistic is:

$$t = \frac{MD}{(S_d / \sqrt{N})} \quad (5-5)$$

where: MD = mean difference between assigned and counted volumes
 S_d = standard deviation of the differences
 N = number of observations of approaches (or turns)

Decision: Accept H_a if the calculated value of t is greater than the critical value for $\alpha = 0.10$ and degrees of freedom = N - 1.

A series of paired t-tests were applied to the approach volumes and turning movements. The tests of the difference of approach volumes among the nodal restraint assignment, the iterative assignment, and the ground counts are summarized in Table 6-4. At the 10 percent significance level, the calculated t values for the difference between the nodal restraint assignment and the ground count data ($t=0.01$) and for the difference between the iterative assignment and the counted data ($t=0.48$) are smaller than the critical value ($t_c = 1.70$). As such, the mean of assigned approach volumes from neither assignment

was identified to be statistically significantly different from the mean of counted approach volumes.

However, further contrast between the two models can be made by comparing the magnitude of the calculated t values from different test models. As shown in Table 5-4, the calculated t value for the nodal restraint assignment (0.01) is smaller than that for the iterative assignment (0.48). The components used to calculate the t value (i.e., MD and SD) for the test of the difference between the nodal restraint assignment and the ground counts are smaller than that for the test of the difference between the iterative assignment and the ground counts.

In addition to the comparison between the assignment results and the counted data, the paired t-test was applied to examine the difference between the nodal restraint assignment and the conventional capacity restraint. This test is shown in the last row of Table 5-4. At the 10 percent significance level, the calculated t value (1.68) is close but smaller than the critical t value (1.70). This indicates that the assigned approach volumes of the nodal restraint assignment are not statistically different from the assigned approach volumes of the iterative assignment.

The tests of the difference of turning movements among the nodal restraint assignment, the iterative assignment, and the ground counts are summarized in Table 5-5. At the 10 percent significance level, the calculated t values for the test of the nodal restraint assignment vs. the ground count data ($t=0.02$), the iterative assignment, and the counted data ($t=0.50$) are smaller than the critical value ($t_c=1.66$). Therefore, neither the mean of the assigned turning movements from the nodal restraint assignment nor the iterative assignment was identified to be statistically significantly different from the mean of counted turning movements.

As shown in Table 5-5, the calculated t value for the nodal restraint assignment (0.02) is smaller than that for the iterative assignment (0.50). The MD and the SD for the test of difference between the nodal restraint assignment and the ground counts are smaller than that for the test of difference between the iterative assignment and the ground counts.

The test of difference of assigned turning movements between the nodal restraint assignment and the iterative assignment is shown in the last row of Table 5-5. At the 10

percent significance level, the calculated t value of the test (1.72) is greater than the critical t values (1.66). Therefore, the alternative hypothesis (H_a) was accepted. This indicates that the assigned turning movements of the nodal restraint assignment are statistically different from turning movements of the iterative assignment at the 10 percent significance level.

Based on the above analyses, it can be concluded that the nodal restraint assignment produced better approach volume and turning movement replications of the counted data than the conventional iterative assignment. At the 10 percent significance level, neither the nodal restraint assignment nor the iterative assignment was statistically significantly different from the ground counts. However, the difference in the assigned turning movements between the nodal restraint assignment and the iterative assignment was found to be significant. This provides additional evidence that the nodal restraint assignment performed better than the iterative assignment although neither of them was found to be statistically different from the counted data.

Table 5-4
Summary of Paired t-Tests of Approach Volumes
for the Nodal Restraint Assignment (Equal Weighting Incremental Procedure)
and the Iterative Assignment

Paired t-test	TEST STATISTICS (t)				Are Two Data Sets Statistically Different?
	MD	SD	CALCULATED	CRITICAL	
Nodal Restraint Assignment vs. Ground Counts	0.9	349.7	0.01	±1.70	No
Iterative Assignment vs. Ground Counts	38.1	443.8	0.48	±1.70	No
Nodal Restraint Assignment vs. Iterative Assignment	81.9	271.2	1.68	±1.70	No

Note: Two-tailed test at the 10 percent significance level
degrees of freedom = 31

Table 5-5
Summary of Paired t-Tests of Turning Movements
for the Nodal Restraint Assignment (Equal Weighting Incremental Procedure)
and the Iterative Assignment

Paired t-test	TEST STATISTICS (t)				Are Two Data Sets Statistically Different?
	MD	SD	CALCULATED	CRITICAL	
Nodal Restraint Assignment vs. Ground Counts	0.3	191.0	0.02	±1.66	No
Iterative Assignment vs. Ground Counts	12.7	249.5	0.50	±1.66	No
Nodal Restraint Assignment vs. Iterative Assignment	27.3	154.6	1.72	±1.66	Yes

Note: Two-tailed test at the 10 percent significance level
degrees of freedom = 95

EVALUATION II: EVALUATION OF THE NODAL RESTRAINT ASSIGNMENT (WEIGHTED AVERAGE INCREMENTAL PROCEDURE)

This section evaluates the nodal restraint assignment and the conventional incremental assignment to determine which produces better ground count replications. The evaluation was based upon a weighted average incremental setting (i.e., loading percentage for each iteration may not be equal, but the total percentage must be equal to 100 percent). Both the nodal restraint assignment and the capacity restraint assignment (the weighted average incremental assignment) were iterated 10 times and the loading percentages were 20, 15, 10, 10, 10, 10, 10, 5, 5, and 5 percent.

There were, however, some mechanism differences in these two assignment procedures. First, for the nodal restraint assignment, at each iteration 100 percent of the trips in the trip table were loaded to the network and a portion (the specified loading percentage for the iteration) of the assigned turn volumes were accumulated and used to adjust the nodal impedances. For the capacity restraint assignment, the specified percentages were applied to the trips in the trip table first, and link impedances were adjusted from the accumulated assigned link volumes. Second, for the nodal restraint assignment, the nodal impedances were adjusted according to the expanded turn volumes (the accumulated turn volumes expanded to 100 percent) at selected nodes. For the capacity restraint assignment, the link impedances were adjusted according to the accumulated link volumes without being expanded to 100 percent.

The various micro-level analyses conducted in the previous section were repeated. These analyses include:

1. Analysis of mean difference, percent mean difference, root mean square errors, and percent root mean square errors of approach volumes,
2. Analysis of mean difference, percent mean difference, root mean square errors, percent root mean square errors of turning movements,
3. Analysis of turning movements as a percentage of approach volumes, and
4. Paired t-tests of approach volumes and turning movements.

Analysis of Mean Difference, Percent Mean difference, Root Mean Square Errors, and Percent Root Mean Square Errors of Approach Volumes

The statistical measures of mean difference (MD), percent mean difference (PMD), root mean square error (RMSE), and percent root mean square errors (PRMSE) of the approach volumes from the nodal restraint assignment and the incremental assignment are summarized in Table 5-6. The information was presented in two ways. First, the approach volumes were classified into four groups based on their approaching directions, i.e., NB, WB, SB, and EB. Second, the approach volumes were aggregated, regardless of their approaching directions, to present an average measurement of the data under inspection.

As shown in Table 5-6, at the first level of aggregation the nodal restraint assignment resulted in a smaller mean difference (MD) than the conventional incremental assignment for all the classified groups. The nodal restraint assignment also produced less dispersion of differences (presented by RMSE) than the capacity restraint assignment for most of the

**Table 5-6
Summary of Approach Volume Measures from the Nodal Restraint Assignment (Weighted Average Incremental Procedure) and the Incremental Assignment**

Approach Direction	Sum of Counts	Number of Approaches	Nodal Restraint Assignment				Iterative Assignment			
			MD	PMD	RMSE	PRMSE	MD	PMD	RMSE	PRMSE
NB	20614	8	-55	-2.2	432	16.8	-236	-9.2	528	20.5
WB	7915	8	-26	-2.7	482	48.6	93	9.4	250	25.2
SB	13378	8	60	3.6	143	8.6	-187	-11.2	249	14.9
EB	10349	8	72	5.5	404	31.2	97	7.5	515	39.8
AVERAGE TOTAL	1633 52256	32	12	0.8	369	22.6	-58	-3.6	388	23.8

Statistic Measures:
MD = Mean Difference
PMD = Percent Mean Difference
RMSE = Root Mean Square Error
PRMSE = Percent Root Mean Square Error

groups except the WB approach. At the second level of aggregation, the nodal restraint assignment again produced a smaller average difference (MD) and a somewhat more confined dispersion of differences (RMSE) than the incremental assignment. Overall, the nodal assignment performed better than the incremental assignment at both levels.

Analysis of Mean Difference, Percent Mean difference, Root Mean Square Errors, and Percent Root Mean Square Errors of Turning Movements

The turning movements from the nodal restraint assignment and the capacity restraint assignment were examined at three different levels of aggregation. First, they were classified into 12 groups according to approaching directions (i.e., NB, EB, SB, and WB) and turning directions (i.e., LT, TH, and RT). Second, they were grouped according to turning directions only. Third, they were grouped regardless of approaching and turning directions.

As shown in Table 5-7, the better-or-worse comparisons at the first aggregation level indicate that the nodal restraint assignment generally performed equally well or better than the incremental assignment for most of the classified groups. At the second level of aggregation, the nodal restraint assignment produced better LT replication compared to the ground counts than the incremental assignment. The differences between the two assignments in the TH and RT group were considered to be insignificant. At the third level of aggregation level, the nodal restraint assignment performed apparently better than the conventional incremental assignment with respect to the measures of PMD (0.8 percent vs. -3.6 percent) and RMSE (33.1 percent vs. 42.8 percent). Overall, these measures (MD, PMD, RMSE, and PRMSE) of turning movements indicate that the nodal restraint assignment performed better than the incremental assignment in terms of turning movement replication compared to ground counts.

Table 5-7
Summary of Turning Movement Measures from the Nodal Restraint Assignment (Weighted Average Incremental Procedure) and the Incremental Assignment

Approach & Turning Direction	Sum of Counts	Number of Movements	Nodal Restraint Assignment				Incremental Assignment				Better-or-Worse Comparison	
			MD	PMD	RMSE	PRMSE	MD	PMD	RMSE	PRMSE		
NB	LT	1428	8	66	36.8	156	87.6	-8	-4.6	179	100.0	o
	TH	17226	8	-109	-5.0	215	10.0	-242	-11.2	351	16.3	+
	RT	1960	8	-13	-5.1	223	90.9	14	5.8	201	82.0	o
WB	LT	1812	8	-23	-10.2	240	106.0	-25	-10.9	235	103.9	o
	TH	4737	8	-57	-9.7	306	51.6	91	15.3	263	44.4	o
	RT	1366	8	54	31.6	99	58.2	27	15.5	108	63.0	o
SB	LT	1285	8	17	10.7	105	65.2	-11	-6.5	80	49.6	o
	TH	10761	8	40	2.9	76	5.7	-169	-12.5	210	15.6	+
	RT	1332	8	3	1.8	87	52.1	-8	-4.5	137	82.4	o
EB	LT	2852	8	-43	-12.1	142	39.8	-61	-17.0	218	61.3	+
	TH	5633	8	126	17.8	305	43.4	219	31.0	443	63.0	+
	RT	1864	8	-11	-4.7	143	61.3	-61	-26.2	303	129.9	+
ALL	LT	7377	32	4	1.8	50	21.6	-26	-11.3	51	22.0	
	TH	38357	32	-0	-0.0	39	3.2	-25	-2.1	50	4.1	
	RT	6522	32	8	4.1	59	29.1	-7	-3.4	69	34.0	
AVERAGE	544			4	0.8	180	33.1	-19	-3.6	233	42.8	
TOTAL	52256	96										

Notations for Better-or-Worse Comparison:

- + The nodal restraint assignment is better than the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences must be larger than 5 percent).
- The nodal restraint assignment is worse than the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences must be larger than 5 percent).
- o The nodal restraint assignment is close to the capacity restraint assignment in terms of PMD (compared by absolute values) and PRMSE differences (both differences are less than 5 percent).

Analysis of Turning Movements as a Percentage of Approach Volumes

The analysis considered turning movements as a percentage of the associated approach volumes. As mentioned in the previous section, such a measurement was assumed to be correlated to the functional classifications of the approach and cross streets with which the movement is associated. According to the functional classifications coded in the link data, the intersections under study were classified into three types: (1) a major arterial intersecting with a major arterial, (2) a major arterial intersecting with a minor arterial, and (3) a major arterial intersecting with a collector street. The results from the first and the third type of intersections were not compared with ground counts because the number of data were considered insufficient.

In the second type (major arterial intersecting with minor arterial) of intersections, turning movements were subdivided into six subgroups according to the functional classification of the approach, the cross streets, and the turning directions (LT, TH, or RT),

and then were compared to ground counts. Table 5-8 shows that both the nodal restraint assignment and the conventional incremental assignment produced similar turning percentages; they are also similar to the turning percentage of ground counts. For the turning movements from a major arterial to, or crossing, a minor arterial, the nodal restraint assignment performed slightly worse than the iterative assignment in the LT and RT groups (average error of LT movements: 2.3 percent vs. 0.7 percent; average error of RT movements: -1.1 percent vs. 0.6 percent). For the movements from a minor arterial turning to, or crossing, a major arterial, however, the nodal restraint assignment performed somewhat better than the incremental assignment in the LT and TH groups (average error of LT movements: -3.7 percent vs. -5.4 percent; average error of TH movements: -0.5 percent vs. 3.4 percent). The magnitude of these differences is statistically moderate, and the better-or-worse effects are mixed. As such, the nodal restraint assignment did not produce better turning movement replications than the conventional incremental assignment when the turning movements were regarded as a percentage of approach volumes and when compared to that of ground counts.

Table 5-8
Analysis of Turning Movements as a Percentage of Approach Volumes
for the Nodal Restraint Assignment (Weighted Average Incremental Procedure)
and the Incremental Assignment

Types of Inter.	Functional Classes			Number of Movements	Average Counted Turn Percent ^a	Nodal Restraint Assignment		Incremental Assignment	
	Approach Street	Cross Street	Turn Dir.			Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c
I.	MAJOR - MAJOR		LT	4	14.8	14.3	d	14.3	d
			TH	4	68.4	68.4		71.4	
			RT	4	16.7	17.3		14.3	
II.	MAJOR - MINOR		LT	12	7.9	10.2	2.3	8.6	0.7
			TH	12	81.6	80.4	-1.2	80.2	-1.3
			RT	12	10.6	9.4	-1.1	11.1	0.6
	MINOR - MAJOR		LT	12	24.7	21.0	-3.7	19.3	-5.4
			TH	12	59.8	59.3	-0.5	63.2	3.4
			RT	12	15.6	19.7	4.2	17.5	2.0
III.	MAJOR - COLL.		LT	2	5.2	3.4	d	2.7	d
			TH	2	92.8	91.7		92.0	
			RT	2	2.0	4.8		5.2	
	COLL. - MAJOR		LT	2	31.6	25.1	d	31.3	d
			TH	2	21.8	49.2		59.3	
			RT	2	46.5	25.7		9.4	

Note:

^a Average Counted Turn Percentage = $\Sigma(\text{Counted Turn Volume} \div \text{Counted Approach Volume}) \div (\text{Total Number of Data})$

^b Average Assigned Turn Percentage = $\Sigma(\text{Assigned Turn Volume} \div \text{Assigned Approach Volume}) \div (\text{Total Number of Data})$

^c Average Error = Average Assigned Turn Percentage - Average Counted Turn Percentage

^d Not computed due to insufficient data (only one intersection)

Paired t-Tests of Approach Volumes and Turning Movements

As stated in the previous section, the paired t-test is an appropriate statistical procedure for analyzing turning movements. The test was used to determine whether two assignments were significantly different in terms of the difference between the paired estimates at the same location from the two assignment models. The research hypothesis and test statistics for the test were the same as described in the previous section.

The tests of the difference of approach volumes between the nodal restraint assignment, the conventional incremental assignment, and the ground counts are summarized in Table 5-9. At the 10 percent significance level, the calculated t values for the difference between the nodal restraint assignment and the ground count data ($t=-0.19$) and that between the incremental assignment and the counted data ($t=0.86$) are smaller

than the critical value ($t_c=1.70$). As such, the mean of assigned approach volumes from neither assignment was identified to be statistically significantly different from the mean of counted approach volumes. However, the calculated t value for the nodal restraint assignment (-0.19) is smaller than that for the incremental assignment (0.86). The mean difference (MD) and the standard deviation (SD) for the test of the difference between the nodal restraint assignment and the ground counts are smaller than that for the test of the difference between the incremental assignment and the ground counts.

The paired t-test was also applied to examine the difference between the nodal restraint assignment and the incremental assignment. As shown in Table 5-9, at the 10 percent significance level the calculated t value (1.35) is smaller than the critical t value (1.70). As such, the assigned approach volumes of the nodal restraint assignment were not statistically different from the assigned approach volumes of the incremental assignment.

The tests of the difference of turning movements between the nodal restraint assignment, the incremental assignment, and the ground counts are summarized in Table 5-10. At the 10 percent significance level, the calculated t values for the test of the nodal restraint assignment vs. the ground count data ($t=-0.22$) and that of the iterative assignment and the counted data ($t=0.82$) are smaller, in terms of absolute values, than the critical value ($t_c=\pm 1.66$). Therefore, the mean of assigned turning movements from neither assignment was identified to be statistically significantly different from the mean of counted turning movements. Nevertheless, the calculated t value for the nodal restraint assignment (-0.22) is smaller than that for the incremental assignment (0.82). The MD and the SD for the test of the difference between the nodal restraint assignment and the ground counts are smaller than that for the test of the difference between the iterative assignment and the ground counts.

The test of the difference between the assigned turning movements from the nodal restraint assignment and the turning movements from the incremental assignment is shown in the last row of Table 5-10. At the 10 percent significance level, the calculated t value (1.41) is smaller than the critical t value (1.66). As such, the assigned turning movements from the nodal restraint assignment were not statistically significantly different from turning movements of the incremental assignment.

In summary, the various micro-level analyses show that the nodal restraint assignment produced a better turning movement replication of the counted data than the incremental assignment. However, neither the nodal restraint assignment nor the incremental assignment was identified to be statistically significantly different from the ground counts at the 10 percent significant level.

Table 5-9
Summary of Approach Volume Paired t-Tests
for the Nodal Restraint Assignment (Weighted Average Incremental Procedure)
and the Incremental Assignment

Paired t-test	TEST STATISTICS (t)				Are Two Data Sets Statistically Different?
	MD	SD	CALCULATED	CRITICAL	
Nodal Restraint Assignment vs. Ground Counts	-12.4	363.0	-0.19	±1.70	No
Incremental Assignment vs. Ground Counts	58.3	378.1	0.86	±1.70	No
Nodal Restraint Assignment vs. Incremental Assignment	70.6	291.2	1.35	±1.70	No

Note: Two-tailed test at the 10 percent significance level
degrees of freedom = 31

Table 5-10
Summary of Turning Movement Paired t-Tests of
for the Nodal Restraint Assignment (Weighted Average Incremental Procedure)
and the Incremental Assignment

Paired t-test	TEST STATISTICS (t)				Are Two Data Sets Statistically Different?
	MD	SD	CALCULATED	CRITICAL	
Nodal Restraint Assignment vs. Ground Counts	-4.1	179.4	-0.22	±1.66	No
Incremental Assignment vs. Ground Counts	19.4	231.0	0.82	±1.66	No
Nodal Restraint Assignment vs. Incremental Assignment	23.5	162.8	1.41	±1.66	No

Note: Two-tailed test at the 10 percent significance level
degrees of freedom = 95

OVERALL EVALUATION

In the various micro-level analyses conducted in this chapter, the nodal restraint assignment for both equal weighting and weighted average incremental procedures demonstrated better results than the conventional V/C restraint assignments.

The overall measures of approach volumes for the nodal restraint assignment and the capacity restraint assignment from the two evaluation sets are summarized in Table 5-11. For both evaluation sets, the nodal restraint assignment performed generally better than the conventional capacity restraint assignments. The improvement is shown by both the magnitude of average difference (MD and PMD) and the dispersion of errors (RMSE and PRMSE).

The overall turning movement measures for the nodal restraint assignment and the capacity restraint assignment from the two evaluation sets are summarized in Table 5-12. For both evaluation sets, the nodal restraint assignment performed generally better than the conventional capacity restraint assignments. It was also noted that the improvement in turning movement replications is more evident than the improvement in approach volumes in terms of the measures of RMSE and PRMSE.

In the analysis of turning movements as a percentage of approach volumes, both the nodal restraint and capacity restraint assignments produced very comparable turning percentage replications to the counted data. Overall, the nodal restraint assignment produced somewhat better turning movement replications than the iterative assignment when the movements were regarded as a percentage of approach volumes. The nodal restraint assignment, however, did not produce better turning movement replications than the incremental assignment when the movements were regarded as a percentage of approach volumes.

In the analyses of paired t-test of approach volumes and turning movements, neither the nodal restraint assignment or the capacity restraint assignment was identified to be statistically different from the ground count data at the 10 percent significance level. However, the assigned turning movements of the nodal restraint assignment were found to be statistically different from turning movements of the iterative assignment at the 10 percent significance level.

Table 5-11
Summary of Approach Volume from the Nodal Restraint Assignment and the Capacity Restraint Assignments

Measures / Assignments	Evaluation I			Evaluation II		
	Nodal	Iterative	Improve.*	Nodal	Incremental	Improve.*
MD (Mean Difference)	-1	-38		12	-58	
PMD (Percent MD)	-0.1	-2.3	2.2	0.8	-3.6	2.8
RMSE (Root Mean Square Errors)	355	452		369	388	
PRMSE (Percent RMSE)	21.8	27.7	5.9	22.6	23.8	1.2

Average Counted Volume = 1633 Number of Approaches = 32

* Improvement (in Percent)
= $\left| \frac{\text{Nodal Assignment Measure} - \text{Iterative (or Incremental) Assignment Measure}}{\text{Nodal Assignment Measure}} \right|$

Table 5-12
Summary of Turning Movement Measures from the Nodal Restraint Assignment and the Capacity Restraint Assignments

Measures / Assignments	Evaluation I			Evaluation II		
	Nodal	Iterative	Improve.*	Nodal	Incremental	Improve.*
MD (Mean Difference)	-1	-13		4	-19	
PMD (Percent MD)	-0.1	-2.4	2.3	-0.8	-3.6	2.8
RMSE (Root Mean Square Errors)	192	251		180	233	
PRMSE (percent RMSE)	35.3	46.2	10.9	33.1	42.8	9.7

Average Counted Volume = 544 Number of Movements = 96

* Improvement (in Percent)
= $\left| \frac{\text{Nodal Assignment Measure} - \text{Iterative (or Incremental) Assignment Measure}}{\text{Nodal Assignment Measure}} \right|$

The proposed nodal restraint assignment procedure is expected to be more responsive than the existing capacity restraint assignment procedures. The application of the procedure to the test network did show an improvement over the available capacity restraint assignment procedures. The improvement, however, is considered to be marginal and not as significant as expected. It is believed that more significant improvement would have been found had a larger test network been available. This problem was analyzed by

examining the composition of the extracted trip table and the availability of alternative paths for different O-D pairs in the trip table.

ANALYSIS OF CONSTRAINT DUE TO THE SIZE OF THE TEST NETWORK

The constraint imposed by the small size of the test network was analyzed by examining (1) the composition of the extracted trip table and (2) the availability of alternative paths for different O-D pairs in the trip table. The trip table extracted from the windowing procedure consist of 47 local zones (Zone 1 to Zone 47) and 40 external stations (Zone 48 to Zone 87). As shown in Figure 5-2, these zones were aggregated into six external districts (District 1 to District 6) and four local districts (District 7 to District 10).

The percentage of the number of trips to/from each district with respect to the total number of trips is shown in Table 5-13. As shown, nearly 65 percent of the total trips originate from the external districts, and nearly 69 percent of the total trips leave the subarea through these external districts. The composition of external, external-local, and local trips is further summarized in Table 5-14. Of the total 56,275 trips, 42.2 percent are external-through trips, and 48.9 percent (= 22.4 percent + 26.5 percent) are external-local trips. This leaves only 8.9 percent local trips which were considered more likely to be diverted in the network. However, these local trips, whose average trip length is 5.2 minutes, are mostly short trips.

The average trip length of all trips (including external-through, external-local, and local trips) is 6.3 minutes if the external-through and external-local trips are measured from the cordon line positions. The trip length frequency distribution of these trips also indicates that nearly 40 percent of the trips are shorter than 4 minutes. For the most part, these short trips did not divert in the assignment process.

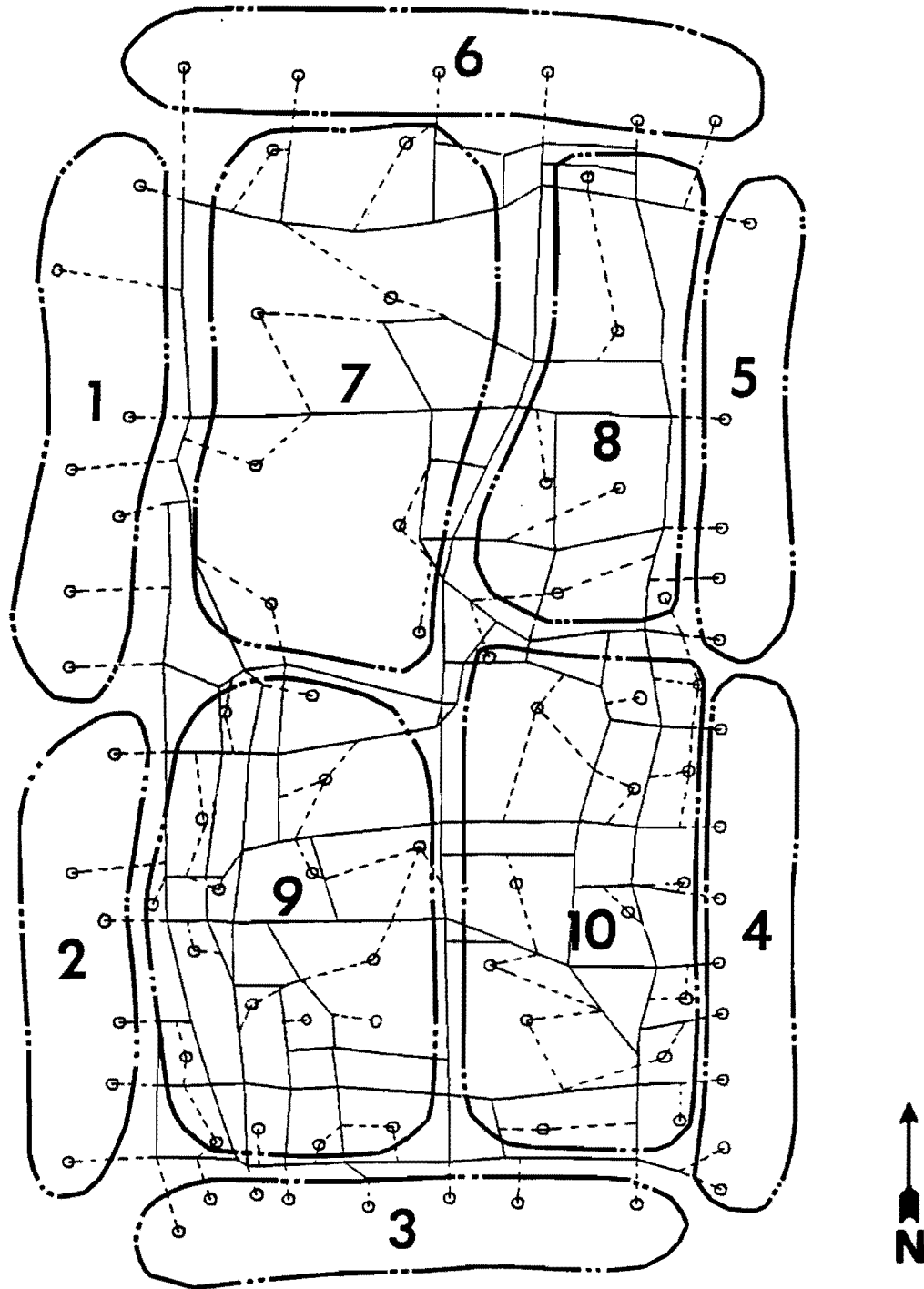
Confined by the network layout and dimension, even some long trips (trip length \geq 6.3 minutes) did not divert during the assignment process. The network layout was especially unfavorable for the east-west oriented trips to divert. As shown in Figure 5-3, the trips from Zone 51 to Zone 80 were never assigned to an alternative path in a 10-iteration equal weighting incremental nodal assignment procedure. In the same assignment procedure (Figure 5-3), the trips from Zone 58 to Zone 73 were mostly assigned to path A;

and trips were assigned to path B only at the second iteration.

The availability of alternative paths for these two O-D pairs did not improve even when the upper bound of the maximum nodal impedance was raised from a maximum nodal impedance constrained at $V/C \leq 1.2$ to a maximum nodal impedance of 6 minutes (3 times the maximum cycle length). As shown in Figure 5-4, the trips from Zone 51 to Zone 80 again were not assigned to an alternative path at any iteration. The trips from Zone 58 to Zone 73 were assigned to alternative paths at two of the ten iterations. The trips were assigned to path B at the second iteration and to path C at the third iteration.

The availability of alternative paths for a north-south oriented O-D pair was analyzed as well. As shown in Figure 5-5, the trips from Zone 66 to Zone 85 were assigned to only one alternative path at the second iteration in a 10-iteration equal weighting incremental nodal restraint assignment procedure. When the upper bound of the nodal impedance was raised from the maximum nodal impedance constrained at $V/C \leq 1.2$ to the maximum nodal impedance of 6 minutes, the assignment produced two more alternative paths. As shown in Figure 5-6, the relaxation of the upper bound of the nodal impedance generated three alternative paths in addition to Path A; the trips were assigned to path B at the second iteration, to path C at the third iteration, and to path D at the fifth iteration. However, the trip length of trips from Zone 66 to Zone 85 is 11.15 minutes which is relatively longer than most of the other trips in the trip table. The analysis of trip length frequency distribution shows that only 11.85 percent of the total trips in the windowed O-D table are longer than 10 minutes.

In summary, the analysis above indicates that the responsiveness of the proposed assignment procedure was confined by size of the test network. However, the various micro-level analyses in this chapter show the nodal restraint assignment did have a definite, though not impressive, improvement over the existing capacity restraint assignments. It is believed that more significant improvement would have been achieved had a larger test network been available. It is suggested that the average trip length of greater than 10 minutes be a major criterion for extracting a test network if further evaluation is to be conducted.



External Districts: 1-6 Local Districts: 7-10

Figure 5-2 Aggregation of Traffic Zones into Traffic Districts

Table 5-13
Proportion of Trips to and from Various Zonal Aggregate Districts
(In Percent)

To From	External Districts						Local Districts				Total
	1	2	3	4	5	6	7	8	9	10	
1	0.0	0.0	0.8	0.5	3.2	0.7	1.1	0.3	0.5	0.0	7.1
2	0.2	1.3	4.9	3.1	1.2	1.0	0.3	0.3	3.5	0.6	16.3
3	0.5	4.1	0.6	3.6	1.2	3.6	1.6	0.7	5.6	1.4	22.8
4	0.6	2.3	2.6	0.0	0.0	0.5	0.1	0.1	1.8	0.9	8.9
5	1.9	0.6	1.0	0.0	0.0	0.7	0.9	1.2	0.2	0.1	6.6
6	0.0	0.1	0.9	0.0	0.5	0.0	0.5	0.4	0.3	0.1	2.9
7	0.7	0.1	0.6	0.1	0.7	0.6	1.0	0.4	0.4	0.1	4.7
8	0.3	0.1	0.4	0.1	1.3	0.6	0.5	0.5	0.2	0.1	4.1
9	1.0	5.1	8.6	3.2	0.7	0.6	0.8	0.3	3.3	0.5	24.1
10	0.1	0.3	0.6	0.7	0.2	0.0	0.1	0.1	0.3	0.2	2.5
Total	5.4	14.0	20.9	11.2	9.0	8.2	7.0	4.1	16.1	4.1	100.0

Total number of trips = 56,275
Average trip length of local trips = 5.2 minutes
Average trip length of all trips = 6.3 minutes

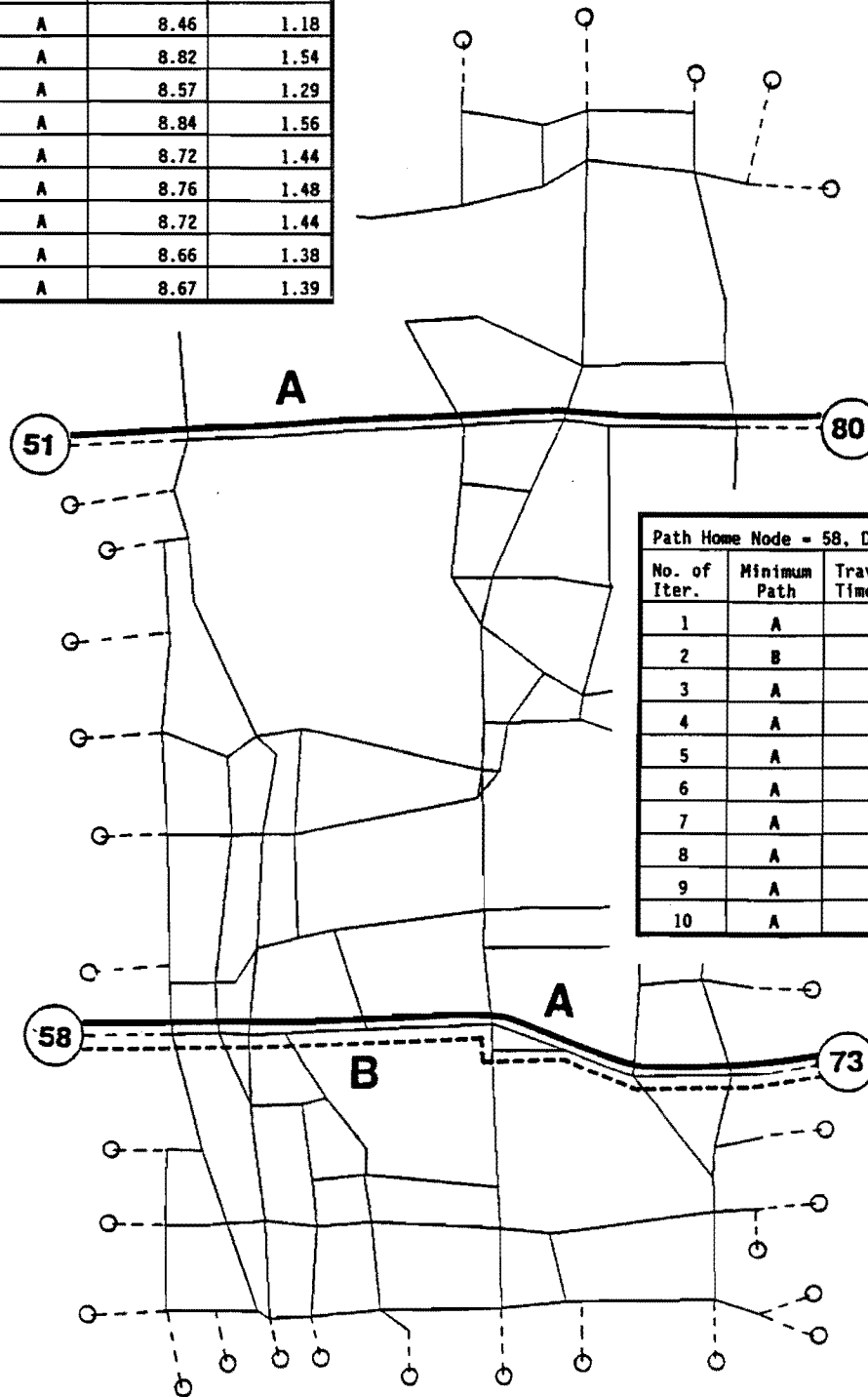
Table 5-14
Composition of External-Through, External-Local, and Local Trips
(In Percent)

From / To	External	Local	Total
External	42.2	22.4	64.6
Local	26.5	8.9	35.4
Total	68.7	31.3	100.0

The availability of alternative paths for a north-south oriented O-D pair was analyzed as well. As shown in Figure 5-5, the trips from Zone 66 to Zone 85 were assigned to only one alternative path at the second iteration in a 10-iteration equal weighting incremental nodal restraint assignment procedure. When the upper bound of the nodal impedance was raised from the maximum nodal impedance constrained at $V/C \leq 1.2$ to the maximum nodal impedance of 6 minutes, the assignment produced two more alternative paths. As shown in Figure 5-6, the relaxation of the upper bound of the nodal impedance generated three alternative paths in addition to Path A; the trips were assigned to path B at the second iteration, to path C at the third iteration, and to path D at the fifth iteration. However, the trip length of trips from Zone 66 to Zone 85 is 11.15 minutes which is relatively longer than most of the other trips in the trip table. The analysis of trip length frequency distribution shows that only 11.85 percent of the total trips in the windowed O-D table are longer than 10 minutes.

In summary, the analysis above indicates that the responsiveness of the proposed assignment procedure was confined by size of the test network. However, the various micro-level analyses in this chapter show the nodal restraint assignment did have a definite, though not impressive, improvement over the existing capacity restraint assignments. It is believed that more significant improvement would have been achieved had a larger test network been available. It is suggested that the average trip length of greater than 10 minutes be a major criterion for extracting a test network if further evaluation is to be conducted.

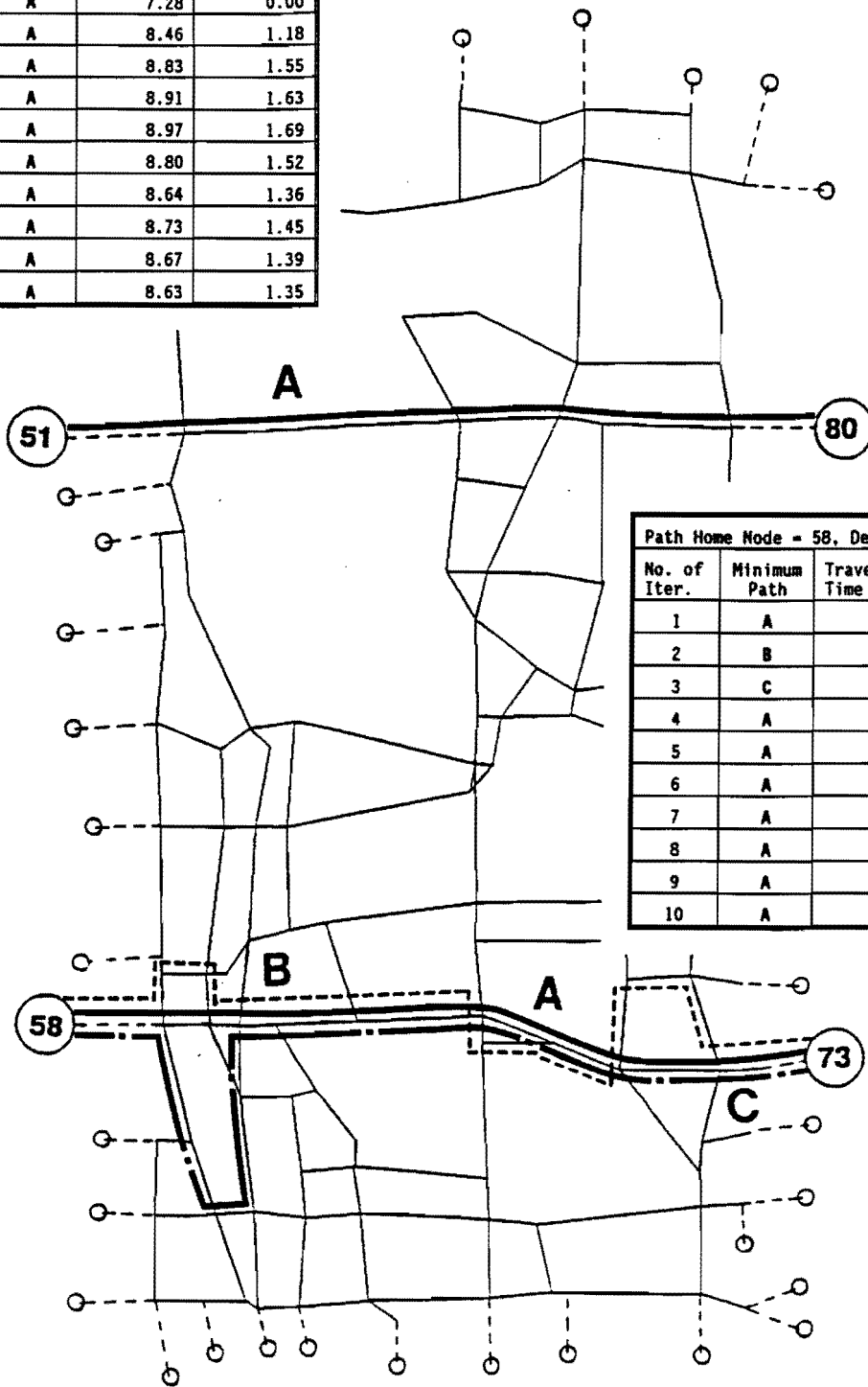
Path Home Node = 51, Dest. Node = 80			
No. of Iter.	Minimum Path	Travel Time (min)	Nodal Imp. (min)
1	A	7.28	0.00
2	A	8.46	1.18
3	A	8.82	1.54
4	A	8.57	1.29
5	A	8.84	1.56
6	A	8.72	1.44
7	A	8.76	1.48
8	A	8.72	1.44
9	A	8.66	1.38
10	A	8.67	1.39



Path Home Node = 58, Dest. Node = 73			
No. of Iter.	Minimum Path	Travel Time (min)	Nodal Imp. (min)
1	A	6.40	0.00
2	B	12.01	5.61
3	A	13.57	7.17
4	A	10.97	4.57
5	A	10.30	3.90
6	A	11.77	5.37
7	A	10.79	4.39
8	A	11.07	4.67
9	A	10.88	4.48
10	A	11.32	4.92

Figure 5-3 Analysis of Alternative Paths for O-D Pairs 51-80 and 58-73 (Nodal Restraint Assignment with Maximum Impedance Constrained by $V/C \leq 1.2$)

Path Home Node = 51, Dest. Node = 80			
No. of Iter.	Minimum Path	Travel Time (min)	Nodal Imp. (min)
1	A	7.28	0.00
2	A	8.46	1.18
3	A	8.83	1.55
4	A	8.91	1.63
5	A	8.97	1.69
6	A	8.80	1.52
7	A	8.64	1.36
8	A	8.73	1.45
9	A	8.67	1.39
10	A	8.63	1.35



Path Home Node = 58, Dest. Node = 73			
No. of Iter.	Minimum Path	Travel Time (min)	Nodal Imp. (min)
1	A	6.40	0.00
2	B	13.40	7.00
3	C	15.73	9.33
4	A	12.61	6.21
5	A	13.75	7.35
6	A	15.25	8.85
7	A	13.69	7.29
8	A	12.09	5.69
9	A	14.09	7.69
10	A	13.04	6.64

Figure 5-4 Analysis of Alternative Paths for O-D Pairs 51-80 and 58-73 (Nodal Restraint Assignment with Maximum Nodal Impedance of 6 Minutes)

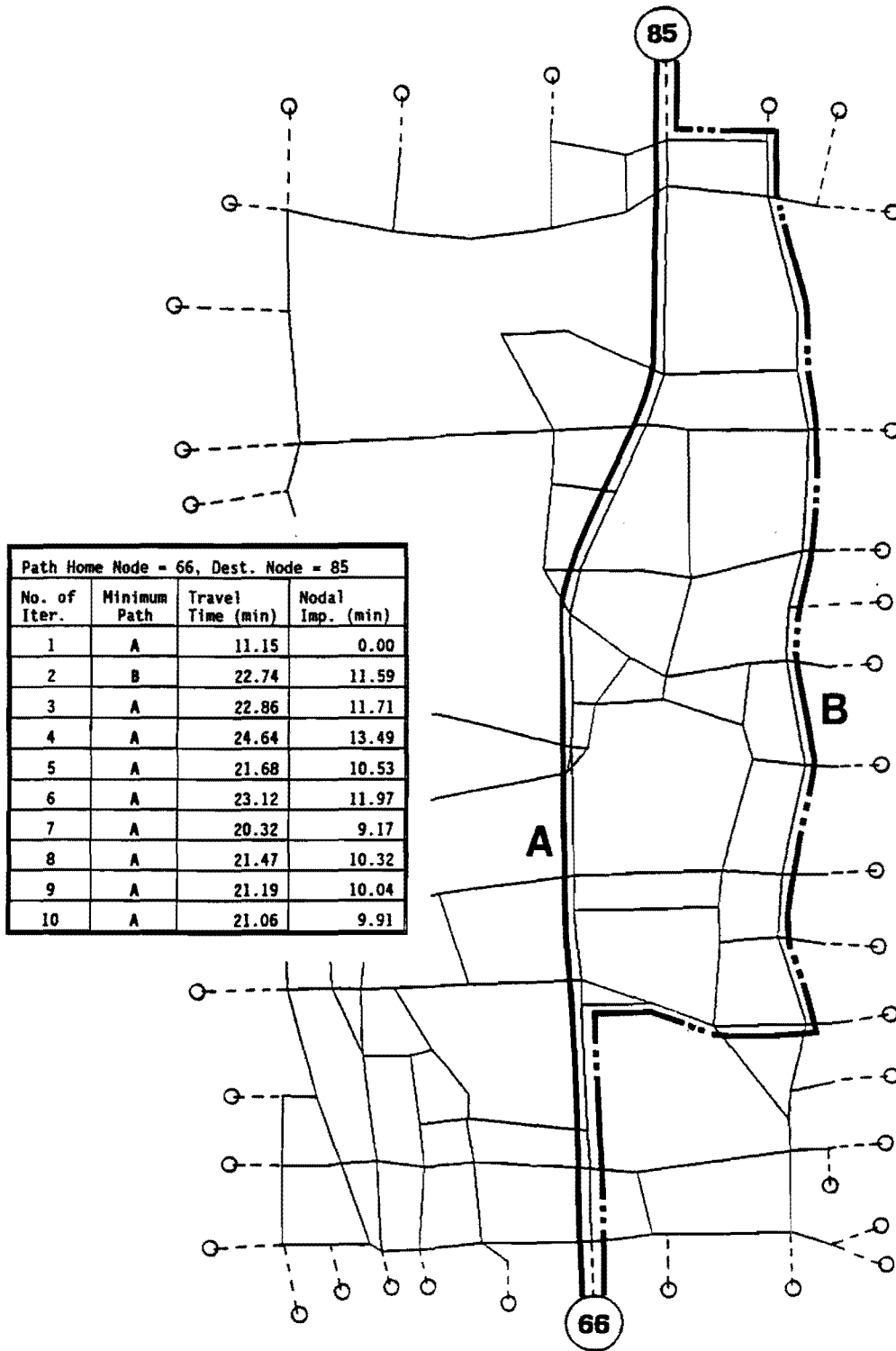


Figure 5-5 Analysis of Alternative Paths for Zone Pair 66-85 (Nodal Restraint Assignment with Maximum Impedance Constrained by $V/C \leq 1.2$)

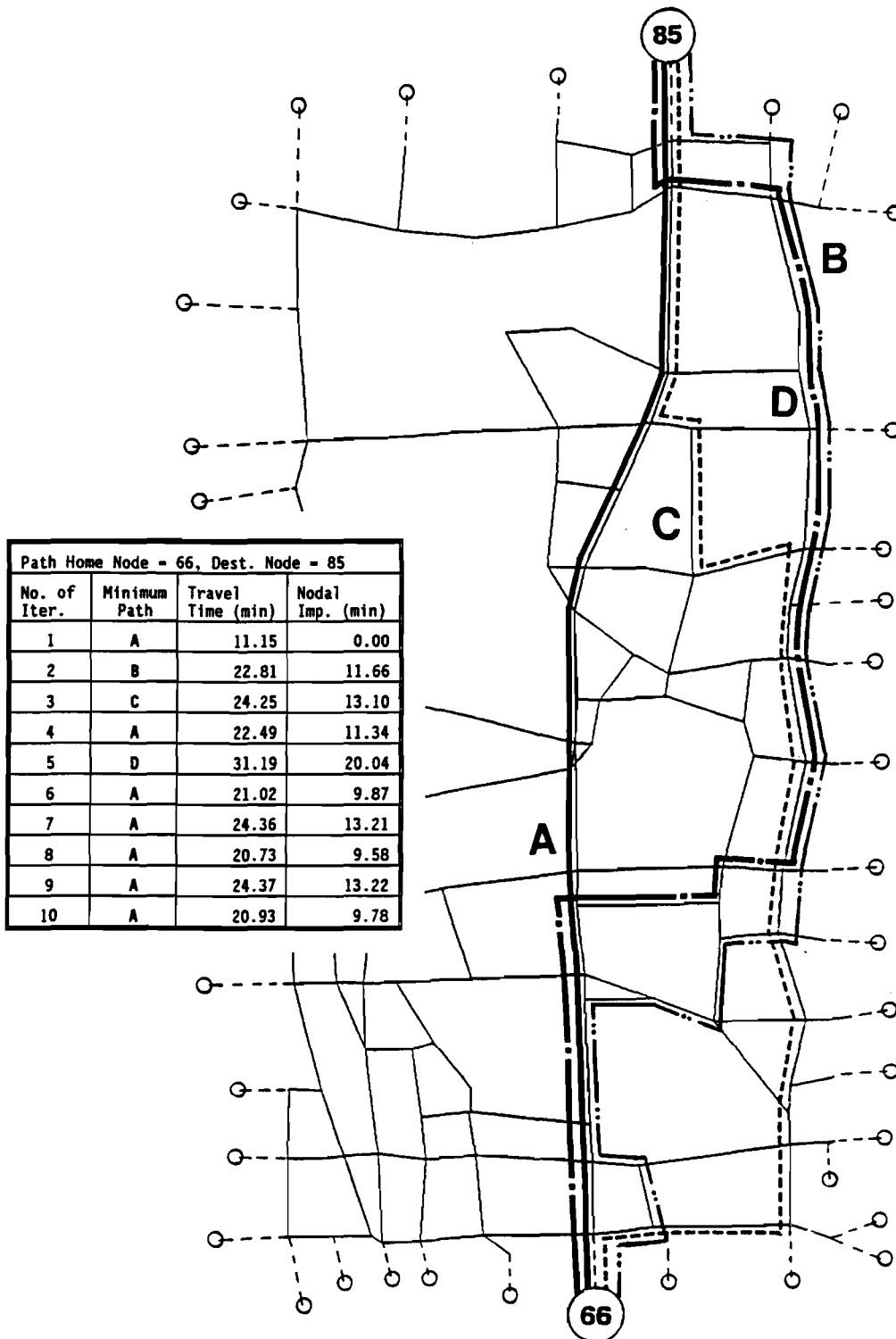


Figure 5-6 Analysis of Alternative Paths for Zone Pair 66-85 (Nodal Restraint Assignment with Maximum Nodal Impedance of 6 Minutes)

CHAPTER VI

FINDINGS AND RECOMMENDATIONS

This research developed and evaluated a traffic assignment procedure in which capacity restraint was applied to nodes instead of links. The conventional traffic assignment techniques consider alternative paths through a successive impedance adjustment process in which link impedances (travel times) are adjusted based upon the ratios of the assigned link volume to a coded link capacity. In reality, the capacity of an urban street system is constrained by intersections (nodes) instead of links. The nodal restraint assignment procedure was, thus, expected to be more responsive than the conventional capacity restraint assignment procedures.

The procedure was developed by utilizing the concept of the intersection sum of critical lane volumes. A nodal impedance adjustment subroutine was incorporated in the assignment process to account for intersection delays where link impedances were held constant and nodal impedances were updated from iteration to iteration. The impedance for each turning movement at a node is determined by the association of all the movements encountered at the node (i.e., the impedance of a movement at a node is a function of all the other movements entering the node). The cycle length of a node is a variable determined by the sum of evaluated critical turning movements. The capacity for each movement is derived from the ratio of green time to cycle length and a specified saturation flow rate. Nodal impedances are adjusted by using the delay function in the **Highway Capacity Manual 1985**.

The proposed procedure then was applied to a test network (Preston Road Corridor in North Dallas). In the application, various assignment procedures and different impedance adjustment function parameters were used to test the robustness of the proposed assignment procedure. The impedance values produced by the nodal impedance subroutine were examined to determine if they were correct according to the computation algorithm. The impedance adjustment function used to update nodal impedances was compared with the delay equation used in the D-FW Joint Model and the widely used BPR impedance adjustment functions. The convergence rate of the proposed procedure was inspected as

well. The stability of the proposed procedure was examined through various network performance measures.

The nodal restraint assignment was evaluated through comparison with the selected "best" of the available conventional capacity restraint assignments based upon traffic counts at major intersections along Preston Road. The evaluation was based on the various micro-level analyses which included (1) analysis of mean difference and root mean square errors of approach volumes, (2) analysis of mean difference and root mean square errors of turning movements, (3) analysis of turning movements as a percentage of approach volume, and (4) paired t-tests of approach volumes and turning movements. These analyses show that the nodal restraint assignment generally produced better turning movement replications than the available capacity restraint assignments.

RESEARCH FINDINGS

Research findings related to the development, testing, and evaluation of the nodal restraint assignment are summarized as follows:

1. The network configuration used to implement the nodal restraint assignment procedure in this research is different from that used in conventional capacity restraint assignment procedures. The network includes turning movement elements in addition to the existing links and nodes. However, the literature review indicates that the network consisting of directional movements and mid-block nodes is the most efficient configuration for implementing nodal restraints.
2. A nodal impedance adjustment subroutine has been developed and incorporated in the assignment process in which the nodal impedance for each movement at each selected node is adjusted according to its assigned turn volume in association with other turning movements at the node. Through examinations of the computation process and resulting nodal impedance values, the subroutine was found to be working properly.
3. For both the equal weighting and the weighted average incremental procedures, the nodal restraint assignment process was found to be more effective when the accumulated volumes were expanded to 100 percent than when they were not expanded.

The assignment process without expansion of the accumulated volumes did not divert many trips until 80 percent of the trips were loaded to the network.

4. For both the equal weighting and weighted average incremental procedures, the nodal restraint assignment converged at the sixth iteration. There was an obvious fluctuation between the second and the third iterations. This might be related to the setting of zero nodal impedance in the first iteration. It is speculated that a smoother convergence curve may occur when certain values are used as the initial nodal impedances.
5. Some nodal performance information, which is absent in the conventional capacity restraint assignment, was also produced by the nodal impedance adjustment subroutine. The information includes the sum of critical lane volumes, capacity, and V/C ratio of each selected node. The information can be used for quick identification of the problem intersections in a subarea.
6. In addition to the commonly used micro-analysis measures such as mean difference and root mean square errors, this research utilized turning movements as a percentage of approach volumes and the paired t-test to evaluate turning movement replications. The paired t-test was found to be an effective statistical test for evaluating the approach volume or turning movement replications.
7. The nodal restraint assignment procedure evaluation showed that the assignment was somewhat more responsive than the conventional capacity restraint assignments. However, the responsiveness of the assignment was confined by the test network layout and dimension. The extracted subarea trip table was composed mainly of short trips (average trip length is 6.3 minutes), and most of them were linked with external stations (more than 90 percent). It is suggested that the average trip length of greater than 10 minutes be one major criterion for selecting a test network if future evaluation is conducted.

Some other issues related to the general traffic assignment practice were also encountered in the process of research. These findings are:

1. In the windowing process the extracted trip table was found to be quite sensitive to the selected links assignment procedure, especially to the impedance adjustment function(s).

2. One effective way to examine the subarea trip distribution was to compress the trip table from several zones to a few districts in which the unbalanced directional splits between districts were quickly identified.
3. Turning movements in a subarea were found to be sensitive to the composition of the trip table as well as to the assignment procedure. It is speculated that the improvement of turning movement replications may not be acquired by revising the assignment procedure unless the trip table is fairly accurate.

RECOMMENDATIONS FOR FUTURE RESEARCH

One of the critical issues challenging transportation planners in the 1990's is improving urban air quality through traffic management. As is well known, the primary source of mobile emissions is traffic congestion (i.e., stop-and-go traffic) in the urban area. A more responsive traffic assignment process which reflects congested traffic patterns, both on urban streets and on freeways, is required for urban air quality evaluation. This research shows that a prototype of the procedure has been successfully developed. Further development and implementation of an operational model is highly recommended. Meanwhile, several issues also require further exploration in the process of developing the operational model. They are summarized as follows:

1. The conventional network and the transformed network should be interchangeable in terms of providing necessary network or assignment information. That is, the operational model should be able to transform the conventional network into one that consists of directional movements and mid-block nodes internally in the computation process.
2. The computation of nodal impedance for nodes with stop and yield operations by using the unsignalized intersection methods should be included in the nodal impedance subroutine.
3. An additional impedance adjustment subroutine for freeway movements should be developed and incorporated in future development.
4. The case of urban traffic progression (i.e., several intersections (nodes) coordinated to provide progression for an urban corridor) should be considered in future development.

5. A flexible travel demand for each O-D pair in the trip table should also be considered in future development.
6. Future development should test a subarea network with various congested scenarios (e.g., AM peak-hour network, PM peak-hour network, and afternoon peak-hour network).

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APPENDIX A

**PROGRAM TO TRANSFORM NETWORK CONFIGURATION:
TRNFORM (TRNFORM.FOR)**

```

C
C
PROGRAM TRNFORM
C
C
INTEGER CRD(30),OLD(8,30),MOD(4,30),NEW(4,3,30)
INTEGER CLET,C1,CX,CY,INTX,INTY
INTEGER T1,TA,TB,TC,TABC
DOUBLE PRECISION XDP,YDP,ZPCT,XDP2,YDP2
CHARACTER*52 JUNK1
CHARACTER*64 JUNK2
INTEGER LIT1,LIT2,LITS,LITT
DATA LIT1 /'1'/
DATA LIT2 /'2'/
DATA LITS /'S'/
DATA LITT /'T'/
C
C   ARRAY OR
C   VARIABLE           CONTENTS
C
C   CRD                FOR READING INPUT LINK DATA FILE
C
C   OLD                ARRAY TO STACK THE OLD LINK DATA
C                   FOR SUBJECT NODE
C
C   MOD                ARRAY TO HOLD THE DUMMY LINKS
C                   (OR PARTIAL LINKS)
C
C   NEW                ARRAY TO HOLD THE NEW LINKS FOR
C                   THE DETAILED MOVEMENTS
C
C   =====
C
C                   PRINT INFO TO SCREEN
C                   AND GET FILE NAMES
C
C   =====
C
100 CONTINUE
WRITE(*,110)
110 FORMAT('1',10X,'PROGRAM TO DETAIL CODE'/
* '1',10X,'THE TURNING MOVEMENTS'/
* '1',10X,'FOR SELECTED USER NODES'////)
DO 113 I=1,5
WRITE(*,112)
112 FORMAT(' ')
113 CONTINUE
WRITE(*,114)
114 FORMAT(' PRESS ENTER TO CONTINUE')
READ(*,115)IANS
115 FORMAT(A1)
C
C   LET'S GET THE INPUT DATA SET NAMES
C
WRITE(*,117)
117 FORMAT('1',10X,'THE FIRST STEP WILL BE TO IDENTIFY THE'/
* '1',10X,'INPUT DATA SET NAMES....'/
* '1',10X,'WARNING!!! SOME INPUT DATA SETS WILL BE'/
* '1',10X,' MODIFIED AS THE PROGRAM'/
* '1',10X,' PROCEEDS '////)
WRITE(*,114)
READ(*,115)IANS
WRITE(*,118)
118 FORMAT('1',10X,'THE INPUT DATA SETS NEEDED WILL BE:'/
* '1',15X,'LINK DATA FILE'/
* '1',15X,'NODE COORDINATE FILE'/
* '1',15X,'TURN PROHIBITS FILE'////)
116 WRITE(*,119)
119 FORMAT('1',10X,'IF YOU DO NOT HAVE BACK-UP COPIES '/

```

```

*      ' ',10X,'OF THESE INPUT FILES THAT WILL BE MODIFIED, '/
*      ' ',10X,'IT IS SUGGESTED THAT YOU STOP THE PROGRAM NOW! '/
*      ' ',15X,'ENTER "1" IF YOU WISH TO PROCEED, '/
*      ' ',15X,'---OR---'/
*      ' ',15X,'ENTER "2"
*          IF YOU WISH TO STOP THE PROGRAM NOW! '//)
      IANS=2
      READ(*,120)IANS
120  FORMAT(11)
      IF(IANS.EQ.2)STOP
      IF(IANS.NE.1) GO TO 116
C
C      NEXT GET THE NAME OF THE INPUT LINK DATA FILE (UNIT 11)
C
121  WRITE(*,122)
122  FORMAT(' NEXT, YOU WILL BE ASKED FOR THE FILE NAME'/
*      ' FOR THE FILE CONTAINING THE INPUT LINK DATA'/
*      ' FOR UNIT 11. '//)
      READ(11,125,END=128)(CRD(J),J=1,25)
125  FORMAT(2I5,11,14,A1,2I4,4I2,2I6,
*      A1,2I4,4I2,2I6,11,15,Z1)
      REWIND 11
      GO TO 130
128  WRITE(*,129)
129  FORMAT(' **ERROR** EMPTY DATA SET PROGRAM TERMINATING')
      STOP
130  CONTINUE
C
C      NEXT GET THE NAME OF THE INPUT NODE COORD FILE (UNIT 12)
C
131  WRITE(*,132)
132  FORMAT(' NEXT, YOU WILL BE ASKED FOR THE FILE NAME'/
*      ' FOR THE FILE CONTAINING THE NODE COORDINATES'/
*      ' FOR UNIT 12. '//)
      READ(12,133,END=128)CLET,C1,CX,CY,JUNK1
133  FORMAT(A1,15,2I11,A52)
      REWIND 12
140  CONTINUE
C
C      NEXT GET THE NAME OF THE LEFT TURN PROHIBITS FILE (UNIT 13)
C
141  WRITE(*,142)
142  FORMAT(' NEXT, YOU WILL BE ASKED FOR THE FILE NAME'/
*      ' FOR THE FILE CONTAINING THE TURN PROHIBITS'/
*      ' FOR UNIT 13. '//)
      READ(13,143,END=144)T1,TA,TB,TC,JUNK2
143  FORMAT(A1,3I5,A64)
144  REWIND 13
150  CONTINUE
C
C      LET'S GET THE TEMPORARY DATA SET NAMES
C
      WRITE(*,152)
152  FORMAT(' ',10X,'THE SECOND STEP WILL BE TO DEFINE FOUR'/
*      ' ',10X,'TEMPORARY DATA SET NAMES....'/
*      ' ',10X,'WARNING!!! THESE TEMPORARY DATA SETS MAY BE'/
*      ' ',10X,' DESTROYED BY THE PROGRAM'//)
      WRITE(*,154)
154  FORMAT(' ',10X,'THE TEMPORARY DATA SETS NEEDED WILL BE: '/
*      ' ',15X,'A TEMPORARY LINK DATA FILE'/
*      ' ',15X,'A TEMPORARY NODE COORDINATE FILE'/
*      ' ',15X,'A TEMPORARY TURN PROHIBITS FILE'/
*      ' ',15X,'A TEMPORARY PRINT FILE'//)
      WRITE(*,114)
      READ(*,115)IANS
155  WRITE(*,156)
156  FORMAT(' ',10X,'IF YOU DO NOT WISH TO DEFINE THESE '/
*      ' ',10X,'WITHOUT CHECKING YOUR DIRECTORY TO AVOID, '/

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*   ' ,10X,'NAMING AN EXISTING DATA SET, '/
*   ' ,10X,'IT IS SUGGESTED THAT YOU STOP THE PROGRAM NOW!!!' /
*   ' ,15X,'ENTER "1" IF YOU WISH TO PROCEED, '/
*   ' ,15X,'---OR---' /
*   ' ,15X,'ENTER "2"
*           IF YOU WISH TO STOP THE PROGRAM NOW! ' //)
IANS=2
READ(*,120)IANS
IF(IANS.EQ.2)STOP
IF(IANS.NE.1)GO TO 155
C
C   NEXT GET THE NAME OF THE TEMP LINK DATA FILE (UNIT 21)
C
161 WRITE(*,162)
162 FORMAT(' NEXT, YOU WILL BE ASKED TO NAME' /
*   ' A TEMPORARY LINK DATA FILE ' /
*   ' (SUGGESTED NAME: "LNKDATA.TMP")' /
*   ' FOR UNIT 21.' //)
WRITE(21,125)(CRD(J),J=1,25)
REWIND 21
C
C   NEXT GET THE NAME OF THE TEMP NODE COORD FILE (UNIT 22)
C
171 WRITE(*,172)
172 FORMAT(' NEXT, YOU WILL BE ASKED TO NAME' /
*   ' A TEMPORARY NODE COORDINATE FILE ' /
*   ' (SUGGESTED NAME: "NCOORD.TMP")' /
*   ' FOR UNIT 22.' //)
WRITE(22,173)C1,CX,CY
173 FORMAT('N',15,2111,52(' '))
REWIND 22
C
C   NEXT GET THE NAME OF THE TEMP TURN PROHIB FILE (UNIT 23)
C
181 WRITE(*,182)
182 FORMAT(' NEXT, YOU WILL BE ASKED TO NAME' /
*   ' A TEMPORARY TURN PROHIBIT FILE ' /
*   ' (SUGGESTED NAME: "PROTRN.TMP")' /
*   ' FOR UNIT 23.' //)
C
TABC=1
WRITE(23,183)TABC,TABC,TABC
183 FORMAT('T',315,64(' '))
REWIND 23
C
C   NEXT GET THE NAME OF THE TEMP OUTPUT PRINT FILE (UNIT 24)
C
191 WRITE(*,192)
192 FORMAT(' NEXT, YOU WILL BE ASKED TO NAME' /
*   ' A TEMPORARY PRINT FILE ' /
*   ' (SUGGESTED NAME: "OUTPRN.TMP")' /
*   ' FOR UNIT 24.' //)
WRITE(24,193)
193 FORMAT('1',80(' '))
REWIND 24
195 CONTINUE
WRITE(*,196)
196 FORMAT(' ',5X,'WE HAVE NOW COMPLETED SPECIFYING THE DATA SETS' /
*   ' ',5X,'DATA SETS TO BE USED....' /
*   ' ',5X,'ARE YOU READY TO START THE NETWORK CHANGES?' /
*   ' ',15X,'ENTER "1" IF YOU WISH TO PROCEED, '/
*   ' ',15X,'---OR---' /
*   ' ',15X,'ENTER "2"
*           IF YOU WISH TO STOP THE PROGRAM NOW! ' //)
IANS=2
READ(*,120)IANS
IF(IANS.EQ.2)STOP
IF(IANS.NE.1)GO TO 195
C

```

```

C =====
C
C          SCAN FOR MAX NODE NUMBER
C
C =====
C
200 CONTINUE
    MAXND=0
    NUMLD=0
    DO 210 I=1,256000
    READ(11,205,END=215)(CRD(J),J=1,25)
205 FORMAT(2I5,11,I4,A1,2I4,4I2,2I6,
*      A1,2I4,4I2,2I6,11,I5,Z1)
    NUMLD=NUMLD+1
    IF((CRD(1).EQ.0).OR.(CRD(2).EQ.0))GO TO 215
    IF(CRD(1).GT.MAXND)MAXND=CRD(1)
    IF(CRD(2).GT.MAXND)MAXND=CRD(2)
210 CONTINUE
215 CONTINUE
    WRITE(24,217)NUMLD,MAXND
217 FORMAT('1',17,' LINK DATA CARDS SCANNED'/
*      ' MAX NODE NUMBER FOUND IS:',17//)
    NEWND=MAXND
    WRITE(*,217)NUMLD,MAXND
    REWIND 11
    GO TO 300

C =====
C
C          READY TO DETAIL CODE AN INTERSECTION
C
C =====
C
300 CONTINUE
    WRITE(*,301)
301 FORMAT('1      ')
310 WRITE(*,311)
311 FORMAT(' ',5X,'PLEASE ENTER THE NODE NUMBER FOR'/
*      ' ',5X,'THE INTERSECTION TO BE CODED IN DETAIL')
    WRITE(24,311)
    READ(*,312)INTND
312 FORMAT(I5)
    IF((INTND.LT.1).OR.(INTND.GT.MAXND))
*      WRITE(*,313)INTND
313 FORMAT(' ',5X,I5,' IS NOT A VALID NODE NUMBER!!')
    IF((INTND.LT.1).OR.(INTND.GT.MAXND))
*      WRITE(24,313)INTND
    IF((INTND.LT.1).OR.(INTND.GT.MAXND))
*      GO TO 310
316 WRITE(*,317)INTND
317 FORMAT(' ',5X,'IS',I6,' THE CORRECT INTERSECTION NODE?'/
*      ' ',15X,'ENTER "1" IF IT IS THE CORRECT NODE NUMBER, '/
*      ' ',15X,'---OR---'/
*      ' ',15X,'ENTER "2"')
*      IF YOU WISH TO RE-ENTER THE NODE NUMBER'//)
    WRITE(24,317)INTND
    IANS=3
    READ(*,318)IANS
318 FORMAT(I1)
    WRITE(*,319)IANS
319 FORMAT(' ANSWER READ: ',I1)
    WRITE(24,319)IANS
    IF(IANS.EQ.1)GO TO 330
    IF(IANS.EQ.2)GO TO 310
    GO TO 316

C
330 CONTINUE
    WRITE(*,332)INTND
332 FORMAT(' ',5X,'OK...NEXT I WILL SCAN TO FIND ALL LINKS'/

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*      ' ',5X,'CONNECTED TO NODE',16)
WRITE(24,332)INTND
REWIND 11
REWIND 21
NUMLGS=0
DO 350 I=1,999999
READ(11,205,END=355)(CRD(J),J=1,25)
IF(CRD(1).EQ.0)GO TO 355
IF((CRD(1).EQ.INTND).OR.(CRD(2).EQ.INTND)) GO TO 345
WRITE(21,205)(CRD(J),J=1,25)
GO TO 350
345 CONTINUE
      NUMLGS=NUMLGS+1
      WRITE(*,346)CRD(1),CRD(2)
346  FORMAT(' ',5X,'LINK',16,' TO',16,' FOUND')
      WRITE(24,346)CRD(1),CRD(2)
      IF(NUMLGS.GT.4)GO TO 350
      DO 347 J=1,25
          OLD(NUMLGS,J)=CRD(J)
347  CONTINUE
350 CONTINUE
355 CONTINUE
REWIND 11
IF(NUMLGS.LT.3) WRITE(*,358)INTND,NUMLGS
358 FORMAT(' ',5X,'TOO FEW LINKS FOUND FOR ',16,
*      ' (ONLY',12,' LINKS FOUND)')//
      IF(NUMLGS.LT.3) WRITE(24,358)NUMLGS
      IF(NUMLGS.LT.3)GO TO 300
      IF(NUMLGS.GT.4) WRITE(*,359)INTND,NUMLGS
359 FORMAT(' ',5X,'TOO MANY LINKS FOUND FOR ',16,
*      ' (',12,' LINKS FOUND)')//
      IF(NUMLGS.GT.4) WRITE(24,359)INTND,NUMLGS
      IF(NUMLGS.GT.4) GO TO 300
360 CONTINUE
361 WRITE(*,362)
362 FORMAT(' ',5X,'BEFORE PROCEEDING, PLEASE VERIFY ONCE MORE...')
WRITE(*,317)INTND
317 FORMAT(' ',5X,'IS',16,' THE CORRECT INTERSECTION NODE?')
C *      ' ',15X,'ENTER "1" IF IT IS THE CORRECT NODE NUMBER, '/
C *      ' ',15X,'---OR---'/
C *      ' ',15X,'ENTER "2"
C *      IF YOU WISH TO RE-ENTER THE NODE NUMBER'//)
      IANS=3
      READ(*,318)IANS
      WRITE(*,319)IANS
      WRITE(24,319)IANS
      IF(IANS.EQ.1)GO TO 370
      IF(IANS.EQ.2)GO TO 300
      GO TO 361
370 CONTINUE
      IF(NUMLGS.EQ.4)GO TO 400
C      IF(NUMLGS.EQ.3)GO TO 800
      WRITE(*,371)NUMLGS
      WRITE(24,371)NUMLGS
371 FORMAT(' CANNOT HANDLE ',12,' LEGGED INTERSECTION'//)
      GO TO 300

C
C
C
C
C      RECODE 4-LEG INTERSECTION
C
C
C
C
C
C
400 CONTINUE
DO 402 I=1,4
IF(OLD(I,1).NE.INTND)OLD(I,26)=OLD(I,1)
IF(OLD(I,2).NE.INTND)OLD(I,26)=OLD(I,2)

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402 CONTINUE
   INTX=-999
   INTY=-999
   DO 403 I=1,4
     OLD(I,29)=-999
     OLD(I,30)=-999
403 CONTINUE
   WRITE(*,405)
   WRITE(24,405)
405 FORMAT(' ',5X,'PROCEEDING TO FIND COORDINATES'//)
407 READ(12,408,END=412)CLET,C1,CX,CY,JUNK1
408 FORMAT(A1,15,2I11,A52)
     IF(C1.EQ.0)GO TO 412
     WRITE(22,408)CLET,C1,CX,CY,JUNK1
     IF(C1.NE.INTND) GO TO 410
     INTX=CX
     INTY=CY
410 DO 411 I=1,4
     IF(C1.NE.OLD(I,26))GO TO 411
     OLD(I,29)=CX
     OLD(I,30)=CY
411 CONTINUE
   GO TO 407
412 CONTINUE
   IERR=0
   IF(INTX.LT.0)IERR=IERR+1
   IF(INTY.LT.0)IERR=IERR+1
   DO 4121 I=1,NUMLGS
     IF(OLD(I,29).LT.0)IERR=IERR+1
     IF(OLD(I,30).LT.0)IERR=IERR+1
4121 CONTINUE
   REWIND 12
C   REWIND 22
   WRITE(*,4123)INTND,INTX,INTY
   WRITE(24,4123)INTND,INTX,INTY
4123 FORMAT(' NODE=',I6,' X=',I11,' Y=',I11)
   DO 4125 I=1,NUMLGS
     WRITE(*,4123)OLD(I,26),OLD(I,29),OLD(I,30)
     WRITE(24,4123)OLD(I,26),OLD(I,29),OLD(I,30)
4125 CONTINUE
     IF(IERR.GT.0)WRITE(*,4127)
     IF(IERR.GT.0)WRITE(24,4127)
4127 FORMAT(' ***ERROR IN COORDINATES-TRY DIFFERENT NODE')
     IF(IERR.GT.0)GO TO 300
415 CALL ANADIR(OLD,NUMLGS,INTND)
     OLD(1,27)=1
     DO 425 I=1,2
       II=5-I
421   WRITE(*,422)OLD(1,26),INTND,OLD(II,26)
422   FORMAT(' ',5X,'IS THE MOVEMENT:/'
*     ' ',10X,'FROM ',I6,' THRU',I6,' TO',I6/
*     ' ',15X,'1 A LEFT TURN MOVEMENT?'/
*     ' ',15X,'2 A THROUGH MOVEMENT? OR'/
*     ' ',15X,'3 A RIGHT TURN MOVEMENT? '/
*     ' ',10X,'PLEASE ENTER EITHER "1" OR "2" OR "3"')
     READ(*,318)IANS
     WRITE(*,319)IANS
     WRITE(24,319)IANS
     IF(IANS.LT.1) GO TO 421
     IF(IANS.GT.3) GO TO 421
     IF(IANS.EQ.1)OLD(II,27)=4
     IF(IANS.EQ.2)OLD(II,27)=3
     IF(IANS.EQ.3)OLD(II,27)=2
425 CONTINUE
*   IF((OLD(3,27).NE.4).AND.(OLD(4,27).NE.4))
*     OLD(2,27)=4
*   IF((OLD(3,27).NE.3).AND.(OLD(4,27).NE.3))
*     OLD(2,27)=3
*   IF((OLD(3,27).NE.2).AND.(OLD(4,27).NE.2))

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*          OLD(2,27)=2
C
C          NOW SORT THEM BY LEG NUMBER
C
DO 475 I=1,NUMLGS
IXCHG=0
DO 450 J=1,NUMLGS-1
JP1=J+1
IF(OLD(J,27).LT.OLD(JP1,27))GO TO 450
DO 445 K=1,30
ITEMP=OLD(J,K)
OLD(J,K)=OLD(JP1,K)
OLD(JP1,K)=ITEMP
IXCHG=IXCHG+1
445 CONTINUE
450 CONTINUE
IF(IXCHG.EQ.0)GO TO 476
475 CONTINUE
476 CONTINUE
C
C          CHECK THE LEG NUMBERS
C
480 CONTINUE
WRITE(*,481)
481 FORMAT(' ',5X,'THE FOLLOW ARE THE LINKS BY LEG NUMBER, '/
* ' ',5X,'THEY SHOULD BE IN A COUNTER-CLOCKWISE ORDER: '/')
WRITE(24,481)
C
DO 485 J=1,NUMLGS
WRITE(*,483)OLD(J,27),OLD(J,1),OLD(J,2)
483 FORMAT(' ',10X,'LEG',12,' LINK',216)
WRITE(24,483)OLD(J,27),OLD(J,1),OLD(J,2)
485 CONTINUE
C
IF(OLD(1,27).GE.OLD(2,27))GO TO 488
IF(OLD(2,27).GE.OLD(3,27))GO TO 488
IF(OLD(3,27).GE.OLD(4,27))GO TO 488
GO TO 490
488 CONTINUE
WRITE(*,489)

WRITE(24,489)
489 FORMAT(' ',2X,'****ERROR DETECTED IN LEG NUMBERING'/
* ' ',6X,'RETURNING TO MOVEMENT DEFINITIONS'/
* ' ',6X,'TO ATTEMPT TO RESOLVE THE DIFFICULTY')
GO TO 415
490 CONTINUE
WRITE(*,492)
WRITE(24,492)
492 FORMAT(' ',5X,'BEFORE PROCEEDING, IT IS IMPORTANT'/
* ' ',5X,'TO VERIFY THAT THE LINKS COMPRISING'/
* ' ',5X,'THE LEGS OF THE INTERSECTION ARE IN'/
* ' ',5X,'COUNTER-CLOCKWISE ORDER. '/
* ' ',5X,'PLEASE CHECK THIS VERY CAREFULLY!!!/')
493 WRITE(*,494)
WRITE(24,494)
494 FORMAT(' ',10X,'ENTER "1" IF THEY ARE IN CORRECT ORDER; '/
* ' ',10X,'--OR-- '/
* ' ',10X,'ENTER "2" IF THEY ARE NOT IN CORRECT ORDER '/')
READ(*,318)IANS
WRITE(*,319)IANS
WRITE(24,319)IANS
IF(IANS.EQ.2)GO TO 496
IF(IANS.EQ.1)GO TO 500
GO TO 493
496 CONTINUE
WRITE(*,497)
497 FORMAT(' ',2X,'****USER DETECTED ERROR IN LINK ORDER, '/
* ' ',6X,'RETURNING TO MOVEMENT DEFINITIONS'/

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*      ',6X,'TO ATTEMPT TO RESOLVE THE DIFFICULTY')
WRITE(24,497)
GO TO 415
C
C =====
C      PROCEEDING WITH LINK SPLITTING
C =====
C
500 CONTINUE
WRITE(*,513)
WRITE(24,513)
513 FORMAT(' ',5X,'PROCEEDING WITH LINK SPLITTING'///)
DO 540 I=1,NUMLGS
DO 520 J=1,30
MOD(I,J)=OLD(I,J)
NEW(I,2,J)=OLD(I,J)
520 CONTINUE
C
C      NEXT PUT IN THE NEW NODE NUMBER
C
NEWND=NEWND+1
IF(MOD(I,1).EQ.INTND)MOD(I,1)=NEWND
IF(MOD(I,2).EQ.INTND)MOD(I,2)=NEWND
IF(NEW(I,2,1).NE.INTND)NEW(I,2,1)=NEWND
IF(NEW(I,2,2).NE.INTND)NEW(I,2,2)=NEWND
NEW(I,2,26) = NEWND
C
C      NEXT HANDLE DISTANCES
C
NEW(I,2,4)=3
MOD(I,4)=OLD(I,4)-3
IF(MOD(I,4).LT.0)MOD(I,4)=0
C
C      COMPUTE COORDINATES FOR NEW NODE
C
IF(MOD(I,4).EQ.0)GO TO 524
ZDST1=MOD(I,4)
ZDST2=OLD(I,4)
ZPCT=0.0
IF(ZDST2.GT.0.5)ZPCT=ZDST1/ZDST2
XDP=INTX-MOD(I,29)
XDP=XDP*ZPCT
XDP2=MOD(I,29)
XDP=XDP+XDP2
MOD(I,29)=XDP
YDP=INTY-MOD(I,30)
YDP=YDP*ZPCT
YDP2=MOD(I,30)
YDP=YDP+YDP2
MOD(I,30)=YDP
524 WRITE(22,525)NEWND,MOD(I,29),MOD(I,30)
525 FORMAT('N',15,2I11,52(' '))
C
C      OUTPUT THE NEW NODE'S X-,Y-COORINATE ON THE SCREEN
C
WRITE(*,526)NEWND,MOD(I,29),MOD(I,30)
WRITE(24,526)NEWND,MOD(I,29),MOD(I,30)
526 FORMAT(' NEW NODE=',16,' X=',111,' Y=',111)
C
C      ASSIGN INITIAL VALUES FOR NEW LEG AND THRU-TURN LINKS
C      (DISTANCE, LEG NUMBER, AND TRAVEL TIME)
C
NEW(I,2,4)=0
MOD(I,4)=OLD(I,4)
MOD(I,8)=1
NEW(I,2,6)=0
NEW(I,2,7)=0
540 CONTINUE

```

```

C
C      INSERT INTERSECTION NODE AND MOVEMENT NUMBER
C      IN FIELDS 24 AND 25 OF THE NEW CARDS
C
DO 545 I=1,4
  DO 544 J=1,3
    NEW(I,J,24)=INTND
    NEW(I,J,25)=((I-1)*3)+J
544  CONTINUE
545  CONTINUE
C
C      NOW BUILD THE LEFT TURN LINKS
C
DO 555 I=1,4
  II=I-1
  IF(II.LT.1)II=4
  NEW(I,1,1)=NEW(I,2,26)
  NEW(I,1,2)=NEW(II,2,26)
  NEW(I,1,3)=9
  NEW(I,1,4)=0
  NEW(I,1,5)=NEW(I,2,5)
  NEW(I,1,6)=0
  NEW(I,1,7)=0
  NEW(I,1,8)=I
  NEW(I,1,9)=NEW(I,2,9)
  NEW(I,1,10)=NEW(I,2,10)
  NEW(I,1,11)=NEW(I,2,11)
  NEW(I,1,12)=0
  NEW(I,1,13)=0
  NEW(I,1,14)=LIT1
  DO 552 K=15,22
    NEW(I,1,K)=0
552  CONTINUE
  NEW(I,1,23)=0
C
C      FLAG IMPOSSIBLE LEFT TURN LINKS
C      DUE TO 1 WAY STREETS
C      WITH ANODE = 99999
C
  IF(NEW(I,2,28).EQ.3)NEW(I,1,1)=99999
  IF(NEW(II,2,28).EQ.1)NEW(I,1,1)=99999
555  CONTINUE
C
C      NOW BUILD THE RIGHT TURN LINKS
C
DO 3555 I=1,4
  II=I+1
  IF(II.GT.4)II=1
  NEW(I,3,1)=NEW(I,2,26)
  NEW(I,3,2)=NEW(II,2,26)
  NEW(I,3,3)=9
  NEW(I,3,4)=0
  NEW(I,3,5)=NEW(I,2,5)
  NEW(I,3,6)=0
  NEW(I,3,7)=0
  NEW(I,3,8)=I
  NEW(I,3,9)=NEW(I,2,9)
  NEW(I,3,10)=NEW(I,2,10)
  NEW(I,3,11)=NEW(I,2,11)
  NEW(I,3,12)=0
  NEW(I,3,13)=0
  NEW(I,3,14)=LIT1
  DO 3552 K=15,22
    NEW(I,3,K)=0
3552  CONTINUE
  NEW(I,3,23)=0
C
C      FLAG IMPOSSIBLE LEFT TURN LINKS
C      DUE TO 1 WAY STREETS

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```

C          WITH ANODE = 99999
C
C          IF(NEW( I,2,28).EQ.3)NEW(I,3,1)=99999
C          IF(NEW(II,2,28).EQ.1)NEW(I,3,1)=99999
3555 CONTINUE
C
C          NOW BUILD THE THRU MOVEMENT LINKS
C
C          DO 2555 I=1,4
C          II=I-2
C          IF(II.LT.1) II=II+4
C          NEW(I,2,1)=NEW(I,2,26)
C          NEW(I,2,2)=NEW(II,2,26)
C          NEW(I,2,3)=9
C          NEW(I,2,4)=0
C          NEW(I,2,5)=NEW(I,2,5)
C          NEW(I,2,6)=0
C          NEW(I,2,7)=0
C          NEW(I,2,8)=I
C          NEW(I,2,9)=NEW(I,2,9)
C          NEW(I,2,10)=NEW(I,2,10)
C          NEW(I,2,11)=NEW(I,2,11)
C          NEW(I,2,12)=0
C          NEW(I,2,13)=0
C          NEW(I,2,14)=LIT1
C          DO 2552 K=15,22
C          NEW(I,2,K)=0
2552 CONTINUE
C          NEW(I,3,23)=0
C
C          FLAG IMPOSSIBLE LEFT TURN LINKS
C          DUE TO 1 WAY STREETS
C          WITH ANODE = 99999
C
C          IF(NEW( I,2,28).EQ.3)NEW(I,3,1)=99999
C          IF(NEW(II,2,28).EQ.1)NEW(I,3,1)=99999
2555 CONTINUE
C
C          OUTPUT THE LINK SPLITTING INFORMATION ON THE SCREEN
C
C          DO 5000 I=1,NUMLGS
C          WRITE(*,527) I,(OLD(I,JJ),JJ=1,6)
C          WRITE(24,527) I,(OLD(I,JJ),JJ=1,6)
527 FORMAT(' ',2X,'LEG NUMBER: ',I2,/,
+         ' ',5X,'OLD LINK: ',2I6,I2,I5,1X,A1,I5)
C          WRITE(*,528)(MOD(I,JJ),JJ=1,6)
C          WRITE(24,528)(MOD(I,JJ),JJ=1,6)
528 FORMAT(' ',5X,'NEW LEG LINK:',2I6,I2,I5,1X,A1,I5)
C          WRITE(*,5291)(NEW(I,1,JJ),JJ=1,6)
C          WRITE(24,5291)(NEW(I,1,JJ),JJ=1,6)
5291 FORMAT(' ',5X,'NEW LEFT-TURN LINK: ',2I6,I2,I5,1X,A1,I5)
C
C          WRITE(*,5292)(NEW(I,2,JJ),JJ=1,6)
C          WRITE(24,5292)(NEW(I,2,JJ),JJ=1,6)
5292 FORMAT(' ',5X,'NEW THRU-TURN LINK: ',2I6,I2,I5,1X,A1,I5)
C
C          WRITE(*,5293)(NEW(I,3,JJ),JJ=1,6)
C          WRITE(24,5293)(NEW(I,3,JJ),JJ=1,6)
5293 FORMAT(' ',5X,'NEW RIGHT-TURN LINK:',2I6,I2,I5,1X,A1,I5,/)
C
C          ASK THE INFORMATION ABOUT NUMBER OF LANES
C          FOR EACH MOVEMENT
C
C          IANS1=0
C          IANS2=0
C          IANS3=0
5200 WRITE(*,5295) I
5295 FORMAT(3X,'HERE, YOU WILL BE ASKED THE NUMBER OF LANES',/
+         3X,'OF EACH TURNING MOVEMENT FOR APPROACH LEG',I2,'.',/,/

```

```

+      5X,'PLEASE NOTE THE NUMBER SHOULD BE LESS THAN 9.'//
+      5X,'ENTER "0" IF IT IS A SHARED MOVEMENT.'//
+      5X,'ENTER "9" IF IT DOES NOT EXIT AT ALL.'//
+      3X,'OK. HOW MANY LANES FOR THE LEFT-TURN MOVEMENT ?'//
5300 READ(*,5301)IANS1
5301 FORMAT(I1)
      WRITE(*,5303)
5303 FORMAT(3X,'HOW MANY LANES FOR THE THRU MOVEMENT ?'//)
5304 READ(*,5301)IANS2
      WRITE(*,5305)
5305 FORMAT(3X,'HOW MANY LANES FOR THE RIGHT-TURN MOVEMENT ?'//)
5306 READ(*,5301)IANS3
5307 WRITE(*,5308) IANS1,IANS2,IANS3
5308 FORMAT(5X,'THE NUMBER OF LEFT-TURN, THRU, AND RIGHT-TURN LANES'/
+      5X,'ARE : ',I2,', ',I2,', ',I2,', AND ',I2,', '.,'//
+      5X,'ARE THEM THE RIGHT NUMBERS ?'//
+      5X,'ENTER "1", IF THEY ARE.'//
+      5X,'ENTER "2", IF THEY ARE NOT'//
+      5X,' AND WE WILL REPEAT THE PROCESS.'//)
      IANS=2
      READ(*,5301)IANS
      IF (IANS.EQ.1) GOTO 5310
      IF (IANS.EQ.2) GOTO 5200
      IF ((IANS.NE.1).AND.(IANS.NE.2)) GOTO 5307
5310   NEW(1,1,23)=IANS1
      NEW(1,2,23)=IANS2
      NEW(1,3,23)=IANS3
      WRITE(24,5311) (NEW(I,J,23),J=1,3)
5311   FORMAT(5X,'THE NUMBER OF LEFT-TURN LANES = ',I2,/,
+      5X,'THE NUMBER OF THROUGH LANES = ',I2,/,
+      5X,'THE NUMBER OF RIGHT-TURN LANES = ',I2,//)
5000 CONTINUE
C
C      NOW OUTPUT THE NEW LEG LINKS AND MOVEMENT LINKS
C
      DO 580 I=1,NUMLGS
      WRITE(21,125)(MOD(I,K),K=1,25)
580 CONTINUE
      DO 585 I=1,NUMLGS
      DO 590 II=1,3
      WRITE(21,125)(NEW(I,II,K),K=1,25)
590 CONTINUE
585 CONTINUE
      REWIND 21
C
C      NOW OUTPUT TURN PROHIBITS AS APPROPRIATE
C
600 CONTINUE
      DO 620 I=1,4
      IL=I-1
      IF(IL.LT.1) IL=IL+4
      ITH=I-2
      IF(ITH.LT.1) ITH=ITH+4
      IR=I+1
      IF(IR.GT.4) IR=IR-4
      IF(NEW(I,1,1).EQ.99999)GO TO 610
      WRITE(23,607)NEW(I,2,26),NEW(IL,2,26),NEW(ITH,2,26),INTND
      WRITE(23,607)NEW(I,2,26),NEW(IL,2,26),NEW(IR,2,26),INTND
      WRITE(23,607)NEW(I,2,26),NEW(ITH,2,26),NEW(IL,2,26),INTND
      WRITE(23,607)NEW(I,2,26),NEW(ITH,2,26),NEW(IR,2,26),INTND
      WRITE(23,607)NEW(I,2,26),NEW(IR,2,26),NEW(IL,2,26),INTND
      WRITE(23,607)NEW(I,2,26),NEW(IR,2,26),NEW(ITH,2,26),INTND
607   FORMAT('T',315,10X,'INT= ',I5,44(' '))
610 CONTINUE
      IF(NEW(I,1,1).EQ.99999)GO TO 615
      IF(NEW(II,1,1).EQ.99999)GO TO 615
      IF(NEW(III,1,1).EQ.99999)GO TO 615
615 CONTINUE
620 CONTINUE

```

```

C
C   NOW COPY THE REST OF THE TURN PROHIBITS TO UNIT 23
C
625 CONTINUE
627 READ(13,143,END=635)T1,TA,TB,TC,JUNK2
C 143 FORMAT(A1,3I5,A64)
    WRITE(23,143)T1,TA,TB,TC,JUNK2
    IF(TA.EQ.0)GO TO 635
    GO TO 627
635 CONTINUE
C
C   NOW COPY UNIT 23 BACK TO 13
C
    REWIND 13
    REWIND 23
637 READ(23,143,END=645)T1,TA,TB,TC,JUNK2
    WRITE(13,143)T1,TA,TB,TC,JUNK2
    IF(TA.EQ.0)GO TO 645
    GO TO 637
645 CONTINUE
    REWIND 13
    REWIND 23

C
C   NOW COPY UNIT 21 BACK TO 11
C
    REWIND 11
    REWIND 21
655 READ(21,125,END=659)(CRD(J),J=1,25)
    WRITE(11,125)(CRD(J),J=1,25)
    GO TO 655
659 CONTINUE
    REWIND 11
    REWIND 21

C
C   NOW COPY UNIT 22 BACK TO 12
C
    REWIND 12
    REWIND 22
660 READ(22,133,END=669)CLET,C1,CX,CY,JUNK1
    WRITE(12,133)CLET,C1,CX,CY,JUNK1
    GO TO 660
669 CONTINUE
    REWIND 12
    REWIND 22

C
    WRITE(*,680)INTND
    WRITE(24,680)INTND
680 FORMAT(' FINISHED PROCESSING FOR INTERSECTION NODE',I6//)
681 WRITE(*,682)
682 FORMAT(' ',10X,' '/
*   ' ',15X,'ENTER "1" IF YOU WISH TO PROCEED, '/
*   ' ',15X,'---OR---'/
*   ' ',15X,'ENTER "2" IF YOU WISH TO STOP THE PROGRAM NOW! '/')
    IANS=2
    READ(*,683)IANS
683 FORMAT(I1)
    WRITE(*,684)IANS
    WRITE(24,684)IANS
684 FORMAT(' ANSWER RECEIVED: ',I1)
    IF(IANS.EQ.2)STOP
    IF(IANS.NE.1) GO TO 681
    GO TO 300
    END
    SUBROUTINE ANADIR(OLD,NUMLGS,INTND)
C   CALL ANADIR(OLD,NUMLGS,INTND)
    INTEGER OLD(8,30)
    INTEGER ALPHNUM(2),LONE,LTWO
    DATA LONE /'1'/

```

```

DATA LTWO /'2'/
ALPHNUM(1)=LONE
ALPHNUM(2)=LTWO
C
C     SUBROUTINE TO INSERT DIRECTION CODE
C     IN COLUMN 28 AND TO SORT BY
C     DIRECTION CODES
C     CODES:
C         1 = ONE-WAY INBOUND TOWARD INTERSECTION
C         2 = TWO WAY
C         3 = ONE-WAY OUTBOUND AWAY FROM INTERSECTION
C         4 = UNDEFINED
C
DO 100 I=1,4
OLD(I,28)=4
100 CONTINUE
C
DO 500 I=1,NUMLGS
IF(OLD(I,14).EQ.ALPHNUM(1)) GO TO 200
C     IF COL 45 IS NOT A 1, WE WILL
C     ASSUME IT IS A TWO WAY LINK
C
OLD(I,28)=2
GO TO 500
C
200 CONTINUE
C
C     THIS IS A ONE-WAY LINK
C     IS IT IN-BOUND
C     OR OUT-BOUND FROM INTERSECTION?
C
IF(OLD(I,1).EQ.INTND) OLD(I,28)=3
IF(OLD(I,2).EQ.INTND) OLD(I,28)=1
GO TO 500
500 CONTINUE
C
C     NOW SORT THEM BY CODES
C
DO 700 I=1,NUMLGS
IXCHG=0
DO 600 J=1,NUMLGS-1
JP1=J+1
IF(OLD(J,28).LT.OLD(JP1,28))GO TO 600
DO 525 K=1,30
ITEMP=OLD(J,K)
OLD(J,K)=OLD(JP1,K)
OLD(JP1,K)=ITEMP
IXCHG=IXCHG+1
525 CONTINUE
600 CONTINUE
IF(IXCHG.EQ.0)GO TO 701
700 CONTINUE
701 CONTINUE
RETURN
END

```


APPENDIX B

**NODAL IMPEDANCE ADJUSTMENT SUBROUTINE:
NODIMP (NODIMP.FOR)**

```

C
C
PROGRAM NODINP
C
C
* This program performs two major tasks:
* 1. To read nodal inventory data and assigned turn volumes
*   from load history file.
* 2. To compute nodal impedances for selected nodes.
* Parameter specifications:
* 1. SFLOW: Saturation Flow Rate
* 2. LOSTM: Lost Time Per Cycle
* 3. LOOPCT(20): Loading Percentage for Each Iteration
C
C
REAL SFLOW,LOSTM
PARAMETER (SFLOW=1800.0)
PARAMETER (LOSTM=16.0)
INTEGER CRD(106),TRN(12,25),VOLAB(12,20)
REAL LOOPCT(20),TOTLOD(20),LOADAB,VBAR
INTEGER LN(12)
REAL VA(12),V(12)
REAL PCE1,PCE4,PCE7,PCE10
REAL CV,CYCLE
REAL INTCAP,CAP(12),INTVC
REAL GVC(12),X(12),D(12)
INTEGER DH(12),ICAP(12)
CHARACTER*1 TURN(12)
INTEGER CLET,C1,CX,CY
CHARACTER*52 JUNK1
INTEGER T1,TA,TB,TC
CHARACTER*64 JUNK2
OPEN(11,FILE='LOD.HST')
OPEN(51,FILE='NOD.DAT')
OPEN(52,FILE='PROH.DAT')
OPEN(61,FILE='LNK.TMP',STATUS='NEW')
OPEN(62,FILE='TRN.TMP',STATUS='NEW')
OPEN(63,FILE='TRNNEW.TMP',STATUS='NEW')
OPEN(71,FILE='PERF.INF',STATUS='NEW')
OPEN(21,FILE='NET.DAT',STATUS='NEW')
*****
* TASK 0 *
*****
*
* DIVIDE THE LINK HISTORY FILE (FROM LNKHIST PROGRAM) INTO TWO FILES:
* (1) LINK DATA HISTORY FILE INCLUDING CENTROID CONNECTORS AND LINKS
* (2) MOVEMENT DATA HISTORY FILE INCLUDING MOVEMENTS AT INTERSECTIONS
*
NUMLNK=0
NUMTRN=0
DO 120 I=1,25600
READ(11,110,END=130)(CRD(J),J=1,106)
110 FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,2I6,I1,I5,Z1,
+       I3,40(I7,I5))
IF (CRD(25).GT.0) THEN
WRITE(62,110) (CRD(J),J=1,106)
NUMTRN=NUMTRN+1
ELSE
WRITE(61,111) (CRD(J),J=1,25)
111 FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,2I6,I1,I5,Z1)
NUMLNK=NUMLNK+1
END IF
120 CONTINUE
130 WRITE(*,131)NUMLNK,NUMTRN
131 FORMAT(1X,'PROCEED DIVIDING THE LINK LOADING HISTORY FILE'/
+       1X,'THE NUBER OF LINK DATA CARDS = ',I6,/
+       1X,'THE NUBER OF TURN DATA CARDS = ',I6,/)
REWIND 61
REWIND 62

```

```

*****
* Initialization *
*****
C
C 1. Load Percentage for Each Iteration
C
      LODPCT(1)=0.10
      LODPCT(2)=0.10
      LODPCT(3)=0.10
      LODPCT(4)=0.10
      LODPCT(5)=0.10
      LODPCT(6)=0.10
      LODPCT(7)=0.10
      LODPCT(8)=0.10
      LODPCT(9)=0.10
      LODPCT(10)=0.10
      LODPCT(11)=0.0
      LODPCT(12)=0.0
      LODPCT(13)=0.0
      LODPCT(14)=0.0
      LODPCT(15)=0.0
      LODPCT(16)=0.0
      LODPCT(17)=0.0
      LODPCT(18)=0.0
      LODPCT(19)=0.0
      LODPCT(20)=0.0
      TOTLOD(1)=LODPCT(1)
      DO 30 I=2,20
      TOTLOD(I) = TOTLOD(I-1)+LODPCT(I)
30  CONTINUE
      WRITE(*,35)(TOTLOD(I),I=1,20)
35  FORMAT(1X,'THE ACCUMULATED LODING PERCENTAGES BY ITERATION ARE:/'
+        1X, 10F6.2, /
+        1X, 10F6.2, /)
C
C 2. Write Turning Movement Types for Output Information
C
      DO 50 I=1,10,3
      TURN(I)='L'
50  CONTINUE
      DO 51 I=2,11,3
      TURN(I)='T'
51  CONTINUE
      DO 52 I=3,12,3
      TURN(I)='R'
52  CONTINUE
C
C 3. Write Listing Headers for Output Nodal Performance Information
C
      WRITE(71,53)
53  FORMAT(1X,'LISTING OF NODAL PERFORMANCE INFORMATION'//
+        3X,'A',4X,'B',2X,'L#',3X,'LN',5X,'V',6X,'VA',
+        4X,'CAP',4X,'X',3X,'CV',2X,'INTCAP',1X,'INTVC',2X,
+        'G/(C-L)',2X,'CYCLE',2X,'DELAY',2X,'INTND',/)
*****
* TASK 1 *
*****
*
* Read Number of Lanes and Assigned Turn Volumes
* from the Movement Load History File
*
      N=1
      WRITE(*,10) SFLOW,LOSTM
10  FORMAT(1X,'PROCEED CALCULATION OF NODAL IMPEDANCES:/'
+        1X,'SATURATION FLOW RATE = ',F6.1, /
+        1X,'LOST TIME PER CYCLE = ',F6.1, /)
11  DO 160 I=1,12
      READ(62,140,END=900)(TRN(I,J),J=1,25),NIT,(VOLAB(I,JJ),JJ=1,NIT)

```

```

140  FORMAT(215,11,14,A1,214,412,216,A1,214,412,216,11,15,Z1,
+      13,20(17,17X))
      VBAR=0.0
      DO 150 J=1,NIT
      LODAB=VOLAB(I,J)
      VBAR=VBAR+(LODAB*(LODPCT(J)/TOTLOO(NIT)))
150  CONTINUE
      LN(1)=TRN(1,23)
      VA(I)=VBAR
160  CONTINUE
*****
*  TASK 2  *
*****
* Assigned Lane Volume Analysis *
*****
*
* Passenger Car Equivalent Factor Calculation for NB Approach
*
      IF ((VA(8)+VA(9)) .EQ. 0.) THEN
        PCE1=0.
      ELSE IF ((VA(8)+VA(9)) .LT. 200.) THEN
        PCE1=1.1
      ELSE IF ((VA(8)+VA(9)) .LT. 600.) THEN
        PCE1=2.0
      ELSE IF ((VA(8)+VA(9)) .LT. 800.) THEN
        PCE1=3.0
      ELSE IF ((VA(8)+VA(9)) .LT. 1000.) THEN
        PCE1=4.0
      ELSE
        PCE1=5.0
      END IF
*
* Assigned Lane Volume Analysis for NB Approach
*
      CALL LNVOL(LN(1),LN(2),LN(3),VA(1),VA(2),VA(3),
+              VA(7),PCE1,V(1),V(2),V(3))
*
* Passenger Car Equivalent Factor Calculation for WB Approach
*
      IF ((VA(11)+VA(12)) .EQ. 0.) THEN
        PCE4=0.
      ELSE IF ((VA(11)+VA(12)) .LT. 200.) THEN
        PCE4=1.1
      ELSE IF ((VA(11)+VA(12)) .LT. 600.) THEN
        PCE4=2.0
      ELSE IF ((VA(11)+VA(12)) .LT. 800.) THEN
        PCE4=3.0
      ELSE IF ((VA(11)+VA(12)) .LT. 1000.) THEN
        PCE4=4.0
      ELSE
        PCE4=5.0
      END IF
*
* Assigned Lane Volume Analysis for WB Approach *
*
      CALL LNVOL(LN(4),LN(5),LN(6),VA(4),VA(5),VA(6),
+              VA(10),PCE4,V(4),V(5),V(6))
*
* Passenger Car Equivalent Factor Calculation for SB Approach *
*
      IF ((VA(2)+VA(3)) .EQ. 0.) THEN
        PCE7=0.
      ELSE IF ((VA(2)+VA(3)) .LT. 200.) THEN
        PCE7=1.1
      ELSE IF ((VA(2)+VA(3)) .LT. 600.) THEN
        PCE7=2.0
      ELSE IF ((VA(2)+VA(3)) .LT. 800.) THEN
        PCE7=3.0

```

```

ELSE IF ((VA(2)+VA(3)) .LT. 1000.) THEN
  PCE7=4.0
ELSE
  PCE7=5.0
END IF
*
* Assigned Lane Volume Asnslysis for SB Approach *
*
  CALL LNVOL(LN(7),LN(8),LN(9),VA(7),VA(8),VA(9),
+          VA(1),PCE7,V(7),V(8),V(9))
*
* Passenger Car Equivalent Factor Calaulation for EB Approach
*
  IF ((VA(5)+VA(6)) .EQ. 0.) THEN
    PCE10=0.
  ELSE IF ((VA(5)+VA(6)) .LT. 200.) THEN
    PCE10=1.1
  ELSE IF ((VA(5)+VA(6)) .LT. 600.) THEN
    PCE10=2.0
  ELSE IF ((VA(5)+VA(6)) .LT. 800.) THEN
    PCE10=3.0
  ELSE IF ((VA(5)+VA(6)) .LT. 1000.) THEN
    PCE10=4.0
  ELSE
    PCE10=5.0
  END IF
*
* Assigned Lane Volume Asnslysis for EB Approach
*
  CALL LNVOL(LN(10),LN(11),LN(12),VA(10),VA(11),VA(12),
+          VA(4),PCE10,V(10),V(11),V(12))
*
* Calculates the sum of critical lane volume
*
  CV = 1.0
  CV = MAX(V(1)+V(8),V(2)+V(7))+
+      MAX(V(4)+V(11),V(5)+V(10))
*****
* Estimates the cycle length *
*****
  IF (CV .LT. (SFLOW*(1.0-LOSTM/60.0))) THEN
    CYCLE = 60.0
  ELSE IF (CV .LT. (SFLOW*(1.0-LOSTM/120.0))) THEN
    CYCLE = (SFLOW*LOSTM) / (SFLOW - CV)
  ELSE
    CYCLE = 120.0
  END IF
*****
* Dealing with Zero CV (Sum of Critical Volume) *
*****
  IF (CV.EQ.0.) WRITE(*,1111) TRN(1,24)
1111  FORMAT(1X,'SUM OF CRITICAL VOLUME AT INTERSECTION NODE',I5,
+        ' IS ZERO.'/
+        1X,'THE CALCULATION OF NODAL IMPEDANCE IS SKIPPED.'/
+        1X,'AND GREEN TIME, V/C, & DELAY ARE ASSUMED ZERO.'/)
  IF (CV.EQ.0.) THEN
    DO 1112 I=1,12
      GVC(I)=0.
      X(I)=0.
      CAP(I)=1800.
      D(I)=0.
1112  CONTINUE
      INTCAP=1800.
      INTVC=0.
      GOTO 499
    ELSE
      GOTO 2222
  END IF
2222  CONTINUE

```

```

*****
* Calculates g/C (green time to cycle-length ratio) *
*****
      IF ((V(1)+V(8).GT.0.) .AND. (V(2)+V(7).GT.0.)) THEN
      IF (V(1)+V(8) .GT. V(2)+V(7)) THEN
          GVC(1) = V(1)/CV
          GVC(8) = V(8)/CV
          GVC(2) = (V(2)/(V(2)+V(7))) * (GVC(1)+GVC(8))
          GVC(7) = (V(7)/(V(2)+V(7))) * (GVC(1)+GVC(8))
      ELSE
          GVC(2) = V(2)/CV
          GVC(7) = V(7)/CV
          GVC(1) = (V(1)/(V(1)+V(8))) * (GVC(2)+GVC(7))
          GVC(8) = (V(8)/(V(1)+V(8))) * (GVC(2)+GVC(7))
      END IF
    ELSE IF ((V(1)+V(8).EQ.0.) .AND. (V(2)+V(7).GT.0.)) THEN
      GVC(1) = 0.
      GVC(8) = 0.
      GVC(2) = V(2)/CV
      GVC(7) = V(7)/CV
    ELSE IF ((V(1)+V(8).GT.0.) .AND. (V(2)+V(7).EQ.0.)) THEN
      GVC(1) = V(1)/CV
      GVC(8) = V(8)/CV
      GVC(2) = 0.
      GVC(7) = 0.
    ELSE
      GVC(1) = 0.
      GVC(8) = 0.
      GVC(2) = 0.
      GVC(7) = 0.
    END IF
    IF ((V(4)+V(11).GT.0.) .AND.
+ (V(5)+V(10).GT.0.)) THEN
      IF (V(4)+V(11) .GT. V(5)+V(10)) THEN
          GVC(4) = V(4)/CV
          GVC(11) = V(11)/CV
          GVC(5) = (V(5)/(V(5)+V(10))) * (GVC(4)+GVC(11))
          GVC(10) = (V(10)/(V(5)+V(10))) * (GVC(4)+GVC(11))
      ELSE
          GVC(5) = V(5)/CV
          GVC(10) = V(10)/CV
          GVC(4) = (V(4)/(V(4)+V(11))) * (GVC(5)+GVC(10))
          GVC(11) = (V(11)/(V(4)+V(11))) * (GVC(5)+GVC(10))
      END IF
    ELSE IF ((V(4)+V(11).EQ.0.) .AND.
+ (V(5)+V(10).GT.0.)) THEN
      GVC(4) = 0.
      GVC(11) = 0.
      GVC(5) = V(5)/CV
      GVC(10) = V(10)/CV
    ELSE IF ((V(4)+V(11).GT.0.) .AND.
+ (V(5)+V(10).EQ.0.)) THEN
      GVC(4) = V(4)/CV
      GVC(11) = V(11)/CV
      GVC(5) = 0.
      GVC(10) = 0.
    ELSE
      GVC(4) = 0.
      GVC(11) = 0.
      GVC(5) = 0.
      GVC(10) = 0.
    END IF
  *
  * Adjustment for Maximum or Minimum g/C Values
  *
    DO 200 I=2,11,3
    IF (GVC(I).GT.0.60) GVC(I)=0.60
    IF (GVC(I).LT.0.15) GVC(I)=0.15
200 CONTINUE

```

```

DO 205 I=1,10,3
  IF (GVC(I).GT.0.40) GVC(I)=0.40
  IF (GVC(I).LT.0.10) GVC(I)=0.10
205 CONTINUE
*
* Adjustment for zero-assigned-volume THRU movement
*
DO 210 I=2,11,3
  IF (VA(I).EQ.0.) GVC(I)=0.50
210 CONTINUE
*
* Adjustment for zero-assigned-volume LT non-shared movement
* Adjustment for zero-assigned-volume LT shared movement
*
DO 220 I=1,10,3
  IF ((LN(I).GT.0.) .AND. (LN(I).LT.9) .AND. (VA(I).EQ.0.)) GVC(I)=0.20
  IF ((LN(I).EQ.0) .AND. (VA(I).EQ.0.)) GVC(I)=GVC(I+1)
220 CONTINUE
*
* Adjustment of g/C for LT movements at "T" intersection
*
  IF ((LN(1).EQ.9) .AND. (LN(2).EQ.9) .AND. (LN(3).EQ.9))
+ GVC(7) = MAX (MIN(GVC(7),0.35),0.10)
  IF ((LN(4).EQ.9) .AND. (LN(5).EQ.9) .AND. (LN(6).EQ.9))
+ GVC(10) = MAX (MIN(GVC(10),0.35),0.10)
  IF ((LN(7).EQ.9) .AND. (LN(8).EQ.9) .AND. (LN(9).EQ.9))
+ GVC(1) = MAX (MIN(GVC(1),0.35),0.10)
  IF ((LN(10).EQ.9) .AND. (LN(11).EQ.9) .AND. (LN(12).EQ.9))
+ GVC(4) = MAX (MIN(GVC(4),0.35),0.10)
*
* Calculation and Adjustment for RT movements
*
  IF ((LN(3).GT.0) .AND. (LN(3).LT.9)) THEN
    GVC(3) = MAX(0.5 , 1.-(V(7)+V(11))/CV)
  ELSE IF (LN(3).EQ.0) THEN
    GVC(3) = GVC(2)
  ELSE
    GVC(3) = 0.
  END IF
  IF ((LN(6).GT.0) .AND. (LN(6).LT.9)) THEN
    GVC(6) = MAX(0.5 , 1.-(V(2)+V(10))/CV)
  ELSE IF (LN(6).EQ.0) THEN
    GVC(6) = GVC(5)
  ELSE
    GVC(6) = 0.
  END IF
  IF ((LN(9).GT.0) .AND. (LN(9).LT.9)) THEN
    GVC(9) = MAX(0.5 , 1.-(V(1)+V(5))/CV)
  ELSE IF (LN(9).EQ.0) THEN
    GVC(9) = GVC(8)
  ELSE
    GVC(9) = 0.
  END IF
  IF ((LN(12).GT.0) .AND. (LN(12).LT.9)) THEN
    GVC(12) = MAX(0.5 , 1.-(V(4)+V(8))/CV)
  ELSE IF (LN(12).EQ.0) THEN
    GVC(12) = GVC(11)
  ELSE
    GVC(12) = 0.
  END IF
*
* Additional Adjustment for Maximum RT g/C Values
*
DO 240 I=3,12,3
  IF (GVC(I).GT.0.75) GVC(I)=0.75
240 CONTINUE

```

```

*****
* Calculate Capacity for each Lane Group *
*****
*
* Calculate the Intersection Capacity
* Option:  INTCAP = SFLOW
*
  INTCAP = 1800.0
  INTCAP = SFLOW * (1.0-(LOSTM/CYCLE))
  INTVC = 0.
  IF (INTCAP.GT.0.) INTVC = CV/INTCAP
  DO 300 I=2,11,3
  CAP(I) = INTCAP * GVC(I) * LN(I)
300  CONTINUE
*
* Adjustment for LT shared movements
*
  DO 310 I=1,10,3
  IF ((LN(I).GT.0).AND.(LN(I).LT.9)) THEN
    CAP(I) = INTCAP * GVC(I) * LN(I)
  ELSE IF ((LN(I).EQ.0).AND.(V(I).GT.0.)) THEN
    CAP(I) = INTCAP * GVC(I)
  ELSE IF ((LN(I).EQ.0).AND.(V(I).EQ.0.)
+      .AND.((VA(I)+VA(I+1)).GT.0.)) THEN
    CAP(I) = CAP(I+1)*(VA(I)/(VA(I)+VA(I+1)))
  ELSE
    CAP(I) = 0.
  END IF
310  CONTINUE
*
* Adjustment for RT shared movements
*
  DO 320 I=3,12,3
  IF ((LN(I).GT.0).AND.(LN(I).LT.9)) THEN
    CAP(I) = INTCAP * GVC(I) * LN(I)
  ELSE IF ((LN(I).EQ.0).AND.(V(I-1).GT.0.)) THEN
    IF (VA(I).LT.V(I-1)) THEN
      CAP(I) = INTCAP*GVC(I-1)*(VA(I)/V(I-1))
    ELSE
      CAP(I) = INTCAP*GVC(I-1)
    END IF
  ELSE
    CAP(I) = 0.
  END IF
320  CONTINUE
*****
* Calculates X (V/C) for Each Movement *
*****
  DO 350 I=1,12
  IF (GVC(I).GT.0.) THEN
    X(I) = MIN (V(I)/(INTCAP*GVC(I)),1.20)
  ELSE
    X(I) = 0.
  END IF
350  CONTINUE
*
* Adjustment for zero-volume LT shared movement
*
  DO 360 I=1,10,3
  IF ((LN(I).EQ.0).AND.(VA(I).EQ.0.)) X(I)=X(I+1)
360  CONTINUE
*
* Adjustment for RT shared movement
*
  DO 370 I=3,12,3
  IF (LN(I).EQ.0) X(I)=X(I-1)
370  CONTINUE

```



```

*****
* Calculates Delay (in minutes) for each each movement *
*****
*
* Calculates Delay for each THRU movement
*
      DO 400 I=2,11,3
      IF ((LN(I).GT.0).AND.(LN(I).LT.9)) THEN
      D(I) = DELAY(CYCLE,X(I),GVC(I),CAP(I))
      ELSE
      D(I) = 0.
      END IF
400  CONTINUE
      DO 405 I=2,11,3
      IF (VA(I).EQ.0) D(I)=0.
405  CONTINUE
*
* Calculates Delay for each RT movement
* (Including adjustment for High-Volume RT shared movement)
*
      DO 410 I=3,12,3
      IF ((LN(I).GT.0).AND.(LN(I).LT.9)) THEN
      D(I) = DELAY(CYCLE,X(I),GVC(I),CAP(I))
      ELSE IF ((LN(I).EQ.0).AND.(VA(I).GT.(INTCAP*0.25))) THEN
      IF (VA(I).GT.V(I-1).AND.(GVC(I-1).GT.0.)) THEN
      CAP(I) = INTCAP*GVC(I-1)
      X(I) = MIN(VA(I)/CAP(I),1.40)
      D(I) = DELAY(CYCLE,X(I),GVC(I-1),CAP(I))
      ELSE IF (VA(I).GT.V(I-1).AND.(GVC(I-1).EQ.0.)) THEN
      D(I) = DELAY(CYCLE,X(I),GVC(I),INTCAP*0.5)
      ELSE
      D(I) = D(I-1)
      END IF
      ELSE IF ((LN(I).EQ.0).AND.(D(I-1).GT.0.)) THEN
      D(I) = D(I-1)
      ELSE IF ((LN(I).EQ.0).AND.(D(I-1).EQ.0.)) THEN
      D(I) = DELAY(CYCLE,X(I),GVC(I),INTCAP*0.5)
      ELSE
      D(I) = 0.
      END IF
410  CONTINUE
      DO 415 I=3,12,3
      IF (VA(I).EQ.0) D(I)=0.
415  CONTINUE
*
* Calculates Delay for each LT movement
*
      DO 420 I=1,10,3
      IF ((LN(I).GT.0).AND.(LN(I).LT.9)) THEN
      D(I) = DELAY(CYCLE,X(I),GVC(I),CAP(I))
      ELSE IF ((LN(I).EQ.0).AND.(V(I).GT.0.)) THEN
      D(I) = MAX(DELAY(CYCLE,X(I),GVC(I),CAP(I)),D(I+1))
      ELSE IF ((LN(I).EQ.0).AND.(V(I).EQ.0.)) THEN
      D(I) = D(I+1)
      ELSE
      D(I) = 0.
      END IF
420  CONTINUE
*
* Adjustment of Small-Assigned-Volume Delay for each movement
*
* (1) For THRU Movements
*
      DO 425 I=2,11,3
      IF ((V(I).GT.0.).AND.(V(I).LE.10.).AND.(LN(I).GT.0)
+      .AND.(LN(I).LT.9)) D(I)=0.
      IF ((V(I).GT.10.).AND.(V(I).LT.60).AND.(LN(I).GT.0)
+      .AND.(LN(I).LT.9)) D(I)=D(I)*(V(I)/60.0)
425  CONTINUE

```

```

* (2) For RT Movements
*
DO 426 I=3,12,3
  IF ((VA(I).GT.0.).AND.(VA(I).LE.10.)) D(I)=0.
  IF ((VA(I).GT.10.).AND.(VA(I).LT.120.).AND.(LN(I).GT.0)
+ .AND.(LN(I).LT.9)) D(I)=D(I)*(V(I)/120.0)
426 CONTINUE
* (3) For LT Movements
*
DO 427 I=1,10,3
  IF ((VA(I).GT.0.).AND.(VA(I).LE.5.).AND.(LN(I).GT.0)
+ .AND.(LN(I).LT.9)) D(I)=0.
  IF ((VA(I).GT.5.).AND.(VA(I).LT.60.).AND.(LN(I).GT.0)
+ .AND.(LN(I).LT.9)) D(I)=D(I)*(V(I)/60.0)
427 CONTINUE
*
* Adjustment for Zeor-Assigned-Volume Dalay for each movement
*
DO 430 I=1,12
  IF (VA(I).EQ.0.) D(I)=0.
  IF (LN(I).EQ.9) D(I)=0.
430 CONTINUE
*
* Additional Adjustment of X for Zero-Assigned-Volume Movement
*
DO 440 I=1,12
  IF (VA(I) .EQ. 0.) X(I)=0.
440 CONTINUE
*
* Additional Adjustment of X, g/C, CAP for NON-Existing Movement
*
DO 445 I=1,12
  IF (LN(I) .EQ. 9) X(I)=0.
  IF (LN(I) .EQ. 9) GVC(I)=0.
  IF (LN(I) .EQ. 9) CAP(I)=0.
445 CONTINUE
*
* Additional Adjustment of THRU Capacity for RT or LT Shared Movement
*
DO 450 I=3,12,3
  IF (LN(I).EQ.0) CAP(I-1)= CAP(I-1) - CAP(I)
450 CONTINUE
DO 455 I=1,10,3
  IF (LN(I).EQ.0) CAP(I+1)= CAP(I+1) - CAP(I)
455 CONTINUE
*
* Transfer the Delay in Minutes to Delay in Hundreds of Minute
* AND Transfer Capacity from Real to Integer (Rounded)
*
499 CONTINUE
DO 500 I=1,12
  DH(I)=INT(100*D(I)+0.5)
  TRN(I,6)=DH(I)
  ICAP(I)=INT(CAP(I)+0.5)
  TRN(I,12)=ICAP(I)
500 CONTINUE
*
* Write Updated Turning Movement Data File for the Next Iteration
*
DO 550 I=1,12
  WRITE(63,110)(TRN(I,J),J=1,25)
550 CONTINUE
*
* Write Nodal Performance Output Information
*
DO 600 I=1,12
  WRITE(71,601) TRN(I,1),TRN(I,2),TRN(I,8),TURN(I),LN(I),V(I),
+ VA(I),CAP(I),X(I),CV,INTCAP,INTVC,GVC(I),CYCLE,
+ D(I),TRN(I,24),TRN(I,25)

```

```

600 CONTINUE
601 FORMAT(1X,2I5,I2,2X,A1,I2,3F7.0,F6.2,F7.0,F7.0,F6.2,F6.2,
+       F7.0,F8.2,I6,Z1)
777 N = N+1
      GOTO 11
*
* Combine the Link Data File and the Updated Movement Data File
* into a New Link Data file
* and then Combine the New Link Data File
* with Node Data File and Turn Prohibitor File
* to be Ready for the Next Iteration Input to TRANPLAN.
*
900 DO 910 I=1,16000
      READ(51,901,END=911) CLET,C1,CX,CY,JUK1
901  FORMAT(A1,I5,2I11,A52)
      WRITE(21,902) CLET,C1,CX,CY
902  FORMAT(A1,I5,2I11)
910 CONTINUE
911 CONTINUE
      DO 920 I=1,20000
          READ(52,912,END=921) T1,TA,TB,TC,JUNK2
912  FORMAT(A1,3I5,A64)
          WRITE(21,913) T1,TA,TB,TC
913  FORMAT(A1,3I5)
920 CONTINUE
921 CONTINUE
          DO 930 I=1,20000
              READ(61,925,END=931) (CRD(J),J=1,25)
925  FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,2I6,I1,I5,Z1)
              WRITE(21,925) (CRD(J),J=1,25)
930 CONTINUE
931 CONTINUE
          REWIND 63
          DO 940 I=1,20000
              READ(63,925,END=941) (CRD(J),J=1,25)
              WRITE(21,925) (CRD(J),J=1,25)
940 CONTINUE
941 CONTINUE
*****
* Close the Files and Terminate the Program *
*****
      CLOSE(11)
      CLOSE(51)
      CLOSE(52)
      CLOSE(61,STATUS='DELETE')
      CLOSE(62,STATUS='DELETE')
      CLOSE(63,STATUS='DELETE')
      CLOSE(71)
      CLOSE(21)
999  NUMNOD = N-1
      WRITE(*,800) NUMNOD
800  FORMAT(/1X,'TOTAL NUMBER OF INPUT NODES IS:',I4)
888  STOP
      END
*
*
* *****
* SUBROUTINE LNVOL *
* *****
*
* This subroutine performs assigned lane Volume Analysis
* for Each Approach
* Variables used:
* LX: Number of LT Lanes
* LY: Number of TH Lanes
* LZ: Number of RT Lanes
* VX: Assigned Volume of LT Movement
* VY: Assigned Volume of TH Movement
* VZ: Assigned Volume of RT Movement
* PCE: Passenger Car Equivalent Factor

```

```

* X: Lane-Volume of LT Movement
* Y: Lane-Volume of TH Movement
* Z: Lane-Volume of RT Movement
*
SUBROUTINE LNVOL(LX,LY,LZ,VX,VY,VZ,VW,PCE,X,Y,Z)
INTEGER LX,LY,LZ
REAL VX,VY,VZ,VW,PCE,X,Y,Z
IF ((LX.LT.9) .AND. (LY.LT.9) .AND. (LZ.LT.9)) THEN
  IF (LX.GT.0) THEN
    X = VX / LX
    IF ((LY.GT.0) .AND. (LZ.EQ.0)) THEN
      Y = (VY+VZ) / LY
    ELSE IF (LY.GT.0) THEN
      Y = VY / LY
    ELSE
      Y = 0.
    END IF
    IF (LZ .GT. 0) THEN
      Z = VZ / LZ
    ELSE
      Z = 0.
    END IF
  ELSE IF ((LY+LZ).GT.1) THEN
    IF ((LY.GT.1).AND.(LZ.EQ.0)) THEN
      X = VX
      Y = MIN((VX*PCE+VY+VZ)/LY,(VY+VZ)/(LY-1))
      Z = 0.
    ELSE IF ((LY.GT.1).AND.(LZ.GT.0)) THEN
      X = VX
      Y = MIN((VX*PCE+VY)/LY,VY/(LY-1))
      Z = VZ / LZ
    ELSE IF ((LY.EQ.1).AND.(LZ.GT.0)) THEN
      X = VX
      Y = MIN((VX*PCE+VY),VY)
      Z = VZ / LZ
    ELSE IF ((LY.EQ.0).AND.(LZ.GT.0)) THEN
      X = VX
      Y = 0.
      Z = VZ/LZ
    ELSE
      X = VX
      Y = 0.
      Z = 0.
    END IF
  ELSE IF ((LY+LZ) .EQ. 1) THEN
    IF (LZ.LT.1) THEN
      IF (VX .GT. VW) THEN
        X = VX-VW
      ELSE
        X = 0.
      END IF
      Y = VX*PCE+VY+VZ
      Z = 0.
    ELSE
      IF (VX .GT. VW) THEN
        X = VX-VW
      ELSE
        X = 0.
      END IF
      Y = 0.
      Z = VX*PCE+VZ
    END IF
  ELSE
    X = 0.
    Y = 0.
    Z = 0.
  END IF
ELSE IF ((LX.EQ.9) .AND. ((LY.LT.9).AND.(LY.GT.0))
+ .AND. (LZ.LT.9)) THEN

```

```

      IF (LZ.GT.0) THEN
        X = 0.
        Y = VY/LY
        Z = VZ/LZ
      ELSE
        X = 0.
        Y = (VY+VZ)/LY
        Z = 0.
      END IF
    ELSE IF ((LY.EQ.9) .AND. (LX.LT.9)
+ .AND. ((LZ.LT.9).AND.(LZ.GT.0))) THEN
      IF (LX.GT.0) THEN
        X = VX/LX
        Y = 0.
        Z = VZ/LZ
      ELSE
        X = 0.
        Y = 0.
        Z = (VX*PCE+VZ)/LZ
      END IF
    ELSE IF ((LZ.EQ.9) .AND. ((LY.LT.9).AND.(LY.GT.0))
+ .AND.(LX.LT.9)) THEN
      IF (LX.GT.0) THEN
        X = VX/LX
        Y = VY/LY
        Z = 0.
      ELSE
        X = 0.
        Y = (VX*PCE+VY)/LY
        Z = 0.
      END IF
    ELSE IF (((LX.LT.9).AND.(LX.GT.0)) .AND. (LY.EQ.9)
+ .AND. (LZ.EQ.9)) THEN
      X = VX/LX
      Y = 0.
      Z = 0.
    ELSE IF ((LX.EQ.9) .AND. ((LY.LT.9).AND.(LY.GT.0))
+ .AND. (LZ.EQ.9)) THEN
      X = 0.
      Y = VY/LY
      Z = 0.
    ELSE IF ((LX.EQ.9) .AND. (LY.EQ.9)
+ .AND. ((LZ.LT.9).AND.(LZ.GT.0))) THEN
      X = 0.
      Y = 0.
      Z = VZ/LZ
    ELSE
      X = 0.
      Y = 0.
      Z = 0.
    END IF
  END IF
END
*****
* FUNCTION DELAY: *
* to calculate nodal impedance for each movement *
*****
FUNCTION DELAY(C,X,G,CP)
REAL C,X,G,CP
IF (CP .GT. 0.) THEN
  DELAY = 0.85*(1./60.)*(0.38*C*((1.- G)**2)/(1.- X*G)
+ 175.*X**2*(X -1.+ SQRT((X-1.)**2+16.*X/CP)))
ELSE
  DELAY = 0.85*(1./60.)*(0.38*C*((1.- G)**2)/(1.- X*G)
END IF
END

```

APPENDIX C

**PROGRAM TO READ AND ARRAY THE ASSIGNED VOLUMES:
LNKHIST (LNKHIST,FOR)**

```

C
C PROGRAM LNKHIST
C
C PROGRAM TO READ THE BINARY TRANPLAN ASSIGNMENT
C AND ADD THE VOLUMES (& IMPEDANCES) TO
C THE LINK HISTORY ASSIGNMENT FILE
C
C
C INTEGER*4 N,IO(500)
C INTEGER*4 IVOL(10),IIMP(10)
C INTEGER*4 IW
C CHARACTER*8 HEAD1(110),JIM
C INTEGER*2 HEAD2(51)
C INTEGER*4 LLNK
C INTEGER*2 KAP(16000),KB(20000),KT(20000),KX(20000)
C INTEGER*4 KVOL(20000)
C INTEGER*4 CRD(25)
C INTEGER*4 IVOLAB(20),IVOLBA(20)
C INTEGER*2 ITIMAB(20),ITIMBA(20)
C INTEGER*2 NNA,NNB
C DATA LLNK/'KNIL'/
C DATA LLNK/'LINK'/
C
C
C INITIALIZE
C
C DO 10 I=1,10
C IVOL(I)=0
C IIMP(I)=0
10 CONTINUE
C DO 12 I=1,16000
C KAP(I)=0
12 CONTINUE
C MAXLK=20000
C DO 15 I=1,MAXLK
C KB(I)=0
C KT(I)=0
C KX(I)=0
C KVOL(I)=0
15 CONTINUE
C ICNTLK=0
C ILINE=1
C
C
C GET DATA SET NAME FOR INPUT DATA SET
C
C WRITE(*,25)
25 FORMAT(' PLEASE GIVE THE NAME OF THE INPUT'/
* ' TRANPLAN ASSIGNMENT DATA SET')
C READ(11)JIM
C REWIND 11
C
C
C READ HEADER RECORD
C
C READ(11)(HEAD1(I),I=1,110), (HEAD2(III),III=1,51)
C
C
C EXTRACT NEEDED DATA
C
C NLINK=HEAD2(6)
C LODPUR=HEAD2(34)
C NUMITR=HEAD2(33)
C INC=5 + NUMITR*(LODPUR+1)
C WRITE(*,45)LODPUR,NUMITR,INC,NLINK
45 FORMAT(' ',LODPUR=',12,', NUMITR=',12,', INC=',13,',
* ' NLINK=',15)
C IF(LODPUR.EQ.1) GO TO 50
C WRITE(*,47)
47 FORMAT(' PROGRAM DESIGNED TO HANDLE ONLY 1 PURPOSE'/
* ' PROGRAM TERMINATING')
C STOP
50 CONTINUE
C IF((NUMITR.GE.1).AND.(NUMITR.LE.1)) GO TO 60

```

```

WRITE(8,52)
52 FORMAT(' MAXIMUM ITERATIONS = 1 : PROG TERMINATING')
60 CONTINUE
C
C   READY TO START READING AND WRITING
C
100 CONTINUE
READ(11,END=200,ERR=250)N,(IO(III),III=1,N)
IF(IO(1).NE.LLNK)GO TO 100
DO 140 I=2,N,INC
IW=IO(I)
C   HANDLE SIGN BIT (BIT 1)
IB1=0
IF(IW.LT.0)IB1=1
IF(IW.LT.0)IW = -IW
C
C   HANDEL TOP BITS 2-4
C
IB24=IW/268435456
IW = IW - ( 268435456*IB24 )
IB14=IB24+(IB1*8)
C
C   GET B-NODE IN BITS 5-18
C
IBN=IW/16384
IW = IW - (16384*IBN)
C
C   GET A-NODE FROM BITS 19-32
C
IAN = IW
C
C   GET IMPEDANCE AND VOL BY ITERATION
C
IT=0
DO 110 IJ= 1+5,1+5+((NUMITR-1)*2),2
IT=IT+1
IIMP(IT)=IO(IJ)
IVOL(IT)=IO(IJ+1)
110 CONTINUE
C
C   STORE THE DATA
C
LP=KAP(IAN)
IF(KAP(IAN).NE.0) GO TO 125
KAP(IAN)=ILINE
LL=ILINE
GO TO 135
125 CONTINUE
IF(KX(LP).NE.0) GO TO 130
KX(LP)=ILINE
LL=ILINE
GO TO 135
130 CONTINUE
LP=KX(LP)
GO TO 125
135 CONTINUE
KB(LL)=IBN
KT(LL)=IIMP(1)
KVOL(LL)=IVOL(1)
ILINE=ILINE+1
ICNTLK=ICNTLK+1
IF(ILINE.GT.MAXLK)WRITE(*,137)MAXLK
137 FORMAT(' I6, 'LIMIT ON ONE WAY LINKS EXCEEDED'/
* ' PROGRAM TERMINATING')
IF(ILINE.GT.MAXLK)STOP
140 CONTINUE
C
C
C

```



```

        IF(ICNTLK.GE.NLINK)GO TO 200
        GO TO 100
200 CONTINUE
        WRITE(*,202)
202 FORMAT(' COMPLETED READING ASSIGNMENT VOLUMES')
        WRITE(*,204)NLINK,ICNTLK,ILINE
204 FORMAT('   NLINK=',I5,'   NO. LINKS FOUND=',I5,
*         '   LINKS SAVED =',I5)
        GO TO 300
250 CONTINUE
        WRITE(*,252)
252 FORMAT(' APPARENT EOF ENCOUNTERED ON ASSIGNMENT FILE'/
*         ' PLEASE CHECK OUTPUT FOR COMPLETENESS ')
        WRITE(*,204)NLINK,ICNTLK,ILINE
        GO TO 300
C
C
300 CONTINUE
301 WRITE(*,303)
303 FORMAT(' IS THIS THE FIRST ASSIGNMENT
*         FOR THIS NETWORK?'/
*         ' IF YES, ENTER "1" '/
*         ' IF NO , ENTER "2" ')
        READ(*,306)IKIK
306 FORMAT(I1)
        IF((IKIK.NE.1).AND.(IKIK.NE.2))GO TO 301
        IF(IKIK.EQ.1)WRITE(*,309)
309 FORMAT(' PROVIDE THE NAME OF THE LINK DATA SET'/
*         ' USED TO CREATE THE ASSIGNMENT')
        IF(IKIK.EQ.2)WRITE(*,311)
311 FORMAT(' PROVIDE THE NAME OF BEING USED TO'/
*         ' ACCUMULATE THE ITERATION VOLUMES'/
*         ' AND IMPEDANCES')
        READ(31,312)(CRD(II),II=1,25)
312 FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,
*         2I6,I1,I5,Z1)
        REWIND 31
        WRITE(*,315)
315 FORMAT(' NEXT GIVE THE NAME OF THE NEW DATA SET TO'/
*         ' OUTPUT THE LINKS WITH THIS ASSIGNMENT ADDED')
        WRITE(32,312)(CRD(II),II=1,25)
        REWIND 32
C
C
        NOW PROCESS THE LINKS ON UNIT 31
C
400 CONTINUE
        IF(IKIK.EQ.1) GO TO 410
        READ(31,404,END=500,ERR=550)(CRD(II),II=1,25),
*         NIT,(IVOLAB(JJ),ITIMAB(JJ),
*         IVOLBA(JJ),ITIMAB(JJ),JJ=1,NIT)
404 FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,2I6,I1,
*         I5,Z1,I3,40(I7,I5))
        NIT=NIT+1
        GO TO 420
410 CONTINUE
        READ(31,414,END=500,ERR=550)(CRD(II),II=1,25)
414 FORMAT(2I5,I1,I4,A1,2I4,4I2,2I6,A1,2I4,4I2,2I6,
*         I1,I5,Z1)
        NIT=1
        GO TO 420
C
C
420 CONTINUE
        NNA=CRD(1)
        NNB=CRD(2)
        CALL FINDIT(NNA,NNB,IVAB,ITAB,KAP,KB,KT,KX,KVOL,MAXLK)
        CALL FINDIT(NNB,NNA,IVBA,ITBA,KAP,KB,KT,KX,KVOL,MAXLK)
        IVOLAB(NIT)=IVAB
        IVOLBA(NIT)=IVBA

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```

ITIMAB(NIT)=ITAB
ITIMBA(NIT)=ITBA
WRITE(32,404)(CRD(II),II=1,25),
*   NIT,(IVOLAB(JJ),ITIMAB(JJ),
*   IVOLBA(JJ),ITIMAB(JJ),JJ=1,NIT)
GO TO 400
C
C
500 CONTINUE
550 CONTINUE
WRITE(*,999)
999 FORMAT(' PROGRAM FINISHED')
STOP
END
SUBROUTINE FINDIT(NNA,NNB,IVAB,ITAB,KAP,KB,KT,
*   KX,KVOL,MAXLK)
INTEGER*2 KAP(16000)
INTEGER*2 KB(MAXLK),KT(MAXLK),KX(MAXLK)
INTEGER*4 KVOL(MAXLK)
INTEGER*2 NNA,NNB
INTEGER*2 IP
IVAB=0
ITAB=0
IP=KAP(NNA)
C
25 CONTINUE
IF(IP.LE.0)RETURN
IF(KB(IP).NE.NNB) GO TO 35
IVAB=KVOL(IP)
ITAB=KT(IP)
RETURN
35 CONTINUE
IP=KX(IP)
GO TO 25
END

```

APPENDIX D

**SELECTION OF THE BEST ASSIGNMENT RESULT
AMONG THE AVAILABLE CAPACITY RESTRAINT ASSIGNMENTS**

D-1 INTRODUCTION

This appendix documents the process of selecting the best performing assignment among various available capacity restraint and then comparing it with the proposed nodal restraint procedure. The existing assignment techniques available in the TRANPLAN package include all-or-nothing, iterative, incremental, stochastic, and equilibrium assignments. Because the all-or-nothing and stochastic assignment techniques are not categorized as capacity restraint procedures, they were eliminated from the study. In addition, the network data provided by the North Central Texas Council of Government (NCTCOG) were originally calibrated for a capacity restraint type of procedure (7) which may not be suitable for stochastic assignment.

Six capacity restraint assignments were investigated. All were executed on a 10-iteration basis. (In practice, four to six iterations are generally considered necessary to produce fairly satisfying results.) The assignments evaluated were:

1. Iterative assignment: At each iteration, all trips (100 percent) are loaded to the network, and link impedances are adjusted according to the assigned volumes from the previous iteration.
2. Equal weighting incremental assignment without adjusting the accumulated assigned volumes to 100 percent: At each iteration, an equal portion (10 percent) of the trips from each O-D pair is loaded to the network, and impedances are adjusted according to accumulated assigned volume. This procedure is referred to as incremental assignment A in this appendix.
3. Equal weighting incremental assignment adjusting the accumulated assigned volumes to 100 percent: At each iteration, an equal portion (10 percent) of the trips from each O-D pair is loaded to the network, and impedances are adjusted according to projected volumes which are expended from the accumulated assigned volumes. The procedure is referred to as incremental assignment B in this appendix.
4. Weighted average incremental assignment without adjusting the accumulated assigned volumes to 100 percent: At each iteration, a weighted portion (which may be different from iteration to iteration) of the trips from each O-D pair is loaded to the network; and impedances are adjusted according to accumulated assigned volume. In this study, the weighted percentages (20, 15, 10, 10, 10, 10, 10, 5, 5, and 5 percent) were directly appropriated from those specified in the TRANPLAN version of the D-FW Joint Model. These percentages are presumed suitable as they were calibrated for the North Dallas subarea. This procedure is referred to as incremental assignment C in this appendix.
5. Weighted average incremental assignment adjusting the accumulated assigned volumes to 100 percent: At each iteration, a weighted portion of the trips from each O-D pair is loaded to the network, and impedances are adjusted according to projected volumes.

These projected volumes are expended from the accumulated assigned volumes. The same loading percentages specified in the last procedure are used. The procedure is referred to as incremental assignment D in this appendix.

6. **Equilibrium assignment:** At each iteration, all the trips are loaded to the network. A portion (λ) of trips, which varies depending on the closure of the objective function, of trips loaded in this current iteration, is combined with the remaining portion ($1-\lambda$) of trips loaded in the previous iteration. This combination is then used to adjust link impedances. The maximum number of iterations was specified as ten but the assignment stopped at the sixth iteration when the closure criterion (0.1) was reached.

The selection of the best assignment was based on a comprehensive evaluation comprised of various macro-level and micro-level analyses. The macro-level analyses are those measures that analyze the entire network or major portions of the network. The micro-level analyses measure the assignment results on a link-by-link or movement-by-movement basis. These analyses include:

Macro-Level Analyses

1. The measures of total vehicle-miles of travel and average V/C ratio.
2. The analysis of directional link V/C distribution in the network .

Micro-Level Analyses

1. The analysis of mean difference, mean absolute difference, and root mean square error of approach volumes.
2. The analysis of mean difference, mean absolute difference, and root mean square error of turning movements.
3. The analysis of turning movements as a percentage of approach volume
4. Paired t-tests of approach volumes and turning movements.

The evaluation was based primarily on the micro-level analyses since the study interest is on the improvement of assigned turning movements replications. The macro-level analyses, nevertheless, provided an overall picture of network performance for each assignment.

D-2 MACRO-LEVEL ANALYSES

It is not unusual that in subarea analyses the ground count information is available for only a few of the links in the detailed subarea network. As a consequence, some conventional macro-level analyses such as travel routes, screen lines, and cut lines may not be applicable. The overall network performance, however, can be described by using other techniques such as the measures of total vehicle-miles of travel and average V/C ratio and the analysis of link V/C distribution in the network.

Measures of Total Vehicle-Miles of Travel and Average V/C Ratio

The total VMT (Vehicle-Miles of Travel) and the average V/C (Volume/Capacity) for the various assignments are summarized in Table D-1. The network links (not including centroid connectors) were classified into three clusters based on the coded link functional classifications: (1) major arterials, (2) minor arterials, and (3) collectors. These assignments produced similar VMT's of travel and average V/C's (Table D-1).

The total VMT of the various assignments ranged from 158,780.7 to 164,487.4 vehicle-miles. The iterative assignment generated the least total VMT; the incremental assignment B produced the most total VMT. The average V/C of various assignments ranged from 0.783 to 0.812. The average V/C's of the iterative assignment, incremental assignment A, and incremental assignment C are very close (around 0.78). Incremental assignment B generated the highest average V/C. For the major arterials, the various assignments generated comparable V/C (around 0.95). For the minor arterials, the iterative assignment generated a lower V/C than other assignments (0.7112 vs. around 0.750). For the collectors, incremental assignments A and C generated lower V/C than other assignments.

Table D-1
Total VMT and Average V/C Assignments Evaluated

	(1)Iter.	(2)Inc.A	(3)Inc.B	(4)Inc.C	(5)Inc.D	(6)Equil.
VMT (Maj.Art.)	53446.4	53974.8	54187.5	54283.2	53836.9	54783.8
VMT (Min.Art.)	59951.7	63453.4	64342.1	63037.0	64082.6	64211.1
VMT (Collectors)	45382.6	41559.8	45957.8	41609.6	45444.8	43590.0
VMT (Total)	158780.7	158988.0	164487.4	158929.8	163364.3	162584.9
V/C (Maj.Art.)	0.946	0.955	0.959	0.960	0.953	0.969
V/C (Min.Art.)	0.712	0.754	0.764	0.749	0.761	0.763
V/C (Collectors)	0.732	0.670	0.741	0.671	0.732	0.703
V/C (Average)	0.783	0.784	0.812	0.784	0.806	0.802

The Assignments Evaluated:

- (1) Iter. -- Iterative assignment
- (2) Inc.A -- Equal weighting incremental assignment
- (3) Inc.B -- Equal weighting incremental assignment with accumulated volumes expanded to 100 percent
- (4) Inc.C -- Weighted average incremental assignment
- (5) Inc.D -- Weighted average incremental assignment with accumulated volumes expanded to 100 percent
- (6) Equil. -- Equilibrium assignment

Measurements:

- VMT (Maj.Art.) -- Total VMT for major arterials
- VMT (Min.Art.) -- Total VMT for minor arterials
- VMT (Collectors) -- Total VMT for collectors
- V/C (Maj.Art.) -- Average V/C for major arterials
- V/C (Min.Art.) -- Average V/C for minor arterials
- V/C (Collectors) -- Average V/C for collectors

Directional Link V/C Distribution in the Network

The directional link V/C distribution across the entire test network of the various assignments was examined. Traffic at high V/C locations was considered to be over-assigned, assuming that the capacities coded for all links in the test network were appropriate. The directional link V/C's were inspected according to three different ranges: (1) unacceptable range, where at least one directional V/C of the link is greater than 2.0; (2) undesired range, where at least one directional V/C of the link is less than 2.0 but greater than or equal to 1.4; (3) acceptable range, where the assignments of the remaining links in the network excluding the above two groups are considered acceptable. The comparisons among the various assignments in terms of percentages of different V/C ranges are summarized in Table D-2. The percentage of each V/C range was approximated by measuring the total length of the links in the range with respect to the total length of all links in the network.

Table D-2
Summary of Directional Link V/C Distribution in the Network
from the Various Assignments (In Percent)

	(1)Iter.	(2)Inc.A	(3)Inc.B	(4)Inc.C	(5)Inc.D	(6)Equil.
I. V/C > 2.0 Percent of Total	6.0	0.0	1.9	0.4	1.9	1.2
II. 1.4 < V/C ≤ 2.0 Percent of Total	15.1	9.3	10.5	7.8	10.9	9.7
IV. 0.0 ≤ V/C ≤ 1.4 Percent of Total	78.9	90.7	87.6	91.8	87.2	89.2

All the assignments yielded fairly similar proportions of the acceptable range (around 90 percent) except the iterative assignment (78.9 percent). The iterative assignment generated somewhat higher percentages for the unacceptable and undesired ranges than other assignments. Among the remaining assignments, incremental assignment B and incremental assignment D produced higher percentages for the unacceptable and undesired ranges (more than 12 percent for both ranges together) than the other three assignments.

In addition to the quantity comparisons, the locations and dispersion patterns of the high and low V/C links in the network of each assignment were examined. These are illustrated in Figures D-1 to D-6. Figure D-1 shows that the unacceptable directional link V/C's of the iterative assignment occurred on scattered locations and on arterials such as Preston Road and Alpha Street.

Figure D-2 shows that incremental assignment A yielded fewer congested link V/C's on major arterials than the iterative assignment. The undesired high V/C's occurred at scattered locations, and no directional link V/C was greater than 2.0. In general, incremental assignment A generated evenly distributed link V/C's in the network.

Compared to incremental assignment A, incremental assignment B generated higher link V/C's on some scattered locations. As shown in Figure D-3, higher link V/C's were found on some segments of arterials such as Preston Road and Alpha Street and on some portion of collectors such as Keller Spring, Montfort, and Meadowcreek.

Incremental assignment C generated a similar V/C distribution pattern as incremental assignment A. As shown in Figure D-4, the assignment yielded only one directional link V/C that was unacceptable ($V/C > 2.0$). The proportion of acceptable ranges in this assignment is comparable to that of incremental assignment A (91.8 percent vs. 90.7 percent).

Incremental assignment D generated higher V/C's on some scattered locations than incremental assignment C. Figure D-5 shows higher link V/C's were found on some arterials such as Keller Spring and Alpha Street.

The equilibrium assignment generated a link V/C distribution pattern similar to that of incremental assignments A and C. As shown in Figure D-6, the equilibrium assignment yielded higher V/C's on some portions of Preston Road compared to the two incremental assignments.

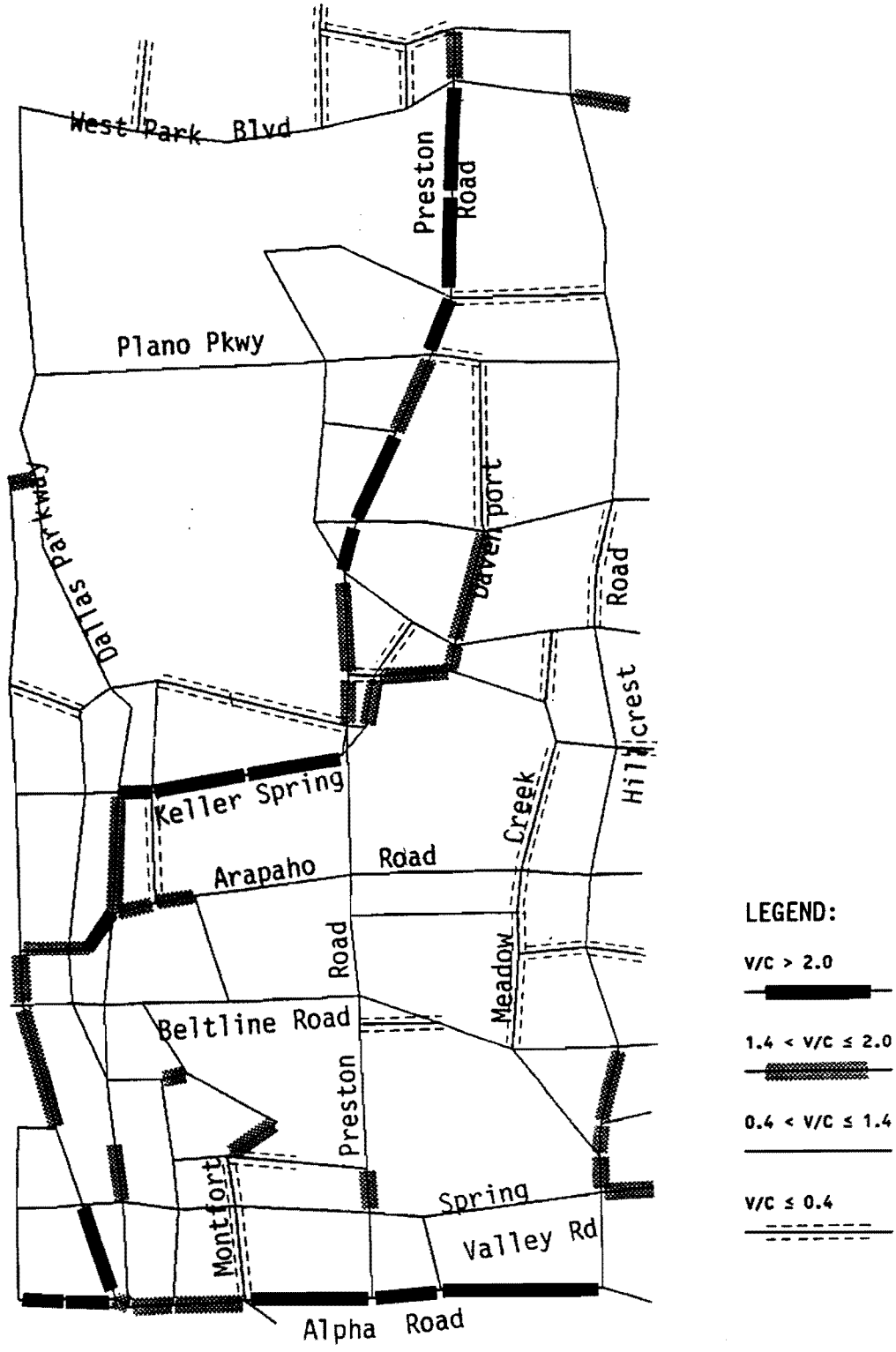


FIGURE D-1 Directional Link V/C Distribution in the Iterative Assignment Network

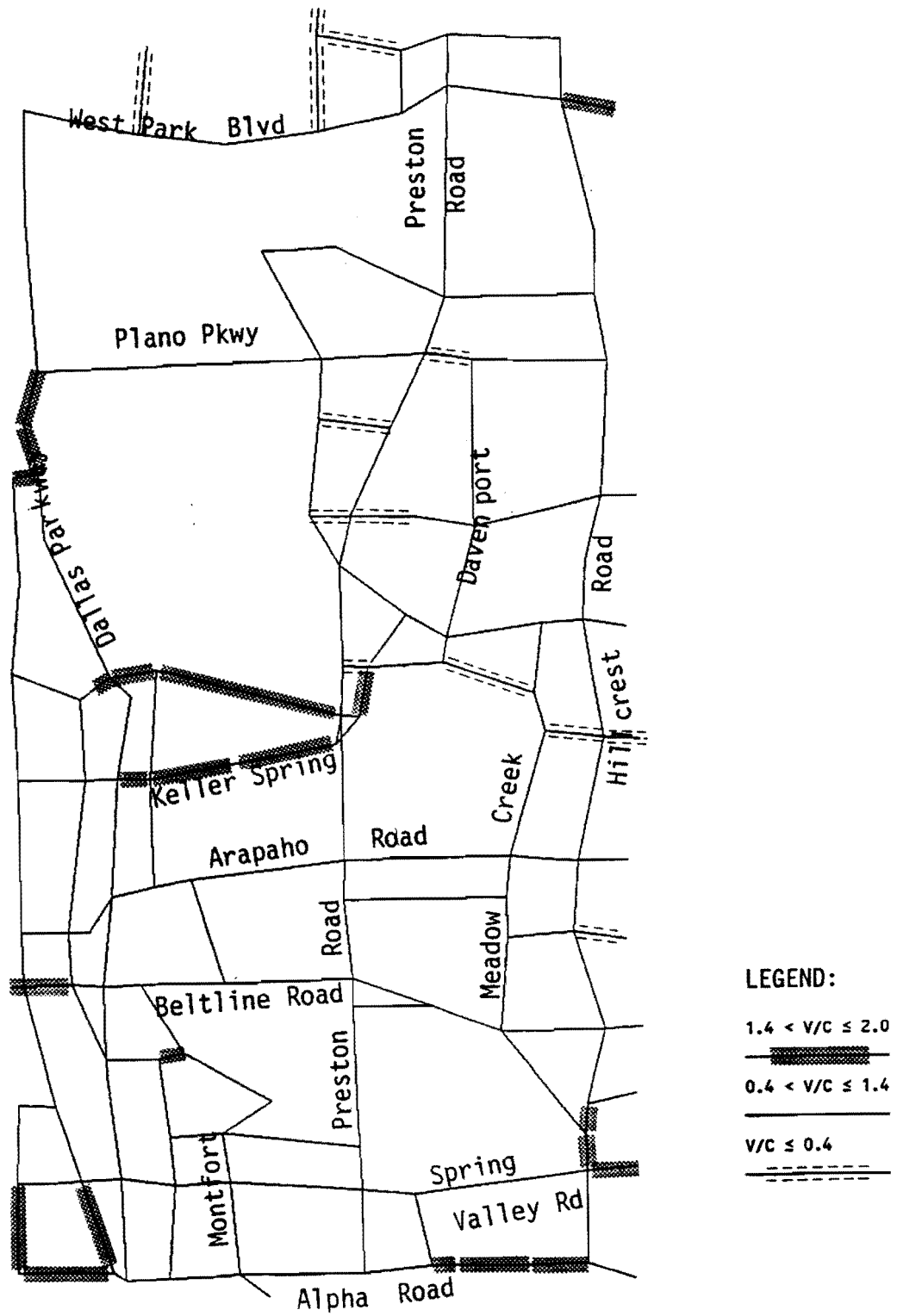


FIGURE D-2 Directional Link V/C Distribution in the Incremental Assignment A Network

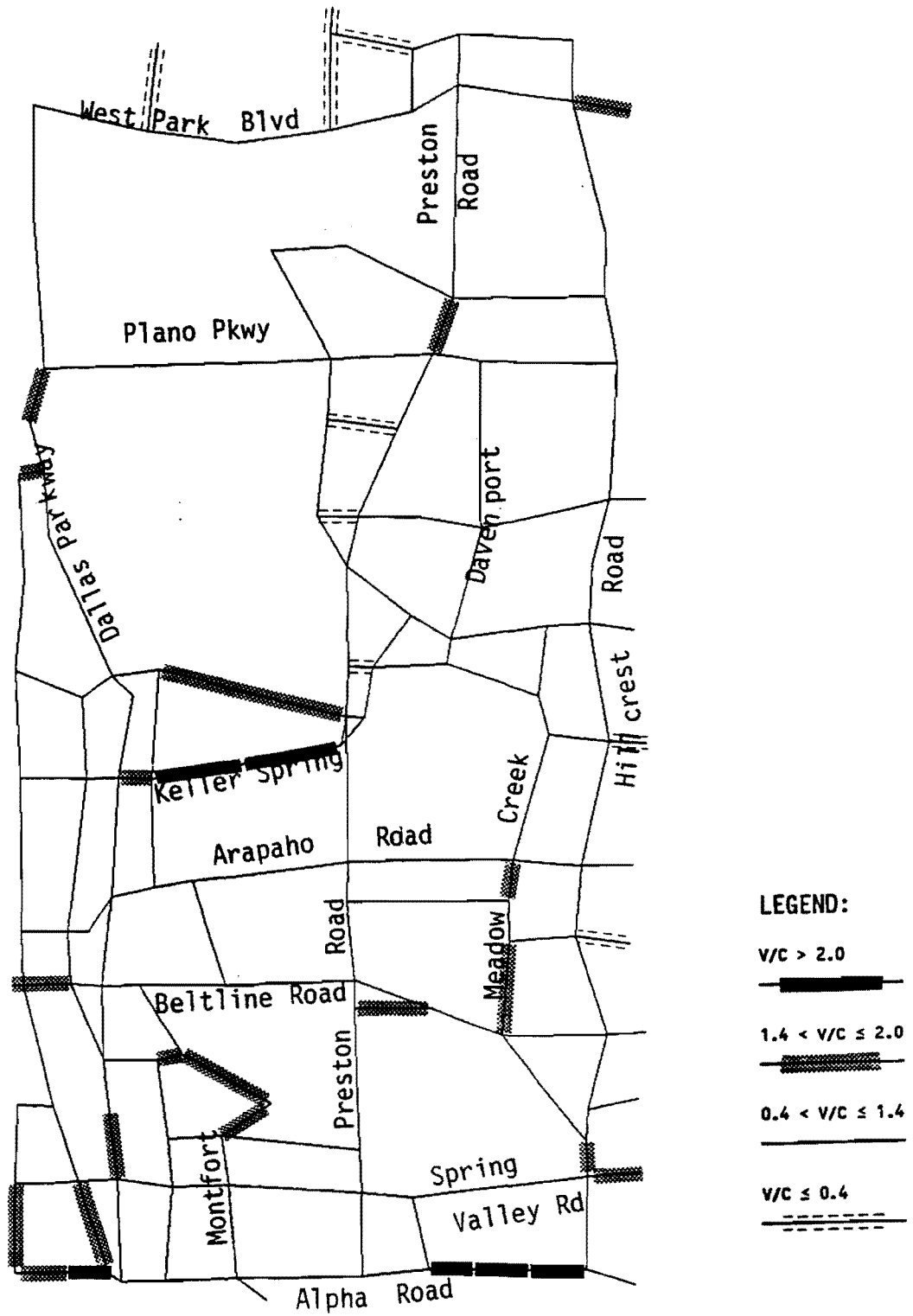


FIGURE D-3 Directional Link V/C Distribution in the Incremental Assignment B Network

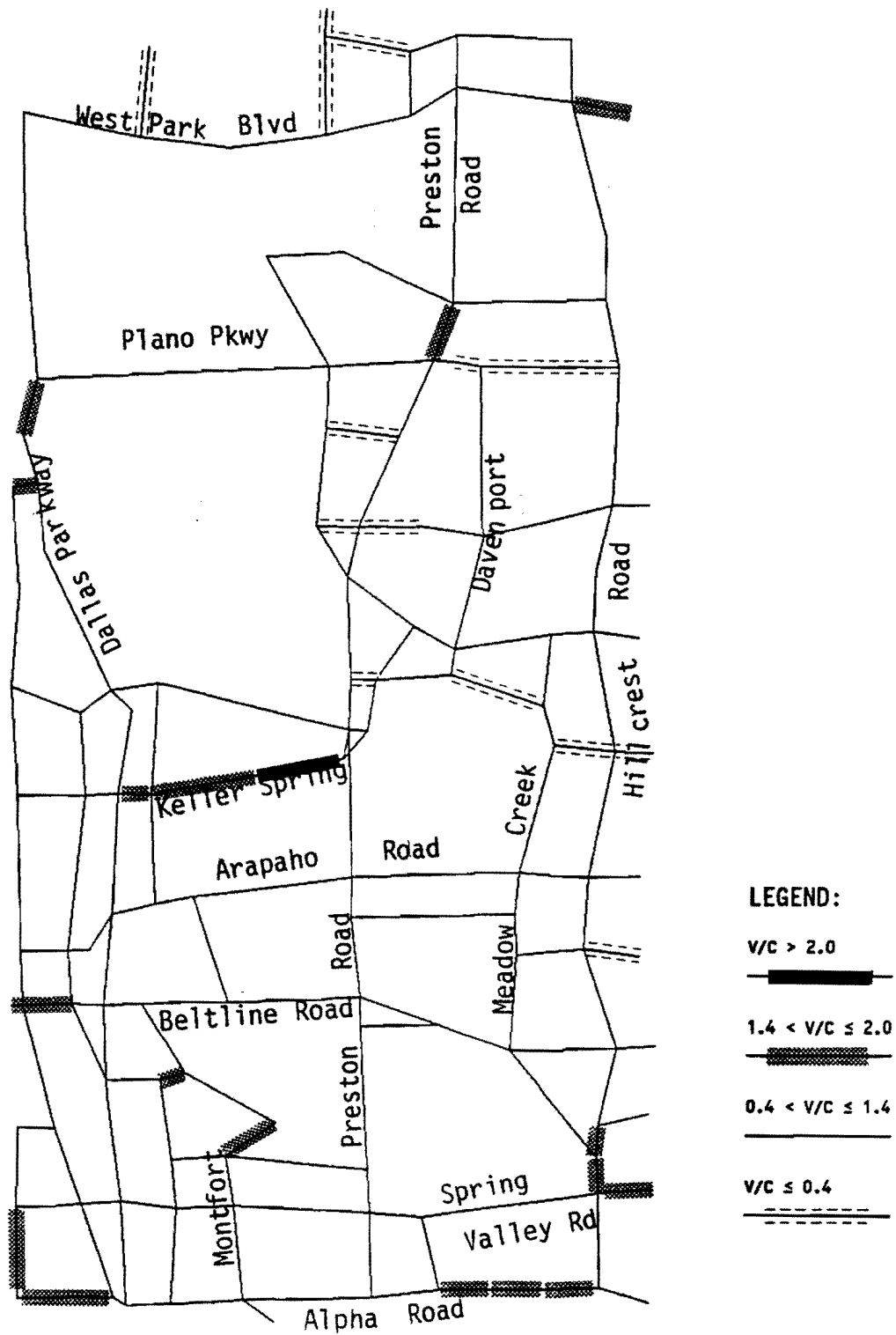


FIGURE D-4 Directional Link V/C Distribution in the Incremental Assignment C Network

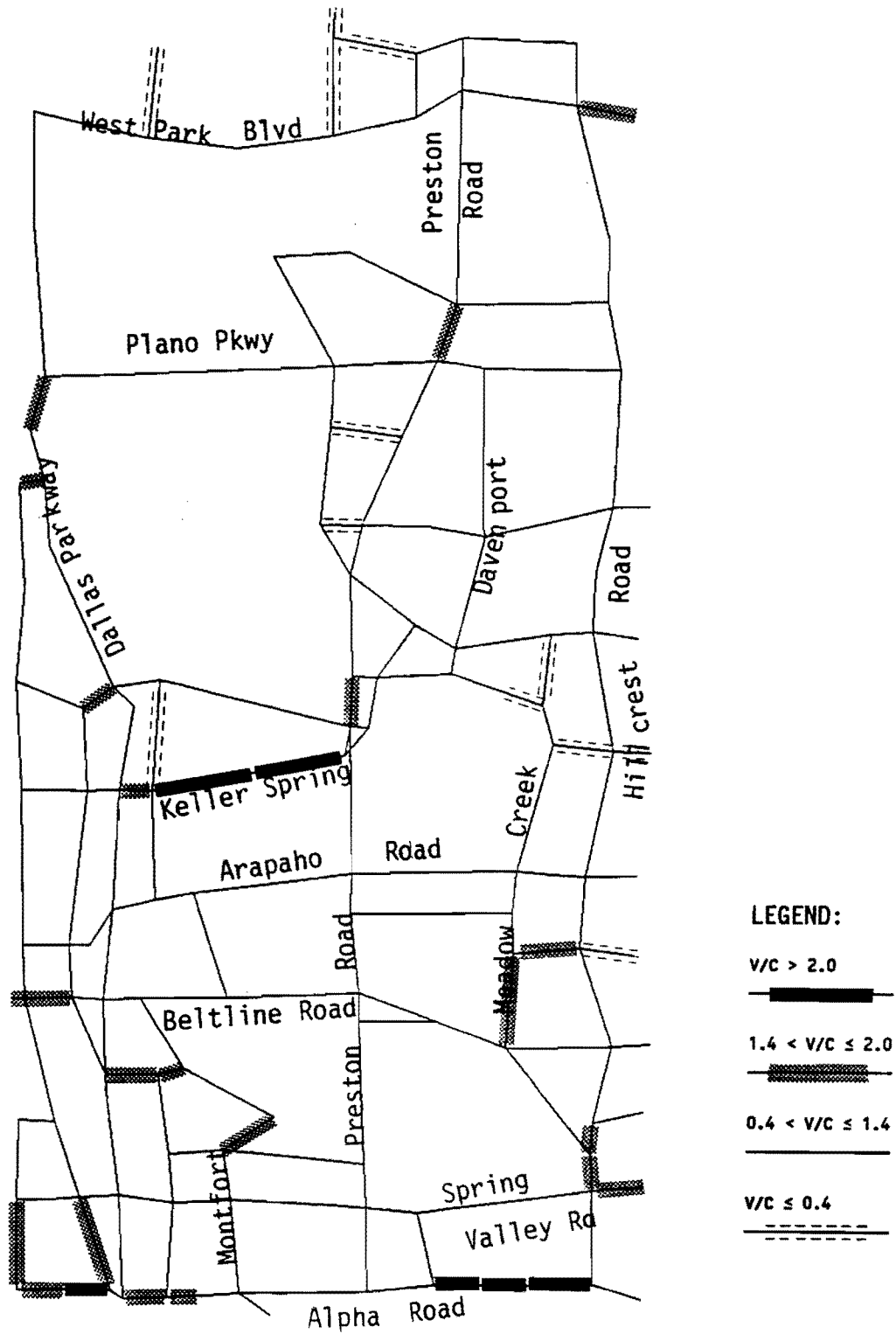


FIGURE D-5 Directional Link V/C Distribution in the Incremental Assignment D Network

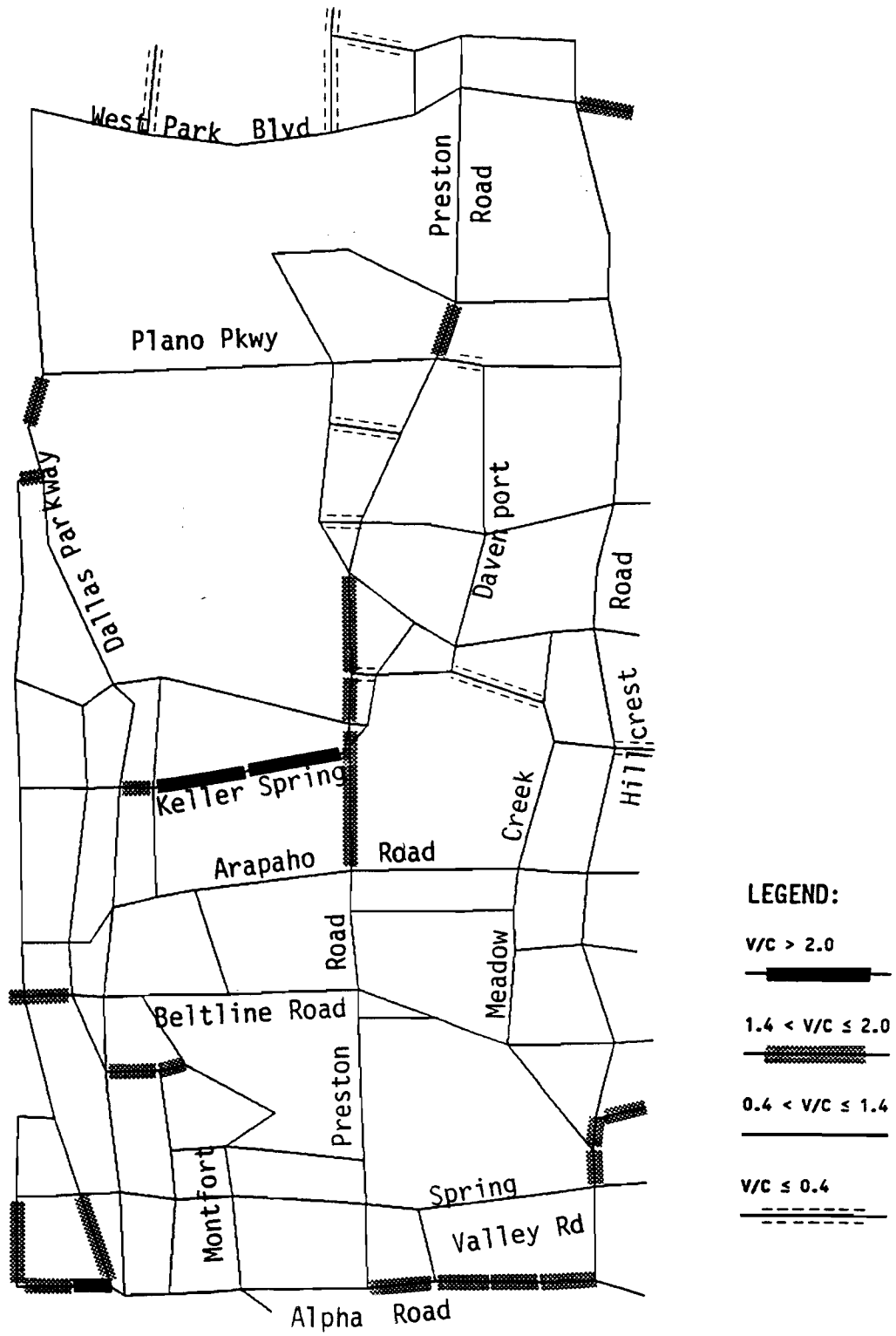


FIGURE D-6 Directional Link V/C Distribution in the Equilibrium Assignment Network

D-3 MICRO-LEVEL ANALYSES

The micro-level analyses focused on eight intersections along Preston Road (see Figure D-7) where ground count information was available. The analyses were conducted on a movement-by-movement, as well as a link-by-link, basis. These analyses include statistical measures (mean difference, mean absolute difference, root mean square error, and percent root mean square error) of approach volumes and turning movements, measures of turning movements as a percentage of approach volume, and statistic tests (paired t-test) of approach volumes and turning movements among the various assignments.

Analysis of Mean Difference, Mean Absolute Difference, and Root Mean Square Errors of Approach Volumes

In transportation planning, various measures are frequently used to compare traffic assignment results with traffic counts for evaluation purposes. The measures employed in this study include mean difference, mean absolute difference, root mean square errors, and percent root mean square error. The mean difference (mean absolute difference) gauges an average measure of the differences (the absolute value of the difference) between the assigned and the counted volumes. The root mean square error describes the dispersion of these differences (errors). They were computed according to the following equations:

$$MD = \frac{\sum (A_i - C_i)}{N} \quad (D-1)$$

$$MAD = \frac{\sum |A_i - C_i|}{N} \quad (D-2)$$

$$RMSE = \sqrt{\frac{\sum (A_i - C_i)^2}{N-1}} \quad (D-3)$$

$$PRMSE = 100\% * \frac{RMSE}{(\sum C_i) / N} \quad (D-4)$$

where: MD = mean difference
MAD = mean absolute difference
RMSE = root mean square error
PRMSE = percent root mean square error
A_i = assigned volume for link (or movement) i
C_i = counted volume for link (or movement) i
N = total number of links (movements)

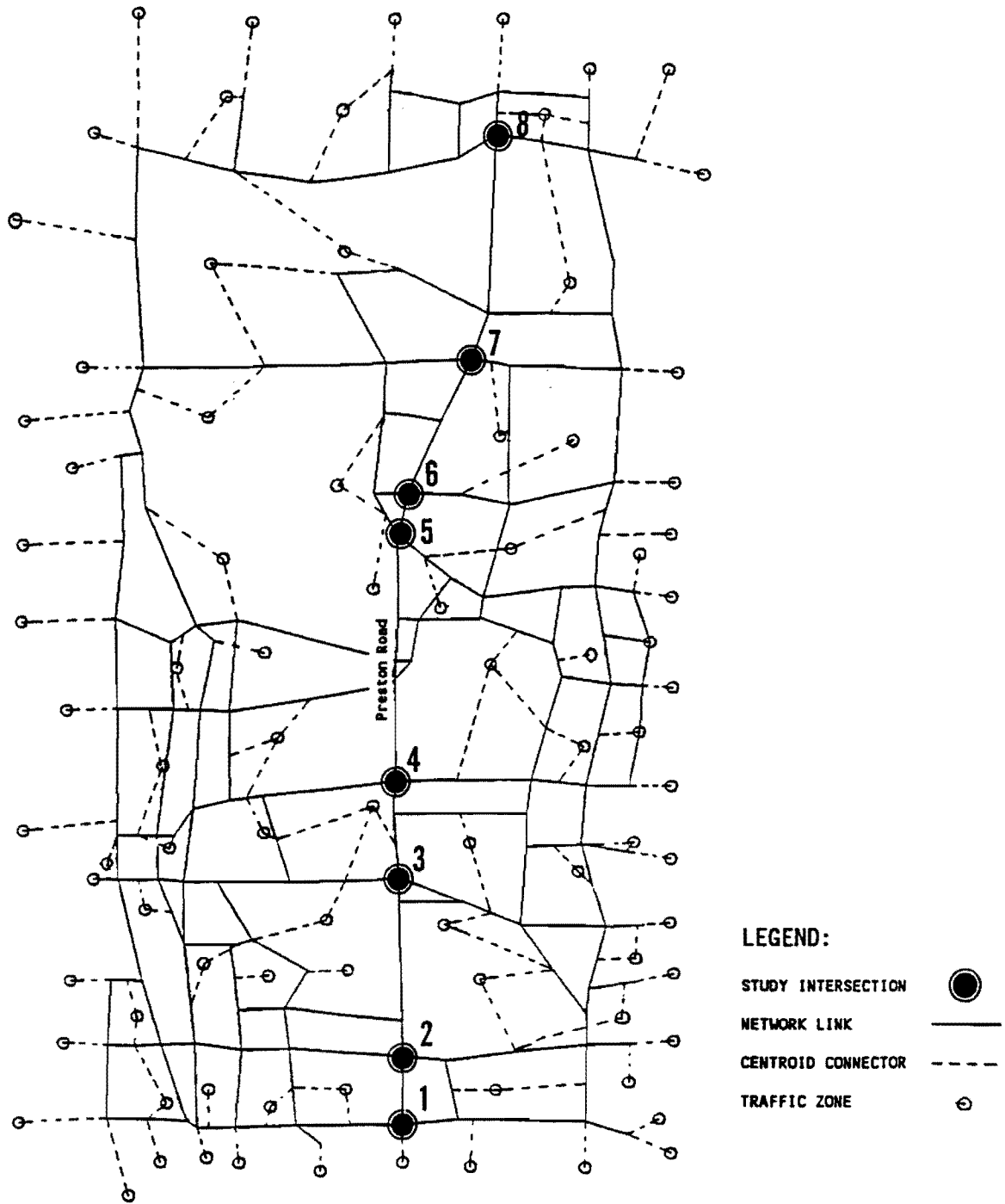


FIGURE D-7 Traffic Count Locations

It is essential to evaluate assignment results based on not only the mean difference (MD) but also the root mean square error (RMSE). The MD describes an average amplitude of the errors with respect to zero difference, and the RMSE characterizes the dispersion of these errors. For example, within a range of counted volumes (say 1,500 to 2,000 vehicles per hour), a group of links with many highly over-assigned volumes and under-assigned volumes may have a relatively small MD in which the positive and negative effects diminish the dimension of MD. In such a case, the measure of RMSE is useful in describing the wide dispersion of these errors.

These measures of the approach volumes were analyzed in two ways. First, the approach volumes were classed into four groups based on their approaching directions, i.e., NB (north bound), WB (west bound), SB (south bound), and EB (east bound); and the MD, MAD, RMSE, and PRMSE of approach volumes for each group were computed. As shown in Table D-3, for the NB approach volumes, there was not much difference among the six assignments. For the WB approach volumes, the result from the iterative assignment was somewhat worse than assignments in terms of RMSE and, thus, PRMSE. For the SB approach volumes, the incremental assignments A and C demonstrated somewhat better results than other assignments. For the EB approach volumes, the iterative assignment, however, showed the best results among the assignments evaluated in terms of both MD and RMSE (and PRMSE).

Second, the approach volumes were aggregated regardless of their approaching directions. This presents an average measure of the data under inspection. As shown in Table D-3, little difference is observed among the six assignments in terms of the measures of MD; only the incremental assignment A produced a somewhat larger MD than other assignments. The RMSE measured from the six assignments are very comparable. The difference between the best PRMSE and the worst PRMSE is less than 5 percent. This indicates that the dispersions of errors of the six assignments are alike. Overall, the measures of the approach volumes from the various assignments did not demonstrate a significant difference.

Analysis of Mean Difference, Mean Absolute Difference, and Root Mean Square Errors of Turning Movements

Next, these measures were applied to turning movements. The turning movements under inspection were stratified at three different levels of aggregation. First, they were classified into 12 groups according to their approaching directions, i.e., NB, WB, SB, and EB, and turning directions, i.e., LT (left-turn), TH (thru), and RT (right-turn). Second, they were grouped according to their turning directions only. Third, they were all grouped together, regardless of their approaching and turning directions. These measures of turning movements at different levels are summarized in Table D-4.

Table D-3
Summary of Mean Difference (MD), Mean Absolute Difference (MAD),
and Root Mean Square Error (RMSE) of Approach Volumes

Approach Direction	Sum of Counts	Num. of Approach	(1) Iterative Assign.				(2) Incremental A				(3) Incremental B				
			MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	
NB	20614	8	208	478	574	22.3	-330	491	609	23.7	-152	333	466	18.1	
WB	7915	8	47	356	455	46.0	104	210	264	26.6	97	207	278	28.1	
SB	13378	8	-466	466	539	32.3	-197	217	260	15.5	-274	274	358	21.4	
EB	10349	8	58	207	280	21.7	91	272	513	39.6	138	263	514	39.7	
AVERAGE TOTAL	1633 52256	32	-38	377	452	27.7	-83	298	417	25.6	-48	269	394	24.1	
			(4) Incremental C				(5) Incremental D				(6) Equilibrium Assign.				
			MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	
			-236	397	528	20.5	-135	368	491	19.1	-165	350	520	20.2	
			93	191	250	25.2	130	197	232	23.5	82	219	280	28.3	
			-187	203	249	14.9	-252	252	332	19.9	-247	247	314	18.8	
			97	263	515	39.8	115	258	480	37.1	129	293	526	40.7	
			-58	263	388	23.8	-36	269	379	23.2	-50	277	404	24.8	
			MD	MAD	RMSE	PRMSE									
			Average of Six Assignments:	-52	292	406	24.8								

The Assignments Evaluated:

- (1) Iterative Assign. Iterative assignment
- (2) Incremental A Equal weighting incremental assignment
- (3) Incremental B Equal weighting incremental assignment with accumulated volumes expanded to 100 percent
- (4) Incremental C Weighted average incremental assignment
- (5) Incremental D Weighted average incremental assignment with accumulated volumes expanded to 100 percent
- (6) Equilibrium Assign. Equilibrium assignment

Analysis Measures:

- MD = Mean Difference
- MAD = Mean Absolute Difference
- RMSE = Root Mean Square Error
- PRMSE = Percent Root Mean Square Error

Table D-4
Summary of Mean Difference, Mean Absolute Difference,
and Root Mean Square Error of Turning Movements

Approach & Turning Direction	Sum of Counts	Num. of Turns	(1) Iterative Assign.				(2) Incremental A				(3) Incremental B			
			MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE
NB LT	1428	8	33	183	223	125.2	-12	1095	168	94.0	55	810	149	83.4
TH	17226	8	218	245	350	16.3	-323	2859	420	19.5	-298	2886	453	21.0
RT	1960	8	-43	139	174	71.2	5	1360	211	85.9	92	1434	287	117.3
WB LT	1812	8	-89	170	279	123.0	-25	1202	225	99.3	-53	1150	218	96.3
TH	4737	8	67	227	310	52.4	95	1796	288	48.7	121	1534	269	45.5
RT	1366	8	69	134	182	106.5	35	704	110	64.5	29	1073	181	106.2
SB LT	1285	8	-47	95	118	73.2	-13	512	75	46.7	-34	681	114	70.9
TH	10761	8	-365	365	423	31.4	-190	1516	237	17.6	-238	2082	315	23.4
RT	1332	8	-54	91	126	75.5	6	598	135	81.1	-2	598	96	57.5
EB LT	2852	8	-110	130	184	51.7	-67	1127	247	69.2	-35	1555	260	72.9
TH	5633	8	223	229	363	51.6	218	2134	445	63.1	141	2262	421	59.8
RT	1864	8	-54	169	269	115.3	-60	1663	305	130.7	33	1132	166	71.4
All LT	7377	32	-53	145	41	17.7	-29	123	47	20.2	-17	131	54	23.4
TH	38357	32	36	266	130	10.8	-50	260	57	4.7	-69	274	50	4.2
RT	6522	32	-21	133	44	21.7	-4	135	72	35.6	38	132	62	30.5
AVERAGE	544		-13	181	251	46.2	-28	173	247	45.3	-16	179	251	46.2
TOTAL	52256	96												
			(4) Incremental C				(5) Incremental D				(6) Equilibrium Assign.			
			MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE	MD	MAD	RMSE	PRMSE
			-8	144	179	100.0	86	1410	244	136.8	14	1174	196	109.9
			-242	293	351	16.3	-333	2686	412	19.1	-281	2455	383	17.8
			14	171	201	82.0	112	1907	309	126.0	102	1765	278	113.3
			-25	164	235	103.9	-40	1265	234	103.4	-38	1143	226	99.8
			91	195	263	44.4	71	1523	230	38.9	118	1739	318	53.7
			27	87	108	63.0	98	1161	212	124.0	2	958	160	93.7
			-11	66	80	49.6	-22	731	117	73.0	-1	870	132	81.9
			-169	169	210	15.6	-227	1997	290	21.6	-251	2070	307	22.8
			-8	86	137	82.4	-4	854	144	86.7	5	723	141	84.4
			-61	126	218	61.3	-38	1165	188	52.6	17	1790	325	91.3
			219	259	443	63.0	177	2218	444	63.1	138	1758	346	49.1
			-61	200	303	129.9	-24	1603	275	118.0	-26	1671	286	122.9
			-26	125	51	22.0	-3	143	76	32.8	-2	156	52	22.5
			-25	229	50	4.1	-78	263	84	7.0	-69	251	76	6.3
			-7	136	69	34.0	46	173	59	28.8	21	160	67	32.7
			-19	163	233	42.8	-12	193	258	47.4	-17	189	254	46.7
			MD	MAD	RMSE	PRMSE								
			-18	180	249	45.8								

Analysis Measures:
MD = Mean Difference
MAD = Mean Absolute Difference
RMSE = Root Mean Square Error
PRMSE = Percent Root Mean Square Error

At the first aggregation level, the measures from the various assignments did not demonstrate a clear picture of which assignment yielded a better result (Table D-4). It did show that for all the assignments, however, some approaching groups (such as NB-LT, NB-RT, WB-LT, WB-RT, and EB-LT) generally produced worse RMSE than other approaching groups. At the second level of aggregation, the results from LT and RT movements were generally not as good as those from TH movements. For the LT movements, incremental assignment D produced a worse PRMSE (32.8 percent) than other assignments (around 20 percent). For the RT movements, the iterative assignment produced a better PRMSE (21.7 percent) than other assignments (around 30 percent). At this level of aggregation, the iterative assignment appeared to perform better than other assignments.

The measures for each assignment at the last level of aggregation (group not considering either the approaching or the turning directions) are shown in the last row of Table D-4. All the assignments yielded comparable MD (ranging from -20 to -10) except incremental assignment A (-28). Incremental assignment D generated somewhat better traffic replication than other assignments in terms of the dispersion error (RMSE). The RMSE of the assignment is 233, while that of other assignments is around 250. However, the difference is minimal when the measures are transferred into PRMSE. The PRMSE of incremental assignment C is 42.8 percent, while the PRMSE of other assignments is around 45 percent.

In summary, it can be concluded that the iterative assignment and incremental assignment C generated somewhat better turning movement replications than other assignments. The results from the remaining assignments are comparable, and it is difficult to make further distinctions. Only incremental assignment D appears to perform slightly worse than the others.

Analysis of Turning Movements as a Percentage of Approach Volumes

Another way to examine turning movements is to consider each turning movement as a percentage of its associated approach volume. Such a percentage, however, is correlated to the functional classification of the approach street and the cross street. For example, the percentage of movements turning to a major arterial are usually dissimilar to those turning to a minor arterial or a collector (the former usually higher than the latter). As such, the functional classifications of intersected streets must be taken into consideration when analyzing turning movements as a percentage of approach volumes.

According to the functional classifications coded in link data, the intersections under study were classified into three types: (1) a major arterial intersected by a major arterial, (2) a major arterial intersected by a minor arterial, and (3) a major arterial intersected by a collector street. The turning movement data then were clustered according to the associated intersection types. As shown in Table D-5, the second type encompasses most

Table D-5
Summary of Analysis of Turning Movements as a Percentage of Approach Volumes

Functional Classification	Major Street	Cross Street	Turn Type	Num. of Turns	Average Counted Turn Percent ^a	(1) Iter. Assign.		(2) Inc. A		(3) Inc. B	
						Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c
						Major Street	Cross Street	Turn Type	Num. of Turns	Average Counted Turn Percent ^a	
I. MAJOR - MAJOR			LT	4	14.8	11.9		14.6		9.7	
			TH	4	68.4	78.1	d	71.5	d	70.6	d
			RT	4	16.7	10.0		13.9		19.8	
II. MAJOR - MINOR			LT	12	7.9	8.5	0.6	8.4	0.5	10.1	2.2
			TH	12	81.6	82.6	1.0	80.0	-1.5	77.1	-4.5
			RT	12	10.6	8.9	-1.6	11.6	1.0	12.9	2.3
MINOR - MAJOR			LT	12	24.7	14.9	-9.8	18.8	-5.9	20.2	-4.4
			TH	12	59.8	65.2	5.4	62.6	2.9	63.6	3.8
			RT	12	15.6	20.0	4.4	18.6	3.0	16.2	0.7
III. MAJOR - COLL.			LT	2	5.2	3.0		2.6		2.9	
			TH	2	92.8	92.6	d	91.9	d	86.4	d
			RT	2	2.0	4.4		5.5		10.7	
COLL. - MAJOR			LT	2	31.6	26.8		26.4		13.6	
			TH	2	21.8	33.4	d	66.2	d	64.3	d
			RT	2	46.5	39.8		7.4		22.1	
						(4) Inc. C	(5) Inc. D	(6) Equil.			
Functional Classification	Major Street	Cross Street	Turn Type	Num. of Turns	Average Counted Turn Percent ^a	Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c	Average Assigned Turn Percent ^b	Average Error ^c
I. MAJOR - MAJOR			LT	4	14.8	14.3		12.0		12.1	
			TH	4	68.4	71.4	d	73.1	d	66.6	d
			RT	4	16.7	14.3		14.9		21.3	
II. MAJOR - MINOR			LT	12	7.9	8.6	0.7	11.2	3.3	10.1	2.2
			TH	12	81.6	80.2	-1.3	76.3	-5.3	77.3	-4.2
			RT	12	10.6	11.1	0.6	12.6	2.0	12.6	2.1
MINOR - MAJOR			LT	12	24.7	19.3	-5.4	20.9	-3.8	20.8	-3.9
			TH	12	59.8	63.2	3.5	58.5	-1.3	62.6	2.8
			RT	12	15.6	17.5	2.0	20.6	5.1	16.6	1.0
III. MAJOR - COLL.			LT	2	5.2	2.7		1.5		2.0	
			TH	2	92.8	92.0	d	86.3	d	88.3	d
			RT	2	2.0	5.2		12.1		9.7	
COLL. - MAJOR			LT	2	31.6	31.3		15.9		20.4	
			TH	2	21.8	59.3	d	73.2	d	73.1	d
			RT	2	46.5	9.4		10.9		6.5	

Note:

^a Average Counted Turn Percentage = $\Sigma(\text{Counted Turn Volume} + \text{Counted Approach Volume}) \div (\text{Total Number of Data})$

^b Average Assigned Turn Percentage = $\Sigma(\text{Assigned Turn Volume} + \text{Assigned Approach Volume}) \div (\text{Total Number of Data})$

^c Average Error = Average Assigned Turn Percentage - Average Counted Turn Percentage

^d Not computed due to insufficient data (only one intersection)

of the intersections along the Preston Road. The first type (major-major) includes only one intersection, the intersection of Preston Road and Belt Line. The third type (major-collector) also includes only one intersection, the intersection of Preston Road and McCallum. Therefore, the results of the first and the third intersections types were not compared with the ground counts because the number of data were considered insufficient. The average assigned turn percentages of movements at intersections of these two types from each assignment are displayed only for references.

The turning movements at the intersections of the second type (major-minor) were divided into six subgroups according to approach and cross street functional classifications and to turning directions (LT, TH, or RT), and then they were compared to ground counts. As shown in Table D-5, the measures of average error of the turning movements approaching from a major arterial toward a minor arterial show that the iterative assignment and incremental assignments A and D produced generally better results than other assignments. The measures of average error of the turning movements approaching from a minor arterial toward a major arterial indicate that the iterative assignment produced a somewhat worse turn percentage replication than other assignments.

In summary, no distinct difference could be discerned among the various assignments when the turning movements were regarded as a percentage of the approach volumes. Overall, incremental assignments A and C and the equilibrium assignment generated better turn percentage replications than other assignments.

Paired T-Tests of Approach Volumes and Turning Movements

The last micro-level analysis conducted was a series of paired t-tests. This statistical test was used to examine whether the mean of the assigned approach (or turn) volumes from each assignment was significantly different from that of counted approach (or turn) volumes.

The paired t-test is an appropriate statistical procedure for analyzing turning movements. The assigned volumes from the selected locations are estimates from one assignment model. The corresponding counted volumes from the same locations can be regarded as estimates from another assignment model. The statistical test was used to determine whether the two assignments are significantly different in terms of the difference between the paired estimates at the same location. Approach (or turn) volumes are correlated to their locations. If they are grouped together, instead of being paired by their distinctive locations, the difference between the two assignments may be canceled due to the variability among estimates within each given assignment. By having each assignment provide an estimate at the same location, the difference between the two assignments for each location can be calculated; and hence, the location-to-location variability is not canceled.

The research hypothesis for the test was as follows:

H₀: Assigned approach (or turn) volumes are distributed with the same mean as the ground counts.

H_a: Assigned approach (or turn) volumes are not distributed with the same mean as the ground counts.

The test statistic is:

$$t = \frac{D}{(S_d / \sqrt{N})} \quad (D-5)$$

where: D = mean difference between assigned and counted volumes
S_d = standard deviation of the differences
N = number of observations of approaches (or turns)

Decision: Accept H_a if the calculated value of t is greater than the critical value for α = 0.10 and degrees of freedom = N -1.

A series of paired t-tests were applied to the approach volumes and turning movements. The tests of approach volumes for the assignments are summarized in Table D-6. At the 10 percent significance level, the calculated t values for the various assignments are all smaller than the critical value (1.70). As such, none of the assignment's mean of assigned approach volumes is identified to be different from the mean of counted approach volumes. However, further distinctions among the assignments can be made through comparisons of the calculated t values for the various assignments. As shown in Table D-6, the calculated t value for incremental assignment A is apparently higher than other assignments. This indicates that the mean of incremental assignment A's assigned approach volumes is more likely to be different from the mean of counted approach volumes than that of other assignments. On the other hand, the mean of the iterative assignment's assigned approach volumes is much less likely to be different from the mean of the counted approach volumes than that of other assignments.

The paired t-tests of turning movements for the various assignments are summarized in Table D-7. At the 10 percent significance level, the calculated t values for the six assignments are all smaller than the critical value (1.66). Therefore, none of the assignment's mean of assigned turning movements is identified to be different from the mean of counted turning movements. As shown in the Table D-7, the standard deviations from the various assignments are very comparable (around 250). In such case, when computing the t values for the assignments, the mean difference (numerator) of each assignment then becomes the dominant factor, since the standard deviations (denominators) of the assignments are quite close.

Table D-6
Summary of Paired t-Tests of Approach Volumes

ASSIGNMENT	MD	SD	TEST STATISTICS		
			CALCULATED	CRITICAL	DECISION
(1) Iter.	38.1	443.8	0.48	1.70	H_0 could be true
(2) Inc. A	82.9	402.0	1.15	1.70	H_0 could be true
(3) Inc. B	47.6	384.7	0.69	1.70	H_0 could be true
(4) Inc. C	58.3	378.1	0.86	1.70	H_0 could be true
(5) Inc. D	35.6	371.4	0.53	1.70	H_0 could be true
(6) Equil.	50.3	394.8	0.71	1.70	H_0 could be true

Note: Two-tailed test at the 10 percent significance level, d.f. = 31.

Table D-7
Summary of Paired t-Tests of Turning Movements

ASSIGNMENT	MD	SD	TEST STATISTICS		
			CALCULATED	CRITICAL	DECISION
(1) Iter.	12.7	249.5	0.50	1.66	H_0 could be true
(2) Inc. A	27.6	243.7	1.10	1.66	H_0 could be true
(3) Inc. B	15.9	249.5	0.62	1.66	H_0 could be true
(4) Inc. C	19.4	231.0	0.82	1.66	H_0 could be true
(5) Inc. D	11.8	256.3	0.45	1.66	H_0 could be true
(6) Equil.	16.8	252.4	0.65	1.66	H_0 could be true

Note: Two-tailed test at the 10 percent significance level, d.f. = 95.

Based on this observation, it can be concluded that incremental assignment A is more likely to produce different estimates from the counted turning movements than other assignments. By contrast, the iterative assignment and incremental assignment D are less likely to produce different estimates from the counted turning movements than other assignments. It should be noted that the standard deviation of incremental assignment D is larger than that of iterative assignment (256.3 vs. 249.5) though the calculated t value of the incremental assignment D is smaller than that of the iterative assignment (0.45 vs. 0.50).

D-4 OVERALL EVALUATION

The overall evaluation aims to provide a basis for selecting the best among the available capacity restraint assignments. The results from the macro-level analyses were not included in the evaluation. Also, some items of the micro-level analyses were not included if no major difference was observed among the various assignments. The evaluation measures include (1) MD of turning movements, (2) RMSE of turning movements, (3) PRMSE of turning movements, (4) turning movements as a percentage of approach volumes, (5) paired t-tests of the approach volumes, and (6) paired t-tests of the turning movements.

To identify the best among the six assignments, a scoring system was designed. Each evaluation measure was assigned a total of 21 points; these points were distributed among the six assignments. The score each assignment obtained was determined by rank of the assignment. The score can be regarded as a penalty reckoning for each assignment. The rank of the various assignments for each evaluation measure was primarily based on the conclusion drawn from the related analysis in the previous section. If two or more assignments were tied, an average score was assigned to each of them. For example, the MD of incremental assignment A was identified to be worse than other assignments. The assignment was ranked last and thus obtained a score of 6. The MD of the remaining assignments were comparable. Therefore, they were assigned to the same rank and each of them obtained a score of 3 $((1+2+3+4+5) \div 5 = 3)$.

For the second and third evaluation measures (the RMSE and PRMSE of the turning movements), the iterative assignment performed generally better than other assignments in terms of measures by turning directions (especially for LT and RT movements); incremental assignment C performed better than other assignments in terms of the average measure. These two assignments were considered generally better than other assignments, and each was assigned a score of 1.5 $((1+2) \div 2 = 1.5)$. Incremental assignment D was considered to be the worst and was assigned a score of 6; the remaining assignments (incremental assignments A and B and the equilibrium assignment) produced comparable results and each of them was assigned a score of 4 $((3+4+5) \div 3 = 4)$. The same ranking and grading rules were applied to assignments for the remaining evaluation items.

**Table D-8
Summary of Overall Evaluation for the Assignments Evaluated**

Evaluation Measures	(1) Ite.	(2) Inc.A	(3) Inc.B	(4) Inc.C	(5) Inc.D	(6) Equ.	Total
1) MD of Turning Movements	3	6	3	3	3	3	21
2) RMSE of Turning Movements	1.5	4	4	1.5	6	4	21
3) PRMSE of Turning Movements	1.5	4	4	1.5	6	4	21
4) Turning Movements as a Percentage of Approach Volumes	5	3.5	3.5	1.5	6	1.5	21
5) Paired-T of Approach Volumes	1	6	3.5	3.5	3.5	3.5	21
6) Paired-T of Turning Movements	1.5	6	4.5	3	1.5	4.5	21
Total Scores	13.5	29.5	22.5	14	26	20.5	126
Final rank	1	6	4	2	5	3	

The Assignments Evaluated:

- (1) Iter. = Iterative assignment
- (2) Inc.A = Equal weighting incremental assignment
- (3) Inc.B = Equal weighting incremental assignment with loaded volumes adjusted to 100 percent
- (4) Inc.C = Weighted average incremental assignment
- (5) Inc.D = Weighted average incremental assignment with loaded volumes adjusted to 100 percent
- (6) Equil. = Equilibrium assignment

The final rank of the various assignments was evaluated based on the sum of scores from the evaluation measures. The lower the total score, the higher rank. As shown in Table D-8, the iterative assignment obtained the lowest penalty score (13.5). Incremental assignment C obtained the second lowest. These two assignment results were, thus, ranked as the first and the second best assignments, respectively. It should be noted that the scores of these two assignment are very close (just 0.5 point difference), and both are much better than that of other assignments (about 6 to 15 penalty points less) as far as the selected evaluation measures are concerned. Therefore, these two assignments were both selected as the best results among the capacity restraint assignments evaluated.

APPENDIX E

**NETWORK PERFORMANCE MEASURES
OF THE NODAL RESTRAINT ASSIGNMENT**

E-1 INTRODUCTION

This appendix describes the various macro-level analyses applied to the nodal restraint assignment. These analyses include measures of total vehicle-miles of travel and average volume to capacity ratio of all network links and of directional link V/C distribution in the network. Since no ground count data other than the turning movement counts at major Preston Road intersections were available, the analyses were conducted in an analogical way (i.e., results from the nodal restraint assignment were compared with results from the parallel capacity restraint assignments). Two incremental procedures were selected for the nodal restraint assignment. Therefore, the following analyses consist of two sets of comparisons: (1) the nodal restraint assignment and capacity restraint assignments using the equal weighting incremental procedure and (2) the nodal restraint and the capacity restraint assignment using the weighted average incremental procedure.

E-2 MEASURES OF VMT AND AVERAGE LINK V/C

The VMT and average link V/C of the proposed assignment compared to the parallel capacity restraint assignments were examined first. The VMT and the average V/C, not including centroid connectors, were classified into three clusters based on the coded link functional classifications: (1) major arterials, (2) minor arterials, and (3) collectors. As shown in Table E-1, the nodal restraint assignment and the capacity restraint assignments produced similar VMT's and average V/C's.

For the equal weighting incremental procedure, the average V/C of major arterials of the nodal restraint assignment is somewhat higher than that of the capacity restraint assignments. This means that the nodal restraint assignment assigned more traffic to major arterials than the capacity restraint assignments. On the other hand, the average V/C of minor arterials of the nodal restraint assignment is lower than that of the capacity restraint assignments. The total average V/C of the nodal restraint assignment (0.790) is higher than the no-expansion capacity restraint assignment (0.784), but lower than that of the expand-100 percent capacity restraint assignment.

For the weighted average incremental procedure, the nodal restraint assignment again produced results similar to the capacity restraint assignments. The average V/C of major arterials of the nodal restraint assignment is somewhat higher than that of the capacity restraint assignments, whereas the average V/C of minor arterials of the nodal restraint assignment is lower. The overall average V/C (0.794) of the nodal restraint assignment also lies in between the two capacity restraint assignments (0.784 and 0.806).

Table E-1
Summary of VMT and Average Link V/C of
the Nodal Restraint Assignment and the Capacity Restraint Assignments

	Equal Weighting Incremental Procedure		
	Capacity Restraint Assignments		Nodal Restraint Assignment
	(No-Expansion) ^a	(Expand-100%) ^b	(Expand-100%) ^c
VMT (Maj.Art.)	53974.8	54187.5	55266.6
VMT (Min.Art.)	63453.4	64342.1	61578.0
VMT (Coll.)	41559.8	45957.8	43475.0
total VMT	158988.0	164487.4	160319.6
V/C (Maj.Art.)	0.955	0.959	0.978
V/C (Min.Art.)	0.754	0.764	0.732
V/C (Coll.)	0.670	0.741	0.701
Average V/C	0.784	0.812	0.790

	Weighted Average Incremental Procedure		
	Capacity Restraint Assignments		Nodal Restraint Assignment
	(No-Expansion) ^a	(Expand-100%) ^b	(Expand-100%) ^c
VMT (Maj.Art.)	54283.2	53836.9	56016.8
VMT (Min.Art.)	63037.0	64082.6	60612.9
VMT (Coll.)	41609.6	45444.8	44243.8
Total VMT	158929.8	163364.3	160319.6
V/C (Maj.Art.)	0.960	0.953	0.991
V/C (Min.Art.)	0.749	0.761	0.720
V/C (Coll.)	0.671	0.732	0.713
Average V/C	0.784	0.806	0.794

The Assignments Evaluated:

- ^a The No-Expansion Capacity Restraint Assignment
 - Incremental procedure without expanding the accumulated volumes to 100 percent
- ^b The Expand-100% Capacity Restraint Assignment
 - Incremental procedure with the accumulated volumes expanded to 100 percent
- ^c The Expand-100% Nodal Restraint Assignment
 - Incremental procedure with the accumulated volumes expanded to 100 percent

Network Performance Measurements:

- VMT (Maj.Art.) -- VMT for major arterials
- VMT (Min.Art.) -- VMT for minor arterials
- VMT (Coll.) -- VMT for collectors
- V/C (Maj.Art.) -- Average V/C for major arterials
- V/C (Min.Art.) -- Average V/C for minor arterials
- V/C (Coll.) -- Average V/C for collectors

E-3 DIRECTIONAL LINK V/C DISTRIBUTION IN THE NETWORK

The directional link V/C distribution in the network of the nodal restraint assignment was examined next. Traffic at locations with high V/C's were considered to be over-assigned, assuming that the capacities coded for all links in the test network were appropriate. The directional link V/C was inspected according to three different ranges: (1) unacceptable range, where at least one directional V/C of the link is greater than 2.0, (2) undesired range, where at least one directional V/C of the link is less than 2.0 but greater than or equal to 1.4, and (3) acceptable range, where the assignments of the remaining links in the network excluding the above two groups are considered acceptable. The comparisons between the nodal restraint assignment and the parallel capacity restraint assignments, for both the equal weighting and weighted average incremental procedures, in terms of the percentages of these different V/C ranges are summarized in Table E-2. The percentage of each V/C range was computed by measuring the total length of the links in the range with respect to the total length of all links in the network.

In general, the larger the portion of acceptable range, the better the assignment model is considered to perform. For the equal weighting incremental procedure, the nodal restraint assignment and the capacity restraint assignments yielded fairly comparable percentages of the acceptable range (around 90 percent). The locations and dispersion patterns of the high and low directional link V/C's of the capacity restraint assignments and the nodal restraint assignment were compared as well. These are presented in Figures E-1 to E-3. The locations of high directional link V/C's in the nodal restraint assignment (Figure E-3) are somewhat different from that in the no-expansion capacity restraint assignment (Figure E-1) but are similar to that in the expand-100 percent capacity restraint assignment (Figure E-2).

The same analysis process was conducted for the weighted average incremental procedure. The quantitative comparisons of network V/C distribution between the nodal restraint assignment and the capacity restraint assignments are summarized in the second section of Table E-2. The percentage of acceptable V/C range of the nodal restraint assignment (87.6 percent) is less than that of the no-expansion capacity restraint assignment (91.8 percent), but close to that of the expand-100 percent capacity restraint assignment (87.2 percent).

The locations and dispersion patterns of the directional link V/C distribution in the network of the capacity restraint assignments and of the nodal restraint assignment are presented in Figures E-4 to E-6, respectively. The locations of high directional link V/C's in the nodal restraint assignment (Figure E-6) were somewhat different from that in the capacity restraint assignments (Figures E-4 and E-5). Overall, the directional link V/C dispersion patterns in the network of the nodal restraint assignments were comparable to that of capacity restraint assignments for both the equal weighting and weighted average incremental procedures.

Table E-2
Summary of the Comparison of Directional Link V/C Distribution in the Network
Between the Nodal Restraint Assignment and the Capacity Restraint Assignments

	Equal Weighting Incremental Procedure		
	Capacity Restraint Assignments		Nodal Restraint Assignment
	(No-Expansion) ^a	(Expand-100%) ^b	(Expand-100%) ^c
I. Percentage of V/C > 2.0	0.0	1.9	1.9
II. Percentage of 1.4 ≤ V/C ≤ 2.0	9.3	10.5	8.5
III. Percentage of V/C < 1.4	90.7	87.6	89.5

	Weighted Average Incremental Procedure		
	Capacity Restraint Assignments		Nodal Restraint Assignment
	(No-Expansion) ^a	(Expand-100%) ^b	(Expand-100%) ^c
I. Percentage of V/C > 2.0	0.4	1.9	1.2
II. Percentage of 1.4 ≤ V/C ≤ 2.0	7.8	10.9	11.2
III. Percentage of V/C < 1.4	91.8	87.2	87.6

The Assignments Evaluated:

^a The No-Expansion Capacity Restraint Assignment -- Incremental procedure without expanding the accumulated volumes to 100 percent

^b The Expand-100% Capacity Restraint Assignment -- Incremental procedure with the accumulated volumes expanded to 100 percent

^c The Expand-100% Nodal Restraint Assignment -- Incremental procedure with the accumulated volumes expanded to 100 percent

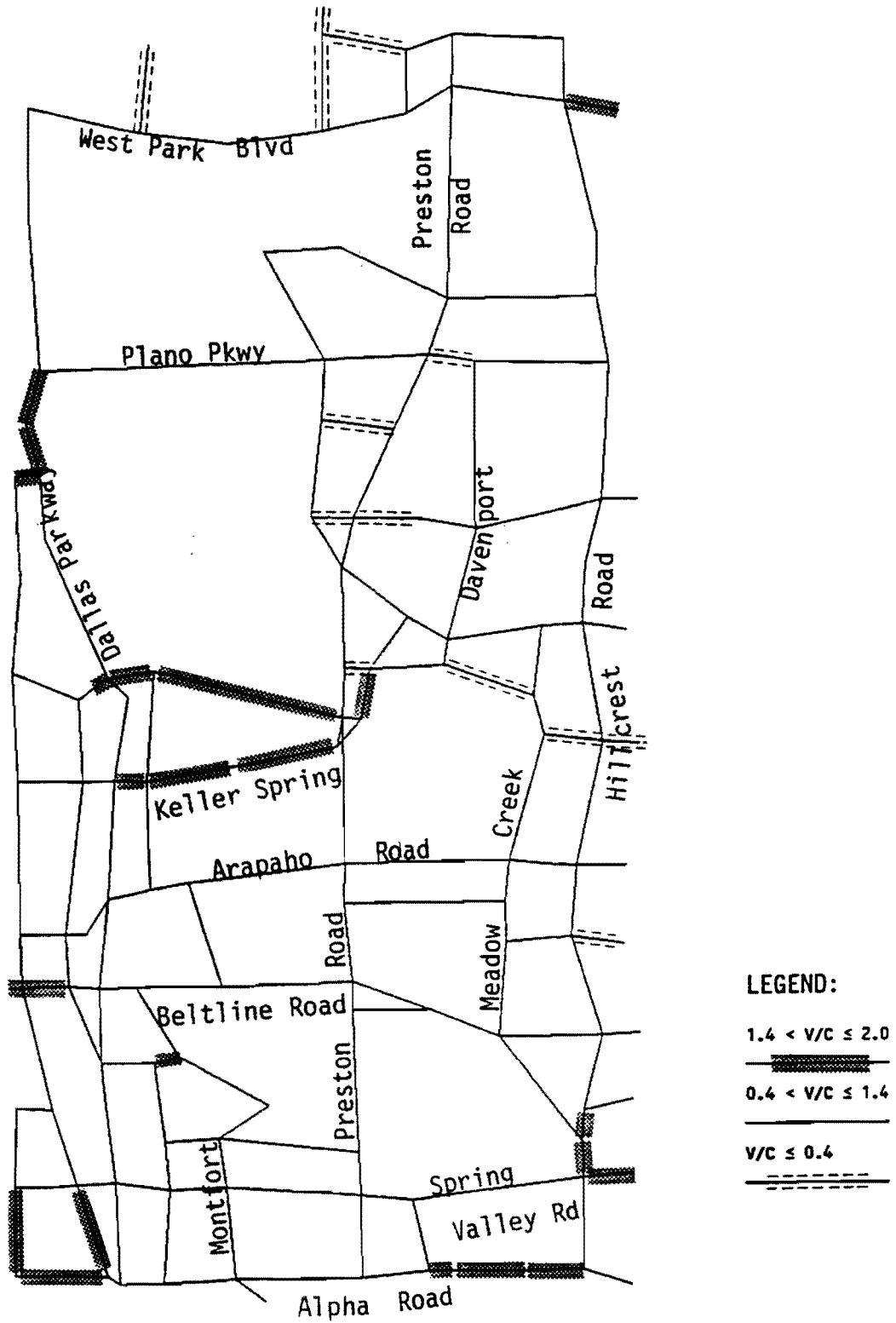


FIGURE E-1 Directional Link V/C Distribution in the Capacity Restraint Assignment Network (Equal Weighting Incremental Procedure without Volume Expansion)

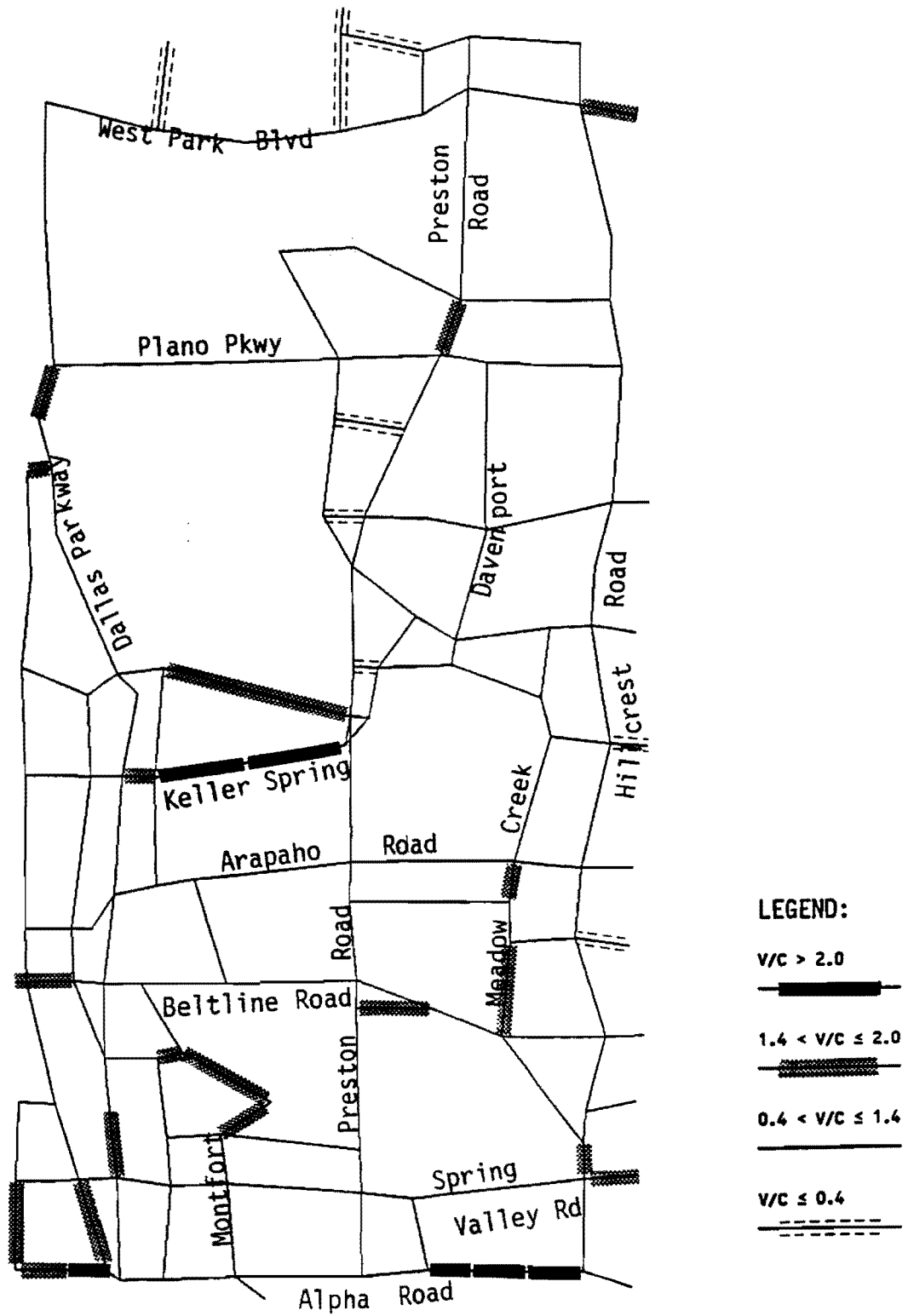


FIGURE E-2 Directional Link V/C Distribution in the Capacity Restraint Assignment Network (Equal Weighting Incremental Procedure with Volumes Expanded to 100 percent)

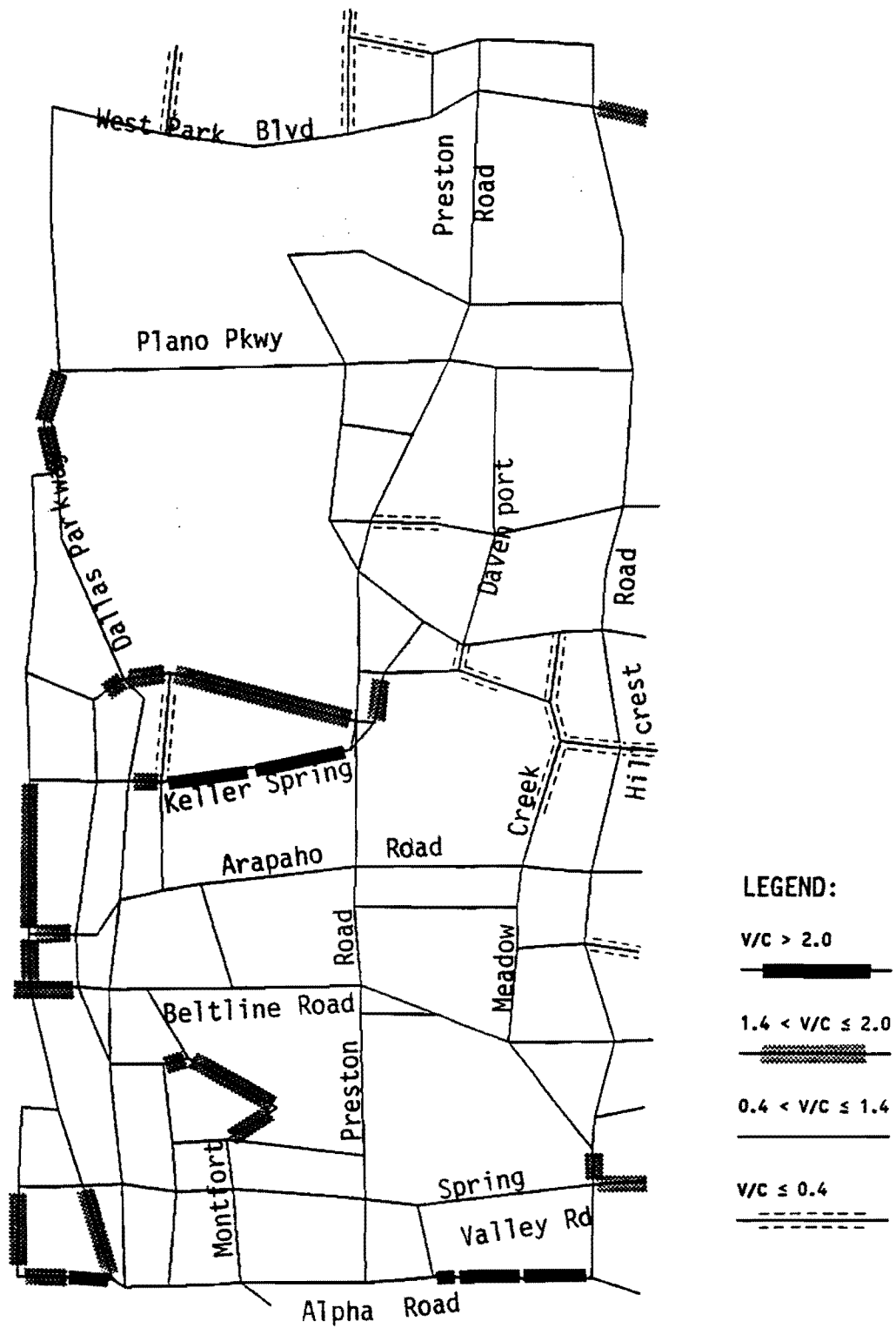


FIGURE E-3 Directional Link V/C Distribution in the Nodal Restraint Assignment Network (Equal Weighting Incremental Procedure)

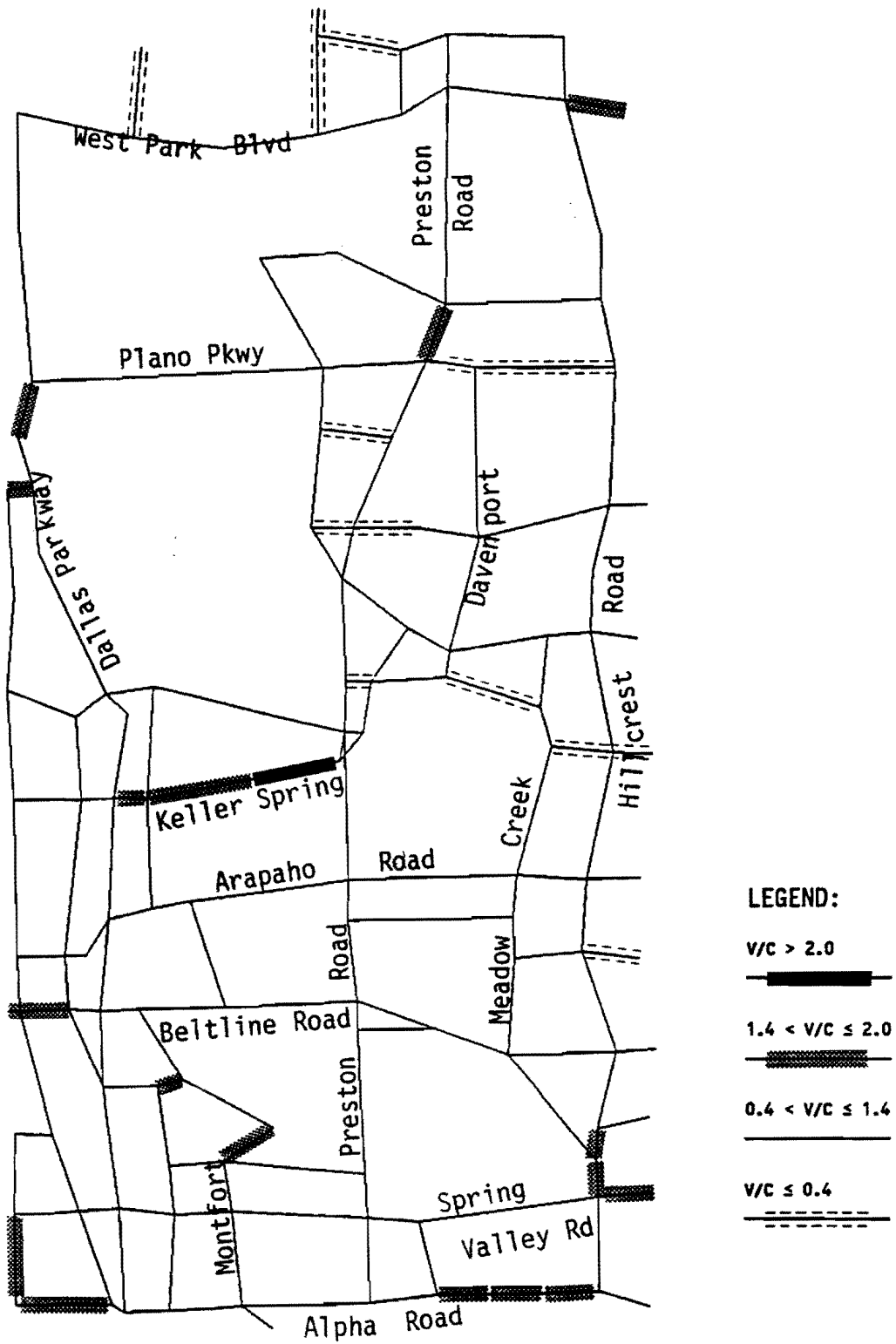


FIGURE E-4 Directional Link V/C Distribution in the Capacity Restraint Assignment Network (Weighted Average Incremental Procedure without Volume Expansion)

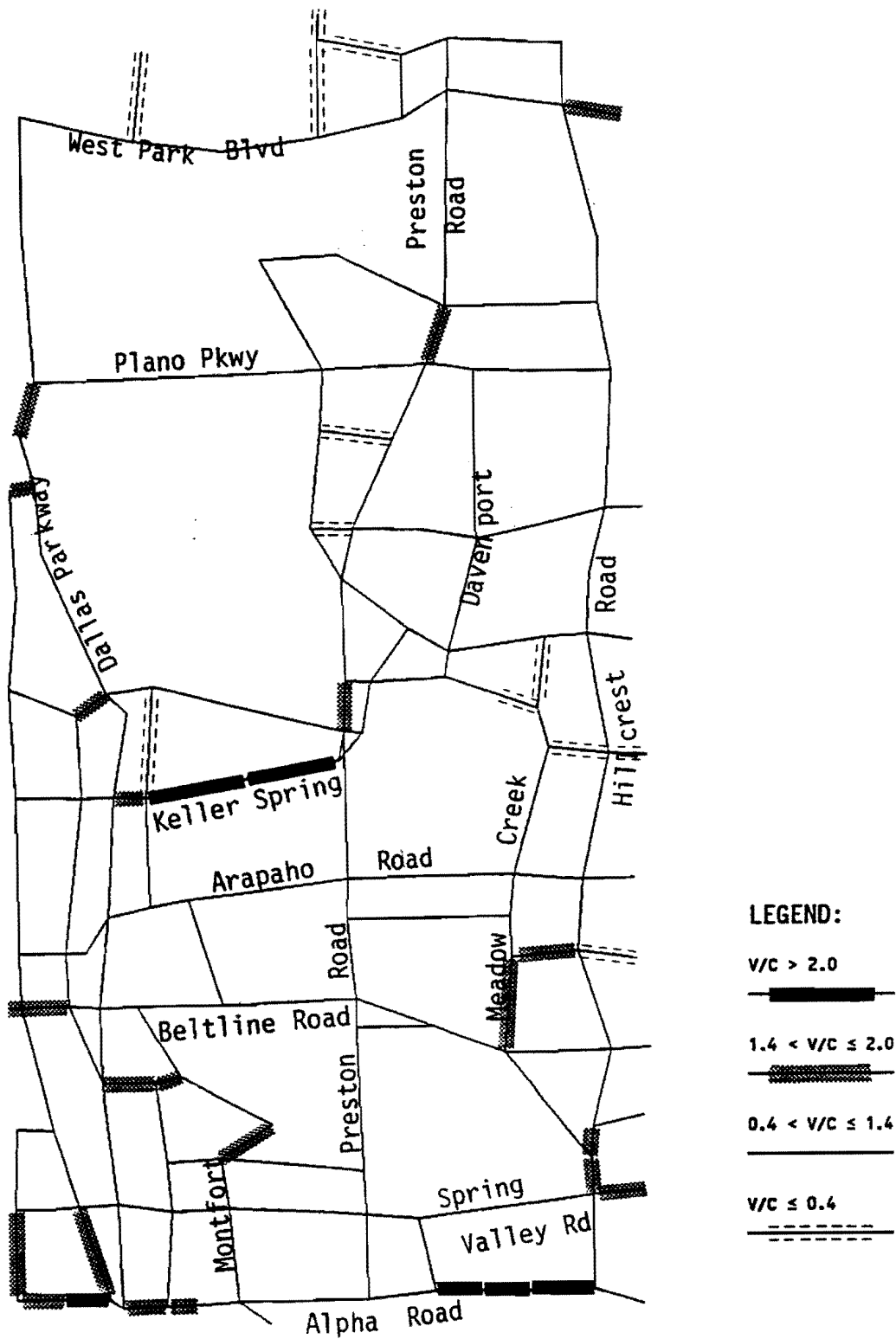


FIGURE E-5 Directional Link V/C Distribution in the Capacity Restraint Assignment Network (Weighted Average Incremental Procedure with Volumes Expanded to 100 percent)

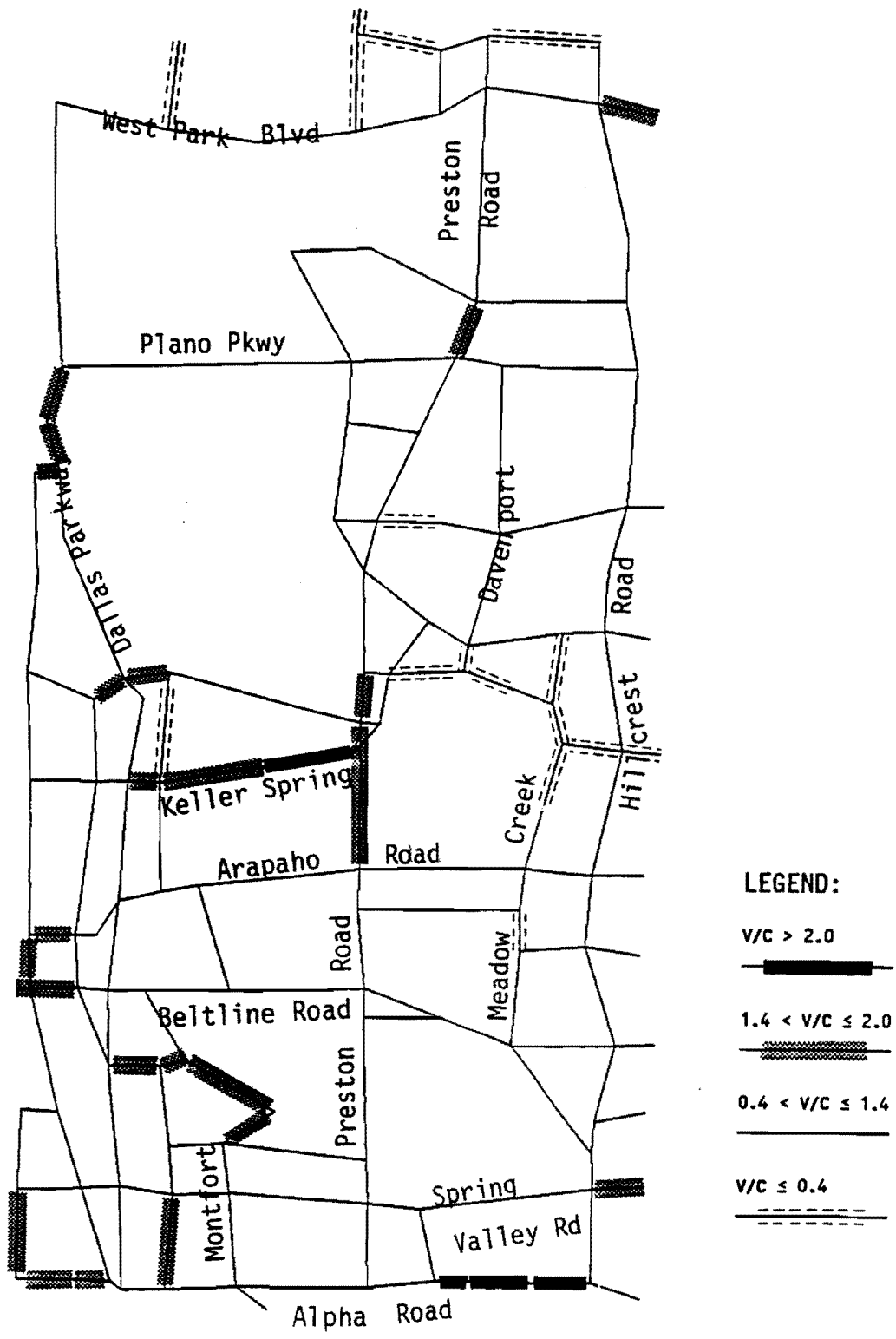


FIGURE E-6 Directional Link V/C Distribution in the Nodal Restraint Assignment Network (Weighted Average Incremental Procedure)

E-4 FINDINGS

In summary, the nodal restraint assignment was considered to be stable. For both the equal weighting and weighted average incremental procedures, the network performance measures of the nodal restraint assignment were found generally within the ranges of the various capacity restraint assignments. The analysis of directional link V/C distribution in the network indicates that the nodal restraint assignment generated an overall comparable traffic pattern to that of capacity restraint assignments. The nodal restraint assignment generated some higher directional link V/C's on a few major arterials than did the no-expansion capacity restraint assignment. However, the nodal restraint assignment generated comparable link V/C distribution to the expand-100 percent capacity restraint assignment. It should also be noted that the V/C measures were based on the coded link capacities which might be underestimated or overestimated. The micro-level analyses of the approach volumes and turning movements of a major arterial, Preston Road, indicate that the nodal restraint assignment produced a better replication of the ground counts than the capacity restraint assignments.