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HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN THE SEATTLE AREA

VOLUME IV: SIMULATION PLANNING AND EVALUATION

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16. ABSTRACT

The main research objective of this study is to improve the limitations of arterial traffic simluation models TRAF-NETSIM and TRANSYT-7F so that they can be used to overcome the above HOV lane planning deficiencies. For instance, after integrating the improved traffic operation models, the evaluation methods can be more adequate for consideration of complex variables associated with arterial HOV lanes. The traffic impacts of HOV lanes can be analyzed from these improved traffic models; therefore, the relationship between traffic impacts and mode shift behavior can be modeled more accurately. Finally, the guidelines to install a successful HOV lane can be derived according to the results of HOV lane evaluation. In brief, the objectives of this study are to:

1. Modify the logic of TRAF-NETSIM turning movements for simulating arterial HOV lanes realistically.

2. Modify the calculation algorithms of TRAF-NETSIM link statistics to provide the travel time of each vehicle type for HOV lane evaluation.

3. Develop the smoothing factor analytical method for TRANSYT traffic platoon dispersion model so that this model can be enhanced and applied appropriately in mixed-flow and priority lane traffic analysis.

4. Develop two iteration algorithms for TRANSYT traffic platoon prediction so that this model can simulate congested flow accurately.

The scope of this study is limited to focus on the planning process of arterial concurrent flow HOV lanes using traffic simulation models TRAF-NETSIM and TRANSYT-7F.

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HOV IMPROVEMENTS ON SIGNALIZED ARTERIALS IN SEATTLE AREA

VOLUME IV: SIMULATION PLANNING AND EVALUATION

by

Nancy L. Nihan
Professor

Ho-Chuan Chen
Graduate Research Assistant

Department of Civil Engineering
University of Washington
Seattle, Washington 98195

Washington State Transportation Center (TRAC)
University of Washington, JD-10
1107 N.E. 45th Street, Suite 535
Seattle, Washington 98105-4631

Washington State Department of Transportation
Technical Monitor
Miguel Gavino
Systems Project Planning Supervisor
Office of Urban Mobility

Prepared for

Washington State Transportation Commission
Department of Transportation, MS: 7370
Olympia, Washington 98504-7370

Transportation Northwest (TransNow)
135 More Hall, FX-10
Seattle, Washington 98195

and in cooperation with
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INTRODUCTION

Problem Statement

For several years now, the implementation of high-occupancy vehicle (HOV) lanes has been one of the most popular methods for alleviating urban peak-hour congestion problems. However, the planning process is still not equipped to provide enough information about traffic impacts for evaluating arterial HOV alternatives.

There are four typical deficiencies in the planning process of arterial HOV lanes that need improvement:

1. The evaluation methods are inadequate for consideration of the complex variables associated with arterial HOV lanes.

For instance, the before-and-after study, the most common HOV lane evaluation method, cannot consider any other alternative. In applying this evaluation method, each alternative would have to be installed and operated in practice. Other common HOV lane evaluation methods, such as the single criterion cost-benefit analysis as well as traditional transportation planning processes, are unable to provide detailed analyses about geometric design, traffic control, parking prohibition, and transit operation variables because no traffic operation model is used in these methods.

2. Current arterial traffic simulation models are presently inadequate in representing and evaluating HOV treatments.

Although TRAF-NETSIM and TRANSYT-7F, the two prevailing tools for arterial traffic analysis in North America, can furnish detailed analysis for general traffic improvement projects, neither simulates or analyzes arterial HOV lanes adequately.

The following problems with TRAF-NETSIM:

a. TRAF-NETSIM cannot simulate HOV lane turning movements realistically. While HOVs or right-turning single-occupancy vehicles (SOVs) actually use the curb-HOV lane for right turns, TRAF-NETSIM simulates the right-turning movements of carpool vehicles and of right-turning SOVs by forcing them all to use the second lane. Similarly, no left-turning vehicles are allowed to use an HOV lane located in the median to turn left -- contrary to actual practice, they must use its adjacent lane to turn left (This is illustrated later in Figures 4.1 and 4.2).

b. TRAF-NETSIM cannot realistically simulate T-intersection HOV lanes.

According to TRAF-NETSIM, carpool vehicles at T-intersection HOV lanes are incorrectly simulated as using the second lane instead of the curb HOV lane to turn right. Thus, TRAF-NETSIM cannot simulate the right-turn-on-red phenomenon at T-intersection HOV lanes realistically.

c. TRAF-NETSIM does not calculate travel time for HOV and general-purpose lanes separately.

The travel time savings comparison between HOVs and SOVs is the most important criterion in the evaluation of HOV alternatives; but TRAF-NETSIM does not differentiate between HOV and SOV lanes in terms of travel time.

d. TRAF-NETSIM cannot simulate the HOV lane queue-jump function.

The TRAF-NETSIM traffic signal timing design is coded for each approach rather than each lane. Therefore, TRAF-NETSIM cannot simulate signal timing for the HOV lane, nor can it simulate the intersection queue-jump function for arterial HOV lanes.

e. TRAF-NETSIM does not optimize traffic signal timing at all.

TRANSYT optimizes traffic signal timing well, but has the following problems :

a. TRANSYT simulation cannot properly distinguish between HOV and general-purpose lane flow patterns.

TRANSYT uses different smoothing factor parameters for the traffic platoon dispersion model to predict traffic-flow arrival and departure patterns. These patterns are then used for calculating measures of effectiveness (MOEs) (e.g., queue, delay, and stop-time). However, this approach offers no way to distinguish the parameters of the traffic-flow patterns for the two different types of traffic: HOV lane and general-purpose lane.

b. TRANSYT does not accurately simulate congested flow.

As free-flow traffic becomes congested, the traffic flow pattern and speed of these links should exhibit significant changes. However, TRANSYT uses no feedback algorithm to reinput these values (platoon dispersion factor and speed) to simulate congested flow.

c. TRANSYT cannot realistically simulate spillover traffic environments.

3) The methodology is not suitable for integrating HOV lane traffic impacts and commuter mode shift behavior.

The benefits of HOVs (e.g., saving travel-time); mode shift, and traffic volume are strongly related in HOV treatments. For instance (Figure 1.1), traffic volume in each general-purpose lane will increase if one existing lane is converted for HOV use. SOV users will be attracted to shift to the HOV mode if the associated benefits are significant. Then, for the existing travel demand, traffic volume of each general-purpose lane will decrease, and traffic volume in the HOV lane will increase accordingly. In this new traffic environment, commuter mode shift behavior will again be affected by the relative value of updated HOV benefits.

In other words, HOV users will return to using SOVs if the HOV's benefits are not significant. The feedback procedure will continue until the benefits of SOV users and HOV users are the same. However, current methodology does not account for interactive feedback between HOV lane traffic impacts and mode shift.

4) The guidelines for installing a successful arterial HOV lane are still limited.

For example, specific recommendations regarding arterial HOV lanes are rarely provided in current planning processes specifically relate to:

- geometric design,
- traffic characteristics (volume, speed, and density),
- congestion (travel time, delays, and stops),
- traffic composition,
- vehicle occupancy,
- traffic analysis method and tools, and
- traffic control strategies.

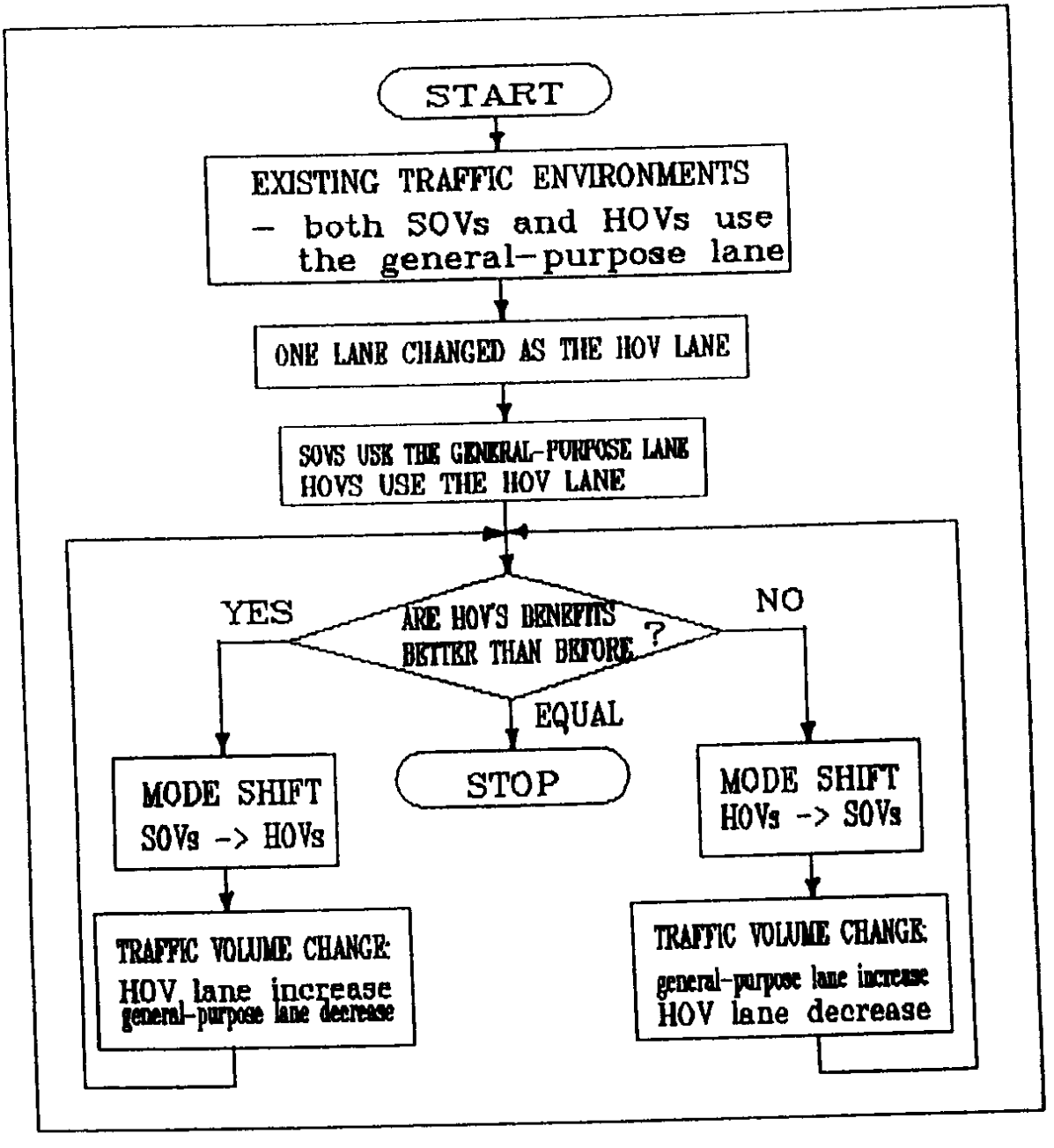


Figure 1.1 The relationship between traffic impacts and mode shift behavior after HOV lane installation (e.g., one existing lane converted to an HOV lane)

Study Objectives

The main research objective of this study is to address and improve upon the HOV lane planning limitations of the TRAF-NETSIM and TRANSYT-7F arterial traffic simulation models. For instance, after integrating the improved traffic operation models, the evaluation methods can more adequately consider complex variables associated with arterial HOV lanes. The traffic impacts of HOV lanes can be analyzed with these improved models; therefore, the relationship between traffic impacts and mode shift behavior can be modeled more accurately. Finally, guidelines for installing a successful HOV lane can be derived from the results of HOV lane evaluation. In brief, the objectives of this study are to:

1) modify the logic of TRAF-NETSIM turning movements to simulate arterial HOV lanes realistically,

2) modify the calculation algorithms of TRAF-NETSIM link statistics to provide the travel time of each vehicle type for HOV lane evaluation,

3) develop the smoothing factor analytical method for the TRANSYT traffic platoon dispersion model so that this model can be applied appropriately in mixed-flow and priority lane traffic analysis, and

4) develop two iteration algorithms for TRANSYT traffic platoon prediction so that this model can accurately simulate congested flow.

Scope of Study

The scope of this study is limited to a focus on the planning of arterial concurrent flow HOV lanes using traffic simulation models TRAF-NETSIM and TRANSYT-7F.

Case Study Areas

To apply and verify the modified traffic simulation models, TRAF-NETSIM and TRANSYT-7F, in a practical arterial HOV lane planning process, two case study locations were chosen. TRAF-NETSIM was modified and applied in a T-

intersection area HOV lane improvement project at NE Pacific Street and Montlake Boulevard NE in Seattle. The platoon dispersion analysis method was developed for TRANSYT-7F and applied in another arterial HOV lane improvement project at NE 85th Street in Redmond and Kirkland.

Study Approach

The first step in this study involved a review of state-of-the-art methods, including traffic operation software, mode shift models, HOV facilities, planning processes, evaluation methods, and implementation experiences.

The experimental design method and the most serviceable arterial traffic simulation models (TRAF-NETSIM and TRANSYT-7F) were then selected for consideration of the complex set of variables necessary for the evaluation of arterial HOV lanes. The alternatives to be evaluated were set up to represent different geometric designs, signal-timing plans, traffic characteristics, transit system operations, and HOV lane treatment strategies.

Next, the TRAF-NETSIM source code was modified for application to arterial HOV lanes. First, the field data were coded to run this model on a personal computer (PC). The travel-time data collected by means of the laptop computer 'license plate method' was used to verify and calibrate the existing baseline. The right-turning movements and travel-time subroutines in TRAF-NETSIM were modified to fit HOV lane traffic analysis. Finally, the sensitivity analysis and vehicle movements traced on the PC graphic display were monitored to confirm that the modified TRAF-NETSIM model performed HOV lane calculations realistically.

In the TRANSYT-7F simulation model, a new analytical methodology was developed for distinguishing HOV and SOV traffic platoon patterns. Geometric Series, travel time distributions, and the Bureau of Public Roads (BPR) link performance formula which describes the relationship between speed and traffic volume, were applied in developing this methodology. Two iteration algorithms for

traffic platoon dispersion prediction were also developed to enable TRANSYT-7F to simulate congested flow accurately.

To simulate the relationship between HOV lane traffic impacts and commuter mode shift behavior, the best method may be to integrate the traffic simulation model and the disaggregate logit model; however, the scenario method was used in this study to simply represent their possibilities in terms of traffic volume manipulation. For example, the carpool percentage was assumed to shift from 5 percent to 8 percent and the bus occupancy is assumed to shift from 27.3 persons/bus to 30 persons/bus following HOV lane implementation.

Finally, some important discoveries and research results from this study were described, summarized, and incorporated as recommendations for the planning and evaluation of arterial HOV alternatives.

Organization of Study

This paper is organized into six chapters. The problem statement, study objectives, and some comments regarding the scope of the study are presented in Chapter 1. Chapter 2 contains a description of the state-of-the-art arterial traffic operations software, including signal timing optimization and traffic simulation models. Chapter 3 introduces objectives, planning processes, evaluation methods, and selected implementation experiences pertaining to HOV treatments. Selection, modification, and application of the TRAF-NETSIM simulation model for arterial HOV lanes are discussed in Chapter 4. TRANSYT-7F simulation model selection, the prediction model and calibration process of platoon dispersion, a new analytical methodology for platoon smoothing factor, and the iteration algorithms for platoon prediction, etc. are discussed in Chapter 5. Chapter 6, the conclusion, contains study results and recommendations for future research.

CHAPTER 2

STATE-OF-THE-ART

ARTERIAL TRAFFIC OPERATIONS SOFTWARE

Introduction

Arterial traffic operations software is designed to examine the characteristics, advantages, and disadvantages of traffic operation alternatives on arterials. Traffic operation alternatives may include traffic regulatory measures and traffic control devices. Traffic regulatory measures include laws, ordinances, and regulations that control vehicles and pedestrians in the traffic stream. Intersections, speed, and parking controls, as well as one-way streets, are fundamental regulatory measures. Traffic control devices include the design, installation, operation, and maintenance of traffic signals, pavement markings, and channelization.

The operation of urban arterials and city streets differs greatly from that of freeways and expressways. Urban street systems can generally be grouped into four classes: freeways, major arterials, collector streets, and local streets:

1) Freeway system: This provides for rapid and efficient movement of large volumes of through traffic between areas and across the urban area. It is not intended to provide land access service.

2) Major arterial system: This provides for through traffic movement between areas and across the city with direct access to abutting property. It is subject to required control of entrances, exits, and curb use.

3) Collector street system: This provides for traffic movement between major arterials and local streets, with direct access to abutting property.

4) Local street system: This provides for direct access to abutting land and for local traffic movement." (51)

The two main types of computer software applications for arterials are signal timing optimization and traffic simulation models. Presently, computer programs

available for traffic signal timing optimization include SOAP (Signal Operations Analysis Package), PASSER II (Progression Analysis and Signal System Evaluation Routine), MAXBAND, and TRANSYT (TRAffic Network StudY Tool). Traffic simulation models include TEXAS (Traffic EXperimental and Analytical Simulation), NETSIM (NETwork SIMulation Model), TRANSYT, SCOOT (Split, Cycle and Offset Optimization Techniques), and other models (65, 13, 2, 69, 64, 33, 84).

Arterial traffic characteristics are examined in the first section of this chapter. The detailed arterial traffic operations software, which includes signal timing optimization and traffic simulation models, is then described in following sections.

Arterial Traffic Characteristics

Interruptions characterize traffic flow on arterials while the traffic flow on freeways and rural highways is uninterrupted. Arterial facilities are designed not only to favor the movement of through traffic, but also to provide access to abutting lands. Most, if not all of the intersections are at-grade, causing traffic flow interruptions. Traffic signals, stop signs, and other types of controls cause arterial traffic to stop periodically or to slow significantly regardless of traffic volume. Parking, driveway entrances, bus stops, turning movements, pedestrians, and other factors further inhibit traffic flow.

Vehicle operation on arterials is influenced by three main factors: (1) the arterial environment (geometric characteristics of the facilities and adjacent land uses); (2) the interaction between vehicles (determined by traffic density, the proportion of trucks and buses, and turning movements); and (3) the effect of traffic signals. Thus, traffic analysis models of arterials are more complex than those of urban freeways or rural highways (25).

Arterial Signal Timing Optimization Models

Computer programs including SOAP, PASSER II, MAXBAND, and TRANSYT are widely used to optimize arterial traffic signal timing plans. SOAP is designed specifically for optimizing isolated intersection signal timing. PASSER II, MAXBAND, and TRANSYT are three computer models especially prevalent in the U.S. (72).

1) SOAP model

SOAP, developed at the University of Florida Transportation Research Center, is designed for use on isolated intersections. It is a macroscopic deterministic model based on a set of simple Webster's equations (20). SOAP provides optimal timing at isolated intersections and is particularly useful in determining the number of phases at each signal (46).

A global optimum cycle length for pre-timed controllers is determined by examining the full range of practical cycles and choosing the cycle length that produces the minimum delay, subject to constraints imposed by specified minimum green times for each movement. Since the cycle computations must allow for minimum green times for each movement, it is essential that the cycle produced by the sum of the minimum green times does not exceed the specified maximum cycle (65).

2) PASSER II model

PASSER II is a macroscopic deterministic optimization model based on the bandwidth principle. It employs a platoon level representation for fixed (uniform) traffic volume and speeds. PASSER II can be used to analyze isolated intersection timing evaluations, progression signal timing optimization, and existing timing evaluations.

PASSER II seeks to maximize arterial two-way progression and to minimize signal delay by pursuing a series of arterial signal timing optimization processes. Signal timings are calculated to minimize the individual intersection delay based on

traffic volume, saturation flow, and minimum phase time for a given cycle length range (13).

PASSER II's optimization procedure implicitly enumerates the minimum interference values and uses a variant of the half-integer synchronization approach for relative offsets. Thus, the lowest minimum interference sum is selected as the optimal bandwidth solution. According to this optimization algorithm, PASSER II identifies the best cycle length, phasing sequence, and offsets to attain the greatest bandwidths in both directions of travel. PASSER II's unique advantage over other optimization programs is that it can be used to consider and select multiple phase sequences (58, 50, 12).

3) MAXBAND model

The MAXBAND program can be classified as a macroscopic optimization model. It uses a mixed integer linear programming technique to obtain offsets, cycle length, and left-turning phase sequences that maximize the weighted sum of bandwidths in both directions on an arterial. The optimization algorithm of this model guarantees that the global optimum solution will be found (40).

4) TRANSYT model

TRANSYT is a macroscopic deterministic simulation and optimization model. Its signal optimizer uses a hill-climbing technique to adjust splits and offsets to minimize the performance index (PI), a linear combination of delays and stops. The optimization process uses an iterative gradient search algorithm and cannot guarantee that the true optimal signal setting will be found (64). The detailed model logics of TRANSYT will be described in section 2.4.

Arterial Traffic Simulation Models

Computer simulation models including TEXAS, NETSIM, TRANSYT, and SCOOT are widely used to analyze arterial traffic flow. TEXAS is specially designed to evaluate isolated intersection alternatives. TRANSYT and NETSIM

can be applied in isolated intersections or urban networks. SCOOT is an adaptive signal timing system and is usually applied to urban arterials.

1) TEXAS Model

The TEXAS Model is a microscopic stochastic simulation model which was developed at the University of Texas to evaluate intersection signal timing.

A powerful simulation tool, TEXAS allows the user to evaluate a complex intersection based on individually characterized driver-vehicle units, in a defined environment. This model can simulate any intersection, from two uncontrolled one-way streets to complex intersections with multiphase traffic control.

TEXAS allows the user to record and subsequently display the progress of each individually characterized vehicle moving through a simulated intersection on a computer graphics screen. This animated graphics display allows the user to study the overall traffic flow or the behavior of any vehicle in detail.

This user-friendly program allows users to evaluate alternative intersection designs and traffic-control schemes quickly, accurately, and cost-effectively. Unfortunately TEXAS does not provide a function for analyzing the effect of adjacent signals and cannot be applied to arterial streets or networks. This model is most useful in evaluating isolated intersection alternatives (33).

2) TRAF-NETSIM model

NETSIM is a microscopic stochastic simulation model designed for application to traffic operations on urban street networks. Developed for the Federal Highway Administration (FHWA) in 1971, NETSIM (formerly called UTCS-1), has been subject to updates and improvements since its creation. The model was later integrated into TRAF simulation systems in the early 1980s hence, the 'TRAF-NETSIM' designation (54). NETSIM is designed a powerful tool primarily to analyze and evaluate a wide range of traffic control and surveillance concepts for complex street networks (42).

TRAF-NETSIM describes the operational performance of vehicles travelling over a network of surface streets in detail. The model is based on a fixed-time, discrete-event simulation approach which describes the dynamics of traffic operations in urban street networks. Each vehicle is individually represented and its performance is determined each second. NETSIM simulates individual vehicle behavior in response to any or all of a set of traffic factors, including: traffic volume, signal operations, turning movements, pedestrians, intersection configurations, bus operations, parking maneuvers, and lane closures due to construction (70).

Most operational conditions on urban streets can be simulated with this model. It is the most powerful computer program available for the analysis of traffic operations on arterial streets (54, 22, 32). NETSIM offers many features not included in other traffic software. For instance, it allows simulation of: isolated intersections, fixed time signals, actuated signals, STOP and YIELD signs, network, signalized intersections with different cycle lengths, saturated conditions, buses, lane closures, parking, HOV lanes, and various combinations thereof. Not included among these features, however, is signal timing optimization (38, 83).

3) <u>TRANSYT model</u>

TRANSYT is among the most widely applied traffic simulation and signal timing optimization programs in the U.S. and Europe. TRANSYT allows traffic engineers to optimize their coordinated traffic signal systems, which results in fewer delays and stops; not to mention a most significant benefit, reduced fuel consumption (14). TRANSYT consists of two main elements: (1) a macroscopic, deterministic traffic flow model that is used to compute the value of a specified performance index for a given signal network and a given set of signal timings; and, (2) a hill-climbing optimization procedure that changes signal timings and determines whether or not these changes improve the performance index.

TRANSYT was developed in 1968 by D.I. Robertson of the Transport and Road Research Laboratory (TRRL) in England (55). The American version of the program, TRANSYT-7F (based on TRANSYT), was modified for the Federal Highway Administration (FHWA) as part of the National Signal Timing Optimization Project. It is a macroscopic deterministic traffic simulation and signal timing optimization model. Macroscopic models consider platoons of vehicles rather than individual vehicles. Among macroscopic models, TRANSYT is especially useful because it simulates traffic flow in small time increments. Consequently, its representations of traffic are more detailed than those of other macroscopic models that assume uniform distributions within the traffic platoons. TRANSYT's traffic flow model divides the cycle into time increments of equal duration, called steps. A step typically ranges from 1 to 3 seconds, although the relationship between seconds and steps need not be an integer conversion. The duration of a step will, however, be the finest resolution to which signal timings can be represented in the simulation model. The smaller the step size, the finer the resolution (73).

Each signal phase is identified by its start and end times, which are then modified to account for the lost start-up time and green extension; these values are then used to calculate effective green times. This model constructs three typical traffic flow patterns: IN, GO, and OUT. 'IN' is the arrival pattern, including the arrivals at the stopline if traffic is not impeded by the downstream signal. 'GO' is the flow rate at each step which would leave the stopline if there were enough traffic to saturate the green signal. 'OUT' is the profile of traffic leaving the stopline, which is usually equal to 'GO' as long as there is a queue. Once the queue dissipates, it is equal to the 'IN' pattern for the duration of the effective green. The start/stop operation of signals tends to create platoons of vehicles that travel along

a link. The traffic model then utilizes a platoon dispersion algorithm to simulate the normal dispersion of platoons as they travel downstream.

TRANSYT includes an excellent traffic model that incorporates network geometry and traffic flows to estimate two measures of effectiveness (MOEs) -- delays and stops. A delay is composed of a uniform element, a random element, and the delay due to oversaturation. Uniform delay is calculated by averaging the queue length over the cycle. Random delay and delay due to saturation are calculated by a formula similar to Webster's (20), but corrected for the point in time at which the degree of saturation approaches unity. The number of vehicles stopped is equal to the number of vehicles arriving while a queue is present. However, if the delay to such vehicles is brief, only partial stops are counted.

TRANSYT employs a hill-climbing optimization technique. This iterative, gradient search technique requires extensive numerical computations. Hill-climbing optimization adjusts offsets and green times separately so as to minimize the value of the performance index (PI), which is equal to the weighted sum of stops and delays. TRANSYT also offers a powerful traffic simulation model useful for studying the variable effects of network configuration, platoon cohesion, stops, delays, fuel consumption, and arrival/discharge patterns at the stopline (53, 78).

Although field tests indicate that TRANSYT simulation produces good signal timing plans, it does have a number of deficiencies. The hill-climbing optimization algorithm, for instance, does not guarantee that a global optimum for the PI will be achieved; therefore, the model cannot guarantee that the best signal timing plan will be found. Moreover, TRANSYT is unable to simulate pedestrians, lane closures, parking, mixed-flow traffic, congested traffic, and carpool lanes in sufficient detail (28, 8, 34, 80).

4) <u>SCOOT model</u>

SCOOT is an adaptive signal timing model, was developed at the Transport and Road Research Lab (TRRL) in the U.K. (56). SCOOT's prime objective is to minimize the sum of average queues, that is, the performance index, in a given area. This model is based on the concept of cyclic flow profiles (CFPs). A CFP is defined as the average one-way flow of vehicles past any chosen point on the road during the cycle time of the upstream signal.

SCOOT's model logic entails three key features. The first is that CFPs can be measured as they occur in the street, rather than calculated off-line. This is achieved by monitoring the output from vehicle sensors that are installed upstream from each signal stop line. The second key idea is to run the traffic model in real time. The third key feature entails the idea that the coordination plan should be able to respond to a new traffic situation in a series of small frequent increments.

SCOOT thus offers an elastic coordination that can be expanded or contracted through optimizing splits, offsets, and cycle times to match the latest situation recorded by the CFPs. One of SCOOT's major advantages is that it does not require periodic updating of flow data in order to develop new timing plans. However, all these applications were tested in the U.K. (84).

5) Other models

Other simulation models, including INTRAS (INtegrated TRAffic Simulation), TRAFFICQ, TRAFLO, CONTRAM (CONtinuous TRaffic Assignment Model), and SATURN may also be applied in urban street networks (2).

INTRAS is a microscopic stochastic model specially developed for studying freeway incidents. It is based on a vehicle-specific, time-stepping simulation designed to represent traffic and traffic control on freeways and surrounding surface streets (Wicks 1980).

TRAFFICQ is a simulation model useful in studying pedestrian delay, vehicle queuing, and platooning behavior. It takes into account dynamic and stochastic variations, variance in road width, and movements temporarily blocked by other vehicles. TRAFFICQ is usually aimed at relatively small-scale systems or on occasion, at complex, isolated intersections (41).

TRAFLO is a system of four traffic simulation models (NETFLO I, NETFLO II, NETFLO III, and FREFLO) and one traffic assignment model which requires use of the Bureau of Public Roads' link travel time relationship. TRAFLO is a microscopic and macroscopic model for analyzing all networks (39).

CONTRAM is a traffic assignment and evaluation package that models traffic flows in urban networks that consists primarily of signalized, priority, and give-way intersections. This program uses a variation of Dijkstra's quickest route algorithm (68) for finding routes between particular origins and destinations. The main purpose of this model is the evaluation of signalized and unsignalized urban networks.

SATURN is a traffic assignment model based on a detailed simulation of intersection delays that employs a more general travel time relationship that is derived from the detailed simulation. Like CONTRAM, this model's main purpose is the evaluation of signalized and unsignalized urban networks (23).

CHAPTER 3

STATE-OF-THE-ART ARTERIAL HOV TREATMENTS:

PLANNING AND EVALUATION EXPERIENCES

Introduction

In recent decades, urban traffic congestion has become the most prominent transportation issue. Since the 1970s, factors including competition for highway and transit system construction funds, limited right of way, and problems pertaining to energy, resources, and the environment have led to increased emphasis on transportation system management (TSM) strategies as a means of addressing this issue (Levinson 1987). Some TSM strategies -- such as intersection traffic signal timing optimization -- can improve traffic speed and reduce vehicle delay. However, the value of these strategies reaches its limit as traffic volume on these nodes and links approaches highway capacity. Therefore, efforts to reduce peak-hour travel demand may be useful in achieving a higher level of service on highway facilities. Other than urban land use planning, the best transportation demand management (TDM) solution for arterial traffic problems is to provide priority incentives that encourage the use of public transit, carpools, or vanpools (37, 9).

HOV priority treatment is one of the most promising methods for reducing peak-hour arterial traffic congestion. Because HOV treatments can be implemented quickly, are inexpensive to build, and theoretically have high potential in terms of encouraging people to use HOV modes; they may reduce traffic volume and traffic problems during the peak-hour period.

This chapter briefly discusses different types of HOV treatments and the major steps involved in their planning and evaluation. Some experiences with the implementation of arterial HOV lanes are also described.

HOV Treatment Types and Objectives

HOV priority treatments are designed to offer specific benefits to people who carpool, vanpool, or use public transportation as opposed to those who do not. Using this definition, priority treatments can be grouped into four categories (6):

1) Economic treatments, which make a specific trip less expensive for HOV users. These include: preferential toll charges, preferential freeway congestion pricing, and preferential parking fees.

2) Convenience treatments, which primarily serve to make a specific trip more convenient for HOV users. These include: park-and-ride lots and preferential parking.

3) Space treatments, which reserve certain areas for HOV users and require low-occupancy vehicle users to change their routes. These treatments include: exclusive freeway ramps, transit malls, auto-restricted zones, reduced parking (with priority given to HOV users), and turning movement restrictions.

4) Time treatments, which reduce travel time for HOV users for a specific trip without requiring non-HOV users to change their routes. These include: separated roadways, contraflow freeway preferential lanes, contraflow arterial preferential lanes, concurrent flow freeway preferential lanes, concurrent flow arterial preferential lanes, exclusive bypass ramps (built to allow HOV users to bypass a congested ramp, usually done with a preferential ramp), preferential bypasses at metered ramps, toll facility preferential lanes, and signal preemptions.

Priority treatment for buses, vanpools and carpools is intended to help maximize the movement of people along a roadway. The advantages of HOV treatments, including travel time reduction, trip time reliability, travel cost reduction, and convenience, serve as significant incentives in encouraging people to choose the rideshare mode. Successful HOV treatments thus accomplish the following goals (21, 18, 75):

- induce mode shift to HOVs

- increase person-carrying capacity of highway facilities
- improve traffic flow and to reduce total travel time
- reduce or defer the need to increase highway vehicle-carrying capacity
- improve efficiency and economy of public transit operations
- reduce commuter transportation cost
- reduce fuel consumption
- reduce air pollution

The HOV Treatment Planning Process

A successful planning process will provide sufficient information to allow planners to propose and choose the HOV alternatives with the greatest potential efficiency prior to implementation. In general, the planning process should also include analysis of demand growth, concept design, operation plans, and consideration of such factors such as support facilities and programs, maintenance, implementation, and administration.

A previously developed generic HOV treatment planning process includes four stages: conceptual viability, alternative development, development of recommended alternatives, and plan adoption (19). Figure 2.1 illustrates the main tasks and their interrelationships at each of the four stages.

Conceptual Viability

Conceptual viability comprises the first stage of the planning process. The main tasks at this stage involve data collection, criteria selection, and viability assessment. Before determining whether HOV lane installation is warranted, data pertaining to transportation demand, traffic characteristics, geometric design, and the transit system must be compiled. Preliminary assessment criteria such as whether the level of congestion warrants treatment, whether adequate travel time savings would be made, and whether sufficient transportation demand exists should

then be selected. Any project that fails to meet these criteria should be excluded from further HOV treatment consideration.

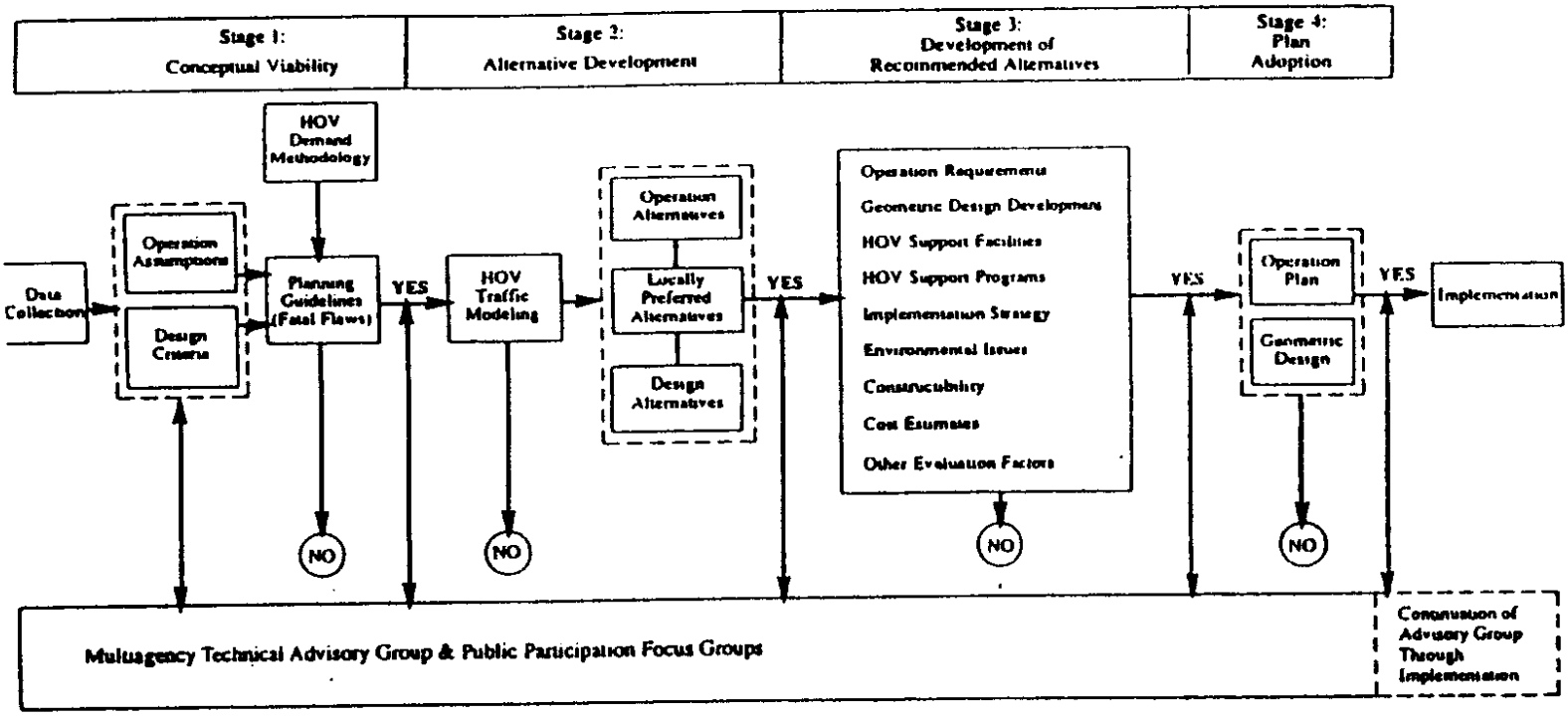


Figure 3.1 HOV lane planning process
Source: 19

Alternative Development

Alternative development comprises the second stage of the HOV treatment planning process. This stage consists of traffic modeling and the development of HOV alternatives. Traffic modeling replicates existing traffic characteristics and predicts possible alternatives, qualitatively or quantitatively. The information provided by traffic modeling is very useful in comparing controlling variables (e.g., demand growth, traffic control, geometric design, and operation management strategy) and for evaluating the effectiveness of each alternative (3, 15). Concurrently, at this stage engineers create a number of feasible design and operation alternatives. Following the evaluation process, the most cost-effective HOV options should be recommended for further study.

Development of Recommended Alternatives

Development of recommended alternatives comprises the third stage of the planning process. An operation plan and a geometric design plan should be included at this stage. The operation plan describes how a given facility is to be operated, maintained and administered, and includes specification pertaining to service and performance standards, operating periods, vehicle and user eligibility, enforcement, safety and incident management, and project administration. The geometric design plan describes a detailed engineering investigation the purpose of which is to respond to environmental issues, to prove the feasibility of recommended alternatives, and to provide input regarding the appropriate scale for subsequent preliminary engineering work.

Plan Adoption

Formal adoption of the HOV plan comprises the final stage of the HOV planning process. The recommendations of the HOV planning study are officially approved by representative boards, commissions, or other official bodies, and an implementation process is set forth.

HOV Alternatives Evaluation

The most difficult tasks involved in the current HOV treatment planning process are the development of new models and the application of existing ones for the purpose of evaluating HOV alternatives. A number of mode shift forecasting models (30, 42, 49, 57, 7, 79) and evaluation methods (52, 27, 43, 24) already exist for the evaluation of the effectiveness of HOV facilities. However, important concerns including traffic operation and environmental impact are seldom discussed. The need to develop an acceptable state-of-the-art HOV traffic model is a nationwide issue; and as such is the subject of continued research and evaluation (19).

HOV Mode Shift Models

In theory, HOV facilities affect commuter behavior, including mode choice and departure time changes. In Parody's study (49), a set of supply and demand models was used to predict peak-hour travel volumes for various freeway HOV strategies. Demand models were created by using a series of empirical before-and-after data from a number of actual HOV facilities throughout the U.S. Supply models were developed on the basis of speed-volume relationships that estimated changes in running speeds and travel times on the general-purpose lanes for different volume levels and capacity configurations. The models were then applied to predict equilibrium travel flows of vehicles on the general-purpose lanes and of carpools and buses on the HOV lanes. The models also forecasted the net change in travel volume due to mode shift, time of day, trip generation, and route diversion behavior.

In another study designed to forecast mode shift related to HOV facilities (79), mode splits were determined on the basis of the amount of travel-time savings that users would enjoy by using the preferential facilities rather than the mixed-flow lanes. Origin and destination characteristics were also taken into account. To predict the HOV mode-split values, a function of corridor statistical trends was also

established using data from before-and-after studies from nationwide HOV priority projects.

The HOV mode shift approaches described above were not based on behavioral models of individual commuter choice; moreover, their ability to account for route and departure time changes was very limited. For these reasons a logit route choice model and a corresponding departure time choice model were developed and then demonstrated in an HOV lane evaluation study (43). The models assume that travelers select route and departure times that provide the highest level of utility (using standard maximum likelihood techniques) and are standard multinomial logit form models.

HOV Alternatives Evaluation Methods

A review of HOV research and literature (52, 27, 31, 75, 43, 24, 74), indicates that common HOV evaluation methods include the following: goal-achievement analysis, cost-benefit analysis, cost-effectiveness analysis, level-of-service method, before-and-after study, and the commuter welfare approach. Each of these methods is described below.

1) Goal-Achievement Analysis

Goal-achievement analysis is often used for a subjective assessment of the extent to which the goals of a transportation system management (TSM) project have been achieved. Criteria considered in this method may include: measurement of improvements in person-carrying capacity, travel time savings, mode shifts, environmental effects, enforcement, and public opinion. This method provides a comprehensive set of data with which to assess the efficiency of a TSM project; but it does not provide a quantitative analysis with which to determine the relative importance of each measure of effectiveness (MOE). MOEs include: average speed, travel time, person through put, vehicle through put, number of accidents, and compliance rates (45).

2) Benefit-Cost Analysis

Cost-benefit analysis estimates all costs and benefits resulting from a project to monetary terms and then compares them. The outcome is a single ratio of costs to benefits. In the case of HOV lane evaluation, the costs and benefits of adding an HOV lane are compared with the hypothetical alternatives of doing nothing or of adding a lane for general traffic. The potential benefits of HOV treatments may include: travel-time savings, reduced vehicle operating costs due to smoother operation of highways, reduced costs through ridesharing, and arrival at destinations without delays. The potential costs of HOV treatments may include: construction, maintenance, and enforcement costs, and subsidies for the provision of additional transit and rideshare services. The chief drawback of cost-benefit analysis is that many MOEs cannot be expressed in economic terms; thus, they must either be excluded from the analysis or be assigned some arbitrary value.

3) Cost-Effectiveness Analysis

Cost-effectiveness analysis is among the most widely applied evaluation methods for HOV treatments. This method compares the costs of gaining an objective with the degree to which each alternative in a series of schemes approaches the same goal or objective. The advantage of this method is that it takes economic efficiency into account. However, it cannot compare the different magnitudes of improvement caused by different variables (75, 74, 24).

4) Level-of-Service Method

Polus (52) sets forth a level of service evaluation procedure in which a panel of decision makers representing the various interests affected by the transportation system allocate weighting factors to selected MOEs. The weighted worth of all MOEs is then totaled to arrive at the level of service of the transportation system, which allows the comparison of one strategy to another, enabling decision makers to select the most suitable alternative.

5) Before-and-After Study

The before-and-after study is another method commonly employed in HOV treatment. For comparing and assessing the practical effectiveness of HOV treatments, data pertaining to the congestion reduction, travel-time improvement, capacity increase, travel cost reduction, and safety are often collected before and after HOV treatment installations. For instance, in the Texas Transportation Institute HOV study, the same comparison items, including traffic speed, travel time, delay time, travel cost, and safety, were used for the evaluation of HOV priority treatment projects (31).

6) Commuter Welfare Approach

The commuter welfare approach is a new method for HOV lane evaluation. In the past, many HOV treatment studies used only selected measures of effectiveness (MOEs) as the criteria for evaluating HOV alternatives. However, using just selected portions of MOEs can result in critical bias in the evaluation process. The commuter welfare measure approach provides a framework for capturing all of the societal impacts, which are measured by assessing total commuter utility before and after HOV treatment implementation (43). It implicitly accounts for all commuter costs (time costs, vehicle operating costs, departure change costs, and route change costs) and provides more reliable evaluation results.

Arterial HOV treatment experiences

Bus priority treatments

Bus priority lanes were the earliest, and are still the most common HOV priority treatment. State-of-the-art freeway and arterial bus lanes in the U.S. and Canada are very diverse (Levinson 1987). Some significant examples follow:

1) freeway busways, such as those on special right-of-ways, and busways in freeway medians or right-of-ways

2) reserved lanes and ramps on freeways, including peak-hour bus preemption lanes, normal flow and contraflow bus lanes, toll plaza bus bypass lanes, exclusive bus access to non-reserved freeway lanes, metered freeway ramps with bus bypass lanes, and bus stops along freeways

3) reserved lanes on arterials and streets, such as bus tunnels, bus streets, CBD bus lanes, arterial curb bus lanes, CBD median bus lanes, arterial median bus lanes, and contraflow bus lanes

HOV Priority Treatments

The essential goal of traffic system management is to maximize overall efficiency. One way to do this is to give arterial HOVs a priority operating environment by providing exclusive HOV lanes. Arterial HOV lanes are designed to improve the speed, reliability, and attractiveness of bus flow or other HOVs, including carpools and vanpools.

Initially, arterial HOV treatments were limited to bus lanes on downtown streets. Priority lanes were less common, but were sometimes found along commuter arterials that had expressway characteristics. Since HOV occupancy is higher than that of SOVs, economic benefits for a transportation system increase when HOV travel time is reduced. Although increasing numbers of arterial HOV lanes have been installed over the past two decades, detailed evaluation results are still unavailable due to a lack of before-and-after data. The statistics that follow capture some of the common contraflow and concurrent flow arterial HOV treatment experiences.

1) <u>The Contraflow Arterial Preferential Lane</u>

In one nationwide study of 256 past and present HOV treatments (Batz 1986), 26 contraflow arterial preferential lane treatments were found, of which eight cases were suspended. Of these, three were suspended because of safety problems,

two because of roadway construction, and one each because of prohibitively high operation cost, low utilization and bicycle lane conversion.

Considering the number of treatments, before-and-after data is surprisingly scarce; but the available data (11 sites) did show increases in bus use, congestion reduction, and travel time and cost savings for HOV users after contraflow arterial preferential lanes were implemented.

2) The Concurrent Flow Arterial Preferential Lane

In the same study, 95 HOV treatments involving concurrent flow arterial preferential lanes were cited. This arterial HOV lane treatment was by far the most common. However, 22 cases of these treatments were suspended for the following reasons: opening of concurrent freeway lane (one), safety problems (one), transit strike (one), high operating costs (one), opening of light rail system (two), enforcement problems (four), reconstruction of the roadway (five), low utilization (six), and unknown (one). In 11 other cases, failure to enforce the treatments led to their suspension. Results from the available before-and-after study data (33 sites) were somewhat mixed. Most treatments of this type increased carpool and transit use, thus reducing congestion and the need to expand the roadway. Travel time and cost were also reduced for HOV users, thus improving HOVs reliability. The most serious problems associated with these treatments were enforcement and the possibility of increased accidents (although seven of ten treatments showed no increase in accidents).

HOV Implementation Problems

HOV treatments can lead to or experience several types of problems. Enforcement, politics, and safety are major potential problem areas (66, 47).

1) Enforcement

HOV enforcement is difficult and expensive to carry out. Although physically separated HOV treatments do not present enforcement problems, concurrent flow lanes can be a headache. Allowing carpools and vanpools to travel on HOV lanes increases enforcement problems because it is necessary not only to see vehicles but to count their occupants. Consistent enforcement is often cited as a key factor in HOV success, but it is usually costly.

2) Accidents

Accident rates probably correlate with enforcement, but they also vary with the type of HOV treatment and are influenced by different alternatives. An HOV lane separated by a permanent concrete barrier is safer. With regard to various non-barrier HOV treatments, the concurrent flow preferential lanes are the least safe because of the speed differential between adjacent lanes and weaving traffic. At the same time increased density in non-priority lanes may increase the potential for accidents.

3) Politics

An increasing accident rate, a lower HOV lane usage rate, and a strict enforcement policy can negatively affect public perception of HOV treatments. For instance, removal of a general-purpose lane on an already congested highway in order to create an HOV lane may lead to controversy over HOV lane treatments. Even in a situation in which a lane is added without undue difficulty, there may later be political repercussions if the added capacity is perceived to be underutilized.

HOV Planning Guidelines

HOV planning guidelines that can serve as preliminary criteria for the assessment of HOV alternatives in the early project development process may be drawn from past studies (21, 10, 19). In establishing a successful HOV priority system, the following factors must be considered:

1) Significant traffic congestion:

An HOV lane treatment should be considered only where there is severe and recurrent traffic congestion on the roadway.

2) Predictable travel time savings:

An HOV lane should be considered only where it will provide a reliable travel time reduction for HOV users. Generally, the single most important predictor of a successful HOV lane is its ability to reduce travel time and to provide reliable travel time to users.

3) Sufficient potential ridesharing trips:

This requires sufficient common trip origins and destinations along the proposed HOV lanes. Sufficient ridesharing trips can provide enough HOV lane usage to avoid public perception of underutilization.

4) Sufficient system support facilities and programs:

HOV lane implementation should include effective collection and distribution support facilities, such as park-and-ride and park-and-pool lots; and on-line or off-line bus transit stations, for the convenience of HOV users. Additionally, HOV support programs, including: transit service marketing, ridesharing promotion, parking demand management, and public information, should be considered in HOV projects because of their value in promoting mode shifts.

5) Other HOV treatment considerations:

The planning and evaluation process of a successful HOV lane proposal should also consider benefits and costs, public support, enforcement, street geometry, and safety.

CHAPTER 4

TRAF-NETSIM SIMULATION MODEL SELECTION, MODIFICATION, AND APPLICATION FOR ARTERIAL HOV LANES

Introduction

The traffic simulation model that can replicate the traffic environment and test each HOV alternative before implementation is one of the most useful tools for the analysis of HOV lane traffic. As described in the section of Chapter 1 entitled "Problem Statement," it is impossible for traffic engineers and urban planners to select the best options by installing all HOV lane alternatives and subsequently applying the before-and-after study method to evaluate each one. It is also very difficult to apply other non-traffic operation models to obtain related performance values such as traffic speed, travel time, delay time, fuel consumption, and vehicle emissions for HOV lane evaluation. What traffic simulation models can do is to test alternative control strategies and geometric configurations in a controlled environment. Some types of detailed information, that is virtually impossible to obtain from field tests, can be gathered very successfully through simulation (29, 63). Because of its ability to overcome current arterial HOV lane planning process deficiencies by providing sufficient detailed traffic impact information, the traffic simulation model was chosen as the main tool for this study.

This chapter will focus on the process by which the simulation model is selected, modified, and applied to arterial HOV lanes. The chapter begins with a discussion of TRAF-NETSIM's advantages and drawbacks, and how these features may influence its selection as a model. Next discussed is the process by which TRAF-NETSIM is modified and calibrated for HOV lane evaluation. Finally, TRAF-NETSIM application in a signalized arterial HOV lane project is described.

TRAF-NETSIM Simulation Model Selection for Arterial HOV Lanes

The criteria for evaluating arterial traffic simulation model alternatives include accuracy and detail, the ability to represent dynamic queuing effects, the resolution of the traffic flow model, and the resolution of the traffic signal representation on parallel arterials (2). The traffic operations software described in Chapter 2 were all considered for application in the arterial HOV lane traffic analysis. However, after a literature review and a preliminary evaluation of fundamental requirements, some models were found to be clearly incompatible with the objectives of modeling geometric design, traffic characteristics, traffic control, and management strategies in arterial HOV lane corridors. For instance, the SOAP and TEXAS models are not appropriate for arterial network traffic modeling, because they are specially designed for the evaluation of isolated intersection alternatives. The PASSER II and MAXBAND signal timing optimization models are not suitable for HOV lane traffic characteristics simulation. Finally, the arterial simulation models, TRAF-NETSIM and TRANSYT-7F, were chosen as the most serviceable study tools for evaluating arterial HOV lanes, although some logic problems needed to be addressed.

Advantages of TRAF-NETSIM for Arterial HOV Lane Application

In general, the arterial HOV lane planning process may involve design variables of considerable complexity, including: geometric designs, traffic signal timing plans, and HOV management strategies. Fortunately, TRAF-NETSIM is able to handle these design variables better than most other traffic simulation models. As mentioned previously, TRAF-NETSIM is a microscopic traffic simulation model in which all vehicles are treated individually (54). This gives it the ability to represent real traffic characteristics in more detail than macroscopic traffic simulation models. In brief, TRAF-NETSIM offers the following advantages for arterial HOV lane applications:

1) Complex HOV lane traffic flow can be simulated with sufficient specificity.

To simulate arterial HOV lane treatment realistically, a more complex, mixed-flow (the distinguishing traffic flow of general-purpose lane and HOV lane) traffic environment needs to be described in the traffic model. TRAF-NETSIM has the capability to simulate HOV lane traffic characteristics; therefore, it provides more detail than other models.

TRAF-NETSIM's microscopic simulation model can provide the resolution of the traffic flow model and the traffic signal representation on arterials. The traffic stream can be modeled very explicitly. Each vehicle on the network is not only treated as an identifiable entity, but is also identified by category and by type. The four categories are: automobile, carpool, truck, and bus. Within these categories, up to 16 different types of vehicles may be specified, based on different operating and performance characteristics. In addition, the driver behavior characteristics (ranging from passive to aggressive) can be specified by the user according to the simulated traffic environment. A vehicle's kinetic properties (position, speed, acceleration), as well as status (queued or free-flowing) are then determined in each 1-sec time step. Turning movements, free-flow speeds, queue discharge headways, and other vehicle-specific behavior attributes are assigned stochastically (random sampling from discrete and continuous distribution). The vehicles are moved each second according to the car-following logics in response to traffic control devices, pedestrian activity, transit operations, the performance of neighboring vehicles, and other conditions that influence driver behavior. As a result, each vehicle can reflect real-world arterial HOV lane traffic flow more specifically.

2) Complicated HOV lane design variables can be considered more completely.

To plan successful arterial HOV lane treatments, all of the controlling variables (e.g., demand growth, traffic control, geometric design, and operation

management strategies) should be compared. Since TRAF-NETSIM represents traffic characteristics in great detail, carpool or HOV lanes can be channelized and simulated accordingly.

TRAF-NETSIM allows the input and simulation of almost all complex traffic environment factors. These include the following: link length, grade, turning pocket, lane channelization, turning movement, start-up lost time, queue discharge headway, free flow speed, sign or pre-timed signal control timing, actual signal coordination, right-turn-on-red, entry link volume, source/sink volume, load factors, short-term events, long-term events, parking activity, spillback, acceptable gap, bus dwell time, bus station, bus path, bus route, bus flow, lane block, traffic compositions, vehicle occupancy. Thus, this model allows for a complete consideration and analysis of arterial HOV lane design variables.

3) HOV lane simulation results that are not obvious can be demonstrated or monitored more clearly with this model.

To date, perhaps the most critical challenge for any simulation model is to persuade people that the simulation outputs already represent the real world. For this reason, TRAF-NETSIM provides an interactive computer graphics system (GTRAF) with a new and highly efficient methodology for analyzing NETSIM's simulation results.

The graphic display, including static and dynamic vehicle animation, can vividly demonstrate simulation input data and output results. For instance, the vehicle animation display allows the viewer to observe the detailed movement of vehicles on a selected link at specified intervals. Each vehicle is color-coded to indicate its intended turn movement through the downstream intersection. At each snapshot, the display can identify the time, the signal indication, the number of vehicles discharged and stopped as well as the position of each vehicle on the link (4).

For the purposes of simulating arterial HOV lane treatment, the dynamic vehicle animation can be a very helpful tool. It allows the user to calibrate and validate the model, and to confirm that all the simulation outputs will indeed represent the simulated traffic environment.

4) Enhanced HOV lane programs can be applied more widely and with more significant results to this program.

Since 1971, TRAF-NETSIM has been applied extensively to a variety of traffic problem areas in the U.S. and is perhaps the most widely-used traffic simulation model (54). However, as described in the section concerning HOV alternatives evaluation, arterial HOV lane studies have seldom used traffic simulation models. In fact, problems in the application of TRAF-NETSIM to HOV lane traffic analysis still remain. Therefore, upgrading this widely-used model to give it the capability of simulating arterial HOV lanes realistically will constitute a significant contribution to the field of transportation planning.

Problems of TRAF-NETSIM for Arterial HOV Lane Application

Researchers working on this study found six typical problems:

1) The HOV lane turning movement logic problem

TRAF-NETSIM lane turning logic with respect to HOV lanes is not realistic. Basically, this model is designed to simulate the most common concurrent, mixed-flow arterial HOV treatments: median and curb HOV lanes. However, in both cases, TRAF-NETSIM allows only through-carpool vehicles to use the carpool or HOV lane.

In other words, no vehicle is allowed to use the curb HOV lane to turn right even if the vehicle is a carpool or SOV. Instead, all right-turning vehicles are assigned to the second lane to turn right (Figure 4.1). Similarly, no left-turning vehicle is allowed to use the median HOV lane to turn left, but must instead use its outside lane (Figure 4.2). This turning movement logic conflicts with the real world

where right-turning vehicles do use the curb HOV lane to turn right, and left-turning vehicles use the median HOV lane to turn left. This logic needs to be modified before this model can be applied to HOV lanes.

2) The turning problem for HOV lane carpool vehicles at T-intersections

The current TRAF-NETSIM T-intersection HOV lane turning treatment is not reasonable. According to the TRAF-NETSIM link characteristics coding process (70), if there are two right-turn general-purpose lanes at a T-intersection, the curb lane should be channelized as a right-turn lane and the second lane should be channelized as a right-diagonal-turn lane (Figure 4.3). Similarly, if there are two right-turn lanes at a T-intersection, but one of them is a carpool or HOV lane, the curb lane should be channelized as a carpool or HOV lane and the second lane should be channelized as a right-diagonal-turn lane (Figure 4.4). As previously stated, TRAF-NETSIM HOV lane turning movement logic allows only through-vehicles to use the carpool or HOV lane, and the right-turning or right-diagonal-turning vehicles must use the second lane to turn right. Therefore, for the above two right-turn lane (one is a curb HOV lane, and the other is a right-diagonal-turn lane) T-intersection traffic environments, no vehicle will be found using the HOV lane since all vehicles are right-turn and no through-vehicle is simulated. In other words, all carpool vehicles are incorrectly simulates as using the second lane instead of the curb HOV lane (Figure 4.5) for right turns. Likewise, two lane left-turn movements (one is a median HOV lane, and the other is a left-diagonal-turn lane) in T-intersection traffic environments have the same problem, which needs be resolved before engineers will be able to use this model to simulate T-intersection HOV lanes.

3) The HOV lane queue-jump function problem

An HOV lane queue-jump or queue-bypass at an isolated signalized intersection bottleneck is one type of short preferential treatment that allows HOVs

to avoid traffic congestion and save time. For example, the early-moving preemption or last-closing signal timing treatment for carpool or HOV lanes can provide significant time savings for HOV users. Unfortunately, the TRAF-NETSIM traffic signal timing design is coded for each approach rather than each lane. Therefore, TRAF-NETSIM cannot simulate signal timing for each lane and cannot simulate the intersection HOV lane queue-jump function.

4) The right-turn-on-red problem for HOV lane carpool vehicles at T-intersections

Another problem with TRAF-NETSIM is that it cannot simulate the right-turn-on-red phenomenon for HOV lane carpools at T-intersections. This is mainly due to the fact that TRAF-NETSIM HOV lane turning movement logic allows only through-carpool vehicles to use carpool or HOV lanes. No right-turning or right-diagonal-turning vehicle may be assigned to the curb HOV lane. Thus all right-turning vehicles must use the second lane to turn right; no right-turn-on-red is permitted.

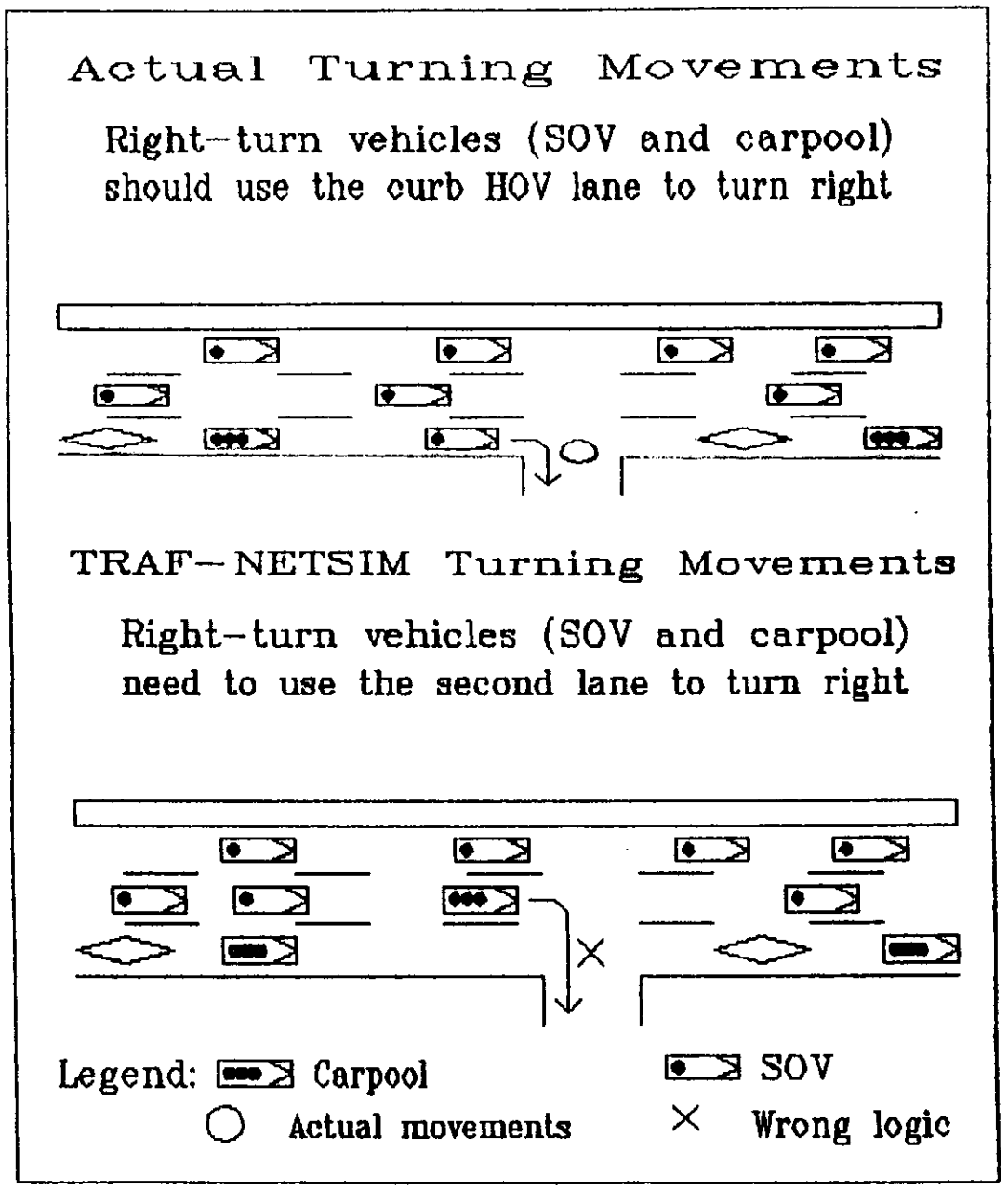


Figure 4.1 The curb HOV lane turning movement logic problem

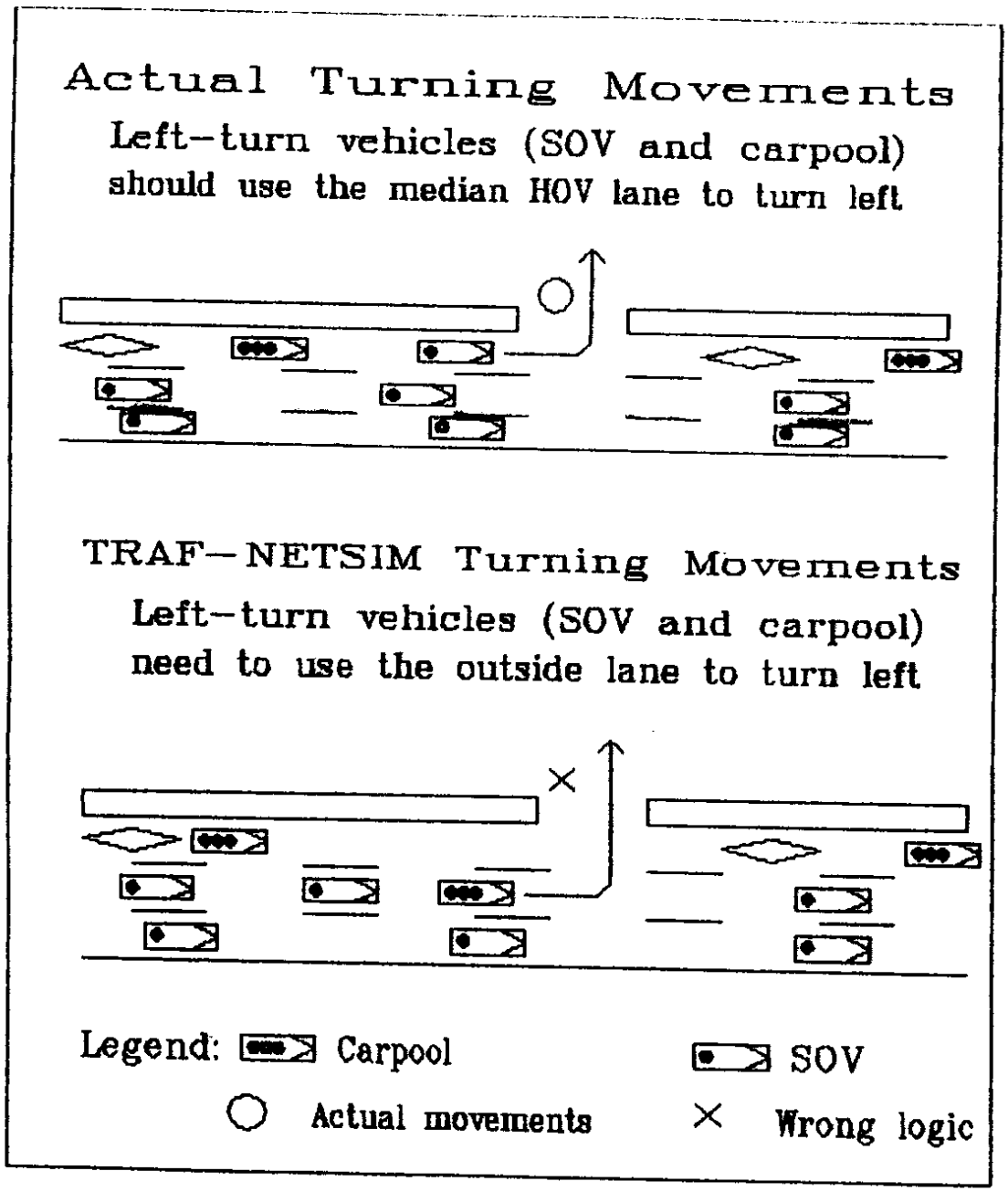


Figure 4.2 The median HOV lane turning movement logic problem

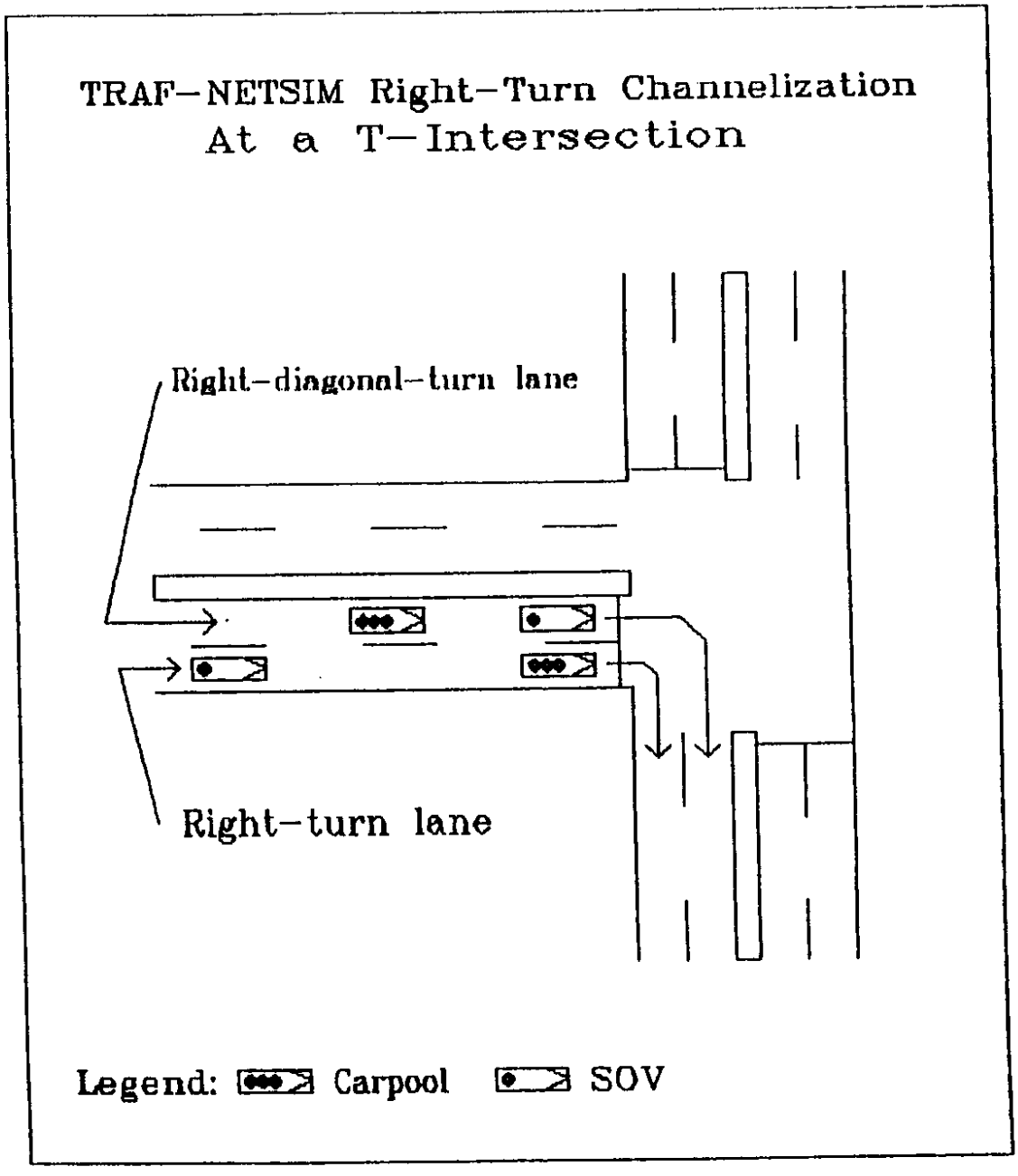


Figure 4.3 The TRAF-NETSIM channelization of two right-turn general-purpose lanes at a T-intersection

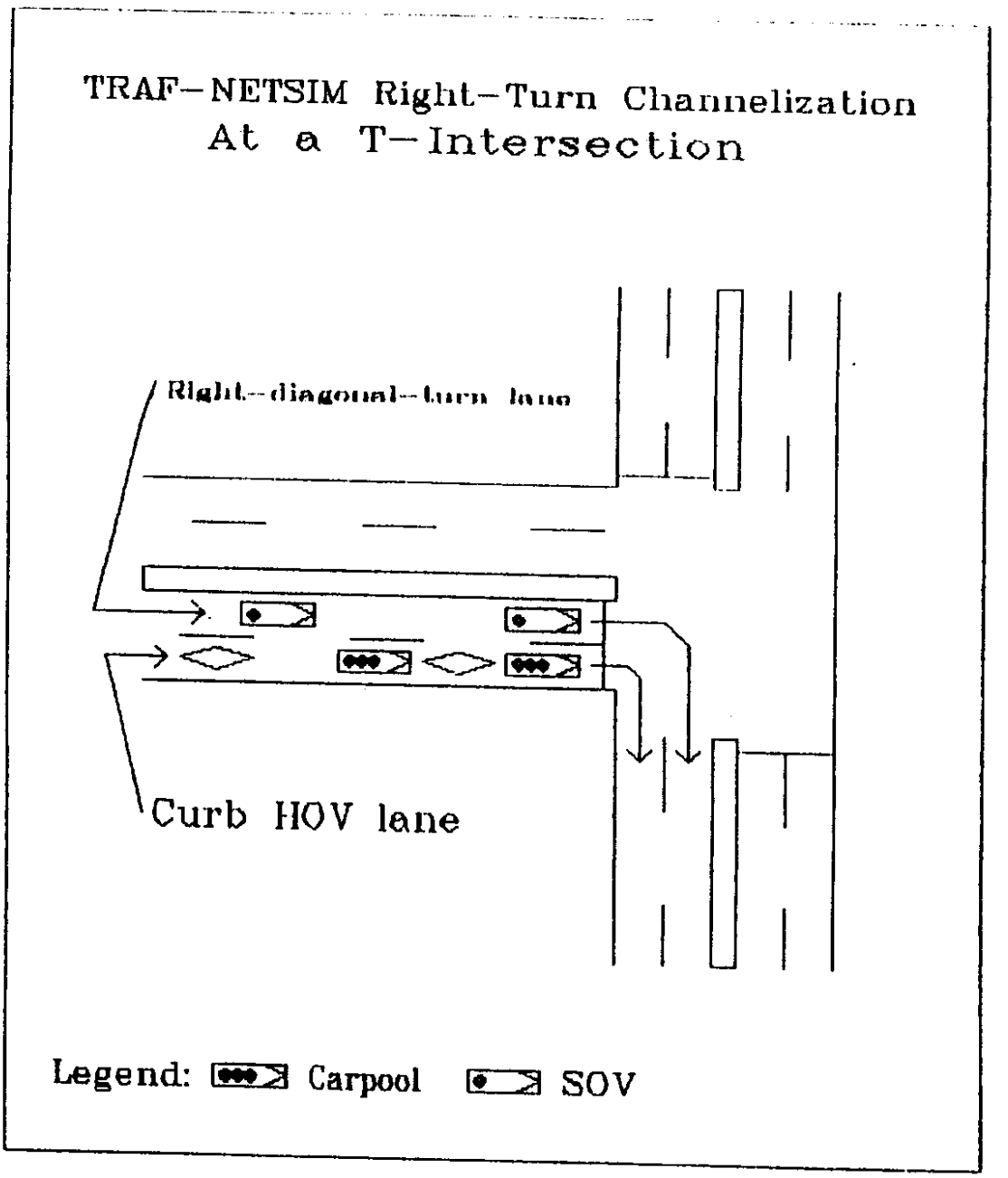


Figure 4.4 The TRAF-NETSIM channelization of two right-turn lanes (One is a curb HOV lane) at a T-intersection

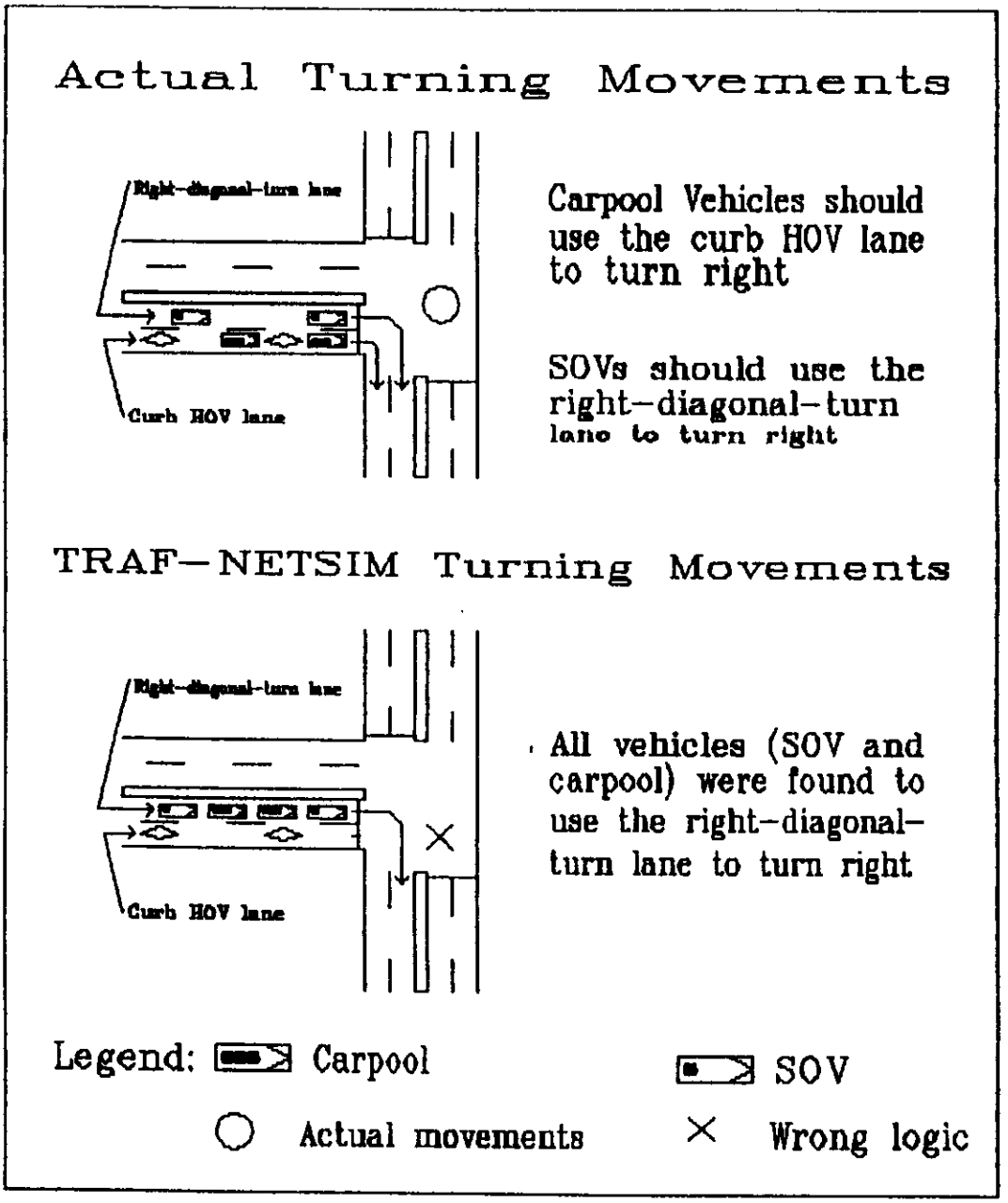


Figure 4.5 The T-intersection HOV lane turning treatment problem

5) The HOV and general-purpose lane travel time output problem

In general, the travel time savings for HOV users is the most important criterion in the evaluation of HOV alternatives. However, TRAF-NETSIM outputs do not provide separate travel times for HOV and general-purpose lanes. The travel time for each vehicle determined by TRAF-NETSIM outputs is based on each link and equals the average travel time of all four vehicle types (auto, truck, carpool, and bus).

Although TRAF-NETSIM outputs are also provided in person-specific units, such as person miles, person trips, and person travel time, these data are not helpful in calculating the travel time savings of HOV users. Furthermore, the person travel time output does not make sense for HOV evaluation, because the average vehicle travel time, rather than the average person travel time, is incorrectly used in the formula. TRAF-NETSIM calculates the person travel time (person-min) of each link by multiplying person trips (Table 4.1) by the average travel time of each vehicle (Table 4.2):

Person travel time = person trips x average travel time of each vehicle

(4.1)

For example, the person travel time (30.0 person-min) of link (1, 11) is equal to person trips (117.6 persons) times average vehicle travel time (15.3 seconds/vehicle). So, if there are five SOVs using the general-purpose lane and one bus using the HOV lane through one link (the occupancy of the SOV is one passenger; and the occupancy of the bus is 50 passengers), and the travel time of the SOV and the bus is 40 seconds and ten seconds, respectively, then using Equation (4.1), the person travel time is equal to 55 person trips times 35 seconds (average vehicle travel time):

Person travel time = $(5 + 50) \times \{[(5 \times 40) + (1 \times 10)] / (5 + 1)\} = 55 \times 35 =$ 1925 person-sec.

However, the real person travel time of five SOV passengers should be 40 seconds (SOV travel time) instead of this 35 second (average vehicle travel time). Likewise, the real travel time of 50 bus passengers should be ten seconds (bus travel time). Therefore, the correct person travel time should be equal to the sum of person trips times the person travel time of each vehicle type:

Person travel time = 5 (SOV passengers) x 40 (SOV travel time) + 50 (bus passengers) x 10 (bus travel time) = 700 person-sec.

Table 4.1 TRAF-NETSIM person measures of effectiveness output

LINK	PERSON MILE	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(8011. 11)				
(8021. 21)				
(8031. 31)				
(8022. 22)				
(8013. 13)				
(8023. 23)				
(8033. 33)				
(1. 11)	11.1	117.6	7.8	30.0
(1. 21)	13.6	144.8	8.6	35.9
(1. 31)	10.6	112.3	8.3	26.5
(2. 22)	4.3	45.3	1.9	12.1
(3. 13)	10.6	112.8	6.5	27.8
(3. 23)	22.7	239.9	39.4	84.8
(3. 33)	29.4	313.7	20.7	71.4
(31. 1)	23.1	243.8	126.2	166.0
(2. 1)	12.4	131.6	93.4	114.8

Table 4.2 TRAF-NETSIM average vehicle travel time output

LINK	VEHICLE MILES	VEHICLE TRIPS	VEHICLE MINUTES MOVE TIME	VEHICLE MINUTES DELAY TIME	VEHICLE MINUTES TOTAL TIME	RATIO MOVE/ TOTAL	MINUTES/MILE TOTAL TIME	MINUTES/MILE DELAY TIME	SECONDS / VEHICLE TOTAL TIME	SECONDS / VEHICLE DELAY TIME	SECONDS / VEHICLE QUEUE TIME	SECONDS / VEHICLE STOP TIME	AVERAGE VALUES STOPS (%)	AVERAGE VALUES VOLUME VPH	AVERAGE VALUES SPEED MPH
(8011. 11)		100												800	
(8021. 21)		75												450	
(8031. 31)		188												1128	
(8022. 22)		42												252	
(8013. 13)		117												702	
(8023. 23)		96												576	
(8033. 33)		96												576	
(1. 11)	8.56	91	17.1	6.1	23.2	0.74	2.71	0.71	15.3	4.0	0.0	0.0	0	546	22.2
(1. 21)	10.54	112	21.1	6.7	27.8	0.76	2.63	0.63	14.9	3.8	0.0	0.0	0	672	22.8
(1. 31)	8.18	87	14.1	6.4	20.5	0.69	2.51	0.78	14.1	4.4	0.0	0.0	0	522	23.9
(2. 22)	3.31	35	7.9	1.4	9.3	0.85	2.81	0.43	16.0	2.5	0.0	0.0	0	210	21.3
(3. 13)	8.19	87	16.4	5.0	21.4	0.76	2.62	0.62	14.8	3.5	0.0	0.0	0	522	22.9
(3. 23)	8.90	94	17.8	15.4	33.2	0.54	3.73	1.73	21.2	9.8	2.3	2.7	20	564	16.1
(3. 33)	22.77	243	39.3	16.0	55.3	0.71	2.43	0.70	13.7	4.0	0.0	0.0	0	1458	24.7
(31. 1)	17.89	189	30.9	97.8	128.7	0.24	7.19	5.47	40.9	31.1	20.8	19.3	72	1134	8.3
(2. 1)	9.64	102	16.6	72.4	89.0	0.19	9.24	7.51	52.4	42.6	32.0	30.2	87	612	6.5

TRAF-NETSIM calculates the person trips of each link according to vehicle trips, traffic composition, and vehicle occupancy.

Person trips = (vehicle trips x auto percentage x auto occupancy) + (vehicle trips x truck percentage x truck occupancy) + (vehicle trips x carpool percentage x carpool occupancy) + (bus trips x bus occupancy) (4.2)

Therefore, the person travel time should be calculated as:

Person travel time = (vehicle trips x auto percentage x auto occupancy x auto travel time) + (vehicle trips x truck percentage x truck occupancy x truck travel time) + (vehicle trips x carpool percentage x carpool occupancy x carpool travel time) + (bus trips x bus occupancy x bus travel time) (4.3)

Unfortunately, the travel time of each vehicle type in Equation 4.3 is not currently available for TRAF-NETSIM statistical manipulation; therefore, the correct person travel time cannot be calculated directly from its outputs. The TRAF-NETSIM source code will need to be modified to provide the travel time for each vehicle type before engineers can apply this model to the HOV lane evaluation process.

6) The traffic signal timing optimization problem

HOV lanes can help to alleviate peak-hour traffic congestion; and they can be even more effective with up-to-date signal timing plans. Signal timing is important for arterial traffic management. Since the traffic flow will change following HOV installation, the signal timing plan should be updated accordingly. In other words, a successful HOV lane plan should also incorporate the optimized signal timing plan. Unfortunately, TRAF-NETSIM does not provide a signal-timing optimization function.

TRAF-NETSIM Simulation Model Modification and Calibration

In order to simulate and evaluate arterial HOV alternatives effectively, the TRAF-NETSIM source code was modified in this study to remove the model's four principal drawbacks: HOV lane turning movement logic, T-intersection HOV lane carpool vehicle turning treatment, T-intersection HOV lane carpool vehicle right-turn-on-red, and HOV and general-purpose lane travel time output problems.

To confirm that all the simulation outputs would indeed represent the simulated traffic environment, two methods were used to calibrate this modified simulation model in the TRAF-NETSIM application to HOV lanes at NE Pacific Street in Seattle (Section 4.4). The first is the graphic display monitoring method. TRAF-NETSIM provides a powerful interactive computer graphics system, GTRAF, with which the model can be calibrated and validated from the dynamic vehicle animation display on a PC. At the same time, the cumulative statistics outputs of TRAF-NETSIM provide other important quantitative data for this model calibration process.

The HOV Lane Turning Movement Logic Problem

As stated above, TRAF-NETSIM HOV lane turning movement logic, which allows only through-carpool vehicles to use the carpool or HOV lane, is not realistic for simulating real world turning traffic. To resolve this problem, the carpool lane logic must be modified to allow right-turning vehicles to use the curb HOV lane to turn right and to allow left-turn vehicles to use the median HOV lane to turn left.

The first step in the modification of the carpool lane logic is to determine which subroutine covers this logic problem. The carpool lane logic was found in the subroutine LANE (Appendix A) by reviewing the TRAF-NETSIM source code. The function of this module is to search for a lane on the receiving link into which the subject vehicle can discharge. In the first step of this subroutine, the lane is initialized to zero, and the fleet component and vehicle type are obtained from the subroutine GETYPE. Buses are then assigned to the channelized lane (bus or

HOV lane) or to the appropriate lane with the best horizon. As for other vehicle types (auto, truck, and carpool), they are first assigned to the best of the available lanes according to their specified turning movements and vehicle horizons. If the vehicle is not a through-carpool vehicle, then this vehicle will not continue to process the carpool or HOV lane assignment algorithm. In other words, only the through-carpool vehicles can be considered to use the carpool lane. Next, if there is a special lane channelized for carpool vehicles and the adequate space (horizon) is available, the through-carpool vehicles will be assigned to this carpool lane rather than to the previously assigned lane.

The carpool lane logic described above -- which specifies that only the through-carpool vehicles can use the carpool lane -- is obviously not accurate in representing real world HOV lane turning movements. The critical program statements of this carpool lane logic are briefly described in Appendix B.

The second step is to modify this logic to allow turning vehicles to use the carpool lane realistically. To resolve the curb HOV lane turning movement problem, the condition statement should be changed to allow all right-turning vehicles and through-carpool vehicles to use the carpool lane (Appendix C). The carpool lane logic can also be modified for median HOV lanes.

After modification, the next step is to verify this updated simulation model. By monitoring vehicle animation displays and simulation statistics output, engineers can confirm that the modification adequately represents HOV lane turning movements.

The HOV Lane Carpool Vehicle Turning Problem at T-Intersections

Although the modified HOV lane turning movement logic described above resolves straight-link HOV lane turning problems, the model's inability to simulate T-intersection HOV lanes realistically still remains. Almost all carpool vehicles are forced to use the second lane rather than the curb HOV lane to turn right, and must

use the second lane rather than the median HOV lane to turn left. The right-turn curb HOV lane and left-turn median HOV lane treatment logics should be modified to resolve this problem.

TRAF-NETSIM offers only six choices for channeling specific function lanes; use may be restricted to vehicles from the following categories: left-turning vehicles, buses, right-turning vehicles, carpool vehicles, and HOV. Specific function lanes may also be closed. To simulate a T-intersection curb HOV lane, the curb lane should be channelized as an HOV lane, and the second lane should be channelized as a right-diagonal-turning lane. If the HOV lane turning movement logic is modified as before, allowing only through-carpool and all right-turning vehicles to use the HOV lane, then all the right-diagonal-turning vehicles will be forced to use the second lane to turn right. To resolve this problem, the HOV lane turning movement logic should allow right-diagonal-turning carpool vehicles to use the HOV lane as well. In other words, the program statements should be modified to allow all non-left-turning vehicles to use the HOV lane (Appendix D).

After this modification (Appendix E), carpool vehicles can use the HOV lane for right turns. This T-intersection carpool lane logic can also be modified for median HOV lanes. However, two other movement logics, (1) SOVs using the carpool lane to turn right and (2) carpool vehicles being unable to turn right on red, are still not modeled realistically at T-intersection HOV lanes and should be modified.

The Right-Turn-On-Red Problem for HOV Lane Carpool Vehicles at T-Intersections

To resolve these two T-intersection HOV lane problems simultaneously, the turning movement percentage input data and the vehicle turning movement assignment subroutine GETCD (Appendix F) should be modified.

The biggest problem is that T-intersection HOV lane turning logic conflicts with straight-link HOV lane right-turning logic. In straight-link HOV lanes, right-

turning SOVs are allowed to use the curb HOV lane to turn right. However, in the case of T-intersection HOV lanes, right-turning SOVs are still limited to use of the second general-purpose lane to turn right. Furthermore, it is very difficult for users to estimate the turning movement percentage for T-intersection HOV lane alternatives prior to implementation. The only traffic volume that users can control in the TRAF-NETSIM input file is the entry link's data. The exact traffic volume that depends internally on traffic simulation is unknown for this downstream T-intersection. Thus, the turning movement percentage for (carpool) vehicles using the HOV lane is also unknown before simulation.

Subroutine GETCD's basic function is to determine the turning movement for a specified vehicle on a specified link. The first step of this subroutine is to determine the vehicle type to be simulated. If this vehicle is a bus, the turn code will be assigned according to its maneuver and its specific array, which is based on its receiving link. As for other vehicle types (auto, carpool, and truck), vehicle turns are coded as 0 (left), 1 (through), 2 (right), 3 (left diagonal), and 4 (right diagonal) randomly based on the turning movement percentage data entered by the user.

If left-turns are not permitted at T-intersection HOV curb lanes, then two different turning movement codes (right and right-diagonal-turn) may be assigned to any vehicle. Thus, some non-HOV vehicles will be designated as right-turning and will be allowed to use the HOV lane to turn right. Likewise, some carpool vehicles will be designated as right-diagonal-turning and will not be allowed to turn right on red. These right-diagonal-turning vehicles are simulated in TRAF-NETSIM as using the second lane to turn right. Thus, the previously modified program is still unable to handle T-intersection HOV lanes realistically.

The first step in solving this problem is to edit the T-intersection turning movement percentage input data as follows: right-diagonal-turning 99.99 percent and right-turning 0.01 percent. In other words, we hope that almost all vehicles

(99.99 percent) will be assigned first as right-diagonal-turning. At the same time, the subroutine GETCD should also be modified, carpool vehicle turning movements previously designated as right-diagonal-turning should be changed to right-turning, (Appendix G). Therefore, all non-carpool vehicles will be assigned as right-diagonal-turning and all carpool vehicles will be assigned as right-turning. The end result is that all non-carpool vehicles are now using the second lane to turn right and all carpool vehicles are now using the curb HOV lane to turn right-on-red at T-intersection HOV lanes.

The Travel Time Output Problem for HOV and General-Purpose Lanes

To compare the travel time savings between HOVs and SOVs, the subroutine LINKLIST (Appendix H) should be modified to enable it to print out the travel time for each vehicle type separately.

The main function of subroutine LINKLIST is to update the cumulative travel time statistics for each link. The first step in this modification is to determine the algorithm used in this subroutine to update travel time statistics for each link. Program testing indicates that the cumulative total of vehicle travel time (vehicle minutes) for each link equals the sum of the total travel time of all four vehicle types (auto, truck, carpool, bus) that have passed the link and of the travel time of some vehicles that remain on the link as the simulation concludes. In other words, the total vehicle travel time for each link can be described as the following formula:

Total vehicle travel time = A (auto total travel time) + T (truck total travel time) + C (carpool total travel time) + B (bus total travel time) + K (the travel time of some vehicles that still exist on the link as simulation concludes)

(4.4)

Thus, the total bus travel time (B) can be calculated, using Equation 4.4, as (A + T + C + B + K) - (A + T + C + K); and the average bus travel time can be calculated as B/bus vehicle trips.

In similar fashion, the average travel time of another vehicle type, e.g., carpool can be calculated as [(A + T + C + K) - (A + T + K)] / carpool vehicle trips.

Therefore, to calculate average travel time for each vehicle type, the subroutine should be modified to provide each link with the related vehicle travel time and vehicle trips for some vehicle types (e.g., T+K, A+T+K, or A+T+C+K) accordingly (Appendix I).

The last step in this travel time program modification is to prove that this method can calculate the travel time for each vehicle type exactly. Fortunately, TRAF-NETSIM provides the bus travel time for each link separately (Table 4.3); and this information can be used to verify the method. In fact, a series of simulation run comparisons proved that the average bus travel time (Table 4.4) calculated using the method modified above was exactly the same as the TRAF-NETSIM output.

Table 4.3 TRAF-NETSIM Bus travel time output

NETSIM BUS STATISTICS

LINK	BUS TRIPS	PERSON TRIPS	TRAVEL TIME (MINUTES)	MOVING TIME (MINUTES)	DELAY TIME (MINUTES)	M/T	SPEED (MPH)	NUMBER STOP
014, 14)	5	137						
023, 23)	4	109						
032, 32)	5	137						
1, 11)	7	191	6.3	0.8	5.5	0.13	3.8	7
2, 32)	5	137	5.5	2.7	2.9	0.49	14.6	4
3, 23)	2	55	1.5	0.3	1.1	0.23	6.9	2
1, 4)	4	109	1.0	0.5	0.5	0.52	15.7	0
4, 2)	4	109	3.7	0.9	2.8	0.24	7.1	2
1, 3)	1	27	1.3	0.4	0.9	0.30	9.0	1
2, 4)	4	109	3.9	0.9	3.0	0.23	6.8	4
4, 1)	4	109	0.8	0.5	0.3	0.64	19.2	0
2, 3)	1	27	1.4	0.3	1.1	0.24	7.2	0
3, 1)	3	82	2.8	1.1	1.6	0.41	12.3	0
3, 2)	1	27	0.5	0.3	0.2	0.66	19.8	0
11, 1)	5	137	5.4	0.6	4.8	0.11	3.2	2
23, 3)	4	109	3.7	0.7	3.0	0.18	5.5	3
32, 2)	5	137	7.7	2.7	5.0	0.35	10.5	5
14, 11)	5	137	1.1	0.6	0.5	0.52	15.7	0
11, 14)	7	191	1.0	0.8	0.2	0.77	23.1	0

Table 4.4 The bus travel time (min) calculation from the modified TRAF-NETSIM outputs

Link (5) el e	(1) A+T+C +B+K Trips	(2) A+T+C +K Trips	(3)= (1)-(2) Bus Trips	(4) A+T+C +B+K Tr. time	(5) A+T+C +K Tr. time	(6)= (4)- Trav Tim
(1,11)	637	630	7	123.9	117.6	6.3
(2,32)	225	220	5	156.7	151.1	5.6
(3,23)	719	717	2	169.3	167.8	1.5
(1,4)	174	170	4	39.3	38.3	1.0
(4,2)	188	184	4	125.0	121.3	3.7
(1.3)	501	500	1	434.2	432.9	1.3
(2,4)	172	168	4	53.4	49.5	3.9
(4,1)	175	171	4	176.0	175.2	0.8
(2,3)	199	198	1	211.9	210.5	1.4
(3,1)	467	464	3	410.7	408.0	2.7
(3,2)	63	62	1	35.5	35.0	0.5
(11,1)	652	647	5	214.1	208.7	5.4
(23,3)	476	472	4	247.8	244.1	3.7
(32,2)	376	371	5	411.6	403.9	7.7
(14,11)	653	648	5	123.2	122.1	1.1
(11,14)	633	626	7	89.7	88.6	1.1

TRAF-NETSIM Application HOV Improvement Project at NE Pacific Street

Researchers at the University of Washington are currently studying HOV improvements on signalized arterials in the Seattle area (48). The objectives of this project are to investigate arterial HOV incentives, to simulate the operation of selected HOV lanes, and to evaluate the traffic impacts of their implementation. To verify that the modified TRAF-NETSIM model is capable of analyzing arterial HOV lane-related traffic impact the model was applied to simulate and evaluate the traffic operation of the proposed HOV lane improvement at N.E. Pacific Street.

Site Description

The SR 520 and I-90 floating bridges across Lake Washington are the two important freeways that connect Seattle with its suburbs on the east side of Lake Washington. N.E. Pacific Street and Montlake Boulevard N.E., located in the University District, are the two main arterials via which commuters enter onto SR 520 to cross Lake Washington or connect with I-5 (Figure 4.6).

The rush hour traffic congestion problem of this area (i.e., eastbound Pacific Street and southbound Montlake Boulevard) is usually caused by heavy traffic, queue backup due to ramp metering at SR 520, and openings of the Montlake drawbridge. PM peak hour traffic congestion becomes particularly heavy on days preceding long weekends.

In this study, feasible HOV lane alternatives in this area are considered mainly on eastbound Pacific Street, because there are more buses and bus routes in this direction. HOV lane improvement projects can provide significant travel time savings for HOV users and thereby encourage people to shift mode to HOVs. As a result, the peak hour traffic congestion problem can be alleviated by reducing SOV traffic volume.

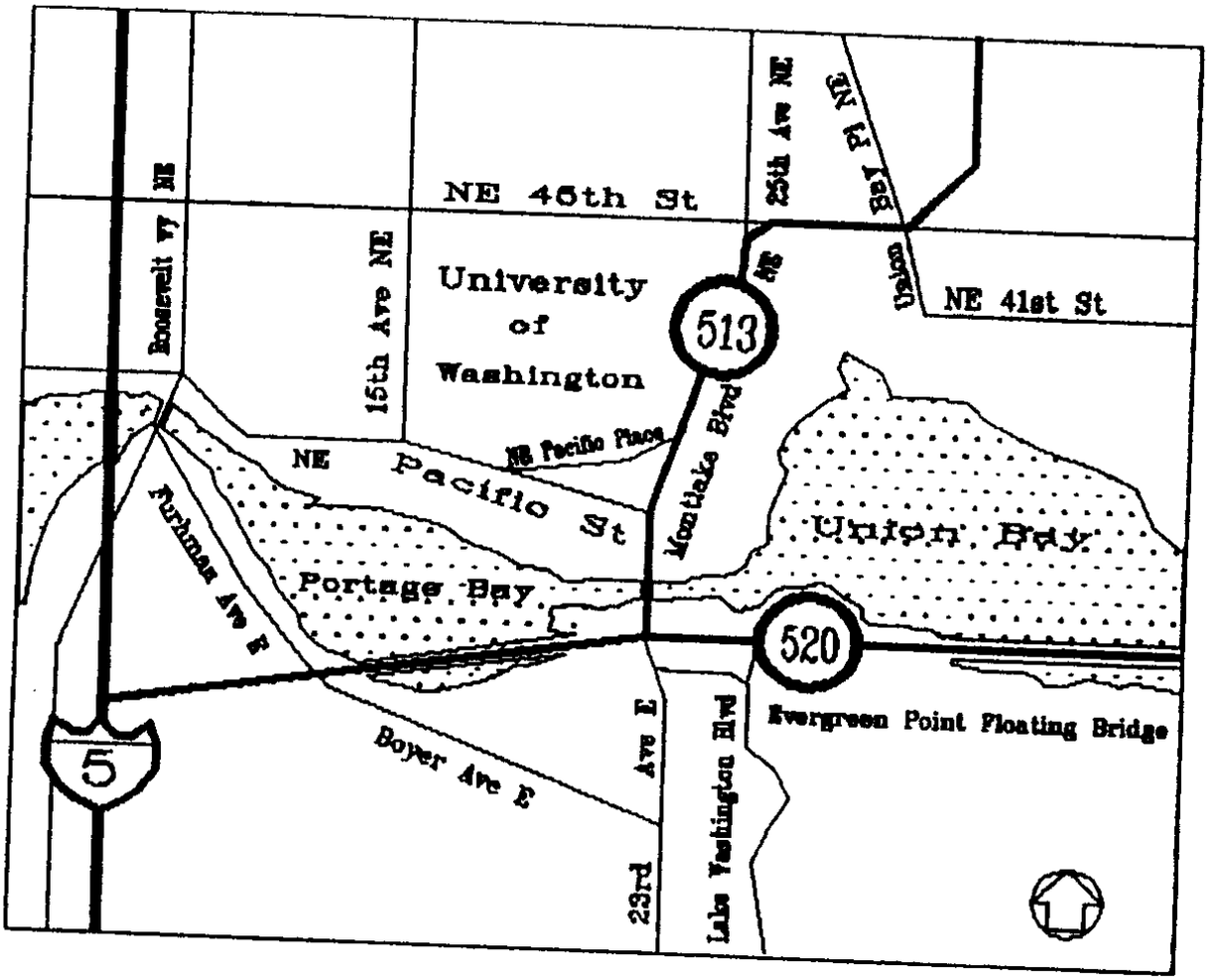


Figure 4.6 Study area for the Pacific Street HOV improvement project

Data Collection

The research project began with an effort to gather the traffic data necessary to simulate the study area using the modified TRAF-NETSIM model. The geometric design and intersection signalization data were obtained from the City of Seattle and from field studies. Data pertaining to traffic volume, turning movements, average car occupancy, and traffic composition for Pacific and Montlake streets were culled from traffic studies conducted at the University of Washington and by the City of Seattle.

There are 11 bus stops and five different bus routes in the study area. Transit ridership data were collected for eastbound vehicles on Pacific Street in front of University Hospital. An average ridership of 27.3 riders/bus was calculated from a sample of 99 buses. For the same area, an average bus dwell time of 28.5 seconds was calculated from a sample of 26 buses. Other transit characteristics, such as the location of stops, bus routes, and headways were determined on the basis of field observations and bus schedules. Headways varied from 15 minutes on the lesser-used routes to four minutes on the busiest. Approximately 16 buses travel eastbound during the PM peak hour on N.E. Pacific Street. Vehicle travel time data was gathered using the license plate matching method. Laptop computers were used to match vehicles travelling along the N.E. Pacific and Montlake links and to calculate travel times (16).

Experimental Design

Arterial HOV lane treatments involve factors that are more complex than those of freeway HOV lanes. Many design variables, including: traffic volume, traffic composition, traffic control, pedestrians, turning movements, car occupancy, lane blocking, bus dwelling time, bus frequency, and bus occupancy may be considered in the alternative development process.

However, it is impossible to simulate all of these alternatives, because running each alternative with the TRAF-NETSIM simulation model is very time

consuming. Thus, the design variables selected for this study will focus on some of the most common arterial HOV lane design factors, including geometric design, traffic volume increase, traffic control, and mode shift.

1) Geometric design (feasible HOV lane alternatives for eastbound Pacific Street)

Feasible geometric design alternatives for eastbound Pacific Street considered in this study include the following cases:

- no change to the existing geometric design (Figure 4.7)
- addition of one general-purpose lane (with no bus bay) in front of University Hospital (Figure 4.8)
- addition of one HOV lane (with bus bay) in front of University Hospital (Figure 4.9)
- addition of one general-purpose lane (with no bus bay) in front of University Hospital and extension to 15th Avenue (Figure 4.10)
- addition of one HOV lane (with bus bay) in front of University Hospital and extension to 15th Avenue (Figure 4.11)

2) Traffic volume

The possible traffic volume increase factors in this study area include: future land development, I-90 bridge closure, long weekends, and special events in the area. Because some significant travel demand management strategies have been proposed by the University of Washington (UW Transportation Management Program 1989), the two following scenarios for traffic volume increase are simulated in this study:

- Traffic volume remains the same as the existing traffic condition (0 percent increase).

The traffic volume of eastbound Pacific Street is 1372 vehs/hr; the traffic volume of southbound Montlake Boulevard is 1778 vehs/hr.

- The traffic volume of eastbound Pacific Street and southbound Montlake Boulevard increases by 10 percent.

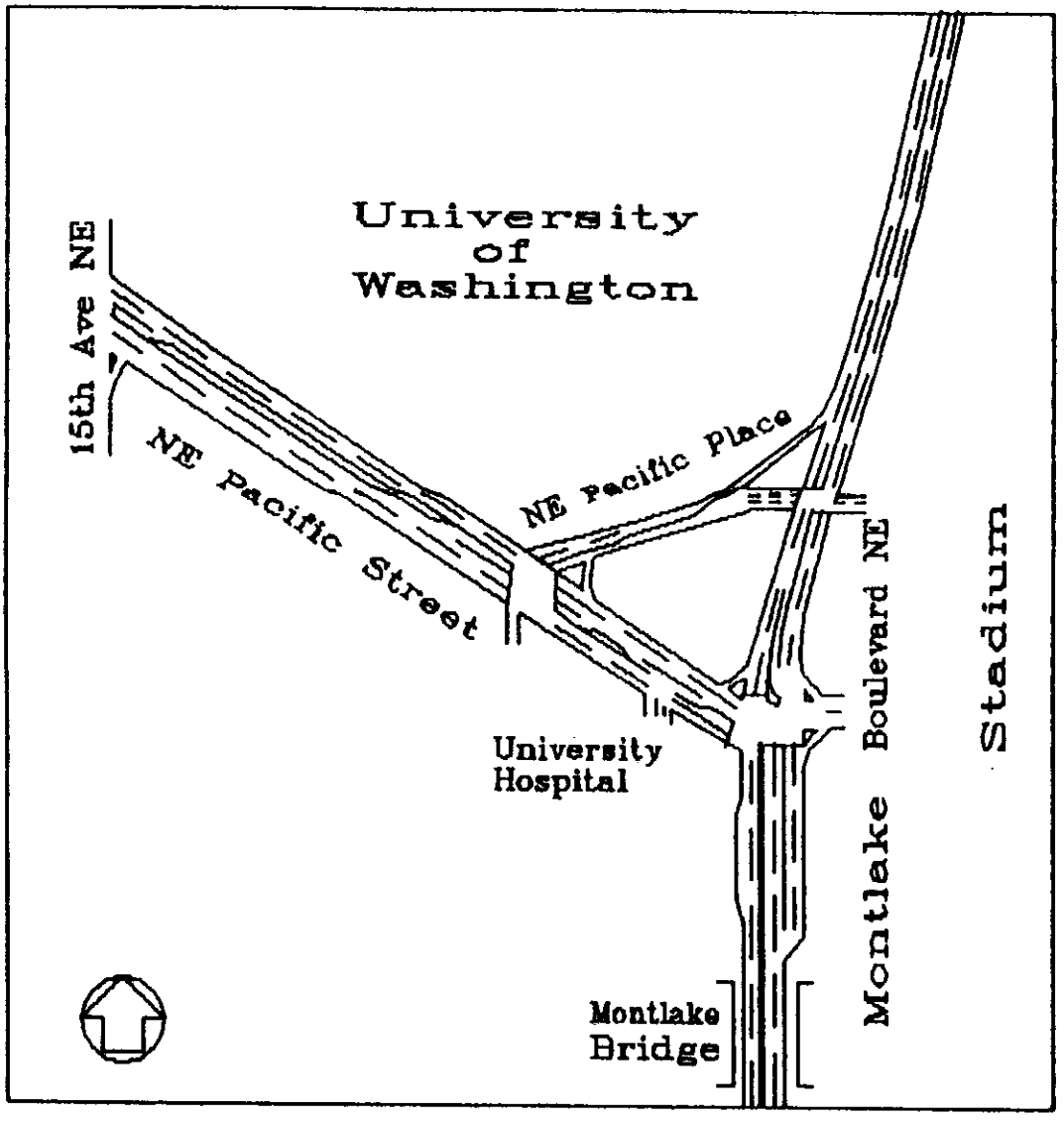


Figure 4.7 Existing geometric design

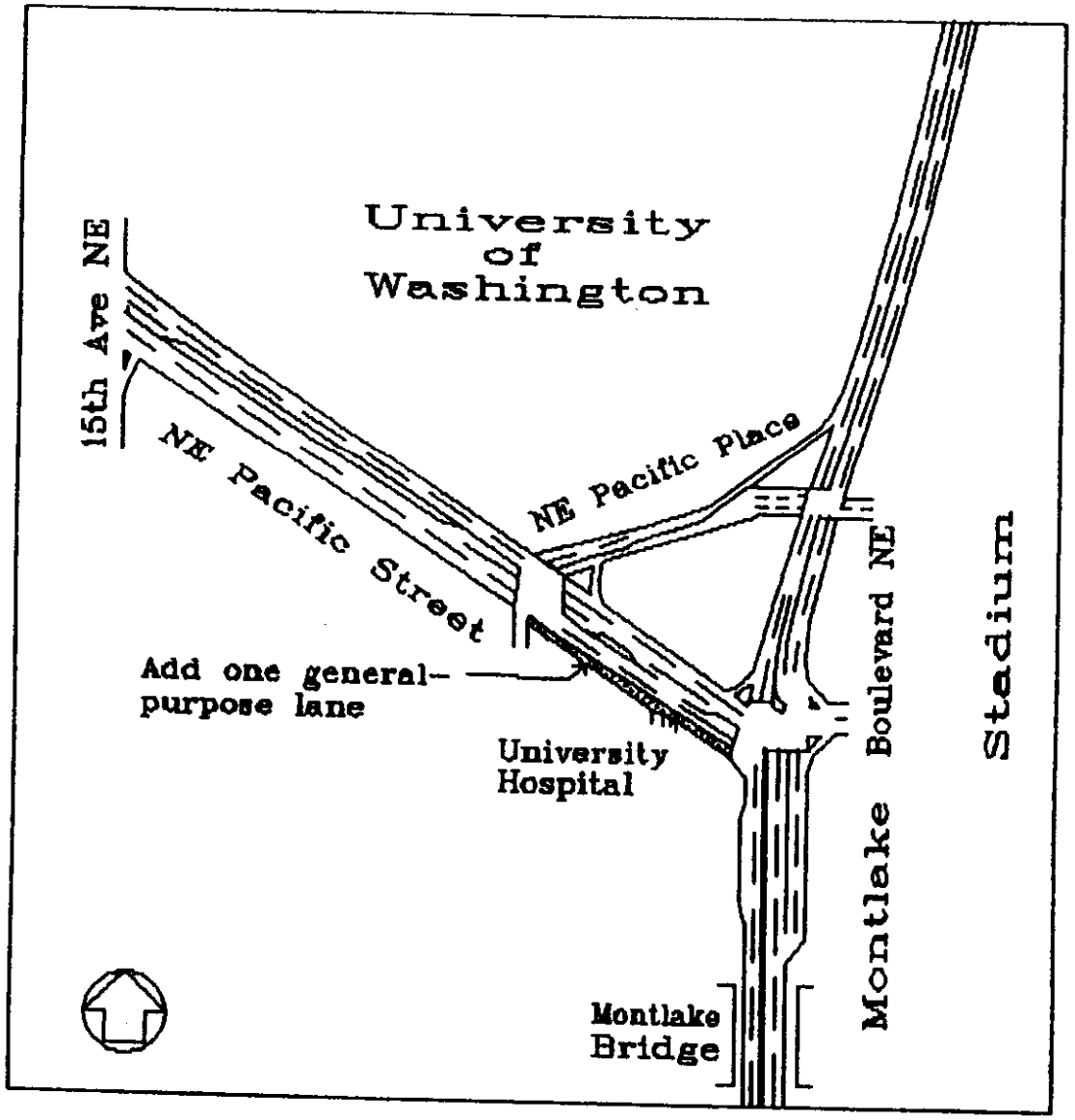


Figure 4.8 Addition of one general-purpose lane (with no bus bay) in front of University Hospital

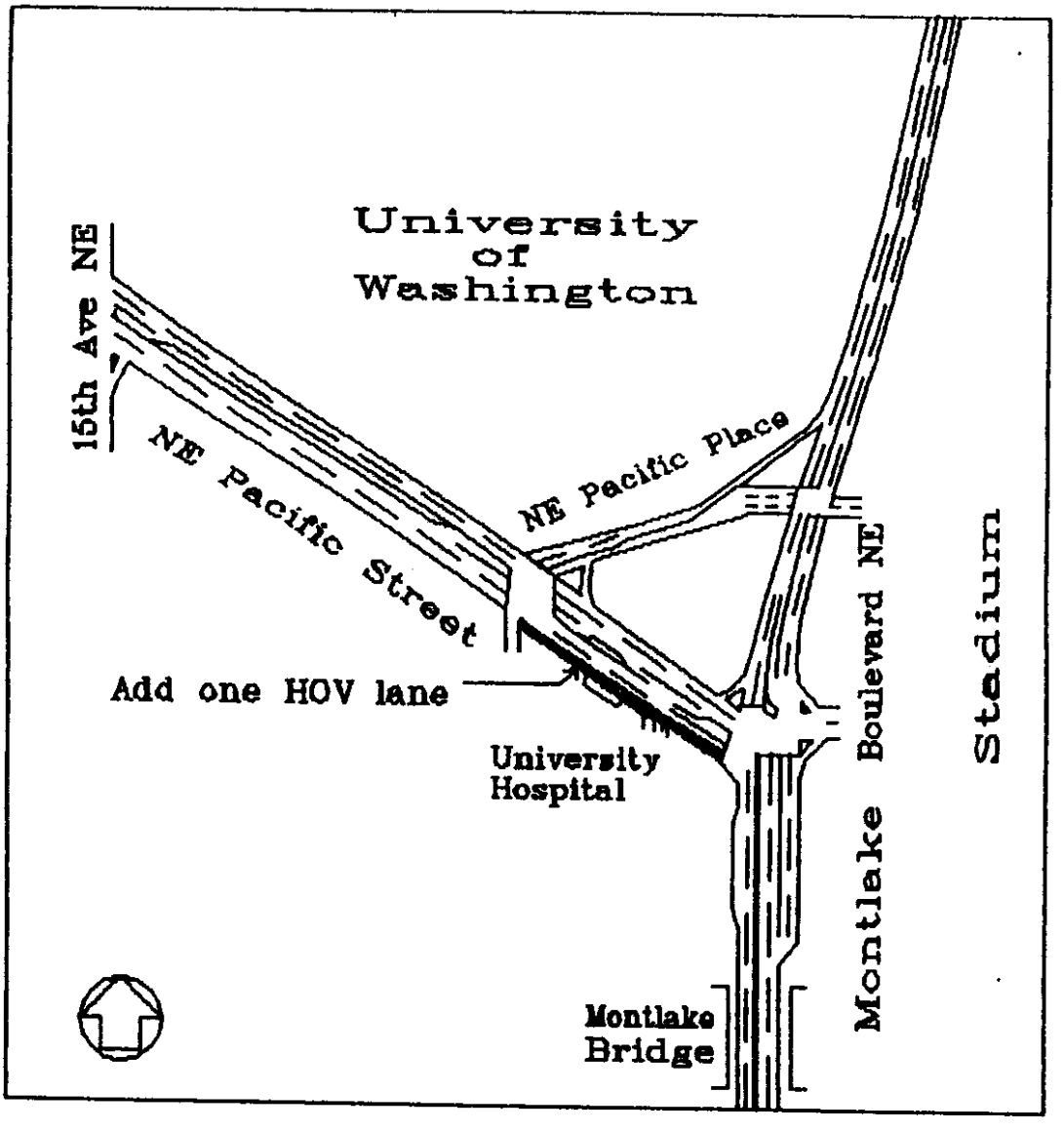


Figure 4.9 Addition of one HOV lane (with bus bay) in front of University Hospital

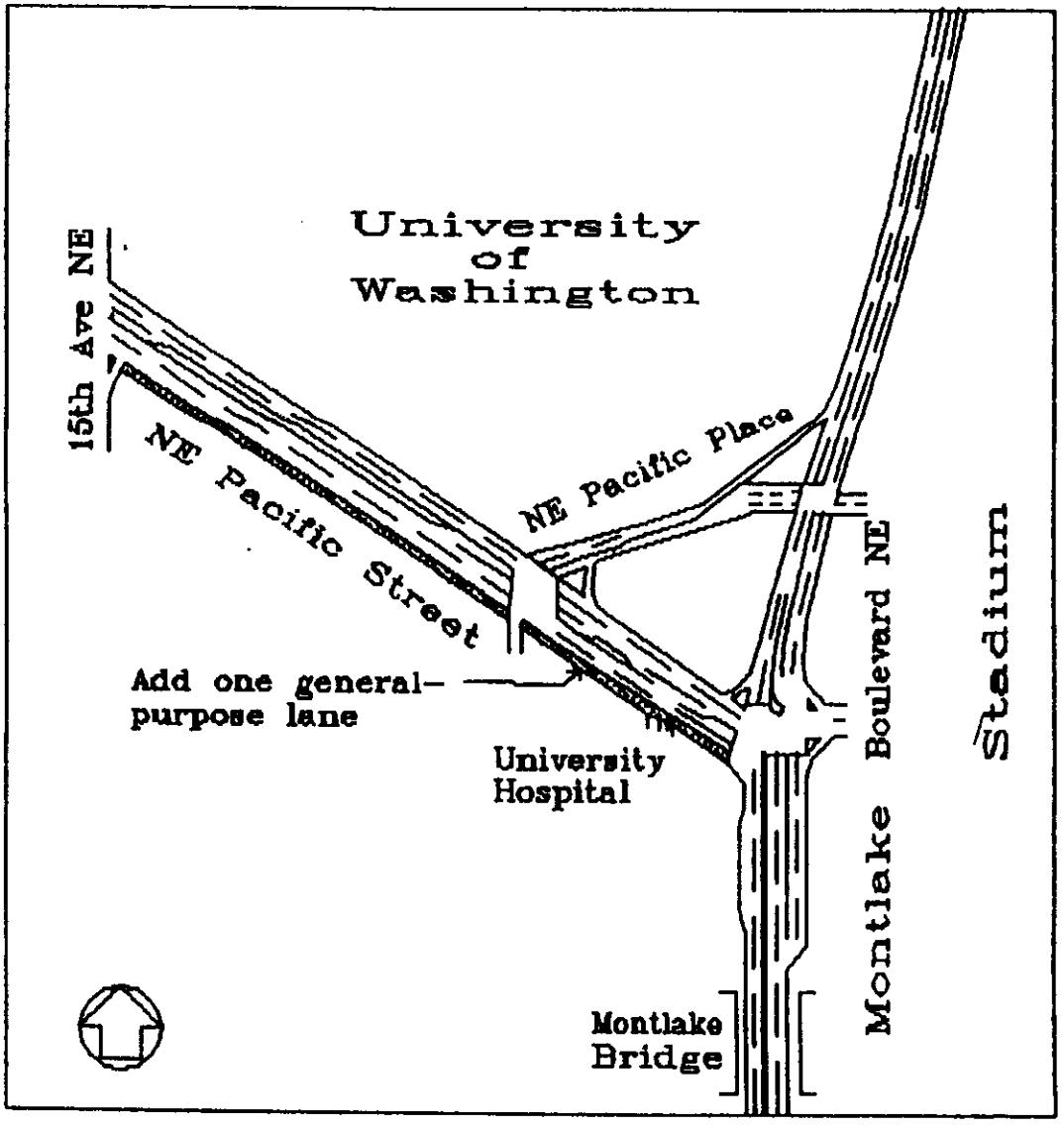


Figure 4.10 Addition of one general-purpose lane (with no bus bay) in front of University Hospital and extending to 15th Avenue

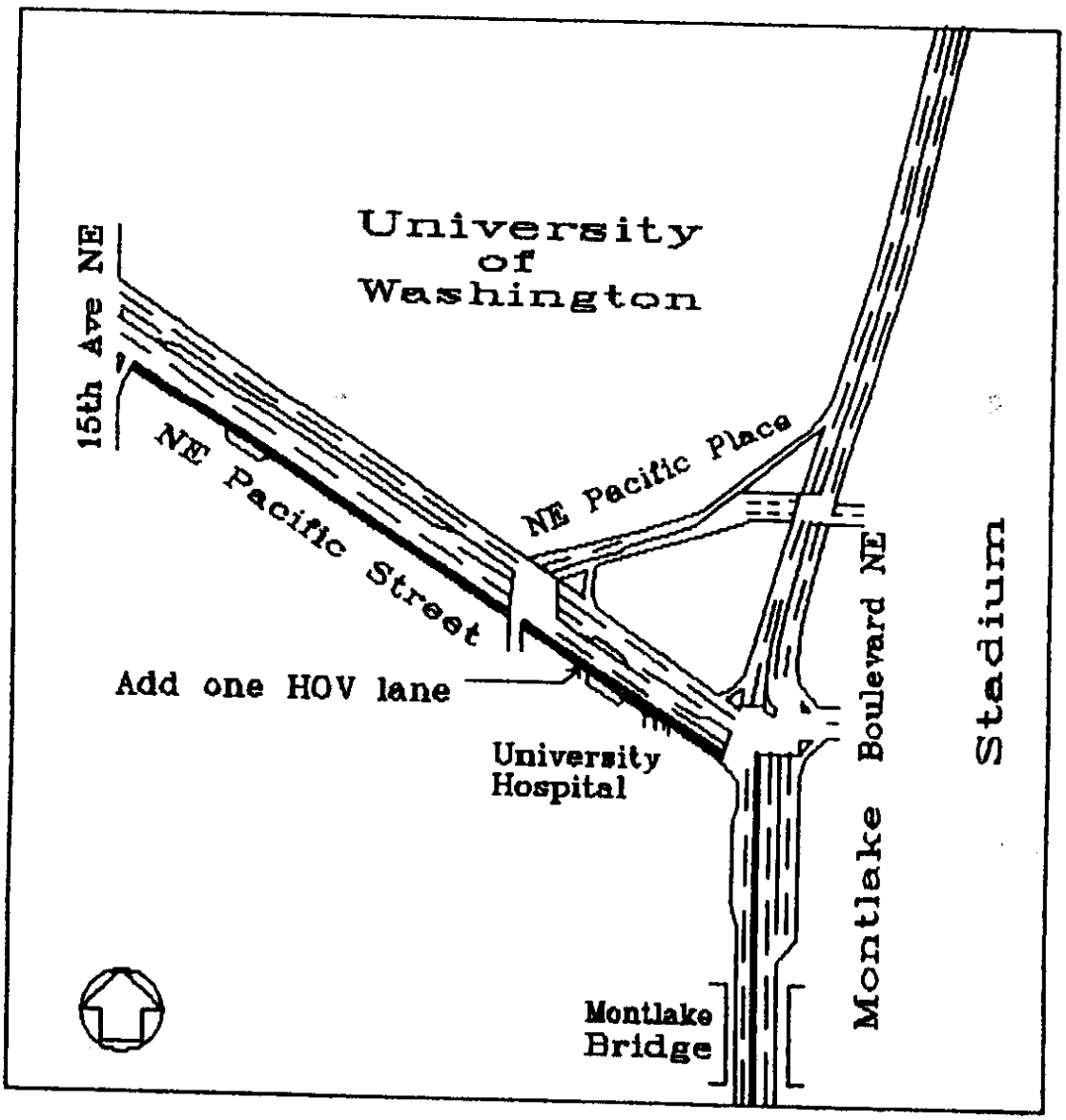


Figure 4.11 Addition of one HOV lane (with bus bay) in front of University Hospital and extending to 15th Avenue

That is, the traffic volume of eastbound Pacific Street increases to 1509 vehs/hr; the traffic volume of southbound Montlake Boulevard increases to 1956 vehs/hr.

3) Traffic control (SR 520 ramp metering impacts)

The most serious congestion at the study area is caused by SR 520 ramp back up and Montlake drawbridge opening. This phenomenon is imitated by an increasing red time interval for each cycle at one downstream intersection:

- no queue backup (red time interval is 3 sec/60 sec cycle length)
- existing traffic condition (red time interval is 15 sec/60 sec cycle length)
- more serious queue backup (red time interval increases to 25 sec/60 sec cycle length)

4) Mode shift (traffic composition)

If the proposed HOV lane can provide significant travel time savings for HOV users, some commuters will be attracted to shift mode from SOV to HOV, which will reduce the total traffic volume for HOV lane direction (i.e. eastbound Pacific Street). The mode shift percentage used in this study is based on an estimate made by the engineering firm CH2M Hill (71):

- Existing traffic composition (carpool percentage 5 percent; bus occupancy 27.3 persons/bus)
- After mode shift (carpool percentage increases to 8 percent; bus occupancy increases to 30.0 persons/bus)

Thus, for a given volume of demand for person trips, traffic volume on eastbound Pacific Street will decrease because SOVs are attracted by travel time savings to change mode to HOVs. For the existing demand, traffic volume will decrease from 1372 to 1301 vehs/hr after mode shift. Similarly, if the travel demand increases 10 percent, the input traffic volume will decrease from 1509 to 1432

vehs/hr.

Simulation Results

Initially, the traffic field data were coded, run, and displayed on a PC. Some input data, such as vehicle headway, driver behavior, and signal timing data had been adjusted until the simulation output travel time of each street was close to the collected travel time. The detailed TRAF-NETSIM simulation outputs, including turning movements, queue lengths, and spillbacks of each intersection, were also monitored from the PC graphic display until the simulation process was confirmed to represent each HOV alternative exactly.

Intensive simulation run outputs for all experimental design alternatives, conducted over a period of on and a half years, demonstrated that the modified TRAF-NETSIM model was very consistent for non-congested arterial HOV lane traffic analysis. However, some unreasonable simulation outputs occurred in TRAF-NETSIM (even in simulating general traffic environments) as traffic flow became congested. To uncover the detailed problems, the general traffic (non-HOV lane) graphic data files of the unreasonable alternatives (e.g., Alt. 14) were generated and displayed on a PC. While monitoring vehicle tuning movements, some strange phenomena were discovered as TRAF-NETSIM simulated congested traffic environments. For instance, at the same approach, one vehicle unexpectedly halted during the green time interval at the stopline and remained stationary for one minute while vehicles in the other lane continued to move. At the T-intersection, all vehicles were found to use the curb lane for the sole purpose of turning right. Some vehicles were found to stop during the green time interval at the stopline even if the moving space in front of the intersection was still available. Consequently, the unreasonable simulation results described below will occur if any of these strange phenomena occur.

Researchers working on this study have tried to correct the strange

occurrences described above through intensive modifications and simulation runs. However, these problems are due not only to specific turning movement logic, but also to other variables, such as geometric designs, random seeds, simulation time periods, and the like. For this reason, modification of the huge TRAF-NETSIM source code, which includes 1170 pages and 453 subroutines, for the purpose of correctly simulating the congested traffic flow is a very complex task and would require more research.

The detailed simulation outputs are discussed as follows:

1) non-congested (no queue backup) traffic conditions

As described in the section entitled "Experimental design," the red time interval of one downstream intersection in this study area was assumed to be 3 sec / 60 sec cycle length to imitate the phenomenon of no queue backup due to SR 520 ramp metering. In this traffic environment, the travel time simulation output of each vehicle type is shown (Table 4.5) to be very consistent for each geometric design alternative:

a. The travel time of Montlake Boulevard is not affected by the improvement of Pacific Street.

Because the traffic characteristics of Montlake Boulevard, which include geometric design, traffic volume, and traffic control are held constant, the MOEs of Montlake Boulevard should not be affected by the traffic improvement of Pacific Street. The travel time simulation results in Table 4.5 correspond with this assumption for all alternatives and vehicle types.

b. The carpool and bus travel time of Pacific Street is improved after adding one HOV lane in front of University Hospital, but auto travel time is increased.

In comparing Alt. 01 (existing geometric design) with Alt. 03 (addition of one HOV lane in front of University Hospital), the researchers found that the average

travel time of a carpool vehicle is reduced from 138.4 sec to 99.7 sec after adding one HOV lane in front of University Hospital. The bus travel time is also reduced from 258.9 sec to 216.9 sec. However, auto travel time is increased from 138.4 sec to 156.2 sec. This increase is due to the fact that the autos of Alt. 03 cannot turn right on red (as can those of Alt. 01) at the eastbound approach of the Pacific and Montlake intersection because the curb lane is reserved for HOV use. Thus, the auto travel times of all HOV lane alternatives (Alt. 03 and Alt. 05) are higher than those of other non-HOV lane alternatives (Alt. 01, Alt. 02, and Alt. 04).

c. Travel time of Pacific Street is improved after extending the general-purpose lane to 15th Avenue.

Comparing Alt. 02 and Alt. 04 (extending the general-purpose lane to 15th Avenue), researchers found that the average travel time of auto and carpool vehicles is reduced from 138.1 sec to 135.5 sec after extending the general-purpose lane to 15th Avenue. However, bus travel time is increased from 259.1 sec to 263.9 sec. The reason for this travel time increase is not clear and may be due to the insufficient bus sample size (average bus volume is 3-5 buses/hr for each link) on these links.

d. Travel time on Pacific Street is improved after extending the HOV lane to 15th Avenue.

Comparing Alt. 03 and Alt. 05 (extending the HOV lane to 15th Avenue), researchers found that the average travel time for autos is reduced from 156.2 sec to 149.5 sec after extending the HOV lane to 15th Avenue. The average travel time for a carpool vehicle is reduced from 99.7 sec to 95.3 sec. Bus travel time is also reduced, from 216.9 sec to 212.0 sec.

Table 4.5 The average travel time (sec) of each vehicle type for each geometric design alternative (no queue backup traffic condition)

Simulation Alt. Name	Pacific Street			Montlake Boulevard		
	Auto	Carpool	Bus	Auto	Carpool	Bus
01. Existing geom. design	138.4	138.4	258.9	93.3	93.3	168.1
02. Add one gen. lane UW Hosp. (no bus bay)	138.1	138.1	259.1	92.9	92.9	168.9
03. Add one HOV lane UW Hosp. (bus bay)	156.2	99.7	216.9	91.3	91.3	165.5
04. Add one gen. lane 15th Ave (no bus bay)	135.5	135.5	263.9	91.1	91.1	167.2
05. Add one HOV lane 15th Ave (bus bay)	149.5	95.3	212.0	91.7	91.7	170.3

2) Existing (some queue backup) traffic conditions

To imitate the existing queue backup due to SR 520 ramp metering, the red time interval of one downstream intersection of this study area was assumed to be 15 sec/60 sec cycle length. The travel time simulation output of each vehicle type in this traffic environment is very consistent (Table 4.6) for the first four geometric design alternatives (Alt. 06 to Alt. 09). However, the result for Alt. 10 is obviously unreasonable.

- The travel time simulation output of each vehicle type is consistent for the first four geometric design alternatives (Alt. 06 to Alt. 09).

For example, the auto travel time on Pacific Street is improved from 159.8 sec (Alt. 06) to 151.8 sec (Alt. 07) after adding one general-purpose lane in front of University Hospital. The carpool travel time of Pacific Street is improved from

159.8 sec (Alt. 06) to 117.5 sec (Alt. 08), and the bus travel time of Pacific Street is improved from 270.3 sec (Alt. 06) to 223.2 sec (Alt. 08) after adding one HOV lane in front of University Hospital. The auto travel time on Pacific Street is improved after extending the general-purpose lane to 15th Avenue from 151.8 sec (Alt. 07) to 148.4 sec (Alt. 09).

- The simulation results of Alt. 10 (extending the HOV lane to 15th Avenue) are obviously unreasonable.

After extending the HOV lane to 15th Avenue, the carpool and bus travel times on Pacific Street should be the shortest among the five geometric alternatives. However, the simulation outputs run contrary to this expectation. For example, the carpool travel time of Alt. 10 (168.3 sec) becomes the longest of all five alternatives. Bus travel time also increases from 223.2 sec (Alt. 08) to 254.0 sec (Alt. 10), after extending the HOV lane to 15th Avenue. These simulation outputs contradict expectations.

- The simulation results on the travel time of Montlake Boulevard are obviously unreasonable.

Travel time on Montlake Boulevard should not be significantly affected by the geometric design improvement of Pacific Street. However, the simulation outputs run contrary to this expectation. For example, the auto and carpool travel times of Alt. 08 (136.8 sec) are less than those of Alt. 06 (171.8 sec) or of Alt. 07 (166.4 sec), which is unreasonable.

Table 4.6 The average travel time (sec) of each vehicle type for each geometric design alternative (some queue backup traffic condition)

Simulation Alt. Name	Pacific Street			Montlake Boulevard		
	Auto	Carpool	Bus	Auto	Carpool	Bus
06. Existing geom. design	159.8	159.8	270.3	171.8	171.8	218.9
07. Add one gen. lane UW Hosp. (no bus bay)	151.8	151.8	271.8	166.4	166.4	226.1
08. Add one HOV lane UW Hosp. (bus bay)	173.1	117.5	223.2	136.8	136.8	200.5
09. Add one gen. lane 15th Ave (no bus bay)	148.4	148.4	269.5	135.2	135.2	189.8
10. Add one HOV lane 15th Ave (bus bay)	195.5	168.3	254.0	159.1	159.1	212.1
21. Mode shift Add one HOV lane UW Hosp. (bus bay)	174.0	123.9	240.5	133.4	133.4	196.1
22. Mode shift Add one HOV lane 15th Ave (bus bay)	166.7	128.6	295.2	121.2	121.2	178.5

3) Queue backup traffic conditions of a more serious nature

To imitate the more serious queue backup due to ramp metering at SR 520, the red time interval of one downstream intersection for this study area was assumed to be 25 sec / 60 sec cycle length. The travel time simulation output of each vehicle type in this traffic environment is shown (Table 4.7) as being very consistent for geometric design alternatives (11, 12, 13, and 15). However, the result of Alt. 14 is obviously unreasonable.

a. The travel time simulation output of each vehicle type is consistent for

some geometric design alternatives (Alts. 11, 12 , 13 and 15).

For example, the auto travel time of Pacific Street is improved from 396.6 sec (Alt. 11) to 308.1 sec (Alt. 12) after adding one general-purpose lane in front of UW Hospital. The carpool travel time of Pacific Street is improved from 396.6 sec (Alt. 11) to 268.5 sec (Alt. 13) and the bus travel time of Pacific Street is improved from 390.8 sec (Alt. 11) to 322.6 sec (Alt. 13) after adding one HOV lane in front of University Hospital. The carpool travel time of Pacific Street is improved from 268.5 sec (Alt. 13) to 257.2 sec (Alt. 15) and the bus travel time of Pacific Street is improved from 322.6 sec (Alt. 13) to 278.4 sec (Alt. 15) after extending the HOV lane to 15th Avenue.

b. The simulation results of Alt. 14 (extending the general-purpose lane to 15th Avenue) are obviously unreasonable.

After extending the general-purpose lane to 15th Avenue (Alt. 14), the travel time of Pacific Street for all vehicle types should be better than Alt. 12 (adding one general-purpose lane in front of University Hospital) and Alt. 11 (existing geometric design). However, the simulation outputs run contrary to this expectation. For example, the auto and carpool travel times of Alt. 14 (425.5 sec) are higher than those of Alt. 12 (308.1 sec) and of Alt. 11 (396.6 sec). The bus travel time of Alt. 14 (484.5 sec) is higher than that of Alt. 12 (403.2 sec) and that of Alt. 11 (390.8 sec) – another unexpected result.

c. The simulation results of the travel time of Montlake Boulevard are obviously unreasonable.

The travel time of Montlake Boulevard should not be significantly affected by the geometric design improvement of Pacific Street. However, the simulation outputs are contrary to this expectation. For example, auto and carpool travel times of Alt. 12 (446.6 sec) are higher than those of Alt. 11 (387.4 sec) or of Alt. 14 (380.6 sec).

Table 4.7 The average travel time (sec) of each vehicle type for each geometric design alternative (serious queue backup traffic condition)

Simulation Alt. Name	Pacific Street			Montlake Boulevard		
	Auto	Carpool	Bus	Auto	Carpool	Bus
11. Existing geom. design	396.6	396.6	390.8	387.4	387.4	438.5
12. Add one gen. lane UW Hosp. (no bus bay)	308.1	308.1	403.2	446.6	446.6	481.5
13. Add one HOV lane UW Hosp. (bus bay)	523.4	268.5	322.6	419.5	419.5	491.0
14. Add one gen. lane 15th Ave (no bus bay)	425.5	425.5	484.5	380.6	380.6	430.6
15. Add one HOV lane 15th Ave (bus bay)	468.5	257.2	278.4	409.8	409.8	470.8

4) Traffic volume increases 10 percent

That is, the traffic volume on eastbound Pacific Street increases from 1372 to 1509 vehs/hr, and traffic volume on southbound Montlake Boulevard increases from 1778 to 1956 vehs/hr. The travel time simulation output for this traffic environment is shown (Table 4.8) as being very consistent for autos, carpools, and buses on Pacific Street.

a. The travel time simulation output for each vehicle type is consistent for Pacific Street autos and carpools.

The auto travel time on Pacific Street is improved from 217.7 sec (Alt. 16) to 198.7 sec (Alt. 17) after adding one general-purpose lane in front of University Hospital. The carpool travel time on Pacific Street is improved from 217.7 sec (Alt. 16) to 159.4 sec (Alt. 18) after adding one HOV lane in front of University Hospital. The auto travel time on Pacific Street is improved from 198.7 sec (Alt. 17) to 168.2

sec (Alt. 19) after extending the general-purpose to 15th Avenue. The carpool travel time on Pacific Street is improved from 159.4 sec (Alt. 18) to 143.9 sec (Alt. 20) after extending the HOV lane to 15th Avenue.

b. The travel time simulation output of each vehicle type is consistent for bus travel on Pacific Street (except Alt. 17).

Bus travel time on Pacific Street is improved from 295.4 sec (Alt. 16) to 245.0 sec (Alt. 18) after adding one HOV lane in front of University Hospital. The bus travel time of Pacific Street is improved from 295.4 sec (Alt. 16) to 285.1 sec (Alt. 19) after extending the general-purpose to 15th Avenue. The bus travel time on Pacific Street is improved from 245.0 sec (Alt. 18) to 240.0 sec (Alt. 20) after extending the HOV lane to 15th Avenue.

However, bus travel time results in the case of Alt. 17 (after addition of one general-purpose lane in front of University Hospital) seem unreasonable. Bus travel time on Pacific Street under Alt. 17 should be better than that of Alt. 16 (existing geometric design). However, the simulation output is contrary to this expectation. The bus travel time of Alt. 17 (311.0 sec) is higher than that of Alt. 16 (295.4 sec), an unexpected result.

c. Travel time savings for carpool users become more significant after traffic volume increases 10 percent.

Generally, HOV lane alternatives provide more travel time savings for carpools as congestion increases. If one HOV lane in front of University Hospital is added, then travel time savings for carpools increase from 42.3 sec (Table 4.6; the carpool travel time difference between Alt. 06 and Alt. 08) to 58.3 sec (carpool travel time difference between Alt. 16 and Alt. 18) after traffic volume increases 10 percent. Similarly, adding one HOV lane to 15th Avenue increases travel time savings for carpools to 73.8 sec (the carpool travel time difference between Alt. 16 and Alt. 20) after traffic volume increases 10 percent.

d. The simulation results regarding time on Montlake Boulevard are unreasonable.

Travel time on Montlake Boulevard should not be significantly affected by the geometric design improvement on Pacific Street. However, the simulation outputs are contrary to this expectation. For example, the auto and carpool travel time of Alt. 20 (194.4 sec) is less than that of Alt. 16 (256.0 sec).

Table 4.8 The average travel time (sec) of each vehicle type for each geometric design alternative (some queue backup and traffic volume increases 10 percent)

Simulation Alt. Name	Pacific Street			Montlake Boulevard		
	Auto	Carpool	Bus	Auto	Carpool	Bus
16. Existing geom. design	217.7	217.7	295.4	256.0	256.0	334.6
17. Add one gen. lane UW Hosp. (no bus bay)	198.7	198.7	311.0	223.8	223.8	264.5
18. Add one HOV lane UW Hosp. (bus bay)	202.2	159.4	245.0	214.7	214.7	273.5
19. Add one gen. lane 15th Ave (no bus bay)	168.2	168.2	285.1	230.8	230.8	272.8
20. Add one HOV lane 15th Ave (bus bay)	204.4	143.9	240.0	194.4	194.4	219.1
23. Mode shift Add one HOV lane UW Hosp. (bus bay)	190.1	157.2	276.9	218.6	218.6	262.0
24. Mode shift Add one HOV lane 15th Ave (bus bay)	281.9	228.5	220.2	192.9	192.9	245.2

5) Mode shift

Assuming that some commuters will shift mode from SOV to HOV, we may expect the following changes after HOV lane installation: carpool percentage increases from 5 percent to 8 percent and bus occupancy increases from 27.3 persons/bus to 30.0 persons/bus. Traffic volume will thus decrease from 1372 to 1301 vehs/hr. If the travel demand increases 10 percent, then traffic volume will decrease from 1509 to 1432 vehs/hr. The simulation outputs for these traffic environments are shown in Tables 4.6 (Alt. 21 and Alt. 22) and 4.8 (Alt. 23 and Alt. 24). Unfortunately, the travel time simulation outputs are mixed and therefore do not clearly explain the mode shift result for Pacific Street.

As depicted in Figure 1.1, traffic volume in the HOV lane will increase after commuters shift mode from SOV to HOV. Therefore, the carpool travel times of HOV lane alternatives Alt. 21, Alt. 22, Alt. 23, and 24 (after mode shift) should be higher than those of HOV lane alternatives Alt. 08, Alt. 10, Alt. 18, and 20 (before mode shift). For example, it is reasonable that the carpool travel time of Alt. 21 (123.9 sec) is longer than the carpool travel time of Alt. 08 (117.5 sec). However, it is unreasonable that the carpool travel time of Alt. 22 (128.6 sec) is shorter than the carpool travel time of Alt. 10 (168.3 sec). However, it is also unreasonable that the carpool travel time of Alt. 23 (157.2 sec) is shorter than that of Alt. 18 (159.4 sec).

CHAPTER 5

SELECTION AND DEVELOPMENT OF THE TRANSYT-7F SIMULATION MODEL PLATOON DISPERSION ANALYTICAL METHODOLOGY DEVELOPMENT: ITS APPLICATION FOR ARTERIAL HOV LANES

Introduction

As noted in the section concerning TRAF-NETSIM Simulation Model Selection for Arterial HOV Lanes in Chapter 2, TRANSYT-7F is another traffic simulation model that can provide detailed traffic impact information useful in planning arterial HOV lanes.

Although the microscopic TRAF-NETSIM simulation model has many features; it does not offer signal timing optimization, the most important factor in the arterial traffic control system. However, TRANSYT-7F does provide traffic signal timing optimization and is widely used to develop arterial signal timing plans. Yet some common traffic model problems, such as how to distinguish platoon dispersion patterns between general-purpose lane and HOV lane links, need to be resolved before applying this model in HOV lane traffic analysis.

This chapter will focus on three concerns: (1) factors pertaining to the selection of the TRANSYT-7F simulation model, (2) the development of platoon dispersion analytical methodology, and, (3) the application of this methodology to the study of arterial HOV lanes. This chapter begins with a discussion of TRANSYT-7F's advantages and drawbacks for arterial HOV lane analysis. The prediction model and calibration process of TRANSYT platoon dispersion are then presented. A description of an innovative analytical methodology developed by the author for TRANSYT platoon dispersion smoothing factor follows. The chapter

concludes with discussion of a TRANSYT-7F application in an arterial HOV lane improvement project in the Seattle area.

Selection of the TRANSYT-7F Simulation Model for the Analysis of Arterial HOV Lanes

TRANSYT-7F is the most popular macroscopic simulation model for signal timing optimization available for the analysis of arterial HOV lane traffic. As explained in Chapter 2 (in the section concerning arterial traffic simulation models), this model describes vehicles as a group rather than representing them as independent identities. Though this model does not simulate traffic environments with the level of detail characteristic of a microscopic model, such as TRAF-NETSIM, its representation is nonetheless realistic if the prediction of traffic is correct. The computer running time of a macroscopic simulation model is much shorter than that of a microscopic traffic simulation model; hence, the iterated optimization algorithm can be added to develop the traffic signal timing plans. Thus, the macroscopic TRANSYT-7F model offers the major advantage of signal timing optimization over the microscopic TRAF-NETSIM model and for this reason has been used widely in the analysis of arterial traffic operations.

TRANSYT-7F's Advantages for Arterial HOV Lane Analysis

In brief, TRANSYT-7F offers the following advantages for arterial HOV lane traffic analysis:

1) TRANSYT-7F allows the development of realistic signal timing plans.

A macroscopic traffic simulation and signal timing optimization model, TRANSYT-7F can incorporate arterial HOV lane simulation with traffic signal timing plans. TRANSYT-7F, the most realistic macroscopic traffic simulation model available, simulates traffic flow in small time increments; therefore, its representation of traffic is more detailed than those of other macroscopic models that assume uniform distribution within the traffic platoons (64, 73).

Four essential elements constitute pretimed signal timing: cycle length, phase sequence, interval and phase length, and offsets. The actuated control signal timing must also be coded as an equivalent pretimed plan in TRANSYT-7F. The cycle length is the period of time during which all movements at a signalized intersection are accommodated. An interval is that segment of the cycle during which all signal displays, both traffic and pedestrian, remain unchanged. A phase is that combination of intervals (the green and change intervals) during which the traffic movements given the right-of-way remain unchanged. Phase sequences may consist of numerous combinations of protected and permitted movements. An offset is normally a period of time extending from a system reference point to the beginning point of the cycle at each of the signal controllers in the system. The number of signal timing plans required is a function of traffic demand. Ideally, a different signal timing plan would be developed for each distinct level of traffic in the network with attention to weeknights and weekends as well as weekdays.

TRANSYT-7F can evaluate a range of cycle lengths and then select the best cycle length for the network. This model also optimizes the pretimed phase lengths and offsets (or yield points). For these reasons, TRANSYT-7F is the most popular tool among traffic engineers for the development of optimized signal timing plans.

2) TRANSYT-7F can differentiate between SOV and HOV lanes in terms of MOEs.

TRANSYT simulates different traffic characteristic movements as separate links; this feature enables it to distinguish between SOV and HOV lanes in terms of MOEs.

Data pertaining to the network of streets and intersections is entered into TRANSYT-7F via a node and link identification scheme. A node may be an intersection of two more conflicting streets or may be a special conflict location. A link is a representation of one or several lanes of traffic approaching an intersection

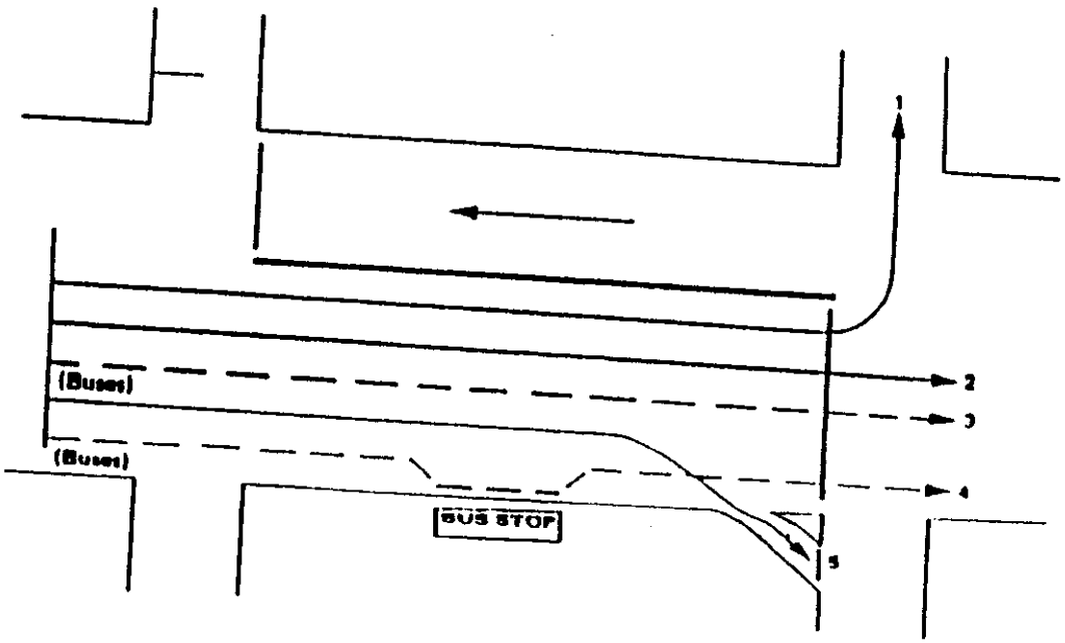
(node). An approach to an intersection may be represented by one or several links, depending on the geometry and traffic control at the intersection. For example, Figure 5.1 shows a set of links between two adjacent nodes, illustrating the variety of traffic characteristics that the user may wish to separate. All these independent links may have different saturation flow rates and may move in separate signal phases. Separate MOEs, including: saturation flow, degree of saturation, total travel, total travel time, average system speed, delay, stops, maximum back of queue, fuel consumption, operating cost, and performance index, can be calculated for each link.

Simply put, the HOV lane and the general-purpose lane, each with its own traffic characteristics, can be simulated as separate links in this model. Therefore, MOEs for HOV lane evaluation, such as the travel time of each link, can be obtained separately.

3) TRANSYT-7F allows simulation of the HOV lane queue-jump function.

As explained in the section concerning problems of TRAF-NETSIM for arterial HOV lane application in Chapter 4, arterial HOV lane queue-jump treatments, such as the early-moving preemption or last-closing signal timing, can result in significant travel time savings for HOV users. Thus, simulation of the HOV lane queue-jump function is important in arterial HOV lane planning.

TRANSYT-7F allows engineers to represent the HOV lane, complete with its specific traffic characteristics, as a separate link. This independent HOV lane link may also move in separate signal phases; thus allowing for the specific simulation of the HOV lane queue-jump function.



LINK NO.	MOVEMENT	REASON FOR SEPARATE LINK
1	Left turn from thru	Separate phase
2	Thru traffic	Progression desired
3	Thru buses	Account for thru buses
4	Stopping buses	Account for bus stops
5	Right turn from thru	Free right turn

Figure 5.1 Possible link assignments for various traffic characteristic flows between two adjacent nodes
SOURCE: TRANSYT-7F User's Manual 1988

4) The creation of a platoon analytical methodology for HOV lanes is an important issue in the development of this model.

Development of an analytical methodology for calculating the platoon smoothing factor for TRANSYT-7F will enhance this model, allowing it to simulate more complex traffic environments. TRANSYT-7F employs the traffic platoon dispersion model to predict the arrival flow rate at the downstream section. Although the TRANSYT-7F User's Manual provides some suggestions on how to determine the parameters of this prediction model under different traffic conditions, they are not sufficient for analysis of mixed-flow or congested traffic environments. This is why researchers seldom use TRANSYT-7F for HOV lane studies, even though the model has been widely applied for other purposes in the traffic engineering field. Thus, development of an analytical methodology for calculating the platoon smoothing factor will overcome one of TRANSYT-7F's most serious deficiencies and allow the simulation of more complex traffic flow. This issue will be discussed in more detail in the following sections.

Problems in the Application of TRANSYT-7F to Arterial HOV Lanes

In attempting to apply TRANSYT for arterial HOV lane traffic analysis, three specific problems were encountered in this study: (1) TRANSYT simulation cannot distinguish the HOV lane and general-purpose lane flow patterns properly, (2) TRANSYT cannot simulate the spillover traffic environments realistically, and, (3), TRANSYT does not simulate the congested traffic flow accurately without iteration.

1) TRANSYT simulation cannot properly distinguish between HOV and general-purpose lane flow patterns.

TRANSYT uses two parameters (α and β) in the platoon dispersion model to predict various types of traffic-flow arrival and departure patterns (see Equations 5.1 and 5.2). These patterns are then used for the calculation of MOEs. However,

no mechanism exists within the model to distinguish between these parameters for the two different types of traffic: that travelling in the HOV lane and that in the general-purpose lane.

Robertson's platoon dispersion model (55) which comprises the core of TRANSYT, may well be the most widely used traffic model in the world. In Card Type 10 (Network Master Card) or Card Type 39 (Platoon Dispersion Modification Card) of TRANSYT-7F input data, the platoon dispersion factor (PDF) α is used for this model (β = 0.8 is assumed in TRANSYT-7F) to predict various types of traffic-flow patterns for network links or specific links (73). An incorrect assumption on this PDF (α) value will result in a large additional number of stopped vehicles, which leave the intersection with the saturation flow rate on the left hand side of the cyclic flow profiles (CFP). It is also obvious that errors in the specification of this PDF (α) value and speed may result in serious errors in the choice of offsets thus causing unnecessary traffic delays and stops (5).

Although the TRANSYT-7F User's Manual provides the calibration process and some suggestions for the determination of PDF (α) value, application to certain traffic situations is still problematic. Table 5.1 suggests only three possible PDF (α) values to predict the platoon dispersion patterns of different traffic characteristics: 0.5 for heavy friction (urban CBD); 0.35 for moderate friction (well-designed CBD arterial); and 0.25 for low friction (suburban arterial). These suggested values do not help users to predict the flow dispersion patterns of traffic links with specific characteristics, such as bus, carpool, and mixed-flow lane links. Meanwhile, the platoon dispersion calibration process is excessively complicated to determine these PDF (α) values for all links.

Table 5.1 Platoon dispersion factor (PDF) values
SOURCE: 73

PDF VALUE	ROADWAY CHARACTERISTICS	DESCRIPTION OF CONDITIONS	CODE
0.5	Heavy friction	Combination of parking, moderate to heavy turns, moderate to heavy pedestrian traffic, narrow lane width. Traffic flow typical of urban CBD.	50
0.35	Moderate friction	Light turning traffic, light pedestrian traffic, 11- to 12-foot (3.4- to 3.6-meter) lanes, possibly divided. Typical of well-designed CBD arterial.	35
0.25	Low friction	No parking, divided, turning provisions 12-foot (3.6-meter) lane width. Suburban high type arterial.	25

Thus, the process for choosing the right PDF (α) value for each individual traffic link is still muddled and needs improvement. As Table 5.2 indicated, a wide range of α values (from 0.10 to 0.70) and β values (the multiplier between the average travel time and the first arriving vehicle travel time; ranging from 0.59 to 0.99) have been used in previous studies (44). Even the default value of α was changed from 0.5 in the original TRANSYT model (55) to 0.35 in the current TRANSYT-7F and TRANSYT-8 models (77).

Several studies have been undertaken for the purpose of resolving this problem, but difficulties still remain. Seddon (59) tried to fix this PDF (α) at 0.25, but failed to explain this result for other traffic situations. Denny (61) developed a mechanism based on the diffusion theory to predict platoon dispersion, but this mechanism did not predict for mixed-flow traffic (17). In Axhausen's study (5), the variety of α values were explained with reference to different level-of-design factors, including: number of lanes, slope, parking activity, crossing pedestrians, and flow

condition at stop line. A wide variation of α values, from 0.06 to 0.87, were found for different study sites. Moreover, the mean α value for each level of design factor (e.g., α = 0.37 for the disturbed flow and α = 0.38 for the smooth flow) is not significant to distinguish the variety of platoon patterns for certain traffic situations. Willumsen and Coeymans developed an improved approach, including a redefinition of cruise times and a recalibration of the platoon dispersion parameters in TRANSYT, to simulate the bus traffic network in a developing country. However, they confessed that they did not have a rigorous statistical methodology to achieve the best fit between modelled and observed platoons, so they simply tested different PDF (α) values and compared them with the CFPs visually. They strongly stated a need for a more systematic procedure for the calibration of the platoon dispersion model (81).

Arterial HOV lanes that have at least two different traffic characteristic links (HOV and general-purpose lane links) are more complicated in terms of platoon dispersion than are non-HOV lanes. HOV lane links characterized by bus stop delay, RTOR, signal priority, and higher relative flow speeds should not use the same PDF (α) value as general-purpose lanes even if they are located at the same road section. Development of a specific analytical methodology for the platoon smoothing factor is indeed necessary for the application of TRANSYT to the traffic analysis of arterial HOV lanes.

2) TRANSYT cannot simulate spillover traffic environments realistically.

Although the new version of TRANSYT-7F (Release 6) will consider the excess maximum back-of-queue in the optimization process, the simulation still does not deal explicitly with spillover.

Table 5.2 A wide range of α and β values used in previous studies
SOURCE: McCoy, et al. 1983

Author	Place	Year	No. of Lanes	Average Width	Slope	Traffic Flow Disturbances: Parking	Driveways	Pedestrians	Left Turns	Stop Line	Peak Period	α	β	α_0[a]
Hillier and Rothery	London, England	1967	Four sites, no individual results reported									0.50	0.80	–
Seddon (8)	Manchester, England	1972	3	11.0[b]	–	–	–	–	–	–	p.m.	–	–	0.49
			2	10.0[b]	–	–	–	–	–	–	p.m.	–	–	0.61
Collins and Gower (9)	London, England	1974	3	–	–	No	–	No	–	–	–	–	–	0.20
Trace (10)	Cracow, Poland	1975	2	4.0	–	–	–	–	–	Smooth	–	–	–	0.30
			2	4.0	–	–	–	–	–	Smooth	–	–	–	0.23
Lam (11)	Toronto, Canada	1977	2	–	–	–	No	–	–	–	a.m.	0.25	0.77	–
			2	–	–	–	No	–	–	–	Noon	0.18	0.72	–
			2	–	–	–	No	–	–	–	p.m.	0.35	0.72	–
Ready and Ashworth (12)	Sheffield, England	1978	–	–	Down	–	–	–	–	–	a.m.	0.09	0.85	0.18
			–	–	Down	–	–	–	–	–	a.m.	0.70	0.59	0.25
Turnoff and Parsonson (13)	Fairfax County, Virginia	1978	–	–	–	–	No	–	No	–	p.m.[c]	–	–	0.24
			–	3.5	–	–	Limited	–	–	–	p.m.[c]	–	–	0.17
McCoy et al. (3)	Lincoln, Nebraska	1981	1	4.2	Level	No	No	–	No	–	p.m.	0.22	0.99	0.51
			1	4.2	Level	No	Limited	–	No	–	p.m.	0.20	0.98	0.35
			2	4.0	Level	No	Limited	–	No	–	a.m.	0.16	0.95	0.38
			2	4.0	Level	No	No	–	No	–	a.m.	0.13	0.97	0.35
			2	4.2	Level	No	No	–	No	–	a.m.	0.14	0.99	0.36
			2	4.0	Level	No	Limited	–	No	–	a.m.	0.16	0.96	0.38
Lorick (14)	Gainesville, Florida	1981	2	3.7	Level	–	No	No	–	–	a.m.	0.35	0.80	–
			2	3.7	Level	–	No	No	–	–	a.m.	0.30	0.65	–
			2	3.7	Level	–	No	No	–	–	a.m.	0.50	0.80	–
Smith (15)	Melbourne, Australia	1984	3	–	–	No	No	No	No	–	a.m.	0.19	0.89	–
Denney (16)	Austin, Texas	1985	3	4.0	–	No	Yes	–	–	–	Noon	–	–	0.29
Gradl (17)	Bochum, Federal Republic of Germany	1986	2	–	–	No	No	No	No	–	p.m.[c]	–	–	0.25
			2	–	–	No	No	Yes	No	–	p.m.[c]	–	–	0.32
			2	–	–	Yes	No	No	No	–	p.m.[c]	–	–	0.26
Vincent[d]	Bern, Switzerland		Six sites, no individual results reported									–	–	0.31

[a] Calibrated with β fixed at 0.80.
[b] In both directions.
[c] Including some off peak measurements.
[d] Private communication.

In optimizing, the new version TRANSYT-7F (Release 6) minimizes an objective function called the performance index (PI). The PI may be defined in either of two ways: (1) as a linear combination of delays, stops and (optionally) excessive maximum back-of-queue, or, (2) as excess operation cost (also optionally weighted by excessive maximum back-of-queue). The maximum back-of-queue value is the (average or 50th percentile) maximum extension of the queue upstream on the link during the cycle. This value can be used to determine whether there is a chance of spillover into an upstream intersection. If cycle failure (failing to clear

the queue on a link during the green time) or spillover actually occurs, the traffic flow model does not render realistic results. On links with high degrees of saturation, the random-plus-saturation delay will make up the largest part of the total delay estimate (see the section entitled "Arterial simulation models: TRANSYT model" in Chapter 2). This will in turn affect the values of other MOEs; therefore, the results of the simulation will not be reliable as long as spillover is a distinct possibility (55, 73).

3) TRANSYT does not simulate congested traffic flow accurately without iteration.

TRANSYT, which uses only the coded PDF value and free-flow travel time without iteration, cannot predict platoon patterns in congested traffic situations correctly. In TRANSYT-7F, the user codes two variables, average cruise speed (or travel time) under prevailing traffic conditions and the PDF (α) value of the existing traffic environment to predict the platoon dispersion of each link. In the case of congested traffic flow, it is obviously unreasonable to use both a free-flow speed and a PDF (α) value of the existing traffic environment to predict platoon dispersion. As free-flow traffic becomes congested, the traffic flow pattern and speed of these links should change significantly. However, TRANSYT offers no feedback algorithm to include these updated values to simulate congested-flow traffic.

The TRANSYT-7F Platoon Dispersion Model and Calibration Process

The platoon dispersion model has constituted one of the most important developments for improving the design of linked traffic signal systems. The Road Research Laboratory (RRL) combination method (26), designed for computer analysis, calculates the offsets that minimize total delays to vehicles within the network. This method produced an important breakthrough and replaced the conventional time/distance diagram method in the design of signal offsets for one and two-dimension systems. The core concept of this method is that the delay for

each time interval can be calculated by the difference between the cumulative demand function (number of vehicles arriving at the end of a link) and the cumulative service function (number of vehicles discharged by the signal at the end of the link). Applying this calculation, the relation between delay and difference-of-offset can be obtained by varying the offset time of signals. Thus the offsets of all signals in the network can be determined to minimize total delays (60).

However, there is one serious problem with the combination method -- no platoon dispersion was assumed for the cumulative demand function. Three major theories have been developed for platoon dispersion to address this concern: the kinematic wave theory, the diffusion theory, and the recurrence theory (60, 61, 62, 17). The recurrence theory was adopted by TRANSYT; it is the simplest and most widely used model in the transportation field.

Platoon Dispersion Model

On arterials and city streets, the vehicle queue created by red lights becomes a moving platoon as the signal changes from red to green. Platoons tend to disperse, or spread out, from a saturation flow rate at the upstream intersection, along the roadway to the downstream intersection. Robertson developed a recurrence model, (Figure 5.2), to describe this phenomenon (55):

$$q'_{(i+t)} = F \times q_i + (1 - F) \times q'_{(i+t-1)} \qquad (5.1)$$

where

$q'_{(i+t)}$: predicted flow rate (in the time interval i+t of the predicted platoon)

q_i : flow rate of the initial platoon in the ith time interval

t : β (0.8 is assumed in TRANSYT) times the average journey time T; or average

arrival time of the first vehicle of the platoon

F : a smoothing factor

The smoothing factor may be understood as a function of "site factors," such as road width, gradient, parking, opposing flow level, pedestrian interference, traffic composition et cetera. The smoothing factor F required for the best fit between the actual and calculated platoon shapes was found to be related to the journey time by the expression:

$$F = 1 / (1 + \alpha t) \tag{5.2}$$

where

α : an empirically derived constant (α = 0.5 is the default value of the original TRANSYT model; α = 0.35 is the current default value of TRANSYT-7F and TRANSYT-8).

TRANSYT-7F uses a different formula to disperse buses, which accounts for their more sluggish movement at bus stops along the link and in regular traffic, regardless of whether the bus is moving in mixed-traffic or in its own lane. The detailed bus platoon smoothing factor formula is not described in the TRANSYT-7F User's Manual. It is, however, described in TRANSYT-8 (77) as:

$$F = (1 + 0.7\, b + 0.3\, t)^{-1} \tag{5.3}$$

where

b: mean stopped time at a bus stop

t: mean cruise time

Platoon Dispersion Calibration Process

In principle, the PDF (α) value in Equation (5.2) should be calibrated with existing traffic conditions for each type of link. Although a default value of PDF (α = 0.35) based on empirical studies and some suggested PDF (α) values (Table 5.1) are available in TRANSYT-7F, the appropriate specific value for each type of link may vary with respect to different localities and traffic characteristics.

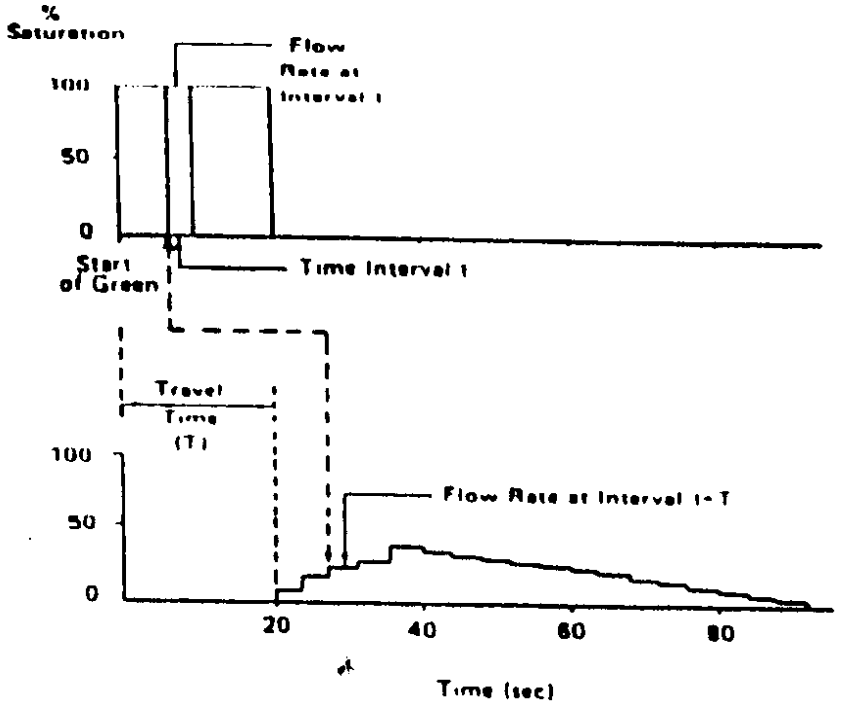
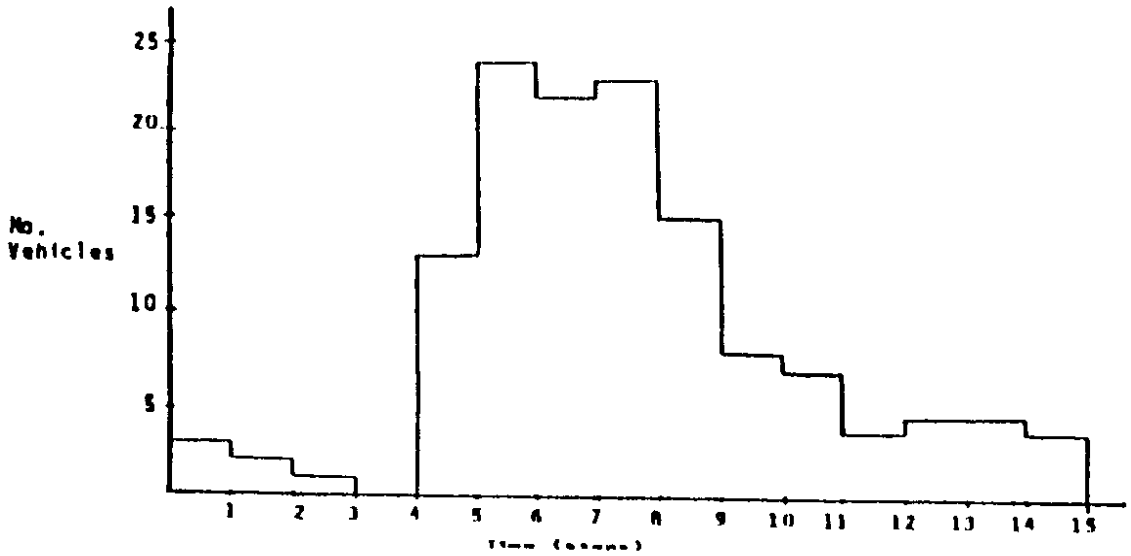


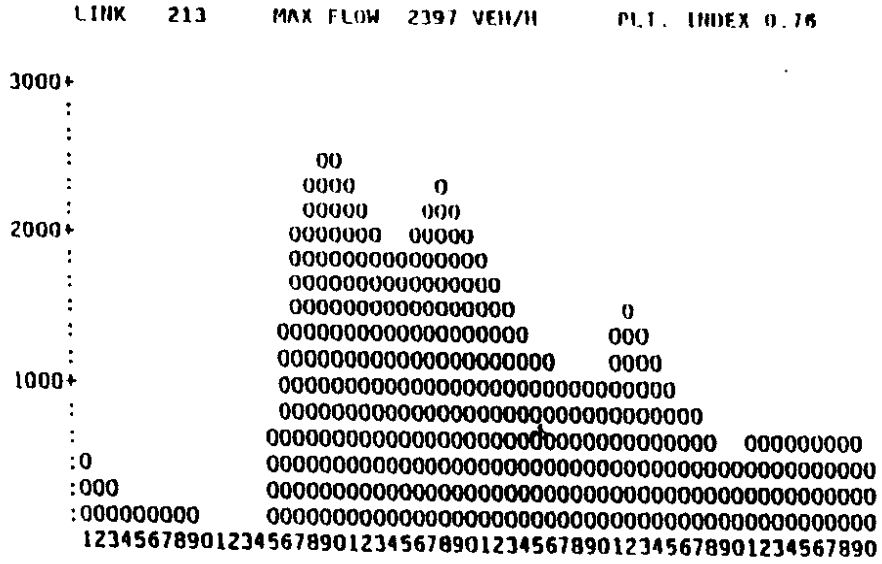
Figure 5.2 Platoon dispersion in TRANSYT
SOURCE: TRANSYT-7F User's Manual 1988

TRANSYT flow profiles and arrival profiles observed in the field are compared in TRANSYT-7F to calibrate speed, travel time, PDFs, and link-to-link flows. The flow profile diagrams represent the arrival and departure rates of traffic at the stopline. The processes for flow profile analysis in TRANSYT-7F are summarized briefly below.

For observing traffic flow on the link, a dummy link should be coded as a mid-block bottleneck link, first at an upstream location that is unaffected by queues. The correct starting point for the study should then be chosen so that the field study and the TRANSYT flow profiles can be synchronized properly. The number of vehicles passing the check point must then be counted for every subsequent "step" in the cycle. At least ten cycles of data should be recorded to obtain a representative sample. The field data are then plotted as histograms for comparison of measured and TRANSYT-7F-predicted flow profiles (Figure 5.3). Finally, in accordance with guidelines, the user should adjust the parameters if differences are found between observed and model-estimated flow profiles. For example, the profiles must be realigned if they are not synchronized to the same reference point. The PDF (α) value should decrease if the measured platoons are more peaked than the TRANSYT-7F platoons. Likewise, the PDF (α) value should increase if the measured platoons are less peaked than the TRANSYT-7F platoons.



A. Histogram of Field Study



B. TRANSYT-7F Flow Profile

Figure 5.3 Comparison of manual and model flow profiles for PDF (α) value calibration
SOURCE: TRANSYT-7F User's Manual 1988

Some problems associated with this calibration process are very difficult and complex. For instance, the unit of measurement of the flow profile (vehicles per step) is different from that of the model flow profile (vehicles per hour); therefore, the magnitudes of the two profiles cannot be compared. It is sometimes quite difficult to align the TRANSYT-7F flow profile with the flow profile measured in the field, especially on relatively short links. Because it is difficult to eliminate the effects of the perception of a queue or of signal indication for drivers, TRANSYT-predicted (free-flow) arrival times tend to be earlier than those measured in the field. It is also difficult to determine an appropriate average cruise speed for the existing condition or for an optimization case (73).

Development and Verification of Platoon Dispersion Analytical Methodology

As described above, the three most serious obstacles to applying TRANSYT-7F to analysis of arterial HOV lanes are: inconsistency of PDF (α) values, complexity of the platoon dispersion calibration process, and problems associated with the incorrect congested flow prediction. In an effort to resolve the first two problems, one methodology for calculating the platoon smoothing factor, which is based on statistical and mathematical theories, has been developed. To address the last problem, that of incorrect congested flow prediction, two platoon dispersion iteration algorithms will be developed in this study.

Development of Platoon Smoothing Factor Analytical Methodology

The platoon dispersion scheme, as shown in Figure 5.2, will be used in this study to develop a platoon smoothing factor methodology. Table 5.3 indicates that the platoon dispersion of an independent upstream flow (e.g., q_A) arriving at downstream is dependent on the value of platoon smoothing factor F and on the upstream flow rate (Equations 5.4, 5.5, 5.6, and 5.7). Figure 5.4 illustrates the platoon dispersion of an independent upstream flow rate (q_A = 100 percent saturation flow is assumed) as the platoon smoothing factor F = 0.5 is used. After t

seconds (average travel time of the first arriving vehicle), the original flow rate will be dispersed continually at the downstream location for some time intervals. The mean travel time of the platoon can be derived from the accumulated flow rate and travel time of each time interval. The detailed development process and findings of this analytical methodology are described in the following subsection.

Methodology Development Process. The flow rate per time interval of upstream traffic can be assumed as: q_A for the first time interval, q_B for the second time interval, q_C for the third time interval, q_D for the fourth time interval, and so on.

After t seconds (average travel time of the first arriving vehicle), the flow arriving downstream can be described by the Robertson's platoon dispersion model (equation 5.1) as follows:

a) the flow rate, including only one part of q_A, which will arrive at the downstream location within the first time interval (after t + 0s seconds; s is the seconds per time interval) (equation 5.4)

$$q'_{(t+0s)} = F \times q_A + 0, \tag{5.4}$$

b) the flow rate, including one part of q_A and q_B, which will arrive at the downstream location within the second time interval (after t + s seconds) (equation 5.5)

$$q'_{(t+1s)} = F \times q_B + (1 - F) \times F \times q_A, \tag{5.5}$$

c) the flow rate, including one part of q_A, q_B, and q_C, which will arrive at the downstream location within the third interval time (after t + 2s seconds) (equation 5.6)

$$q'_{(t+2s)} = F \times q_C + (1 - F) \times [F \times q_B + (1 - F) \times F \times q_A], \text{ and} \tag{5.6}$$

Table 5.3 Platoon dispersion of an independent upstream flow (e.g., q_A) depends on F value and flow rate (q_A = 1 is assumed in this example)

N steps after t sec	Platoon dispersion	F = 0.100	F = 0.300	F = 0.500	F = 0.700	F = 0.900
1	$F*q_A$	0.100	0.300	0.500	0.700	0.900
2	$F*(1-F)**1*q_A$	0.090	0.210	0.250	0.210	0.090
3	$F*(1-F)**2*q_A$	0.081	0.147	0.125	0.063	0.009
4	$F*(1-F)**3*q_A$	0.073	0.103	0.063	0.019	0.001
5	$F*(1-F)**4*q_A$	0.066	0.072	0.031	0.006	0.000
6	$F*(1-F)**5*q_A$	0.059	0.050	0.016	0.002	0.000
7	$F*(1-F)**6*q_A$	0.053	0.035	0.008	0.001	0.000
8	$F*(1-F)**7*q_A$	0.048	0.025	0.004	0.000	0.000
9	$F*(1-F)**8*q_A$	0.043	0.017	0.002	0.000	0.000
10	$F*(1-F)**9*q_A$	0.039	0.012	0.001	0.000	0.000
11	$F*(1-F)**10*q_A$	0.035	0.008	0.000	0.000	0.000
12	$F*(1-F)**11*q_A$	0.031	0.006	0.000	0.000	0.000
13	$F*(1-F)**12*q_A$	0.028	0.004	0.000	0.000	0.000
14	$F*(1-F)**13*q_A$	0.025	0.003	0.000	0.000	0.000
15	$F*(1-F)**14*q_A$	0.023	0.002	0.000	0.000	0.000
16	$F*(1-F)**15*q_A$	0.021	0.001	0.000	0.000	0.000

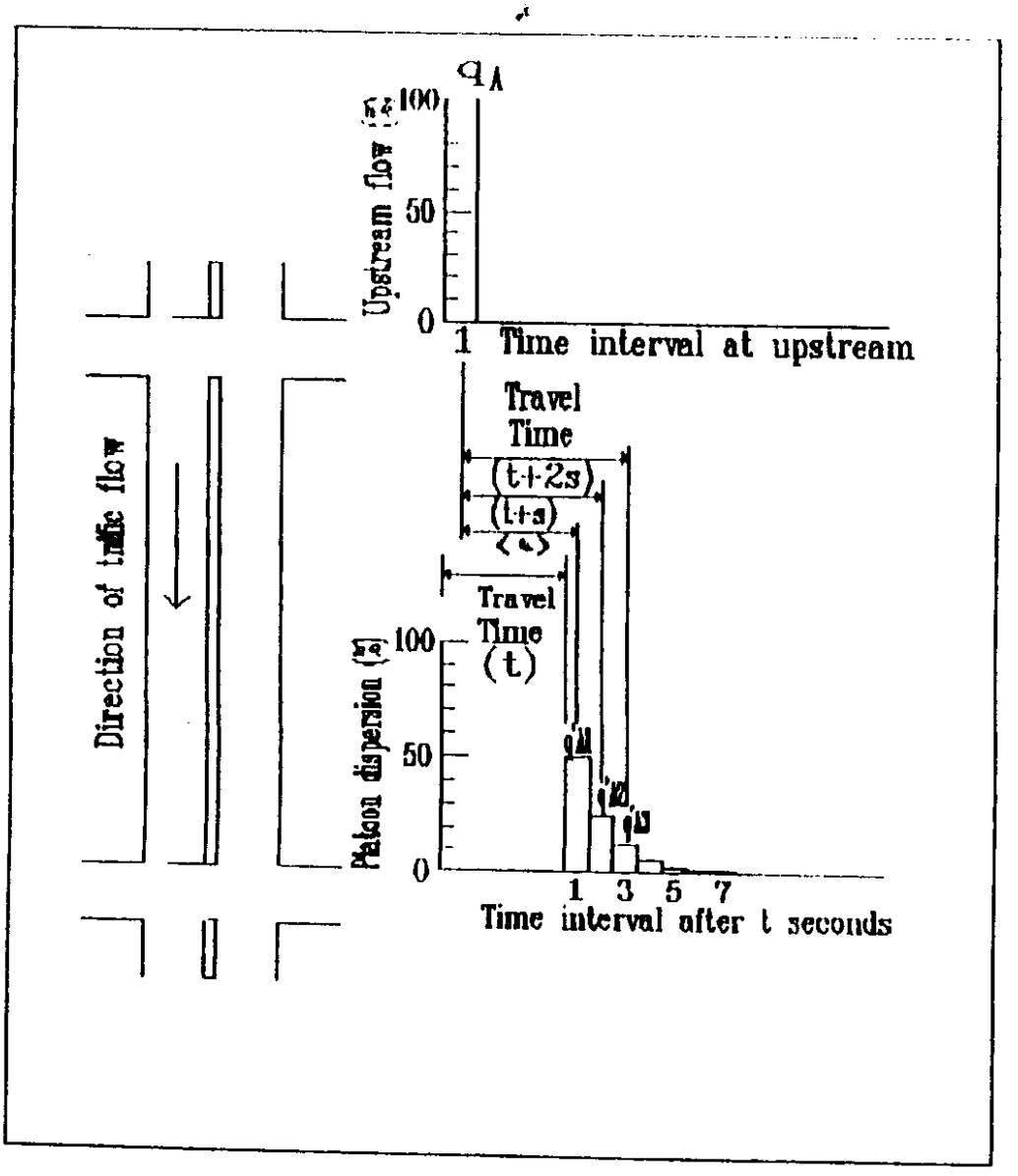


Figure 5.4 The platoon dispersion of an independent upstream flow (F = 0.5 is assumed)

d) the flow rate, including one part of q_A, q_B, q_C, and q_D, which will arrive at the downstream location within the fourth interval time (after t + 3s seconds) (equation 5.7)

$$q'_{(t+3s)} = F \times q_D + (1 - F) \times \{F \times q_C + (1 - F) \times [F \times q_B + (1 - F) \times F \times q_A]\} \quad (5.7)$$

.

.

For example, assuming only four flows ($q_A = q_B = q_C = q_D$ = 100 percent saturation flow rate) existing at upstream time intervals, and F = 0.5, the platoon dispersion at the downstream location for each time interval after t seconds (Figure 5.5) will look like a bar stacked by parts of each upstream flow rate. Table 5.4 shows the detailed flow rate composition of the platoon dispersion for each time interval.

That is, if the platoon is completely dispersed in normal traffic environments (no cycle failure or spillover), the travel time of each flow rate arriving downstream during one specific time interval can be manipulated as follows:

At the first time interval (after t seconds), the predicted flow rate $q'_{(t+0s)}$, including only the first part dispersion (q'_{A1}) of q_A, will arrive at the downstream location; the total travel time of this dispersed flow is equal to:

$$q'_{A1} \times t = F \times q_A \times t + 0 \quad (5.8)$$

At the second time interval (after t + s seconds), the predicted flow rate $q'_{(t+1s)}$, including the first part dispersion (q'_{B1}) of q_B and the second part dispersion (q'_{A2}) of q_A, will arrive at the downstream location; the total travel time of these dispersed flows is equal to:

$$q'_{B1} \times t + q'_{A2} \times (t + s) = F \times q_B \times t + [(1 - F) \times F \times q_A] \times (t + s) \quad (5.9)$$

Table 5.4 The detailed flow rate composition of the platoon dispersion for each time interval

The time inter. (n+1) after t sec	q'_A (Disper. of q_A)	q'_B (Disper. of q_B)	q'_C (Disper. of q_C	q'_D (Disper. of q_D	$q'_{(t+n*s)}$ (Total disper.)
1	0.500				0.500
2	0.250	0.500			0.750
3	0.125	0.250	0.500		0.875
4	0.063	0.125	0.250	0.500	0.938
5	0.031	0.063	0.125	0.250	0.469
6	0.016	0.031	0.063	0.125	0.235
7	0.008	0.016	0.031	0.063	0.118
8	0.004	0.008	0.016	0.031	0.059
9	0.002	0.004	0.008	0.016	0.030
10	0.001	0.002	0.004	0.008	0.015
11	0.000	0.001	0.002	0.004	0.007
..	...	...	...	...	...
..	...	...	...	...	...

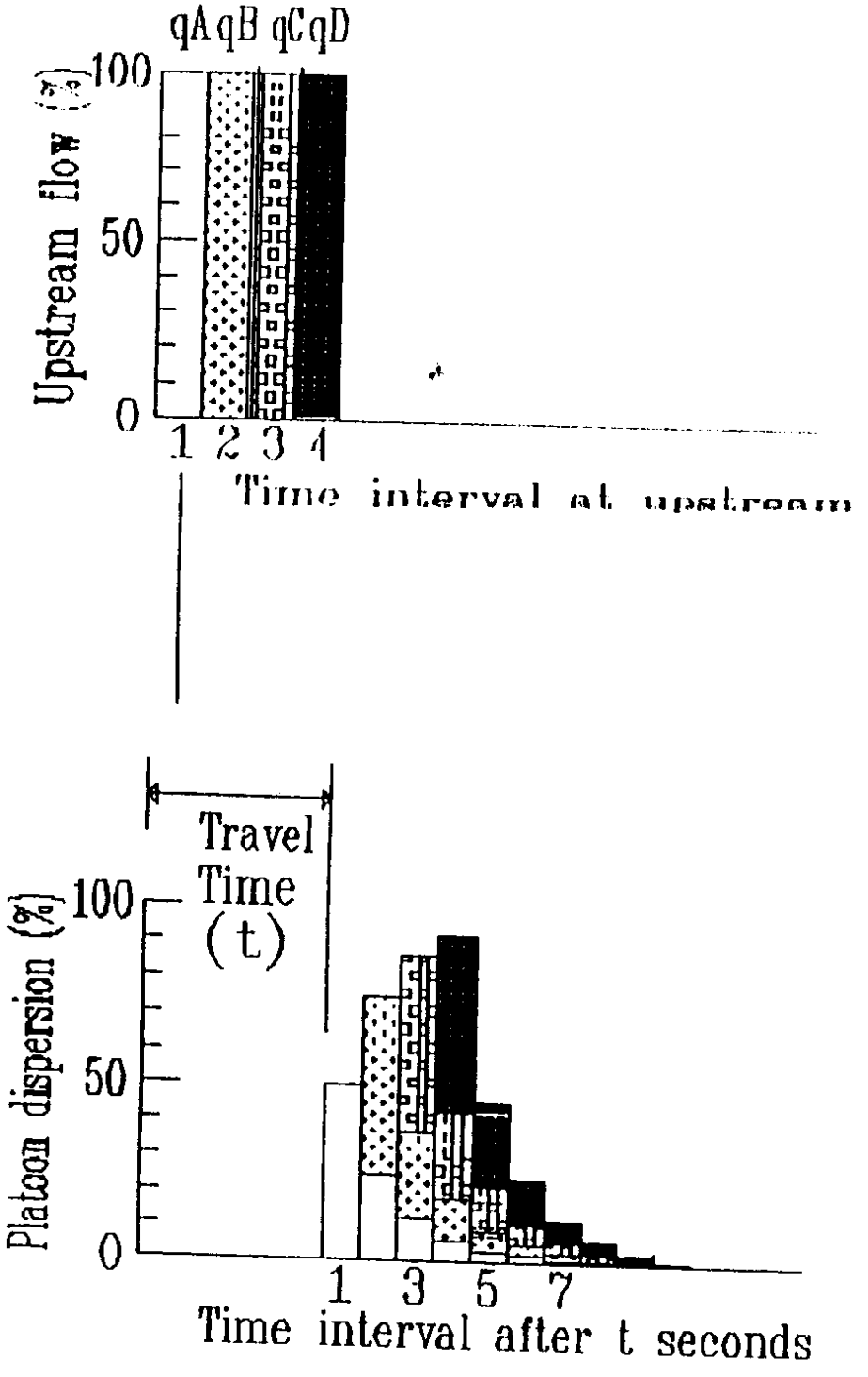


Figure 5.5 Platoon dispersion for each time interval

At the third time interval (after t + 2s seconds), the predicted flow rate $q'_{(t+2s)}$, including the first part dispersion (q'_{C1}) of q_C, the second part dispersion (q'_{B2}) of q_B, and the third part dispersion (q'_{A3}) of q_A, will arrive at the downstream location; the total travel time of these dispersed flows is equal to:

$$q'_{C1} \times t + q'_{B2} \times (t + s) + q'_{A3} \times (t + 2s)$$
$$= F \times q_C \times t + (1 - F) \times F \times q_B \times (t + s) + (1 - F)^2 \times F \times q_A \times (t + 2s) \quad (5.10)$$

Similarly, at the fourth time interval (after t + 3s seconds), the predicted flow rate $q'_{(t+3s)}$, including the first part dispersion (q'_{D1}) of q_D, the second part dispersion (q'_{C2}) of q_C, the third part dispersion (q'_{B3}) of q_B, and the fourth part dispersion (q'_{A4}) of q_A, will arrive at the down stream location; the total travel time of these dispersed flows is equal to:

$$q'_{D1} \times t + q'_{C2} \times (t + s) + q'_{B3} \times (t + 2s) + q'_{A4} \times (t + 3s)$$
$$= F \times q_D \times t + (1 - F) \times F \times q_C \times (t + s) + (1 - F)^2 \times F \times q_B \times (t + 2s) +$$
$$(1 - F)^3 \times F \times q_A \times (t + 3s) \quad (5.11)$$

.

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Therefore, the average travel time T of the dispersed platoon can be calculated as the sum of the above total travel time for each time interval (equations 5.8, 5.9, 5.10, and 5.11, etc.) divided by the total platoon:

$$T = \{q'_{A1} \times t$$
$$+ [q'_{B1} \times t + q'_{A2} \times (t + s)]$$
$$+ [q'_{C1} \times t + (q'_{B2} \times (t + s)) + (q'_{A3} \times (t + 2s))]$$
$$+ [q'_{D1} \times t + (q'_{C2} \times (t + s)) + (q'_{B3} \times (t + 2s)) + (q'_{A4} \times (t + 3s))]$$
$$+ \ldots\} \ / \ (q'_A + q'_B + q'_C + q'_D + \ldots) \quad (5.12)$$

Equation 5.12 can also be described as:

$$
\begin{aligned}
T = \{ & F \times q_A \times t + 0 \\
& + F \times q_B \times t + (1 - F) \times F \times q_A \times (t + s) \\
& + F \times q_C \times t + (1 - F) \times F \times q_B \times (t + s) + (1 - F)^2 \times F \times q_A \times (t + 2s) \\
& + F \times q_D \times t + (1 - F) \times F \times q_C \times (t + s) + (1 - F)^2 \times F \times q_B \times (t + 2s) + \\
& (1 - F)^3 \times F \times q_A \times (t + 3s) \\
& + \ldots\} \ / \ (q'_A + q'_B + q'_C + q'_D + \ldots) \qquad (5.13)
\end{aligned}
$$

If all the parts of the same original flow rate (e.g., q_A) are put together, equation 5.13 can be written as:

$$
\begin{aligned}
T = \{ & F \times q_A \times t + [(1 - F) \times F \times q_A] \times (t + s) + (1 - F)^2 \times F \times q_A \times (t + \\
& 2s) + (1 - F)^3 \times F \times q_A \times (t + 3s) + \ldots \\
& + F \times q_B \times t + (1 - F) \times F \times q_B \times (t + s) + (1 - F)^2 \times F \times q_B \times (t + \\
& 2s) + \ldots \\
& + F \times q_C \times t + F \times q_C \times t + (1 - F) \times F \times q_C \times (t + s) \\
& + \ldots\} \ / \ (q'_A + q'_B + q'_C + q'_D + \ldots.) \qquad (5.14)
\end{aligned}
$$

Because the travel time of each dispersed flow has the same calculation formula, equation 5.14 can also be written as:

$$
\begin{aligned}
T = \{ & (q_A + q_B + q_C + q_D + \ldots) \times F \times t \\
& + (q_A + q_B + q_C + q_D + \ldots) \times F \times (1 - F) \times (t + s) \\
& + (q_A + q_B + q_C + q_D + \ldots) \times F \times (1 - F)^2 \times (t + 2s) \\
& + (q_A + q_B + q_C + q_D + \ldots) \times F \times (1 - F)^3 \times (t + 3s) \\
& + \ldots\} \ / \ (q'_A + q'_B + q'_C + q'_D + \ldots) \qquad (5.15)
\end{aligned}
$$

Because the platoon is assumed to disperse completely within each signal timing cycle, the total flow rate at the upstream location ($q_A + q_B + q_C + q_D + \ldots$) should be the same as the total flow rate after dispersion ($q'_A + q'_B + q'_C + q'_D + \ldots$) at the downstream location. Thus, Equation 5.15 can be simplified (dividing the numerator and the denominator by the total flow rate) as:

$$T = F \times t + F \times (1 - F) \times (t + s) + F \times (1 - F)^2 \times (t + 2s) + F \times (1 - F)^3 \times (t + 3s) + \ldots.$$

$$= F \times t \times [1 + (1 - F) + (1 - F)^2 + (1 - F)^3 + \ldots] + s \times F \times (1 - F) + 2s \times F \times (1 - F)^2 + 3s \times F \times (1 - F)^3 + \ldots$$

$$= F \times t \times [1 + (1 - F) + (1 - F)^2 + (1 - F)^3 + \ldots] + s \times F \times (1 - F) [1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots] \quad (5.16)$$

Since (1-F) < 1, the Geometric Series G_1 (Equation 5.17) can be applied in this manipulation (Salas and Hille 1974):

$$\text{If } u < 1, G_1 = 1 + u + u^2 + u^3 + u^4 + u^5 + \ldots = 1 / (1 - u) \quad (5.17)$$

Let u = (1-F), the sum of $[1 + (1 - F) + (1 - F)^2 + (1 - F)^3 + \ldots]$ in equation 5.16 can be obtained from equation 5.17 as $1 / [1 - (1 - F)]$. Thus equation 5.16 can be written as:

$$T = F \times t \times \{ 1 / [1 - (1 - F)]\} + s \times F \times (1 - F) [1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots]$$

$$= F \times t \times (1 / F) + s \times F \times (1 - F) \times [1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots]$$

$$= t + s \times F \times (1 - F) \times [1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots] \quad (5.18)$$

To further simplify the Geometric Series $[1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots]$ in equation 5.18, other Geometric Series G_2 (equation 5.19) and G_3 (equation 5.23) can be applied in this manipulation:

$$G_2 = S_n = 0 \times u^0 + 1 \times u^1 + 2 \times u^2 + 3 \times u^3 + 4 \times u^4 + \ldots \quad (5.19)$$

Let G_2 be multiplied by u, then

$$u \times S_n = 1 \times u^2 + 2 \times u^3 + 3 \times u^4 + 4 \times u^5 + \ldots \quad (5.20)$$

The result after equation 5.19 minus equation 5.20 can also be simplified by using Geometric Series G_1 (equation 5.17):

$$(1 - u) \times S_n = u^1 + u^2 + u^3 + u^4 + \ldots$$

$$= u \times (1 + u^1 + u^2 + u^3 + u^4 + \ldots)$$

$$= u \times [1 / (1 - u)] \quad (5.21)$$

The sum of Geometric Series G_2 (equation 5.19) can be obtained by dividing equation 5.21 by (1-u):

$$G_2 = S_n = u / (1 - u)^2 \tag{5.22}$$

Furthermore, the Geometric Series G_3 (equation 5.23) can be calculated as G_2 + G_1.

$$G_3 = 1 + 2 \times u^1 + 3 \times u^2 + 4 \times u^3 + 5 \times u^4 + \ldots \tag{5.23}$$

$$\begin{aligned} G_3 &= (0 + 1) \times u^0 + (1 + 1) \times u^1 + (2 + 1) \times u^2 + (3 + 1) \times u^3 + \\ &\quad (4 + 1) \times u^4 + \ldots \\ &= (0 \times u^0 + 1 \times u^1 + 2 \times u^2 + 3 \times u^3 + 4 \times u^4 + \ldots) \\ &\quad + (u^0 + u^1 + u^2 + u^3 + u^4 + \ldots) \\ &= G_2 + G_1 \end{aligned}$$

Since the sum of G_2 is $u / (1 - u)^2$ (equation 5.22) and G_1 is $1 / (1 - u)$ (equation 5.17) respectively, the sum of G_3 can be derived as:

$$\begin{aligned} G_3 &= u / (1 - u)^2 + 1 / (1 - u) \\ &= [u + (1 - u)] / (1 - u)^2 \\ &= 1 / (1 - u)^2 \end{aligned} \tag{5.24}$$

Therefore, the sum of Geometric Series $[1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots]$ can be obtained from equations 5.23 and 5.24 by replacing u with (1-F):

$$[1 + 2 \times (1 - F) + 3 \times (1 - F)^2 + \ldots] = 1 / [1 - (1 - F)]^2 \tag{5.25}$$

Finally, equation 5.18 can be simplified as

$$\begin{aligned} T &= t + s \times F \times (1 - F) \times \{1 / [1 - (1 - F)]^2\} \\ &= t + s \times F \times (1 - F) \times (1 / F^2) \\ &= t + s \times (1 - F) / F \end{aligned} \tag{5.26}$$

To compare this derived result with the TRANSYT-7F smoothing factor formula (equation 5.2), equation 5.26 can be further transferred as:

$$T - t = s \times (1 - F) / F$$

$$(T - t) \times F = s \times (1 - F) = s - s \times F$$

$$(T - t + s) \times F = s$$

$$F = s / (T - t + s)$$

$$= 1 / \{1 + [(T - t) / s]\} \qquad (5.27)$$

This means that the platoon smoothing factor F value can be controlled by T, t, and s parameters. Since the relationship between T and t has been defined by equation 5.1, the derived result (equation 5.27) can finally be written as follows:

$$t = \beta \times T$$

$$T = 1 / \beta \times t$$

$$F = 1 / \{1 + [(1/\beta) \times t - t] / s\}$$

$$F = 1 / \{1 + [(1/\beta - 1) / s] \times t\} \qquad (5.28)$$

<u>Methodology Development Findings.</u> Significant findings can be derived from comparison of the TRANSYT-7F smoothing factor formula (equation 5.2) to the results of the analytical methodology described above (equations 5.27 and 5.28).

1) The result of this analytical methodology, $F = 1 / \{1 + [(1/\beta - 1) / s] \times t\}$ (equation 5.28) has the same format as the empirically derived formula of TRANSYT-7F $F = 1/(1 + \alpha t)$ (equation 5.2). In other words, this analytical methodology may replace the empirically derived formula if researchers can prove that it is more accurate and more efficient in predicting platoon dispersion.

2) This analytical methodology is more convenient and more precise in explaining the platoon dispersion phenomenon.

As described earlier in this chapter ("Problems in the application of TRANSYT-7F to arterial HOV lanes), determination of the PDF (α) value is the most difficult part of applying TRANSYT-7F to HOV lane analysis. However, this analytical methodology provides a more convenient and definite explanation for platoon dispersion.

TRANSYT uses two parameters (α and β) in the platoon dispersion model to predict various types of traffic-flow arrival and departure patterns. The first, α, is an empirically derived constant whose dependency on very complex site factors makes it difficult to estimate or calibrate this parameter. However, β is defined as the multiplier between the average vehicle travel time and the first arriving vehicle travel time. It is easy to obtain this value from traffic field study. The platoon dispersion factor $\alpha = (1/\beta - 1) / s$ can be obtained from the comparison of $F = 1 / \{1 + [(1/\beta - 1) / s] \times t\}$ (equation 5.28) and $F = 1 / (1 + \alpha t)$ (equation 5.2). As described in the subsection of chapter 2 entitled "Arterial traffic simulation models: TRANSYT model", the shorter the time interval, s (step size), the more accurate the platoon dispersion prediction. This time interval, s, of equation 5.28, can be controlled and coded on input data by the user. Consequently, using the analytical methodology described above, the platoon smoothing factor F can be determined with reference to just one controllable factor (β) rather than to the original uncontrollable factor α (and the controllable factor β).

3) The platoon dispersion depends on the value not only of β (or α) but on step size (s) as well.

The parameters that determine the value of the platoon smoothing factor F consist of both β and s factors (equation 5.28). If a new interval time (step) s value is introduced, the platoon dispersion pattern will change accordingly.

For example, because t (the first arriving vehicle travel time) is assumed to equal 0.8 x T (average journey time) according to Robertson's model, the α or F value can be calculated from equation 5.28:

$$t = 0.8 \times T$$

$$T = 5/4 \times t$$

$$F = 1 / \{1 + [(5/4) \times t - t] / s\}$$

$$F = 1 / (1 + 1/4s \times t)$$

Therefore, the PDF (α) value should be 0.125 if the β value is 0.8 and s is 2 sec. However, if the time interval 1 sec is used, then the α value should be 0.25. Similarly, if the time interval of 4 sec is used, then the α value should be 1/16. On the other hand, if the default platoon dispersion factor α = 0.35 and s = 1 sec, then the β value should be equal to 0.74 (1/1.35) instead of 0.8. A detailed explanation follows in the subsection of this chapter, entitled, "Verification of platoon dispersion analytical methodology."

4) Platoon dispersion depends on the difference between the minimum and average travel times.

From another type of development result, $F = 1 / \{1 + [(T - t) / s]\}$ (Equation 5.27), the F value is closely related to the difference between the average and minimum travel times. The greater the difference, the lower (slower) the F value (platoon dispersion). This conclusion can also be matched with the empirically derived formula (equation 5.3) of the bus (or carpool) platoon smoothing factor:

The TRANSYT formula (equation 5.3) for the bus (or carpool) platoon smoothing factor may also be described as:

$$F = (1 + 0.7\,ST + 0.3\,RT)^{-1} \tag{5.29}$$

where

ST: mean stop time at a bus stop

RT: mean cruise time along the link

To match this empirically derived TRANSYT formula with the result of this methodology development, equation 5.29 can also be rewritten as

$$F = (1 + T_{mean} - T_{min})^{-1} \tag{5.30}$$

where

T_{mean}: ST + RT

T_{min}: (1-a) ST + (1-b) RT

a and b: parameters of the effect of bus stop and cruise time.

The comparison of equations 5.27 and 5.30, makes it clear that this methodology can be applied not only to automobile but to bus (or carpool) platoon dispersion as well.

The Relationship between Travel Time and Platoon Dispersion

Because the methodology development findings described above indicate that platoon dispersion can be decided by β (the multiplier between the average travel time and the first arriving vehicle travel time), the role of travel time (or β) is crucial for predicting platoon dispersion. Platoon dispersion is closely related to site factors. The slower the platoon dispersion, the longer the average travel time. For this reason, the β value should be flexible to allow representation of various traffic environments rather than being fixed, as in TRANSYT, where $\beta = 0.8$. The following cases demonstrate the value of flexible β values for different traffic environments.

From the definition of equation 5.1, the relationship between t (the first arriving vehicle travel time) and T (average vehicle travel time) can be described as:

$$t = \beta \times T \tag{5.31}$$

If the first traffic platoon is dispersed in a lower-volume traffic environment, the relationship between t and T (equation 5.31) can be described as:

$$t1 = \beta 1 \times T1 \tag{5.32}$$

Similarly, the relationship between t and T of the second higher-volume traffic environment can be described as:

$$t2 = \beta 2 \times T2 \tag{5.33}$$

In actual traffic, the travel time of the first arriving vehicle (t) is definitely restricted by the posted speed limit for this link. According to Guerin's study (Figure 5.6), the minimum travel time (below 1 percent of observations of travel time) is almost the same regardless of whether the volume is increased or decreased

(20). In other words, the first arriving vehicle travel time of the lower-volume traffic environment (t1 of Equation 5.32) can be assumed to be the same as that of the higher-volume traffic environment (t2 of Equation 5.33). Thus, the equation for the lower-volume and higher-volume traffic environments can be described as $\beta 1 \times T1 = \beta 2 \times T2$. It is also obvious that the average travel time of the higher-volume traffic environment should be greater than the that of lower-volume traffic environment (T2 > T1). Consequently, it can be proven that the $\beta 1$ value of the lower-volume (shorter average travel time) case should be larger than the $\beta 2$ value of the higher-volume (longer average travel time) case. From the new analytical methodology result, $F = 1 / \{1 + [(1/\beta - 1) / s] \times t\}$ (equation 5.28), the smaller the Ã value, the smaller the platoon smoothing factor F value. Therefore, the longer the average vehicle travel time (smaller β value), the slower the platoon dispersion (smaller F value).

Platoon Dispersion Prediction Algorithms

As described in subsection of this chapter entitled, "Problems in the application of TRANSYT-7F to arterial HOV Lanes," defining α value through reference to a free-flow speed and the existing traffic environment is unreasonable. Furthermore, although the complicated PDF (α) value calibration process has been simplified by the new analytical methodology to decide only those β values that can be easily obtained from field study, it is still too complex to calibrate all links in a network. Therefore, an algorithm that can automatically calculate β is much needed for the prediction of platoon dispersion.

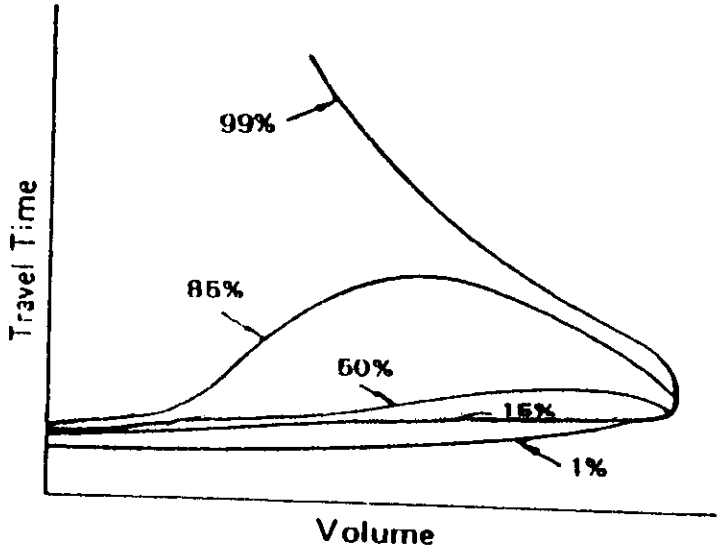

Figure 5.6 Guerin's travel time relationships
SOURCE: Gerlough and Huber 1975

As illustrated in Figure 5.1, the traffic flow has distinct traffic signals and characteristics, which should be considered as independent links in TRANSYT. A simple arterial intersection usually has four approaches. Each approach may have up to three (left, through, and right turning movements) different links. Therefore, a total of 12 links may need to be calibrated for one intersection. HOV lane traffic analysis may entail more links. For this reason, it is impossible to calibrate all links in TRANSYT without developing a new algorithm.

To date, no study has addressed this specific concern. However, two algorithms are discussed in this study as a possible means of solving this problem. They are the simulation feedback iteration algorithm and the BPR (Bureau of Public Roads) travel time-flow function algorithm. However, it should be noted at the outset that the modification of these two algorithms was not completed due to resource limitations. Further studies are needed.

Simulation Feedback Iteration Algorithm. The basic concept of the simulation feedback iteration algorithm is to compare the consistency of the β value between TRANSYT input and simulation output data. If the values are significantly different, then α is updated and the simulation is rerun until the β value difference converges within a tolerable range. This allows TRANSYT to calculate the β value automatically without having to resort to time-consuming calibration.

The simulation feedback iteration algorithm can be broken down into the following steps (Figure 5.7):

Step 1: Calculate the travel time (t) of the first arriving vehicle (assuming speed limit restrictions) using the link length divided by the speed limit.

Step 2: Calculate $\beta 1$ using equation 5.28 (0.35 is used as the α default value in input data).

Step 3: Run simulation.

Step 4: Calculate $\beta 2$ using t divided by T (average travel time) obtained from

simulation output.

Step 5: Compare the output $\beta 2$ value with the input $\beta 1$ value. If $|\beta 1 - \beta 2| / \beta 1 < 5$ percent, then stop.

Step 6: Otherwise, let $\beta 1 = \beta 2$, update α value using equation 5.28, and return to Step 3.

For example, take a TRANSYT simulation involving one 500-ft 2-through lane link (cruise speed = 30 MPH, volume = 1200 veh/hr). The t value can be calculated as 500 / (30 x 5280 / 3600) = 11.36 sec. The $\beta 1$ value (α = 0.35, s = 3 sec) can be calculated using equation 5.28 as 1 / (α x s + 1) = 0.49. At the first simulation run, a total travel time of 6.44 veh-hr/hr is obtained from the output. Then the average travel time T value can be calculated as 6.44 x 3600 / 1200 = 19.32 sec. From t = β x T (equation 5.31), $\beta 2$ can be calculated as 11.36 / 19.32 = 0.59. Since $|\beta 1 - \beta 2| / \beta 1$ = 20.41 percent (> 5 percent), the process reverts to Step 3. At this time, the new $\beta 1$ value is reset as 0.59 and the new α value can be calculated using equation 5.28 as $(1/\beta - 1) / s$ = 0.23. After the second simulation run, T becomes 18.48 sec and β is 0.61. Since $|\beta 1 - \beta 2| / \beta 1$ = 3 percent (< 5 percent), the iteration can be stopped. Thus, the final β = 0.59 (or α = 0.23) is the more accurate value for predicting the platoon dispersion of this link.

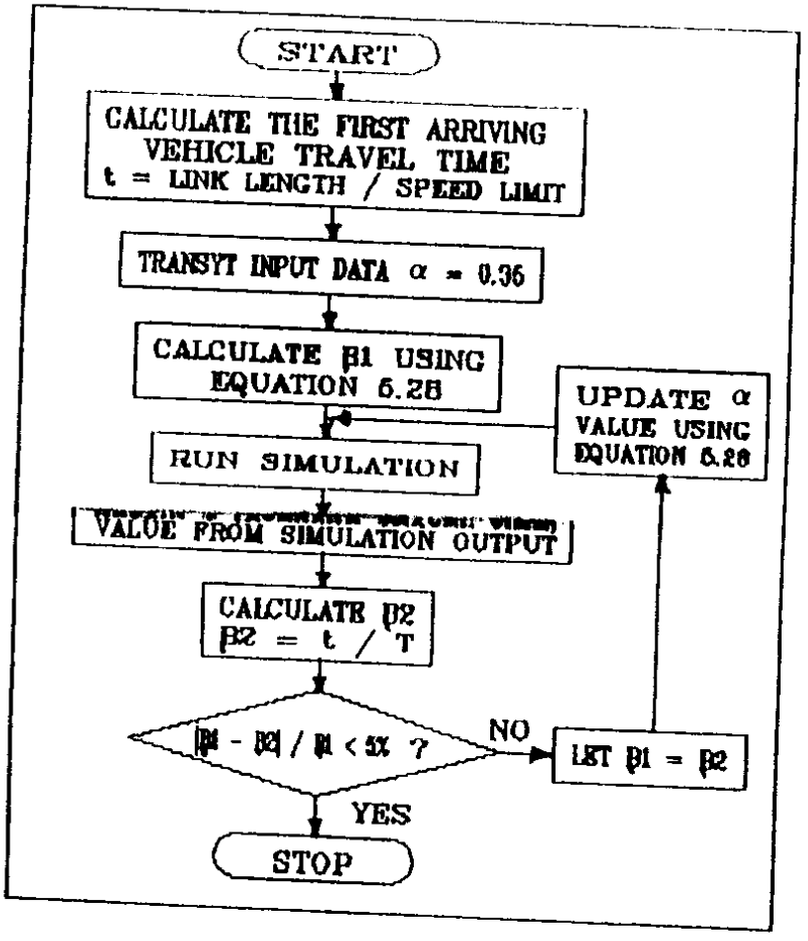

Figure 5.7 Simulation feedback iteration algorithm

BPR Travel Time-Flow Function Algorithm. As described earlier in this chapter, "Methodology development findings," platoon dispersion can be determined by the difference between the average travel time (T) and the minimum travel time (t), the BPR function (equation 5.34), which expresses the relationship between the travel time and flow, is another algorithm which may be used to calibrate platoon dispersion (11).

$$T = t\,[1 + a\,(V/C)^b] \tag{5.34}$$

Where

V: the flow on a link

C: the capacity of the link

T: the travel time on the link at flow V

t: the travel time on the link at zero flow

a and b: model parameters

Table 5.5 lays out three empirical categories and model parameters that pertain to the BPR travel time-flow function for different link characteristics (1, 43). This table provides the information necessary to calculate the average travel time (T) of each link type based on this BPR travel time-flow function. The platoon dispersion smoothing factor can then be derived from equation 5.27. The BPR travel time-flow function algorithm thus allows the user to calibrate platoon dispersion in TRANSYT according to flow rate and link characteristics.

Verification of platoon dispersion analytical methodology

To verify that the new analytical methodology developed herein is more accurate and convenient than existing TRANSYT methods; one example, drawn from Tarnoff (67) is tested below.

Table 5.5 Categories and model parameters of the BPR travel time-flow function for different link characteristics
SOURCE: Abu-Eisheh and Mannering, 1986

Category of Link Performance Function	Characteristics of the Link		Model Parameters	
	Speed Limit (mph)	Practical Capacity (veh/hr)	α	β
1	0–30	0–240	0.7312	3.6596
2	0–30	249–499	0.6128	3.5038
3	0–30	500–749	0.8774	4.4613
4	0–30	750–999	0.6846	5.1644
5	0–30	1000+	1.1465	4.4239
6	31–40	250–499	0.6190	3.6544
7	31–40	500–749	0.6662	4.9432
8	31–40	750–999	0.6222	5.1409
9	31–40	1000+	1.0300	5.5226
10	41–50	500–750	0.6609	5.0906
11	41–50	750–999	0.5423	5.7894
12	41–50	1000+	1.0091	6.5856
13	+50	500–749	0.8776	4.9287
14	+50	750–999	0.7699	5.3443
15	+50	1000+	1.1491	6.8677

In this example, traffic flow data were collected on Route 7, east of its intersection with Towlston Road in Fairfax County, Virginia. During this study, data were collected (time interval = 4 sec) at 100, 400, and 800 feet from the intersection. Vehicle speeds were 55 MPH corresponding to travel time 3.72 and 8.68 sec between the first and second and the first and third data collection stations respectively.

Robertson's recursive equation (equation 5.1) was then applied to data collected at the 100-ft station to estimate the resulting flow patterns at the stations located 400 and 800 feet from the intersection. A PDF value, $\alpha = 0.24$, derived from the empirical data (using the TRANSYT-7F calibration method) was used to represent the free-flow case. Figures 5.8 and 5.10, drawn from Tarnoff's study, show the comparisons of actual and predicted 400-foot and 800-foot platoon dispersion.

1) Verification of analytical methodology

To demonstrate that the new analytical methodology is more accurate than that developed in Tarnoff's study, the PDF (α) value is first calculated from Equation 5.28:

$$\alpha = (1/\beta - 1) / s = (1/0.8 - 1) / 4 = 0.06$$

The comparisons of actual and predicted ($\alpha = 0.06$) 400-ft and 800-ft platoon dispersion are then plotted (Figures 5.9 and 5.11 respectively). The matched plottings (Figures 5.8 and 5.9 for 400-ft, and Figures 5.10 and 5.11 for 800-ft), make it clear that this new analytical methodology is both more accurate and more convenient for platoon dispersion prediction than its predecessor.

2) Step size verification

To demonstrate that the step size (s), which is also important for deciding platoon dispersion as described in the subsection of this chapter entitled, "Methodology development findings," the platoon dispersion predictions of 4-sec

and 8-sec time intervals are compared with each other.

Figure 5.12 shows that the platoon prediction of the 8-sec step differs from that of the two 4-sec step. The detailed prediction data (flow rate) are represented in Table 5.6. This comparison makes it clear that platoon dispersion depends not only on α (or β) but on step size (s) as well.

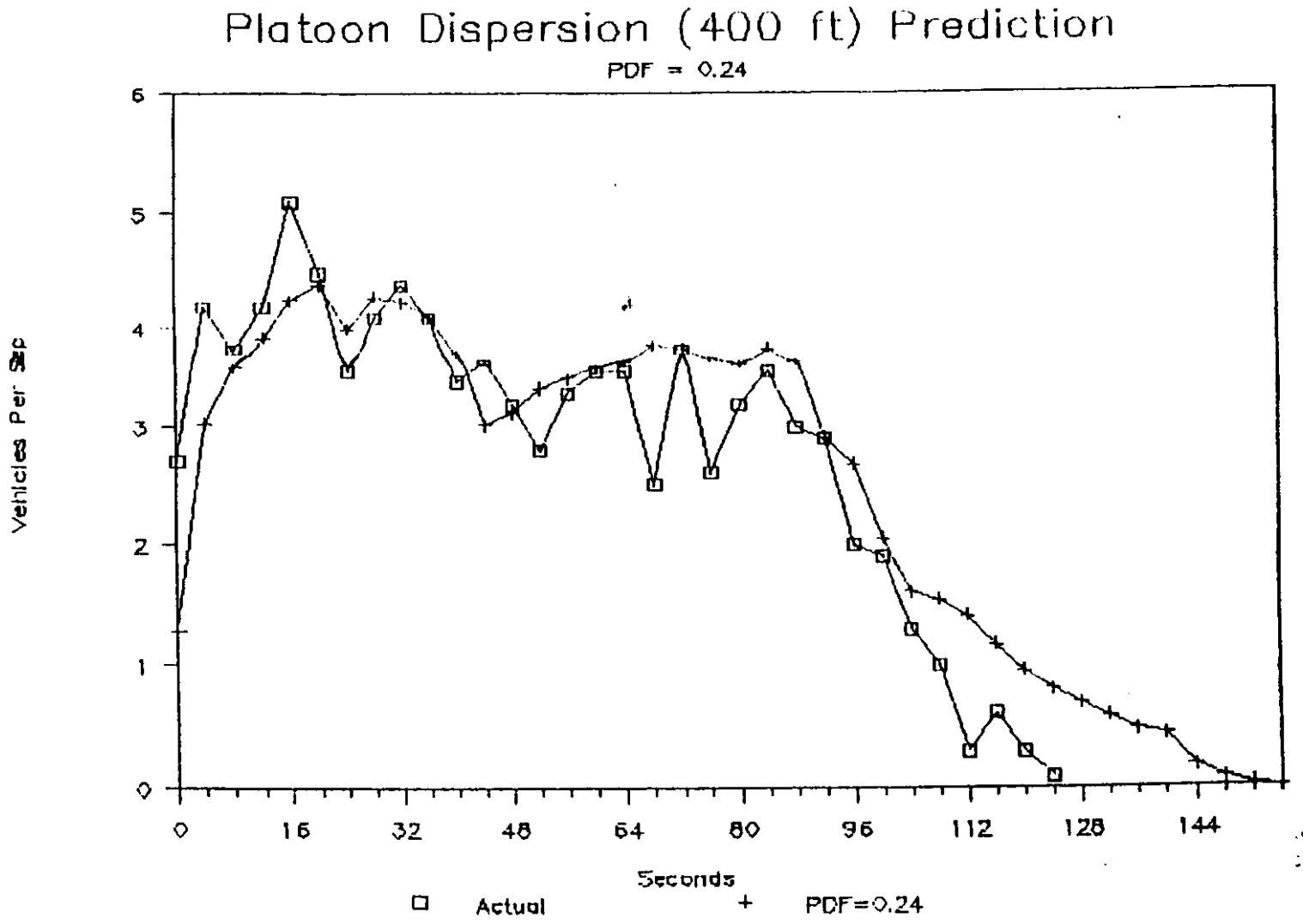

Figure 5.8 The comparison of the actual and predicted 400-ft platoon dispersion (α = 0.24)

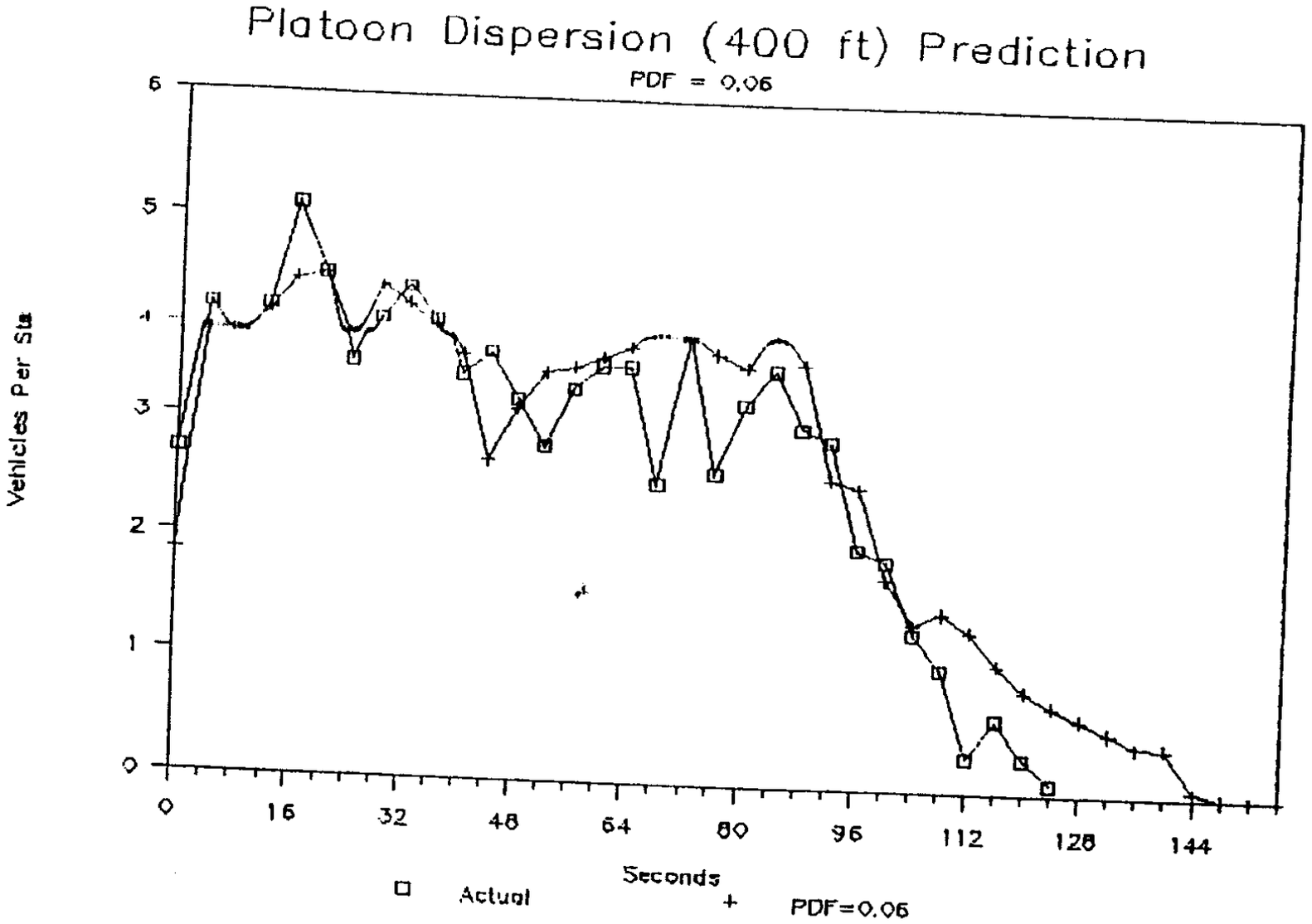

Figure 5.9 The comparison of the actual and predicted 400-ft platoon dispersion (α = 0.06)

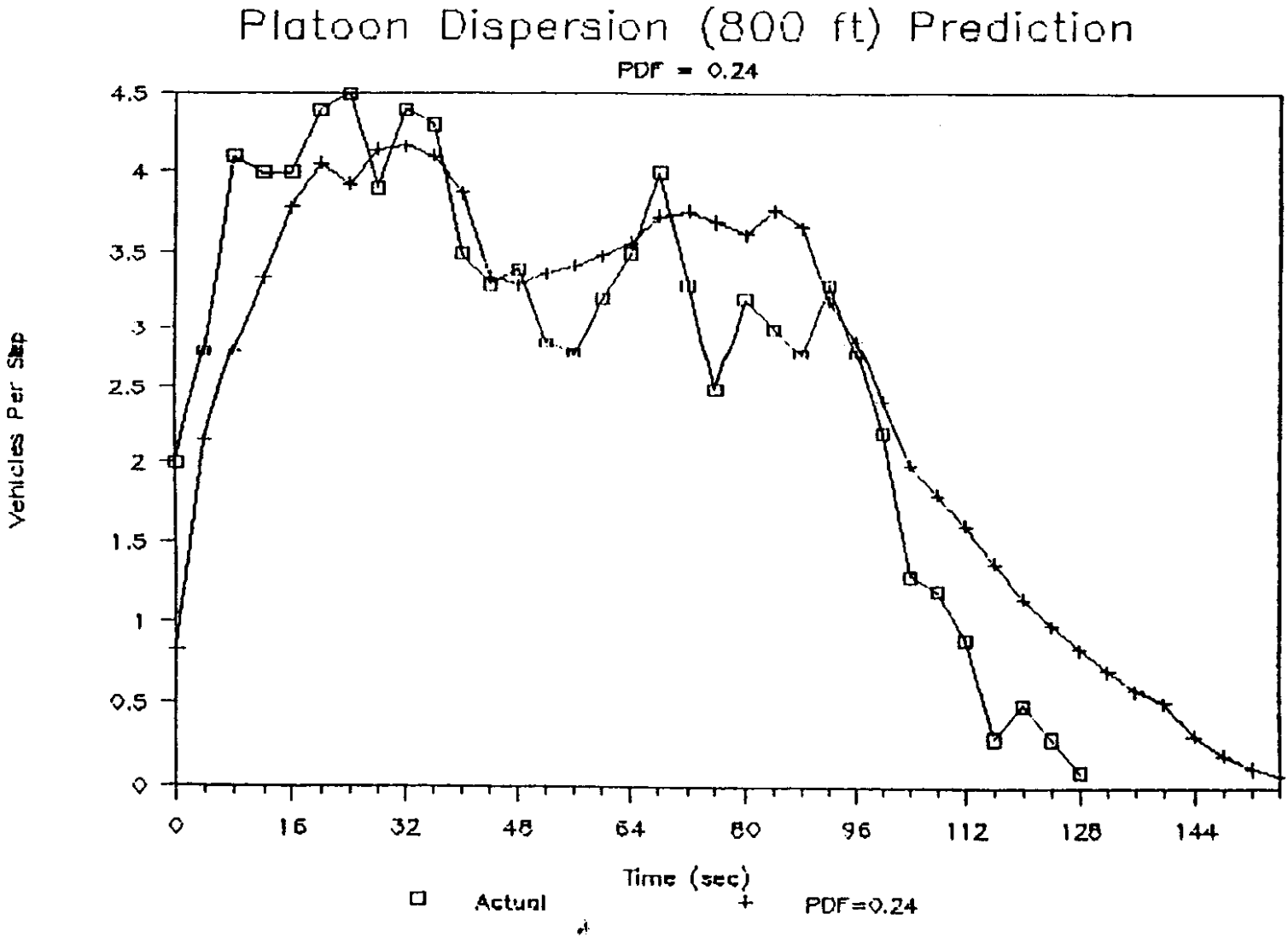

Figure 5.10 The comparison of the actual and predicted 800-ft platoon dispersion (α = 0.24)

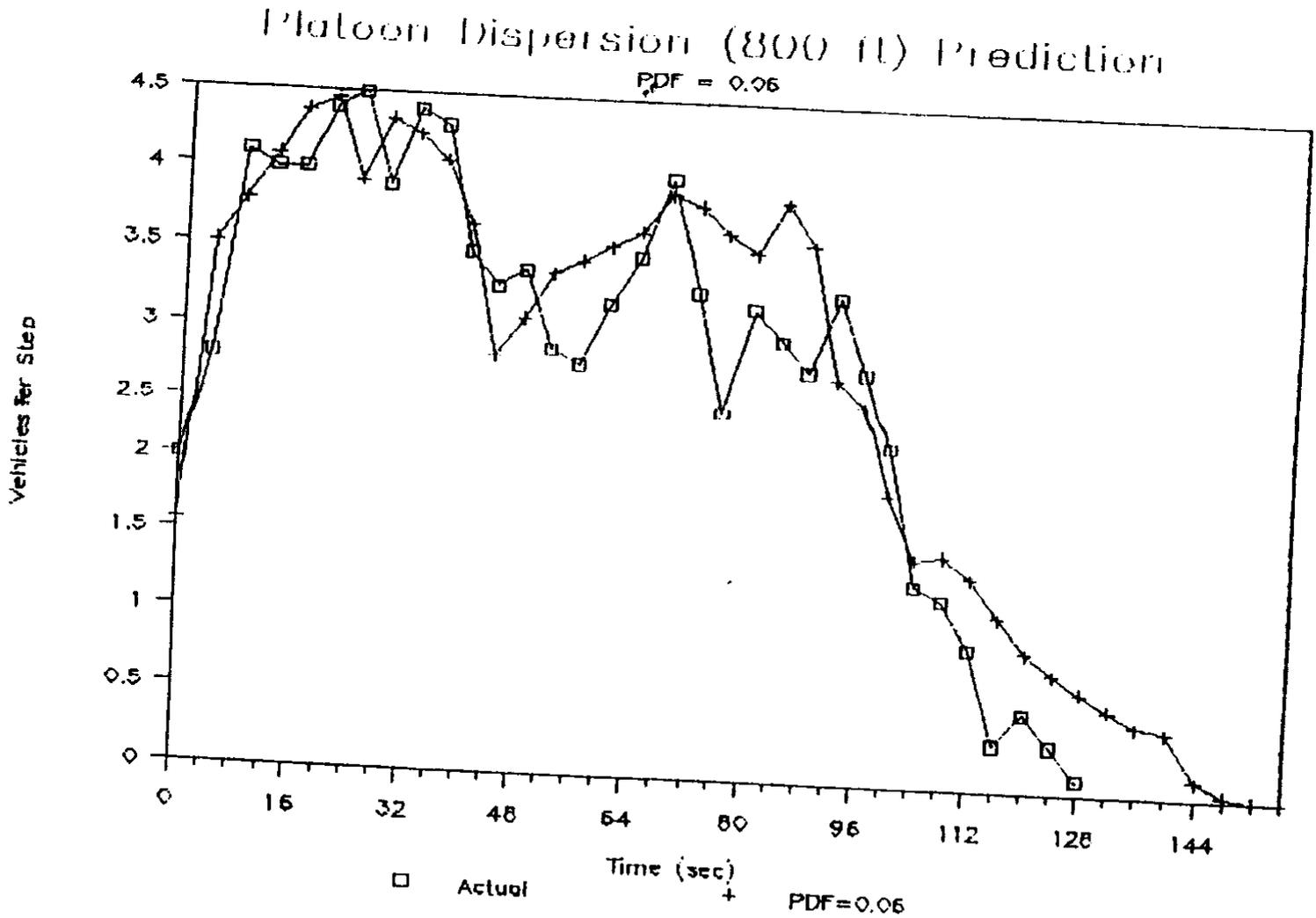

Figure 5.11 The comparison of the actual and predicted 800-ft platoon dispersion (α = 0.06)

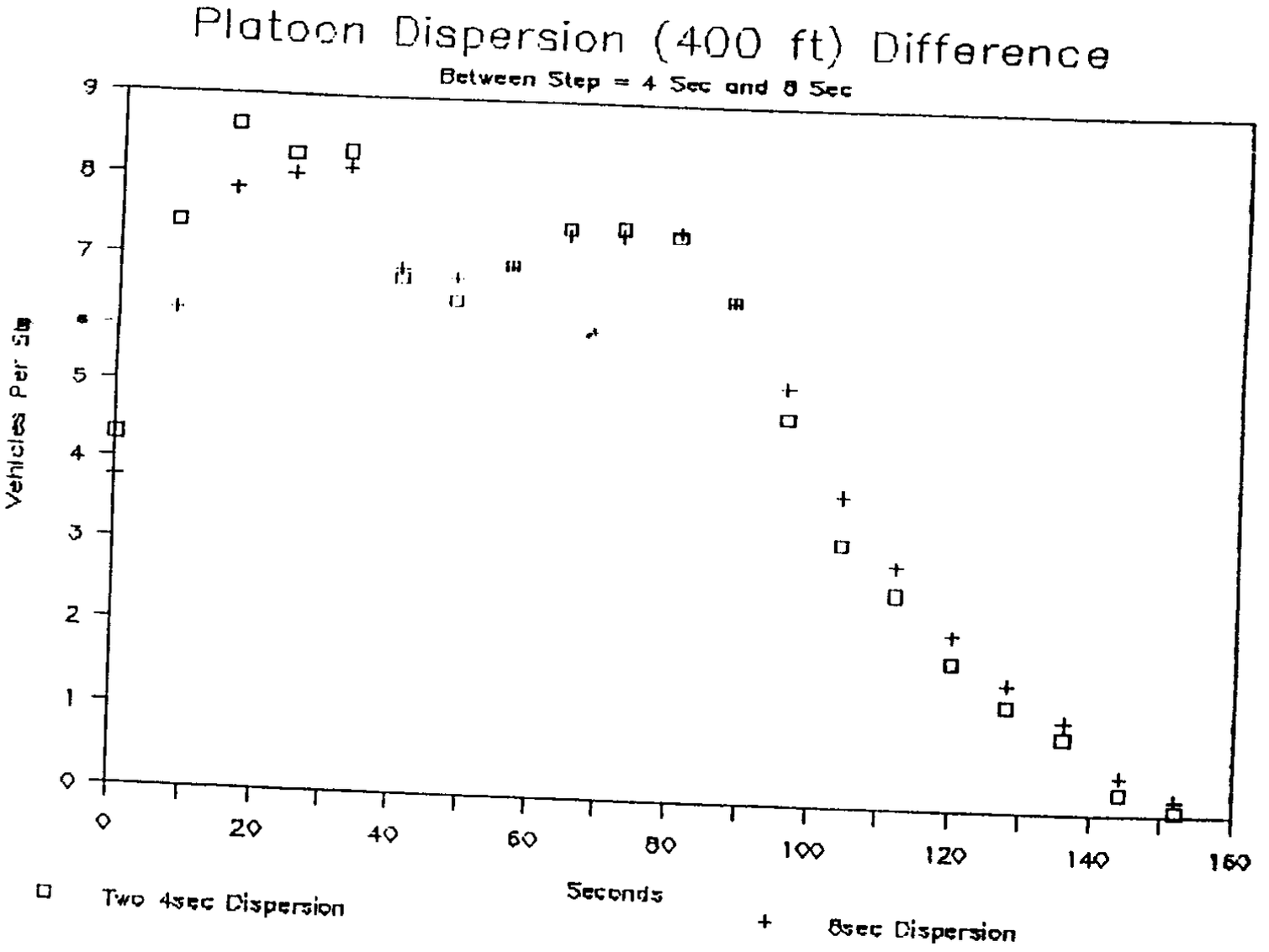

Figure 5.12 The comparison of 4-sec and 8-sec steps 400-ft platoon dispersion (α = 0.24)

Table 5.6 The platoon dispersion prediction (400-ft) difference between 4-sec and 8-sec steps

100 feet recorded data (Step = 4-sec)		100 feet recorded data (Step = 8-sec)		Pred. flow (Step =4-sec)	Pred. flow (Step =8-sec)	Pred. flow (Two 4-sec steps)
No. of step	Flow rate	No. of step	Flow rate	$\alpha = 0.24$ F=0.58	$\alpha = 0.24$ F=0.58	$\alpha = 0.24$ F=0.58
1	2.2			1.28		
2	4.3			3.03		
		1	6.5		3.77	4.31
3	3.9			3.53		
4	4.2			3.92		
		2	8.1		6.28	7.46
5	4.5			4.26		
6	4.5			4.40		
		3	9		7.86	8.65
7	3.7			3.99		
8	4.5			4.29		
		4	8.2		8.06	8.28
9	4.2			4.24		
10	4			4.10		
		5	8.2		8.14	8.34
11	3.5			3.75		
12	2.5			3.03		
		6	6		6.90	6.78
13	3.2			3.13		
14	3.5			3.34		

Table 5.6 The platoon dispersion prediction difference between time interval 4-sec and 8-sec (continued)

		7	6.7		6.78	6.47
15	3.5			3.43		
16	3.6			3.53		
		8	7.1		6.97	6.96
17	3.7			3.63		
18	4.0			3.84		
		9	7.7		7.39	7.47
19	3.8			3.80		
20	3.6			3.69		
		10	7.4		7.40	7.51
21	3.5			3.58		
22	4.0			3.82		
		11	7.5		7.46	7.40
23	3.5			3.64		
24	2.4			2.92		
		12	5.9		6.55	6.56
25	2.5			2.68		
26	1.6			2.05		
		13	4.1		5.13	4.73
27	1.3			1.62		
28	1.5			1.55		
		14	2.8		3.78	3.16
29	1.3			1.40		
30	1.0			1.17		
		15	2.3		2.92	2.57

Table 5.6 The platoon dispersion prediction difference between time interval 4 sec and 8 sec (continued)

31	0.8			0.96		
32	0.7			0.81		
		16	1.5		2.10	1.76
33	0.6			0.69		
34	0.5			0.58		
		17	1.1		1.52	1.27
35	0.4			0.47		
36	0.4			0.43		
		18	0.8		1.10	0.91
37	0			0.18		
38	0			0.08		
		19	0.0		0.46	0.26
39	0			0.03		
40	0			0.01		
		20	0.0		0.19	0.05
Sum	100.9		100.9	100.89	100.76	100.89

TRANSYT-7F Application for the Kirkland-Redmond NE 85th Street HOV Lane Improvement Project

Traffic data for NE 85th Street in Kirkland-Redmond and Seattle NE Pacific Street were collected and coded into a TRANSYT-7F simulation input data file prior to applying the model to the study of arterial HOV lanes. After running the simulation with the existing timing plan, the MOE values (travel time, delay, stops, and queue backup) were compared with actual street conditions to calibrate the model. The input data was checked and modified until TRANSYT-7F outputs reflected existing conditions. The new platoon dispersion methodology was then used to adjust the platoon dispersion factor (PDF) for HOV lane alternatives. Judging from the simulation outputs, this new methodology has proven to be a useful tool for arterial HOV lane traffic analysis.

Site Description

NE 85th St and Redmond-Kirkland Way (State highway 908) constitute the main arterial between the cities of Redmond and Kirkland (Figure 5.13). There are six signalized intersections (120th Avenue, 124th Avenue, 132nd Avenue, 140th Avenue, 148th Avenue, and Willows Way) and six unsignalized intersections (122nd Avenue, 126th Avenue, 128th Avenue, 131st Avenue, 139th Avenue, and 142nd Avenue) (Figure 5.14) along this arterial. During the PM peak period, traffic congestion usually queues back from Willows Way to 148th Avenue eastbound, and from 124th Avenue to 126th Avenue westbound. In an effort to solve this congestion problem, several HOV alternatives are planned and evaluated in this study.

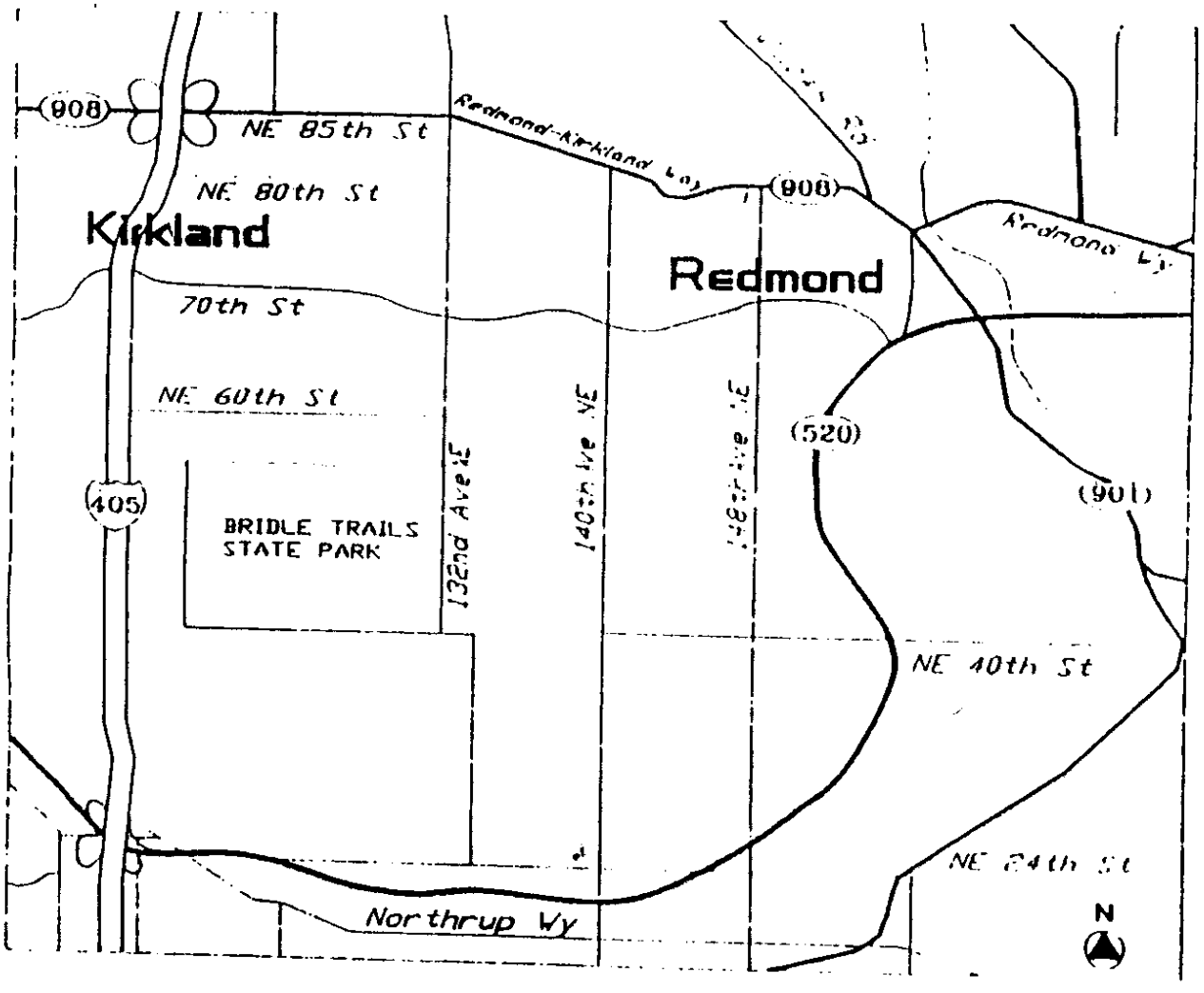

Figure 5.13 Study area for the NE 85th Street HOV improvement project

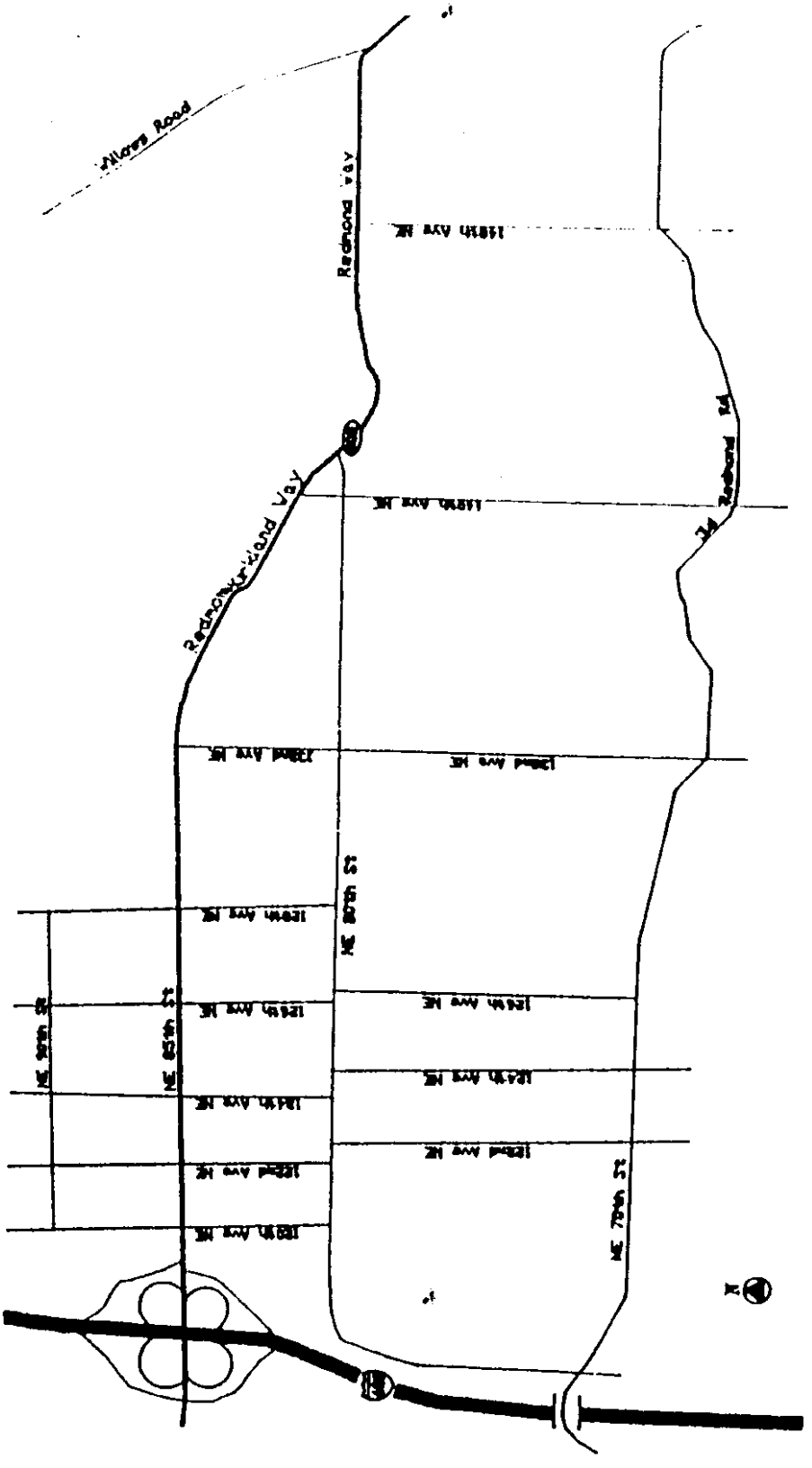

Figure 5.14 The NE 85th Street arterial networks

Data Collection

The purpose of the field study described herein was to collect and update street configuration and traffic regulation information on this arterial in order to carry out TRANSYT-7F simulation. Data were collected from maps provided by the cities of Redmond and Kirkland and from field study; they included information regarding the following factors: link length, geometric design, lane numbers, turning pocket length, park/turn restriction, intersection configuration, speed limit, slope, and pedestrian traffic. The data cover all links and intersections on NE 85th St and Redmond-Kirkland Way from 120th Avenue to Willows Way. Data collection methods used in July 1990 consisted of field inventory and tape measurement.

1) Turning Movement Counts

Peak periods for each intersection were determined on the basis of total traffic volume data. Previous traffic data (provided by the cities of Redmond and Kirkland) and observation methods indicated that the PM peak period on this arterial was between 4:00 PM and 6:00 PM. To prepare TRANSYT-7F traffic volume input data, turning movements were counted at each intersection for a two-hour (4-6 PM) period between July and August 1990, using TOSHIBA laptop computers. The turning movement survey program, which researchers modified, was provided by the Washington State Department of Transportation (WSDOT).

2) Design Hour Volumes

TRANSYT-7F requires users to convert traffic volume samples into design hour volumes for each period for which a signal timing plan is to be developed or analyzed. Traffic volume samples were converted into design hour volumes according to the intervals suggested in the manual for each intersection. The task was completed in September 1990.

3) Link Input Volumes

Input flows from one approach at the downstream intersection are composed of three different movements from the upstream intersection: through, right turning,

and left turning. To prepare TRANSYT-7F traffic volume input data, link-to-link traffic volume data must be collected from field studies or calculated by estimation methods. However, link-to-link traffic counts are extremely difficult to implement in the field. For this reason, link-to-link traffic volume data were estimated in this study in September 1990 in accord with TRANSYT-7F guidelines for each link.

4) Signal timing data

All signalized intersections at 85th St and Redmond-Kirkland Way use actuated signal timing plans. However, TRANSYT-7F execution requires conversion on the actuated signal timing data into pretimed signal timing data. Ten observations of each interval time were collected at every actuated intersection. The signal timing data were collected and converted in September 1990. The average time for each interval was then treated as the equivalent pretimed signal interval time.

5) Travel time

These data were collected to assemble total distance travel time samples for use in calibrating the TRANSYT-7F model. The License Plate Match Program, developed by WSDOT and modified by Transportation Northwest (TransNow), was run on Toshiba laptop computers to collect travel times on this arterial in August 1990. Three control intersections were set up as travel time collection stations (120th Avenue, 132nd Avenue, and Willows Way).

6) Traffic classification

Existing traffic count data from Redmond and Kirkland indicated that the percentage of truck and trailer traffic on this arterial was not high enough (less than 5 percent) to affect traffic patterns. Consequently, the truck and trailer affecting factor was not considered in the process of converting design hour volumes.

7) Bus-stop location and service frequency

Currently, there is only one bus route on this arterial. Its service frequency is

30 minutes, and the lane is blocked when the bus stops to load and unload passengers.

Experimental Design

Three feasible HOV alternatives for 85th St and Redmond-Kirkland Way were considered in the experimental design of TRANSYT-7F HOV lane application:

1) existing geometric design
2) addition of one general-purpose lane for one part of 85th St; addition of one general-purpose lane for westbound 85th St from 132nd Avenue to 120th; addition of one general-purpose lane for eastbound 85th St from 140th Avenue to Willows.
3) addition of one HOV lane for one part of 85th St; addition of one HOV lane for westbound 85th St from 132nd Avenue to 120th; addition of one HOV lane for eastbound 85th St from 140th Avenue to Willows.

Simulation Results

As seen from the simulation outputs in Table 5.7, the platoon dispersion analytical methodology of TRANSYT-7F as applied to the 85th St HOV lane improvement project seems to be effective for arterial HOV lane traffic analysis. Its effectiveness is seen in the fact that the travel time of unchanged links (eastbound 120th to 132nd and westbound Willows to 132nd) is not affected by the improvements of other links. This result corresponds with reality if there is no spill-back onto this network. As for other improved links (eastbound 132nd to Willows and westbound 132nd to 120th), the auto travel time after adding one general lane (Alt. 02) is lower than that of the existing geometric design (Alt. 01), but is higher than that of the carpool travel time after adding one HOV lane (Alt. 03). At the same time, the auto travel time of Alt. 03 is longer than that of Alt. 02 because autos need to use two general-purpose lanes rather than three lanes. These simulation

results indicate that the new platoon dispersion analytical methodology for TRANSYT-7F developed in this study is significant for arterial HOV lane application.

Table 5.7 TRANSYT-7F simulation travel time (sec) outputs

Eastbound NE 85th Street

	120th to 132nd		132nd to Willows		Total	
	Auto	Carpool	Auto	Carpool	Auto	Carpool
Alt. 01 Existing Geometric Design	122.6	122.6	344.0	344.0	466.6	466.6
Alt. 02 Add one Gen. Lane (140th-Wil.)	122.6	122.6	231.3	231.3	353.9	353.9
Alt. 03 Add one HOV Lane (140th-Wil.)	122.6	122.6	278.5	213.5	401.1	336.0

Westbound NE 85th Street

	Willows to 132nd		132nd to 120th		Total	
	Auto	Carpool	Auto	Carpool	Auto	Carpool
Alt. 01 Existing Geometric Design	195.0	195.0	203.9	203.9	398.9	398.9
Alt. 02 Add one Gen. Lane (132nd-120th)	195.0	195.0	145.9	145.9	340.9	340.9
Alt. 03 Add one HOV Lane (132nd-120th)	195.0	195.0	171.6	134.3	366.6	329.3

Therefore, the simulation outputs of the feasible alternatives will provide very useful and reliable information for arterial HOV lane planning and evaluation. The possible travel time savings for HOVs can be calculated and compared for each alternative. Then the most attractive (cost-effective) alternative that encourages people to shift mode from SOV to HOV can be selected and recommended for further development. However, the performance value (i.e., travel time savings for HOVs) for an attractive arterial HOV lane alternative needs to be defined clearly before the evaluation process. So far, no standard threshold value has been established for arterial HOV lane evaluation. It may be reasonable to apply the existing threshold value usually used in freeway HOV lanes for evaluating arterial HOV lane alternatives too. The detailed evaluation results will be discussed in Section 5.5.3.

5.5.2 Seattle NE Pacific Street HOV Lanes

The simulation outputs of Pacific Street HOV lanes (Table 5.8 Existing traffic conditions) shows that the platoon dispersion analytical methodology of TRANSYT-7F is also very useful for the traffic analysis of congested (some queue-backup) arterial HOV lanes.

For instance, the travel time on Montlake Boulevard (Table 5.8) is not affected by the improvement of Pacific Street as expected. As explained in Section 4.4.4, since the traffic factors of Montlake Boulevard, such as geometric design, traffic volume, traffic control, and other traffic characteristics are kept the same as before, the MOEs of Montlake Boulevard should not be affected by the traffic improvement of Pacific Street. Also, the travel time on Pacific Street is improved as expected after adding one general lane in front of UW Hospital or extending the general-purpose lane to 15th Ave. By adding one HOV lane in front of UW Hospital or extending the HOV lane to 15th Ave, the carpool and bus travel time on Pacific Street is lower and the travel time of auto is higher than a non-HOV lane

alternative. The result can be explained as the autos of HOV lane alternatives (Alt. 03 and Alt. 05) cannot turn right on red as the non-HOV lane alternatives (Alt. 01, Alt. 02, and Alt. 04) because the curb lane is reserved for HOVs use. Thus, the auto travel time for HOV lane alternatives is higher than for other non-HOV lane alternatives. All these simulation results are shown to be very consistent with the real world.

Table 5.8 Seattle NE Pacific Street TRANSYT-7F Simulation Travel Time (sec) Outputs (Existing traffic conditions)

Simulation Alt. Name	Pacific St			Montlake Boulevard		
	Auto	Carpool	Bus	Auto	Carpool	Bus
01.Existing Design	175.8	175.8	266.4	181.2	181.2	258.0
02.Add one gen. lane UW Hosp.	157.1	157.1	249.6	181.7	181.7	258.0
03.Add one HOV lane UW Hosp.	167.7	151.9	244.8	181.4	181.4	258.0
04.Add one gen. lane 15th Ave	139.3	139.3	240.0	181.7	181.7	258.0
05.Add one HOV lane 15th Ave	162.2	126.3	235.2	181.4	181.4	258.0

5.5.3 Arterial HOV Alternatives Evaluation

As described in Section 5.5.1.4, the performance value (i.e., travel time savings for HOVs) for an attractive arterial HOV lane alternative needs to be defined clearly before the evaluation process. The most popular performance (threshold) value used in freeway HOV lane evaluation is 1 minute/per hour (Fuhs 1990 and Henk and Lomax 1991) or 5 minutes/per trip (Wesemann 1988).

However, no documentation has been found discussing this threshold value for arterial HOV lane evaluation. The following method is developed for justifying whether the above freeway HOV lane threshold value is reasonable or unreasonable for arterial HOV lane evaluation.

In general, the vehicle speed on urban and suburban arterial streets is lower than 40 mph. The travel time per distance (min/mile) for different vehicle speeds can be described specifically in Table 5.9. From this table, the travel time difference between two speed levels can be calculated accordingly. For instance, the travel time difference is 2 minutes/per mile between 30 mph and 15 mph. Thus the travel time savings for HOVs (Table 5.10), depending on the speed of the general-purpose lane and the HOV lane, can be calculated reasonably from Table 5.9.

Next, the concept of level-of-service is used to define the acceptable threshold value (travel time savings for HOVs) for an attractive arterial HOV lane alternative. As defined by the 1965 Highway Capacity Manual (Table 5.11) (Pignataro 1973), the delay becomes unacceptable for road users if level-of-service is worse than C (e.g., travel speed is slower than 20 mph). The general-purpose lane SOV mode, in a congested traffic situation (speed < 20 mph), should shift to HOV if the HOV lane has better level-of-service (speed > 20 mph). Thus to find the threshold value for an attractive arterial HOV lane, the domain of the general-purpose lane speed should be less than 20 mph. The underlined numbers on the right of Table 5.10 seem to allow that the range of this threshold value, based on the level-of-service concept, should be greater than 1.0 min/mile. The only exceptional value, 0.6 min/mile (less than 1.0 min/mile), can be explained reasonably; the HOV lane speed of 25 mph is not too significant for the general-purpose lane SOVs (speed 20 mph) to shift modes. The SOVs just begin to feel the delay unacceptable at this level-of-service. Therefore, the threshold value of 1.0 min/mile used in

freeway HOV lane evaluation can also be applied for arterial HOV lane evaluation.

Based on this threshold value, the results of the evaluation of Kirkland-Redmond NE 85th Street and Seattle NE Pacific Street HOV lanes are as follows:

Table 5.9 The Travel Time Per Distance (min/mile) for Different Speed (mph) of Arterial Streets

mph	min/mile
40	1.5
35	1.7
30	2.0
25	2.4
20	3.0
15	4.0
10	6.0
5	12.0

Table 5-10 The Travel Time Savings (min/mile) for HOVs at Different Traffic Situations
General-Purpose Lane Speed (mph)

	40	35	30	25	20	15	10	5
HOV Lane Speed(mph)								
40	0.0	0.2	0.5	0.9	1.5	2.5	4.5	10.5
35		0.0	0.3	0.7	1.3	2.3	4.3	10.3
30			0.0	0.4	1.0	2.0	4.0	10.0
25				0.0	0.6	1.6	3.6	9.6
20					0.0	1.0	3.0	9.0
15						0.0	2.0	8.0
10							0.0	6.0
5								0.0

For the eastbound NE 85th Street HOV alternative (adding one HOV lane from 140th Ave to Willows), the link length of the HOV lane is 4200 ft. Thus the threshold value of travel time savings for this HOV lane link (47.7 sec) can be calculated from:

1 min/mile = 60 sec/5280 ft = 47.7 sec/4200 ft

If the simulation output of travel time savings for HOVs is greater than this threshold value, the eastbound NE 85th Street HOV alternative will be evaluated as an attractive HOV lane.

As indicated in Table 5.7, the travel time savings for HOVs (65.1 sec) can be calculated from the difference between auto total travel time (401.1 sec) and carpool total travel time (336.0 sec). Since this value (65.1 sec) is greater than the threshold value (47.7 sec), this alternative can be recommended as an attractive HOV lane for further study.

The threshold value of travel time savings for the westbound NE 85th Street HOV lane link (adding one HOV lane from 132nd Ave to 120th Ave) can be calculated as:

1 min/mile = 60 sec/5280 ft = 46.0 sec/4050 ft

The travel time savings for westbound NE 85th Street HOVs (37.3 sec) can also be calculated as the difference between auto total travel time (366.6 sec) and carpool total travel time (329.3 sec). According to the results of the evaluation, this alternative seems not to be an attractive HOV lane at this moment since the travel time savings (37.3 sec) is less than the threshold value (46.0 sec).

Similarly, the alternative 02 for Seattle NE Pacific Street HOV lanes (adding one HOV lane in front of UW Hospital), the travel time savings for HOVs (15.8 sec) can be calculated from Table 5.8. And the threshold value of travel time savings (10.5 sec) for this HOV lane link is from:

1 min/mile = 60 sec/5280 ft = 10.5 sec/925 ft

This alternative is evaluated as an attractive HOV lane because the travel time savings for HOVs (15.8 sec) is greater than the threshold value (10.5 sec).

Another Seattle NE Pacific Street HOV lane alternative -- adding and extending the HOV lane to 15th Ave -- has the same positive evaluation results since its travel time savings for HOVs (35.9 sec) is greater than the threshold value (26.7 sec).

Overall, three of the four arterial HOV lane alternatives were evaluated to be attractive for shifting from SOV mode to HOV. Although the westbound NE 85th Street HOV alternative was not evaluated as an attractive HOV lane in this study, this alternative could make sense if some other HOV facilities of the whole traffic network are also considered. For instance, the travel time savings for HOVs could be accumulated to be greater than the threshold value by using the I-405 HOV ramp bypasses, I-405 HOV lanes, SR-520 HOV ramp bypasses, SR-520 HOV lanes, and other HOV supplemental facilities. Therefore, all these HOV lane projects will contribute to improving the existing traffic congestion by encouraging people to shift mode from SOV to HOV.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Research results for arterial HOV lane planning from this study can be organized as follows:

1) The ability to model HOV lane traffic is one of the most important aspects of the arterial HOV planning and evaluation process. Improvement in this area is needed.

Current HOV lane evaluation methods are inadequate for consideration of complex variables because these methods generally lack traffic operation models. Traffic models for HOV lanes need to be built or modified in order to provide enough information about traffic impacts. In this study, several TRAF-NETSIM subroutines have been modified, and TRANSYT-7F's platoon dispersion analytical methodology has been enhanced. These developments have improved the models, making them more useful for arterial HOV lane application.

2) TRAF-NETSIM and TRANSYT-7F are popular arterial traffic simulation models that may be used for detailed HOV lane traffic analysis. However, they have several limitations in terms of HOV lane treatment and traffic modeling that need to be corrected before applying them in practical arterial HOV lane traffic analysis.

Researchers found six application problems for arterial HOV lane traffic analysis in TRAF-NETSIM. The problems are associated with the following areas: HOV lane turning movement logic, T-intersection HOV lane carpool vehicle turning treatment, T-intersection HOV lane carpool vehicle right-turn-on-red, HOV and general-purpose lane travel time output, HOV lane queue-jump function, and traffic signal timing optimization. The researchers' modifications of TRAF-

NETSIM appear to have successfully resolved the first four problems. The last two problems remain unsolved and may be the subject of future research.

TRANSYT-7F presented three specific problems in terms of its applicability to arterial HOV lane traffic analysis. They included: distinguishing between HOV and general-purpose lane flow patterns, congested traffic flow simulation, and spillover traffic environment simulation problems. In an effort to resolve these problems, a new platoon dispersion analytical methodology based on statistical and mathematical theories has been developed in this study. The verification process indicates that it is more accurate and more convenient than the existing platoon dispersion prediction method to which it was compared.

3) Common criteria in the evaluation of HOV alternatives include the following: travel time savings, trip time reliability, travel cost reduction, person-carrying capacity, environmental effects, safety, and public opinions. Of them, travel time savings comprises the single most important criterion in assessing a successful arterial HOV lane.

HOV treatments may entail a number of advantages, such as travel time reduction, trip time reliability, travel cost reduction, and travel convenience, which serve as incentives encouraging people to use HOVs. Thus, some related MOEs are usually chosen as the criteria for evaluating HOV alternatives. MOEs may include: average speed, travel time, person throughput, vehicle throughput, number of accidents, compliance rate, travel cost, and capacity. Of these criteria, travel time savings is the most important. However, currently available traffic operation software is inadequate for the simulation and analysis of HOV lane travel time savings.

TRAF-NETSIM has been modified in this study to provide travel times for each vehicle type in order to compare SOVs and HOVs in terms of travel time savings. TRANSYT-7F has been enhanced via the development of a new platoon

dispersion analytical methodology, which is been designed to distinguish between HOV and SOV links.

4) Preliminary criteria to consider in assessing HOV lane needs include: significant traffic congestion, predictable travel time savings, sufficient potential ridesharing trips and sufficient support facilities and programs. Beyond these factors, the costs and benefits, public support, enforcement, street design, and traffic safety should also be considered in the planning and evaluation process.

5) Dominant factors in the prediction of traffic platoon dispersion are average travel time, or the flow rate and the link characteristics. Traffic platoon dispersion depends on the difference between minimum and average travel times. Because minimum travel time is restricted by the posted speed limit, traffic platoon dispersion will be more dependent on average travel time. In sum, the longer the average vehicle travel time, the slower the platoon dispersion.

The BPR function expresses the relationship between travel time and flow. Thus, the platoon dispersion can also be decided by the flow rate and the link characteristics. Two algorithms were developed in this study for platoon dispersion calibration: the simulation feedback iteration and the BPR travel time-flow function. These algorithms now allow researchers to distinguish the platoon dispersion patterns of HOV and SOV lanes more accurately in TRANSYT-7F.

6) The platoon dispersion or cyclic flow profile (CFP) depends on step size as well as travel time. Thus, it is incorrect to calibrate the CFP outputs with field study if their time intervals differ.

Recommendations

1) Channelization codes for right-turning carpool vehicles (curb HOV lane) and left-turning carpool vehicles (median HOV lane) is needed for future enhancement should be added to TRAF-NETSIM.

Although some aspects of TRAF-NETSIM have been corrected and have

been proven useful in arterial HOV lane traffic analysis (such as logic pertaining to HOV lane and T-intersection turning movements), the concept of preparing the input data file for an HOV alternative may be too complex for some users to understand. For instance, right-turning SOVs use the right-diagonal lane to turn right at T-intersections; however, they must use the curb HOV lane to turn right on straight links. The best way to reduce this obstacle to HOV lane application is to add channelization codes for right-turning carpool vehicles (curb HOV lane) and left-turning carpool vehicles (median HOV lane).

2) Vehicle occupancy codings for each link should be added to TRAF-NETSIM for HOV lane traffic analysis.

Because TRAF-NETSIM only allows the occupancy of each vehicle type to be coded for the whole network, the mode shift impact (HOV ridership increase) caused by HOV lane installation for some links still cannot be simulated discretely. In other words, occupancy adjustment for specific HOV lane links for the purpose of evaluating HOV lane traffic impacts is not yet possible -- any occupancy adjustment must be made to the whole network. Vehicle occupancy codings for each link would resolve this problem.

3) TRAF-NETSIM output pertaining to congested flow (spillover) is inconsistent and needs to be improved.

Simulation experiences produced some unreasonable simulation outputs as traffic flow became congested (even in simulating general traffic environments). Intensive program modifications and numerous simulation runs were attempted in this study to resolve this problem. However, researchers found that inconsistent simulation outputs were associated not only with specific turning movement logic, but with other variables, (e.g., geometric designs, random seeds, and simulation time periods) as well. Modifying TRAF-NETSIM to enable the program to simulate congested traffic flow correctly will be a complex process and will reuqire additional

research.

4) Signal timing optimization should be added to TRAF-NETSIM to enable the program to simulate selected traffic environments.

The main obstacle to adding the algorithms of signal timing optimization to TRAF-NETSIM is the time-consuming simulation process. However, signal timing optimization cannot be ignored in any arterial traffic operation. No specific package has yet been developed for the purpose of integrating the microscopic TRAF-NETSIM with the macroscopic TRANSYT-7F -- and the lack of signal timing optimization consitutes a major weakness for TRAF-NETSIM. Fortunately, computers are becoming faster and more powerful, a trend that bodes well for the addition of signal timing optimization to TRAF-NETSIM in the future.

5) TRAF-NETSIM produces incorrect output in calculating person travel time. This aspect of the program needs modification.

TRAF-NETSIM uses average vehicle travel time, instead of average person travel time, in the formula calculating person travel time output. For this reason, the model's output, which runs in the form of person-specific units, cannot be used for the evaluation of arterial HOV alternatives. Thus, modification of this formula in order to provide person travel time in appropriate units is very important.

6) The calibration algorithms of platoon dispersion prediction developed in this study should be added to TRANSYT-7F.

Inconsistent PDF (α) values, the complicated process of platoon dispersion calibration, and prediction problems in the case of congested flow are the major obstacles to applying TRANSYT-7F to the analysis of arterial HOV lanes. To resolve these problems, it is suggested that the platoon dispersion analytical methodology (including platoon smoothing factor analytical methodology and the simulation feedback iteration algorithm) developed in this study be added to TRANSYT-7F. Such action should result in more accurate and efficient arterial

HOV lane simulation.

7) A methodology capable of integrating HOV lane traffic impacts and commuter mode shift behavior for the purpose of planning and evaluating arterial HOV lanes is still needed.

The addition of HOV lanes can result in a number of changes, including mode shift, traffic volume reduction and travel time savings. To determine whether or not an arterial HOV lane has been successful, mode shift, traffic impacts, and traffic volume should be considered simultaneously. Therefore, a methodology that allows consideration of interactive feedback between HOV lane traffic impacts and mode shift is still needed.

8) Guidelines for the installation of a successful arterial HOV lane need improvement.

Specific recommendations concerning the implementation and operation of arterial HOV lanes are needed. Such guidelines should cover the following issues:

- selection of appropriate methods and tools for traffic analysis,
- implementation situations (geometric design, traffic volume, travel times, stops and delays, vehicle occupancy, carpool percentage),
- transportation system management strategies (signal timing plans, parking and turning prohibitions, and transit system planning),

and,

- incentive policies (two or three plus as carpool definition, HOV lane enforcement time).

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```
      SUBROUTINE LANE (I1, I2, I3, JALN)
C
C
C --- CODED    08-03-79 BY M. BURNS
C
C --- TITLE - IDENTIFY THE RECEIVING LANE - MODULE 3231.2.2.2
C
C --- FUNCTION - THIS MODULE DETERMINES THE LANE ON THE SUBJECT LINK
C ---              INTO WHICH VEHICLE, I1, WILL DISCHARGE.
C
C --- ARGUMENTS - I1      - VEHICLE NUMBER (CAN BE ZERO IF BEING
C -----                     EMITTED FROM A SOURCE NODE)
C -----                     FROM THE CALLING ROUTINE
C ---               I2    - RECEIVING LINK NUMBER, FROM CALLING ROUTINE
C ---               I3    - TURN CODE AT END OF LINK, I2, FROM CALLING
C ---                       ROUTINE
C ---               JALN  - LANE VEHICLE WILL DISCHARGE INTO (SET
C ---                       NEGATIVE IF NO ROOM), TO CALLING ROUTINE
C                           ROUTINE
C -------------------------   DESCRIPTION   ---------------------------
C                             -----------
C
C     THIS MODULE SEARCHES FOR A LANE, JALN, FOR THE SUBJECT VEHICLE
C     TO DISCHARGE INTO ON ITS RECEIVING LINK. IF A LANE IS ALREADY
C     CHANNELIZED FOR A BUS OR CAR-POOL, IT WILL BE ASSIGNED. ELSE,
C     MODULE 3231.2221 IS CALLED TO EXAMINE ALL THE ACCESSIBLE LANES
C     FOR THE SPECIFIED TURN MOVEMENT AND CHOOSE THE ONE WITH THE
C     LARGEST HORIZON.
C
C -------------------   THIS ROUTINE CALLED BY   ----------------------
C                       ----------------------
C
C                   PLAZEV - MODULE 3231.2.2
C                   SRZVEH - MODULE 3231.3
C                   TSTSAT - MODULE 3232.2.2
C ---------------------   THIS ROUTINE CALLS   -----------------------
C                         ------------------
C
C                   BSTLNE - MODULE 3231.2221
C                   HORIZN - MODULE 3231.2221.1
C --------------    GLOSSARY OF VARIABLE NAMES   -------------------
C                   -------------------------
C
C     CANDL   LINK SPECIFIC ARRAY - RIGHT TURN LANES, LEFT TURN LANES
```

```
C       CODES    VEHICLE SPECIFIC ARRAY - VEHICLE TYPE
C       IB       BUS VEHICLE NUMBER
C       IBITS    ARRAY OF NO OF BITS TO RIGHT OF ACCEPTABLE LANES IN CANDL
C       IBS      BUS STATION NUMBER ON THIS LINK IF ANY
C       ICODE    TURN CODE AT END OF LINK, I2
C       ICPLNE   LANE CHANNELIZED FOR CAR-POOLS
C       IHORZN   HORIZON IN LANE, ILANE
C       IL       RECEIVING LINK NUMBER
C       ILANE    LANE NUMBER ASSIGNED TO VEHICLE ON NEW LINK
C       INDEX    NUMBER OF BITS TO THE RIGHT OF THOSE TO BE UNPACKED + 1
C       ITURN    TURN CODE AT END OF LINK, I2
C       ITYPE    FLEET COMPONENT CODE (0,1,2,3)=(AUTO,TRUCK,CARPOOL,BUS)
C       IUP      UPSTREAM NODE NUMBER / 1000
C       IV       SUBJECT VEHICLE NUMBER
C       IVLEN    LENGTH OF VEHICLE OF TYPE, ITYP
C       J        INDEX TO MANUVR ARRAY
C       JSPD     SPEED OF LEADER
C       JTYP     VEHICLE TYPE WITHIN FLEET COMPONENT
C       K        INDEX TO STASHN ARRAY
C       MANUVR   NEXT BUS STATION SERVICED ON ROUTE
C       PNTER    BUS SPECIFIC ARRAY - POINTER TO MANUVR ARRAY
C       SPDLN    VEHICLE SPECIFIC ARRAY - SPEED (FT/SEC), LANE OCC.
C       STASHN   STATION SPECIFIC ARRAY - LANE BLOCKED WHEN BUS IS AT
C                STATION
C       TYPLN    LINK SPECIFIC ARRAY - LANE CHAN. FOR BUSES, FOR CAR-POOLS
C       UPNOD    LINK SPECIFIC ARRAY - UPSTREAM NODE NUMBER
C       VTYPE    VEHICLE SPECIFIC ARRAY - PREFERRED LANE, VEH. TYPE-1
C       VTYPLS   VEHICLE TYPE ARRAY - EFF. LENGTH AND MAX. SPEED
C
C ----------------------------------------------------------------------
C
      IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
      COMMON /SIN023/ CANDL (1)
      COMMON /SIN003/ CODES (1)
      COMMON /GLR026/ MANUVR(1)
      COMMON /SIN012/ PNTER (1)
      COMMON /SIN008/ SPDLN (1)
      COMMON /GLR027/ STASHN(1)
      COMMON /SIN061/ TYPLN (1)
      COMMON /SIN062/ UPNOD (1)
      COMMON /SIN133/ VTYPE (1)
      COMMON /SIN135/ VTYPLS(    16)
C
      DIMENSION IBITS(5)
C
      DATA IBITS / 10, 3, 0, 3, 3/
C
      IV = I1
      IL = I2
      ITURN = I3
C
C -----  INITIALIZE LANE TO ZERO. THEN, GET FLEET COMPONENT, ITYPE,AND
C -----  VEHICLE TYPE, JTYP.
```

```
C
      ILANE = 0
      ICPLNE = 0
      ITYPE = 0
      IVLEN = 0
      IF (IV .GT. 0) THEN
         ITYPE = MOD (CODES(IV) / 2**3, 2**3)
         JTYP  = MOD (VTYPE(IV), 2**4) + 1
         IVLEN = MOD (VTYPLS(JTYP), 2**7)
      ENDIF
C
C -----  TRA IF VEHICLE NOT A BUS. ELSE, ASSIGN VEHICLE TO
C -----  CHANNELIZED LANE FOR BUSES. TRA IF LANE EXISTS.
C
      IF (ITYPE .NE. 3)
      ILANE = MOD (TYPLN(IL), 2**3)                          GO TO 30
      IF (ILANE .GT. 0)
C                                                            GO TO 20
C -----  NO LANE ON THIS LINK IS CHANNELIZED FOR BUSES. IF THERE
C -----  IS A BUS STATION ON THIS LINK, SET LANE, ILANE, TO THE
C -----  LANE BLOCKED BY OR ADJOINING A BUS AT THIS STATION AND
C -----  TRA.
C
      IB = MOD (CODES(IV) / 2**6, 2**8)
      J = PNTER(IB)
      J = IABS(J) + 1
      IBS = IABS (MOD (MANUVR(J), 2**12))
      IF (IBS .NE. 0) K = 1 + 10 * (IBS - 1)
      IF (IBS .NE. 0) ILANE = MAX0 (MOD (STASHN(K), 2**3), 1)
   20 CONTINUE
C
C -----  MODULE IS CALLED TO DETERMINE HORIZON OF LANE FOR BUS AS
C -----  LONG AS THIS IS NOT AN ENTRY-INTERFACE LINK.  HORIZON IS
C -----  USED TO SEE IF THERE IS ROOM TO ENTER LINK NOW. BUS ON
C -----  INTERFACE LINK MAY NOT ACTUALLY ARRIVE UNTIL LATER.
C
      IF (ILANE .EQ. 0)
      IHORZN = IVLEN                                         GO TO 25
      IF (UPNOD (IL) / 1000 .NE. 7)
     1    CALL HORIZN (IL, ILANE, IHORZN, IV, JSPD)
      IF (IHORZN .EQ. -1) IHORZN = IVLEN
   25 CONTINUE
   30 CONTINUE
      IF (ILANE .GT. 0)
C                                                            GO TO 60
C -----  NO LANE HAS BEEN ASSIGNED. GET AVAILABLE LANES FOR THE
C -----  SPECIFIED TURN MOVEMENT. THEN, CHOOSE THE BEST LANE
C -----  BY EXAMINING VEHICLE HORIZON IN THOSE LANES.
C
      J = 7
      IF (IABS(ITURN-1) .EQ. 1) J = 3
      INDEX = IBITS(ITURN+1) + 1
      ICODE = MOD (CANDL(IL) / 2**(INDEX-1), 2**J)
      CALL BSTLNE (IL, ICODE, ITURN, IV, ILANE, IHORZN)
```

```
C
C -----  TRA IF NOT A CARPOOL OR VEHICLE IS A TURNER. ELSE,
C -----  ASSIGN VEHICLE TO CARPOOL LANE AND GET ITS HORIZN.
C
      IF (ITYPE .NE. 2 .OR. ITURN .NE. 1)                    GO TO 50
      ICPLNE = MOD (TYPLN(IL) / 2**3, 2**3)
C
C -----  TRA IF NO SPECIAL LANE FOR CARPOOLS. ELSE,
C -----  ASSIGN CARPOOL LANE AND TRA IF ENTRY INTERFACE LINK
C -----  (IMPOSSIBLE TO DETERMINE IF ROOM EXISTS NOW SINCE VEHICLE
C -----  MAY NOT ARRIVE UNTIL LATER IN THE T.I.)
C
      IF (ICPLNE .EQ. 0)                                     GO TO 48
      IUP = UPNOD(IL) / 1000
      IF (IUP .EQ. 7) ILANE = ICPLNE
      IF (IUP .EQ. 7) IHORZN = IVLEN
      IF (IUP .EQ. 7)                                        GO TO 45
C
C -----  CARPOOL LANE EXISTS AND LINK IS NOT AN ENTRY INTERFACE
C -----  LINK. GET AVAILABLE ROOM ON LINK (HORIZON) AND
C -----  ASSIGN CARPOOL LANE IF ADEQUATE ROOM TO ENTER NOW.
C
      CALL HORIZN (IL, ICPLNE, IHORZN, IV, JSPD)
      IF (IHORZN .EQ. -1) IHORZN = IVLEN
      IF (ICPLNE .GT. 0 .AND. (IHORZN .GE. IVLEN / 2 .OR. JSPD
     1           .GE. MOD (SPDLN(IV), 2**7) -4))
     2           ILANE = ICPLNE
   45 CONTINUE
   48 CONTINUE
   50 CONTINUE
   60 CONTINUE
C
C -----  SET LANE NEGATIVE IF THERE IS NOT ENOUGH ROOM IN LANE,
C -----  ILANE, FOR VEHICLE TO ENTER.
C
      IF (IV .GT. 0 .AND. IHORZN .NE. -1 .AND. IHORZN .LT. IVLEN / 2)
     1        ILANE = -ILANE
      JALN = ILANE
C
      RETURN
      END
```

Appendix B: The Critical Program Statements of the Carpool Lane Logic

```
      IF (ITYPE .NE. 2 .OR. ITURN .NE. 1)  GO TO 50
      .
      .
      .
      [Statements for carpool lane assignment algorithm]
   50 CONTINUE
```

Where

ITYPE : fleet component code (0,1,2,3) = (auto,truck,carpool,bus)

ITURN : turn code (0,1,2,3,4) = (left,through,right,left-diagonal,right-diagonal)

Appendix C: The Logic to Allow Turning Vehicles to Use the Carpool Lane

```
      IF (ITYPE .NE. 2 .AND. ITURN .NE. 2)  GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 0)  GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 3)  GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 4)  GO TO 50
      .
      .
      .
      [Statements for carpool lane assignment algorithm]
   50 CONTINUE
```

Appendix D: The Logic to Allow Turning Vehicles to Use the Carpool Lane

```
      IF (ITYPE .NE. 2 .AND. ITURN .NE. 2)  GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 0)  GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 3)  GO TO 50
      .
      .
      .
      [Statements for carpool lane assignment algorithm]
50 CONTINUE
```

```
      SUBROUTINE LANE (I1, I2, I3, JALN)
C
C
C --- CODED    08-03-79 BY M. BURNS
C
C --- TITLE - IDENTIFY THE RECEIVING LANE - MODULE 3231.2.2.2
C
C --- FUNCTION - THIS MODULE DETERMINES THE LANE ON THE SUBJECT LINK
C ---              INTO WHICH VEHICLE, I1, WILL DISCHARGE.
C
C --- ARGUMENTS - I1      = VEHICLE NUMBER (CAN BE ZERO IF BEING
C -----                     EMITTED FROM A SOURCE NODE)
C -----                     FROM THE CALLING ROUTINE
C ---               I2      = RECEIVING LINK NUMBER, FROM CALLING ROUTINE
C ---               I3      = TURN CODE AT END OF LINK, I2, FROM CALLING
C ---                         ROUTINE
C ---               JALN    = LANE VEHICLE WILL DISCHARGE INTO (SET
C ---                         NEGATIVE IF NO ROOM), TO CALLING ROUTINE
C
C -------------------------   DESCRIPTION   ---------------------------
C
C
C     THIS MODULE SEARCHES FOR A LANE, JALN, FOR THE SUBJECT VEHICLE
C     TO DISCHARGE INTO ON ITS RECEIVING LINK. IF A LANE IS ALREADY
C     CHANNELIZED FOR A BUS OR CAR-POOL, IT WILL BE ASSIGNED. ELSE,
C     MODULE 3231.2221 IS CALLED TO EXAMINE ALL THE ACCESSIBLE LANES
C     FOR THE SPECIFIED TURN MOVEMENT AND CHOOSE THE ONE WITH THE
C     LARGEST HORIZON.
C
C -------------------   THIS ROUTINE CALLED BY   ----------------------
C
C
C                     PLAZEV - MODULE 3231.2.2
C                     SRZVEH - MODULE 3231.3
C                     TSTSAT - MODULE 3232.2.2
C ---------------------   THIS ROUTINE CALLS   ------------------------
C
C
C                     BSTLNE - MODULE 3231.2221
C                     HORIZN - MODULE 3231.2221.1
C --------------      GLOSSARY OF VARIABLE NAMES   -------------------
C
C
C     CANDL   LINK SPECIFIC ARRAY - RIGHT TURN LANES, LEFT TURN LANES
C     CODES   VEHICLE SPECIFIC ARRAY - VEHICLE TYPE
```

```
C       IB        BUS VEHICLE NUMBER
C       IBITS     ARRAY OF NO OF BITS TO RIGHT OF ACCEPTABLE LANES IN CANDL
C       IBS       BUS STATION NUMBER ON THIS LINK IF ANY
C       ICODE     TURN CODE AT END OF LINK, I2
C       ICPLNE    LANE CHANNELIZED FOR CAR-POOLS
C       IHORZN    HORIZON IN LANE, ILANE
C       IL        RECEIVING LINK NUMBER
C       ILANE     LANE NUMBER ASSIGNED TO VEHICLE ON NEW LINK
C       INDEX     NUMBER OF BITS TO THE RIGHT OF THOSE TO BE UNPACKED + 1
C       ITURN     TURN CODE AT END OF LINK, I2
C       ITYPE     FLEET COMPONENT CODE (0,1,2,3)=(AUTO,TRUCK,CARPOOL,BUS)
C       IUP       UPSTREAM NODE NUMBER / 1000
C       IV        SUBJECT VEHICLE NUMBER
C       IVLEN     LENGTH OF VEHICLE OF TYPE, ITYP
C       J         INDEX TO MANUVR ARRAY
C       JSPD      SPEED OF LEADER
C       JTYP      VEHICLE TYPE WITHIN FLEET COMPONENT
C       K         INDEX TO STASHN ARRAY
C       MANUVR    NEXT BUS STATION SERVICED ON ROUTE
C       PNTER     BUS SPECIFIC ARRAY - POINTER TO MANUVR ARRAY
C       SPDLN     VEHICLE SPECIFIC ARRAY - SPEED (FT/SEC), LANE OCC.
C       STASHN    STATION SPECIFIC ARRAY - LANE BLOCKED WHEN BUS IS AT
C                 STATION
C       TYPLN     LINK SPECIFIC ARRAY - LANE CHAN. FOR BUSES, FOR CAR-POOLS
C       UPNOD     LINK SPECIFIC ARRAY - UPSTREAM NODE NUMBER
C       VTYPE     VEHICLE SPECIFIC ARRAY - PREFERRED LANE, VEH. TYPE-1
C       VTYPLS    VEHICLE TYPE ARRAY - EFF. LENGTH AND MAX. SPEED
C
C ---------------------------------------------------------------------
C
      IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
      COMMON /SIN023/ CANDL (1)
      COMMON /SIN003/ CODES (1)
      COMMON /GLR026/ MANUVR(1)
      COMMON /SIN012/ PNTER (1)
      COMMON /SIN008/ SPDLN (1)
      COMMON /GLR027/ STASHN(1)
      COMMON /SIN061/ TYPLN (1)
      COMMON /SIN062/ UPNOD (1)
      COMMON /SIN133/ VTYPE (1)
      COMMON /SIN135/ VTYPLS(   16)
C
      DIMENSION IBITS(5)
C
      DATA IBITS / 10, 3, 0, 3, 3/
C
      IV = I1
      IL = I2
      ITURN = I3
C
C -----  INITIALIZE LANE TO ZERO. THEN, GET FLEET COMPONENT, ITYPE,AND
C -----  VEHICLE TYPE, JTYP.
C
```

```
      ILANE = 0
      ICPLNE = 0
      ITYPE = 0
      IVLEN = 0
      IF (IV .GT. 0) THEN
         ITYPE = MOD (CODES(IV) / 2**3, 2**3)
         JTYP  = MOD (VTYPE(IV), 2**4) + 1
         IVLEN = MOD (VTYPLS(JTYP), 2**7)
      ENDIF
C
C -----  TRA IF VEHICLE NOT A BUS. ELSE, ASSIGN VEHICLE TO
C -----  CHANNELIZED LANE FOR BUSES. TRA IF LANE EXISTS.
C
      IF (ITYPE .NE. 3)                                          GO TO 30
      ILANE = MOD (TYPLN(IL), 2**3)
      IF (ILANE .GT. 0)                                          GO TO 20
C
C -----  NO LANE ON THIS LINK IS CHANNELIZED FOR BUSES. IF THERE
C -----  IS A BUS STATION ON THIS LINK, SET LANE, ILANE, TO THE
C -----  LANE BLOCKED BY OR ADJOINING A BUS AT THIS STATION AND
C -----  TRA.
C
      IB = MOD (CODES(IV) / 2**6, 2**8)
      J = PNTER(IB)
      J = IABS(J) + 1
      IBS = IABS (MOD (MANUVR(J), 2**12))
      IF (IBS .NE. 0) K = 1 + 10 * (IBS - 1)
      IF (IBS .NE. 0) ILANE = MAX0 (MOD (STASHN(K), 2**3), 1)
   20 CONTINUE
C
C -----  MODULE IS CALLED TO DETERMINE HORIZON OF LANE FOR BUS AS
C -----  LONG AS THIS IS NOT AN ENTRY-INTERFACE LINK.  HORIZON IS
C -----  USED TO SEE IF THERE IS ROOM TO ENTER LINK NOW. BUS ON
C -----  INTERFACE LINK MAY NOT ACTUALLY ARRIVE UNTIL LATER.
C
      IF (ILANE .EQ. 0)                                          GO TO 25
      IHORZN = IVLEN
      IF (UPNOD (IL) / 1000 .NE. 7)
     1    CALL HORIZN (IL, ILANE, IHORZN, IV, JSPD)
      IF (IHORZN .EQ. -1) IHORZN = IVLEN
   25 CONTINUE
   30 CONTINUE
      IF (ILANE .GT. 0)                                          GO TO 60
C
C -----  NO LANE HAS BEEN ASSIGNED. GET AVAILABLE LANES FOR THE
C -----  SPECIFIED TURN MOVEMENT. THEN, CHOOSE THE BEST LANE
C -----  BY EXAMINING VEHICLE HORIZON IN THOSE LANES.
C
      J = 7
      IF (IABS(ITURN-1) .EQ. 1) J = 3
      INDEX = IBITS(ITURN+1) + 1
      ICODE = MOD (CANDL(IL) / 2**(INDEX-1), 2**J)
      CALL BSTLNE (IL, ICODE, ITURN, IV, ILANE, IHORZN)
C
```

```
C -----   TRA IF NOT A CARPOOL AND VEHICLE IS NOT A RIGHT-TURNER;
C -----   TRA IF A CARPOOL AND VEHICLE IS A LEFT-TURNER;
C------   TRA IF A CARPOOL AND VEHICLE IS A LEFT-DIAGONAL-TURNER. ELSE,
C -----   ASSIGN VEHICLE TO CARPOOL LANE AND GET ITS HORIZN.
C
      IF (ITYPE .NE. 2 .AND. ITURN .NE. 2)
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 0)                    GO TO 50
      IF (ITYPE .EQ. 2 .AND. ITURN .EQ. 3)                    GO TO 50
C                                                             GO TO 50
      ICPLNE = MOD (TYPLN(IL) / 2**3, 2**3)
C
C -----   TRA IF NO SPECIAL LANE FOR CARPOOLS. ELSE,
C -----   ASSIGN CARPOOL LANE AND TRA IF ENTRY INTERFACE LINK
C -----   (IMPOSSIBLE TO DETERMINE IF ROOM EXISTS NOW SINCE VEHICLE
C -----   MAY NOT ARRIVE UNTIL LATER IN THE T.I.)
C
      IF (ICPLNE .EQ. 0)
      IUP = UPNOD(IL) / 1000                                  GO TO 48
      IF (IUP .EQ. 7) ILANE = ICPLNE
      IF (IUP .EQ. 7) IHORZN = IVLEN
      IF (IUP .EQ. 7)
C                                                             GO TO 45
C -----   CARPOOL LANE EXISTS AND LINK IS NOT AN ENTRY INTERFACE
C -----   LINK. GET AVAILABLE ROOM ON LINK (HORIZON) AND
C -----   ASSIGN CARPOOL LANE IF ADEQUATE ROOM TO ENTER NOW.
C
      CALL HORIZN (IL, ICPLNE, IHORZN, IV, JSPD)
      IF (IHORZN .EQ. -1) IHORZN = IVLEN
      IF (ICPLNE .GT. 0 .AND. (IHORZN .GE. IVLEN / 2 .OR. JSPD
     1            .GE. MOD (SPDLN(IV), 2**7) -4))
     2            ILANE = ICPLNE
   45 CONTINUE
   48 CONTINUE
   50 CONTINUE
   60 CONTINUE
C
C -----   SET LANE NEGATIVE IF THERE IS NOT ENOUGH ROOM IN LANE,
C -----   ILANE, FOR VEHICLE TO ENTER.
C
      IF (IV .GT. 0 .AND. IHORZN .NE. -1 .AND. IHORZN .LT. IVLEN / 2)
     1        ILANE = -ILANE
      JALN = ILANE
C
      RETURN
      END
```

Appendix F: The TRAF-NETSIM Subroutine GETCD (Before Modification)

```
      SUBROUTINE GETCD (I1, I2, JCODE)
C
C
C --- CODED    08-02-79 BY M. BURNS
C --- REVISED  9-15-87 BY AJAY K. RATHI FOR IDENTICAL TRAFFIC STREAMS
C --- REVISED  1-14-88 BY O. SHARAF-ELDIEN TO REPLACE CALL EXIT BY STOP
C
C --- TITLE - GET TURN MOVEMENT ON RECEIVING LINK - MODULE 3231.2.2.1
C
C --- FUNCTION - THIS MODULE DETERMINES THE TURN MOVEMENT FOR THE
C ---            SPECIFIED VEHICLE ON THE SPECIFIED LINK.
C
C --- ARGUMENTS - I1     - VEHICLE NUMBER, FROM CALLING ROUTINE
C ---             I2     = LINK NUMBER, FROM CALLING ROUTINE
C ---             JCODE  = TURN CODE AT END OF LINK, I2, TO CALLING
C ---                      ROUTINE
C
C -------------------------   DESCRIPTION   --------------------------
C                             -----------
C
C     WHEN THIS MODULE IS CALLED, WE KNOW THAT VEHICLE, I1, WILL
C     ENTER LINK, I2. THIS MODULE DETERMINES THE TURN MOVEMENT THAT
C     WILL BE MADE AT THE END OF THIS LINK.
C
C -------------------   THIS ROUTINE CALLED BY   ---------------------
C                       ----------------------
C
C                    PLAZEV - MODULE 3231.2.2
C                    SRZVEH - MODULE 3231.3
C                    CHKDIS - MODULE 3232.2
C
C ---------------------   THIS ROUTINE CALLS   ------------------------
C                         ------------------
C
C                    RANDMN - MODULE 3231.1.1.5
C
C --------------     GLOSSARY OF VARIABLE NAMES   -------------------
C                    --------------------------
C
C     ARIGHT  LINK SPECIFIC ARRAY - RIGHT-TURN RECEIVING LINK
C     CODES   VEHICLE SPECIFIC ARRAY - CURRENT TURNING CODE,VEH. TYPE,
C             BUS VEHICLE NUMBER
C     CTDATA  CONDITIONAL TURN MOVEMENT ARRAY - UPSTREAM ENTERING MVMT
C             CODES WITH THEIR ASSOCIATED DOWNSTREAM TURN PERCENTS
C     CTVECT  LINK SPECIFIC ARRAY - POINTERS TO CTDATA ARRAY FOR
C             CONDITIONAL TURN MOVEMENT DATA
C     DIAGNL  LINK SPECIFIC ARRAY - DIAGONAL RECEIVING LINK
```

```
C       DWNOD   LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
C       I       RUNNING SUM OF TURN PERCENTS
C       IB      BUS VEHICLE NUMBER
C       ICODE   CODE (1,2,3,4) FOR (LEFT,THRU,RIGHT,DIAG) TURN USED
C               BY CURRENT VEHICLE TO ENTER LINK IL
C       IL      RECEIVING LINK NO. OF DISCHARGING VEHICLE
C       IP      POINTER TO XLSEED ARRAY
C       IPCT    ARRAY OF TURN PERCENTS FOR THIS LINK
C       IR      TWO DIGIT RANDOM NUMBER
C       ISEED   RANDOM NUMBER SEED
C       ITRN    ARRAY OF CUMULATIVE COUNTS OF VEHICLES MAKING EACH TURN
C               MOVEMENT
C       ITURN   UPSTREAM TURN CODE (1,2,3,4) FOR (LEFT,THRU,RIGHT,
C               DIAGONAL) FOR CURRENT LINK
C       IV      SUBJECT VEHICLE NUMBER
C       IVP     POINTER TO BEGINNING OF CONDITIONAL TURN MOVEMENT DATA
C               FOR CURRENT LINK
C       J       INDEX TO MANUVR ARRAY AND IPCT ARRAY
C       JJ      TURN MOVEMENT ASSIGNED
C       JTURN   TEMPORARY STORAGE FOR NEXT UPSTREAM TURN CODE IN
C               CTDATA ARRAY
C       LEFT    LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
C       LU6     PERIPHERAL UNIT NUMBER 6
C       MANUVR  BUS SPECIFIC ARRAY - TURN CODE AT DOWNSTREAM END OF LINK
C       NMAX    MAXIMUM ALLOWABLE NODE NUMBER
C       PCTLR   LINK SPECIFIC ARRAY - PCT LEFT AND PCT RIGHT TURNERS
C       PLSEED  LINK SPECIFIC ARRAY - POINTER TO XLSEED ARRAY
C       PNTER   BUS SPECIFIC ARRAY - POINTERS TO MANUVR ARRAY
C       PTHRU   LINK SPECIFIC ARRAY - PCT THRU AND PCT DIAG. MOVEMENTS
C       THRU    LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
C       TOTCTD  TOTAL NUMBER OF UPSTREAM TURN MOVEMENTS AND THEIR
C               ASSOCIATED DOWNSTREAM TURN PERCENTS
C       UPNOD   LINK SPECIFIC ARRAY - UPSTREAM NODE NUMBERS
C       WC      FLAG (T, F) IF CONDITIONAL TURN MVMTS (DO, DONT) APPLY
C       XLSEED  ARRAY OF RANDOM NUMBER SEEDS FOR ENTRY AND ENTRY-INTERFACE
C               LINKS AND INTERNAL LINKS WITH SOURCE POINTS
C ----------------------------------------------------------------------
C
      IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
      COMMON /SIN018/ ARIGHT(1)
      COMMON /SIN003/ CODES (1)
      COMMON /SIN172/ CTDATA(1)
      COMMON /SIN173/ CTVECT(1)
      COMMON /SIN033/ DIAGNL(1)
      COMMON /SIN036/ DWNOD (1)
      COMMON /SIN041/ LEFT  (1)
      COMMON /GLR106/ LU6
      COMMON /GLR026/ MANUVR(1)
      COMMON /GLR011/ NMAX
      COMMON /SIN047/ PCTLR (1)
      COMMON /SIN179/ PLSEED(1)
      COMMON /SIN012/ PNTER (1)
```

```
      COMMON /SIN048/ PTHRU (1)
      COMMON /SIN059/ THRU  (1)
      COMMON /SIN175/ TOTCTD
      COMMON /SIN062/ UPNOD (1)
      COMMON /SIN178/ XLSEED(1)
C
      DIMENSION IPCT(4)
      DIMENSION ITRN(4)
C
      IV = I1
      IL = I2
C
C -----  GET VEHICLE TYPE. TRA IF NOT A BUS. ELSE, GET BUS
C -----  VEHICLE NUMBER AND ITS TURN MOVEMENT CODE, ICODE,
C -----  AT DOWNSTREAM END OF LINK. INCREMENT POINTER TO MANUVR
C -----  ARRAY AND TRA.
C
      IF (IV .EQ. 0)
      IF (MOD (CODES(IV) / 2**3, 2**3) .NE. 3)                GO TO 20
      IB = MOD (CODES(IV) / 2**6, 2**8)                       GO TO 10
      J = PNTER(IB)
      J = IABS(J) + 1
      JJ = MANUVR(J) / 4096
      JJ = IABS(JJ)
      IF (JJ .LT. 5)
C                                                             GO TO 100
C -----  BUS BOUND FOR EXIT LINK OR THIS LINK IS AN EXIT INTERFACE
C -----  LINK. IF LATTER IS TRUE, SET TURN CODE TO 1 AND TRA. ELSE,
C -----  LOCATE EXIT LINK AND SET TURN CODE ACCORDINGLY. EXIT IN N.G.
C
      IF (DWNOD(IL) / 1000 .EQ. 7) JJ = 1
      IF (JJ .EQ. 1)
      IF (-DIAGNL(IL) .GE. 8000) JJ = 3                       GO TO 90
      IF (DIAGNL(IL) .GE. 8000) JJ = 4
      IF (LEFT(IL) .GE. 8000) JJ = 0
      IF (ARIGHT(IL) .GE. 8000) JJ = 2
      IF (THRU(IL) .GE. 8000) JJ = 1
      IF (JJ .LT. 5)
      WRITE (LU6, 1000) IB, IL, J, JJ                         GO TO 80
      STOP 'GETCD'
   10 CONTINUE
   20 CONTINUE
C
C -----  INITIALIZE ARRAYS OF TURN PERCENTS AND UPSTREAM TURN CODES
C
         DO 25 I = 1, 4
            IPCT(I) = 0
            ITRN(I) = 0
   25    CONTINUE
C
C ----------------------------------------------------------------------
C
C     IF VEHICLE, IV, IS NOT BEING PLACED ON AN INTERFACE LINK AND NOT
C     EMITTED ONTO LINK VIA A SOURCE NODE (IV = 0), DETERMINE IF TURN
```

```
C     MOVEMENT DISTRIBUTION IS CONDITIONAL.  CONDITIONAL ASSIGNS TURN
C     MOVEMENTS AT DOWNSTREAM END OF LINK BASED ON THE TURN MOVEMENT
C     USED BY THIS VEHICLE TO ENTER LINK.
C
C ---------------------------------------------------------------------
C
      WC = .FALSE.
      IF (UPNOD(IL) .LE. NMAX .AND. IV .GT. 0) THEN
         IVP = CTVECT(IL)
         IF (IVP .GT. 0) THEN
            ICODE = MOD (CODES(IV), 2**3) + 1
            IF (ICODE .EQ. 5) ICODE = 4
            ITURN = CTDATA(IVP)
            JTURN = IABS (ITURN)
   30       CONTINUE
            ITURN = JTURN
            IF (ITURN .EQ. ICODE) THEN
               WC = .TRUE.
C
C -----  VEHICLE IS ENTERING LINK, IL, VIA UPSTREAM MOVEMENT, ITURN,
C -----  SPECIFIED BY USER AS A MOVEMENT THAT AFFECTS THE DOWNSTREAM
C -----  TURN MOVEMENTS DIFFERENTLY THAN THE NORMAL DISTRIBUTION.
C
               J = 0
   40          CONTINUE
               J = J + 1
               IPCT(J) = CTDATA(IVP+J)
               IF (J .LT. 4)                                  GO TO 40
            ELSE
               IVP = IVP + 5
               IF (IVP .LT. TOTCTD) THEN
                  JTURN = CTDATA(IVP)
               ELSE
                  JTURN = -1
               ENDIF
            ENDIF
            IF (.NOT. WC .AND. JTURN .GT. 0)                  GO TO 30
         ENDIF
      ENDIF
C
C -----  STORE NORMAL TURN PERCENTS IN IPCT ARRAY IF THIS LINK HAS
C -----  NO CONDITIONAL TURN MOVEMENTS ASSIGNED.
C
      IF (.NOT. WC) THEN
         IPCT(1) = MOD (PCTLR(IL), 2**7)
         IPCT(2) = MOD (PTHRU(IL), 2**7)
         IPCT(3) = PCTLR(IL) / 128
         IPCT(4) = PTHRU(IL) / 128
      ENDIF
C
C -----  DETERMINE TURN MOVEMENT RANDOMLY AND STORE ITS
C -----  CODE IN JJ.
C
      IF (IV .EQ. 0) THEN
```

```
         IP = PLSEED(IL)
         ISEED = XLSEED(IP)
         ISEED = MOD (ISEED * 3 + MOD (ISEED, 10000) * 10000,
     1                100000000)
         IR = ISEED / 1000000
      ELSE
         CALL RANDMN (IV, IR)
      ENDIF
      JJ = 0
      J = 0
      I = 0
   50 CONTINUE
      J = J + 1
      I = I + IPCT(J)
      IF (IR .LT. I) JJ = J
      IF (J .LT. 4 .AND. JJ .EQ. 0)                                GO TO 50
      IF (JJ .NE. 4 .OR. (JJ .EQ. 4 .AND. DIAGNL(IL) .LT. 0))
     1    JJ = JJ - 1
   80 CONTINUE
   90 CONTINUE
  100 CONTINUE
      JCODE = JJ
C
      RETURN
C
 1000 FORMAT (1H0, 5X, 3HBUS, I4, 8H ON LINK, I4,
     1        18H POINTS TO ELEMENT, I4,  16H OF MANUVR ARRAY,/,6X,
     2        25H WHICH HAS A TURN CODE OF, I2,
     3        25H BUT NO EXIT LINK PRESENT)
      END
```

Appendix G: The TRAF-NETSIM Subroutine GETCD (After Modification)

```
      SUBROUTINE GETCD (I1, I2, JCODE)
C
C
C --- CODED    08-02-79 BY M. BURNS
C --- REVISED  9-15-87 BY AJAY K. RATHI FOR IDENTICAL TRAFFIC STREAMS
C --- REVISED  1-14-88 BY O. SHARAF-ELDIEN TO REPLACE CALL EXIT BY STOP
C
C --- TITLE - GET TURN MOVEMENT ON RECEIVING LINK - MODULE 3231.2.2.1
C
C --- FUNCTION - THIS MODULE DETERMINES THE TURN MOVEMENT FOR THE
C ---              SPECIFIED VEHICLE ON THE SPECIFIED LINK.
C
C --- ARGUMENTS - I1     - VEHICLE NUMBER, FROM CALLING ROUTINE
C ---               I2     - LINK NUMBER, FROM CALLING ROUTINE
C ---               JCODE  - TURN CODE AT END OF LINK, I2, TO CALLING
C                            ROUTINE
C
C -------------------------   DESCRIPTION   --------------------------
C                             -----------
C
C     WHEN THIS MODULE IS CALLED, WE KNOW THAT VEHICLE, I1, WILL
C     ENTER LINK, I2. THIS MODULE DETERMINES THE TURN MOVEMENT THAT
C     WILL BE MADE AT THE END OF THIS LINK.
C
C -------------------   THIS ROUTINE CALLED BY   ----------------------
C                       ----------------------
C
C                    PLAZEV - MODULE 3231.2.2
C                    SRZVEH - MODULE 3231.3
C                    CHKDIS - MODULE 3232.2
C
C ---------------------   THIS ROUTINE CALLS   -----------------------
C                         ------------------
C
C                    RANDMN - MODULE 3231.1.1.5
C
C --------------   GLOSSARY OF VARIABLE NAMES   -------------------
C                  -------------------------
C
C     ARIGHT  LINK SPECIFIC ARRAY - RIGHT-TURN RECEIVING LINK
C     CODES   VEHICLE SPECIFIC ARRAY - CURRENT TURNING CODE,VEH. TYPE,
C             BUS VEHICLE NUMBER
C     CTDATA  CONDITIONAL TURN MOVEMENT ARRAY - UPSTREAM ENTERING MVMT
C             CODES WITH THEIR ASSOCIATED DOWNSTREAM TURN PERCENTS
C     CTVECT  LINK SPECIFIC ARRAY - POINTERS TO CTDATA ARRAY FOR
C             CONDITIONAL TURN MOVEMENT DATA
C     DIAGNL  LINK SPECIFIC ARRAY - DIAGONAL RECEIVING LINK
C     DWNOD   LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
```

```
C       I        RUNNING SUM OF TURN PERCENTS
C       IB       BUS VEHICLE NUMBER
C       ICODE    CODE (1,2,3,4) FOR (LEFT,THRU,RIGHT,DIAG) TURN USED
C                BY CURRENT VEHICLE TO ENTER LINK IL
C       IL       RECEIVING LINK NO. OF DISCHARGING VEHICLE
C       IP       POINTER TO XLSEED ARRAY
C       IPCT     ARRAY OF TURN PERCENTS FOR THIS LINK
C       IR       TWO DIGIT RANDOM NUMBER
C       ISEED    RANDOM NUMBER SEED
C       ITRN     ARRAY OF CUMULATIVE COUNTS OF VEHICLES MAKING EACH TURN
C                MOVEMENT
C       ITURN    UPSTREAM TURN CODE (1,2,3,4) FOR (LEFT,THRU,RIGHT,
C                DIAGONAL) FOR CURRENT LINK
C       IV       SUBJECT VEHICLE NUMBER
C       IVP      POINTER TO BEGINNING OF CONDITIONAL TURN MOVENENT DATA
C                FOR CURRENT LINK
C       J        INDEX TO MANUVR ARRAY AND IPCT ARRAY
C       JJ       TURN MOVEMENT ASSIGNED
C       JTURN    TEMPORARY STORAGE FOR NEXT UPSTREAM TURN CODE IN
C                CTDATA ARRAY
C       LEFT     LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
C       LU6      PERIPHERAL UNIT NUMBER 6
C       MANUVR   BUS SPECIFIC ARRAY - TURN CODE AT DOWNSTREAM END OF LINK
C       NMAX     MAXIMUM ALLOWABLE NODE NUMBER
C       PCTLR    LINK SPECIFIC ARRAY - PCT LEFT AND PCT RIGHT TURNERS
C       PLSEED   LINK SPECIFIC ARRAY - POINTER TO XLSEED ARRAY
C       PNTER    BUS SPECIFIC ARRAY - POINTERS TO MANUVR ARRAY
C       PTHRU    LINK SPECIFIC ARRAY - PCT THRU AND PCT DIAG. MOVEMENTS
C       THRU     LINK SPECIFIC ARRAY - DOWNSTREAM NODE NUMBER
C       TOTCTD   TOTAL NUMBER OF UPSTREAM TURN MOVEMENTS AND THEIR
C                ASSOCIATED DOWNSTREAM TURN PERCENTS
C       UPNOD    LINK SPECIFIC ARRAY - UPSTREAM NODE NUMBERS
C       WC       FLAG (T, F) IF CONDITIONAL TURN MVMTS (DO, DONT) APPLY
C       XLSEED   ARRAY OF RANDOM NUMBER SEEDS FOR ENTRY AND ENTRY-INTERFACE
C                LINKS AND INTERNAL LINKS WITH SOURCE POINTS
C ------------------------------------------------------------------------
C
      IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
      COMMON /SIN018/ ARIGHT(1)
      COMMON /SIN003/ CODES (1)
      COMMON /SIN172/ CTDATA(1)
      COMMON /SIN173/ CTVECT(1)
      COMMON /SIN033/ DIAGNL(1)
      COMMON /SIN036/ DWNOD (1)
      COMMON /SIN041/ LEFT  (1)
      COMMON /GLR106/ LU6
      COMMON /GLR026/ MANUVR(1)
      COMMON /GLR011/ NMAX
      COMMON /SIN047/ PCTLR (1)
      COMMON /SIN179/ PLSEED(1)
      COMMON /SIN012/ PNTER (1)
      COMMON /SIN048/ PTHRU (1)
```

```
      COMMON /SIN059/ THRU  (1)
      COMMON /SIN175/ TOTCTD
      COMMON /SIN062/ UPNOD (1)
      COMMON /SIN178/ XLSEED(1)
C
      DIMENSION IPCT(4)
      DIMENSION ITRN(4)
C
      IV = I1
      IL = I2
C
C -----  GET VEHICLE TYPE. TRA IF NOT A BUS. ELSE, GET BUS
C -----  VEHICLE NUMBER AND ITS TURN MOVEMENT CODE, ICODE,
C -----  AT DOWNSTREAM END OF LINK. INCREMENT POINTER TO MANUVR
C -----  ARRAY AND TRA.
C
      IF (IV .EQ. 0)                                          GO TO 20
      IF (MOD (CODES(IV) / 2**3, 2**3) .NE. 3)                GO TO 10
      IB = MOD (CODES(IV) / 2**6, 2**8)
      J = PNTER(IB)
      J = IABS(J) + 1
      JJ = MANUVR(J) / 4096
      JJ = IABS(JJ)
      IF (JJ .LT. 5)
C                                                             GO TO 100
C -----  BUS BOUND FOR EXIT LINK OR THIS LINK IS AN EXIT INTERFACE
C -----  LINK. IF LATTER IS TRUE, SET TURN CODE TO 1 AND TRA. ELSE,
C -----  LOCATE EXIT LINK AND SET TURN CODE ACCORDINGLY. EXIT IN N.G.
C
      IF (DWNOD(IL) / 1000 .EQ. 7) JJ = 1
      IF (JJ .EQ. 1)
      IF (-DIAGNL(IL) .GE. 8000) JJ = 3                       GO TO 90
      IF (DIAGNL(IL) .GE. 8000) JJ = 4
      IF (LEFT(IL) .GE. 8000) JJ = 0
      IF (ARIGHT(IL) .GE. 8000) JJ = 2
      IF (THRU(IL) .GE. 8000) JJ = 1
      IF (JJ .LT. 5)
      WRITE (LU6, 1000) IB, IL, J, JJ                         GO TO 80
      STOP 'GETCD'
   10 CONTINUE
   20 CONTINUE
C
C -----  INITIALIZE ARRAYS OF TURN PERCENTS AND UPSTREAM TURN CODES
C
         DO 25 I = 1, 4
            IPCT(I) = 0
            ITRN(I) = 0
   25    CONTINUE
C
C ----------------------------------------------------------------------
C
C     IF VEHICLE, IV, IS NOT BEING PLACED ON AN INTERFACE LINK AND NOT
C     EMITTED ONTO LINK VIA A SOURCE NODE (IV = 0), DETERMINE IF TURN
C     MOVEMENT DISTRIBUTION IS CONDITIONAL.  CONDITIONAL ASSIGNS TURN
```

```
C     MOVEMENTS AT DOWNSTREAM END OF LINK BASED ON THE TURN MOVEMENT
C     USED BY THIS VEHICLE TO ENTER LINK.
C
C ---------------------------------------------------------------------
C
      WC = .FALSE.
      IF (UPNOD(IL) .LE. NMAX .AND. IV .GT. 0) THEN
         IVP = CTVECT(IL)
         IF (IVP .GT. 0) THEN
            ICODE = MOD (CODES(IV), 2**3) + 1
            IF (ICODE .EQ. 5) ICODE = 4
            ITURN = CTDATA(IVP)
            JTURN = IABS (ITURN)
   30       CONTINUE
            ITURN = JTURN
            IF (ITURN .EQ. ICODE) THEN
               WC = .TRUE.
C
C -----  VEHICLE IS ENTERING LINK, IL, VIA UPSTREAM MOVEMENT, ITURN,
C -----  SPECIFIED BY USER AS A MOVEMENT THAT AFFECTS THE DOWNSTREAM
C -----  TURN MOVEMENTS DIFFERENTLY THAN THE NORMAL DISTRIBUTION.
C
               J = 0
   40          CONTINUE
               J = J + 1
               IPCT(J) = CTDATA(IVP+J)
               IF (J .LT. 4)                                GO TO 40
            ELSE
               IVP = IVP + 5
               IF (IVP .LT. TOTCTD) THEN
                  JTURN = CTDATA(IVP)
               ELSE
                  JTURN = -1
               ENDIF
            ENDIF
            IF (.NOT. WC .AND. JTURN .GT. 0)                GO TO 30
         ENDIF
      ENDIF
C
C -----  STORE NORMAL TURN PERCENTS IN IPCT ARRAY IF THIS LINK HAS
C -----  NO CONDITIONAL TURN MOVEMENTS ASSIGNED.
C
      IF (.NOT. WC) THEN
         IPCT(1) = MOD (PCTLR(IL), 2**7)
         IPCT(2) = MOD (PTHRU(IL), 2**7)
         IPCT(3) = PCTLR(IL) / 128
         IPCT(4) = PTHRU(IL) / 128
      ENDIF
C
C -----  DETERMINE TURN MOVEMENT RANDOMLY AND STORE ITS
C -----  CODE IN JJ.
C
      IF (IV .EQ. 0) THEN
         IP = PLSEED(IL)
```

```
          ISEED = XLSEED(IP)
          ISEED = MOD (ISEED * 3 + MOD (ISEED, 10000) * 10000,
     1                    100000000)
          IR = ISEED / 1000000
       ELSE
          CALL RANDMN (IV, IR)
       ENDIF
       JJ = 0
       J = 0
       I = 0
   50  CONTINUE
       J = J + 1
       I = I + IPCT(J)
       IF (IR .LT. I) JJ = J
       IF (J .LT. 4 .AND. JJ .EQ. 0)
       IF (JJ .NE. 4 .OR. (JJ .EQ. 4 .AND. DIAGNL(IL) .LT. 0))  GO TO 50
     1    JJ = JJ - 1
   80  CONTINUE
   90  CONTINUE
  100  CONTINUE
C
C -----  CARPOOL VEHICLE RIGHT-DIAGONAL-TURN CHANGED AS RIGHT-TURN
C
       IF (JJ .EQ. 4 .AND. MOD (CODES(IV) / 2**3, 2**3) .EQ. 2)
     1    JJ = JJ - 2
C
C -----  BUS RIGHT-DIAGONAL-TURN CHANGED AS RIGHT-TURN
C
       IF (JJ .EQ. 4 .AND. MOD (CODES(IV) / 2**3, 2**3) .EQ. 3)
     1    JJ = JJ - 2
C
       JCODE = JJ
C
       RETURN
C
 1000  FORMAT (1H0, 5X, 3HBUS, I4, 8H ON LINK, I4,
     1         18H POINTS TO ELEMENT, I4,  16H OF MANUVR ARRAY,/,6X,
     2         25H WHICH HAS A TURN CODE OF, I2,
     3         25H BUT NO EXIT LINK PRESENT)
       END
```

```
      SUBROUTINE LINKST (IV, IL, ITIME)
C
C
C --- CODED    11-29-79 BY M. BURNS
C --- REVISED   3-26-88 BY O. SHARAF-ELDIEN TO REMOVE REDUNDANT ARRAYS
C --- REVISED   4-30-88 BY O. SHARAF-ELDIEN TO FIX REF.TO CODES ARRAY
C --- REVISED 12-13-88 BY A. KANAAN TO REMOVE SPLIT OF ENTRTM & TRVLTM
C
C --- TITLE - UPDATE LINK STATISTICS FOR DISCHARGING VEHICLE
C ---             - MODULE 3232.3.6
C
C --- FUNCTION - THIS MODULE UPDATES THE LINK STATISTICS FOR THE
C ---              LINK THE SUBJECT VEHICLE IS DISCHARGING FROM.
C
C --- ARGUMENTS - IV     = VEHICLE DISCHARGING FROM LINK, FROM CALLING
C ---                      ROUTINE
C ---               IL   = LINK NUMBER, FROM CALLING ROUTINE
C ---               ITIME = TIME USED TO DISCHARGE VEHICLE, FROM
C                           CALLING ROUTINE
C
C -------------------------   DESCRIPTION   -------------------------
C
C
C     THIS MODULE UPDATES THE LINK SPECIFIC DATA FOR LINK, IL, WHICH
C     VEHCILE, IV, IS DISCHARGING FROM. THE LINKAGE IS UPDATED TO
C     REMOVE THE DISCHARGING VEHICLE FROM THIS LINK.
C
C -------------------   THIS ROUTINE CALLED BY   ---------------------
C
C
C                   GOQ     - MODULE 3232.3
C
C --------------------   THIS ROUTINE CALLS   ----------------------
C
C
C                           NONE
C
C --------------   GLOSSARY OF VARIABLE NAMES   --------------------
C
C
C     BSTIME  LINK SPECIFIC ARRAY - TOTAL TRAVEL TIME ON LINK FOR BUS,
C             SEC * 10
C     BUSES   BUS SPECIFIC ARRAY - TOTAL NO. BUSES TRAVERSING THIS LINK
C     BUSRT   BUS SPECIFIC ARRAY - BUS ROUTE NUMBER
C     CLOCK   ELAPSED TIME SINCE BEGINNING OF SIMULATION, SEC
C     CNTENT  LINK SPECIFIC ARRAY - NO. OF VEHICLES CURRENTLY ON LINK
C     CODES   LINK SPECIFIC ARRAY - TURN CODE, BUS VEH. NUMBER
```

```
C       CUMVEH  LINK SPECIFIC ARRAY - NO. OF VEHICLES DISCHARGED FROM
C               LINK SINCE BEGINNING OF SIMULATION
C       CUMVL   LINK SPECIFIC ARRAY - COUNT OF LEFT TURN DSCHG VEHS.
C       CUMVR   LINK SPECIFIC ARRAY - COUNT OF RIGHT TURN DSCHG VEHS.
C       ENTRTM  VEHICLE SPECIFIC ARRAY - TIME VEH. ENTERED CURRENT LINK,
C               SEC * 10
C       FOLOWR  VEHICLE SPECIFIC ARRAY - VEHICLE BEHIND SUBJECT VEHICLE
C       IB      BUS VEHICLE NUMBER
C       IBR     BUS ROUTE NUMBER
C       IFV     VEHICLE FOLLOWING SUBJECT VEHICLE
C       ITURN   TURN CODE (0,1,2,3,4) FOR (LT,TH,RT,LD,RD) MOVEMENTS
C       ITYP    VEHICLE TYPE CODE + 1
C       JTIME   TRAVEL TIME OF VEHICLE, IV, ON LINK, IL, SEC * 10
C       K       INDEX TO LANEV AND LANEF ARRAYS
C       KTIME   TRAVEL TIME OF VEHICLE, IV, ON LINK, IL, (SECONDS)
C       LANEF   LINK SPECIFIC ARRAY - FIRST VEHICLE IN LANE
C       LANEV   LINK SPECIFIC ARRAY - LAST VEHICLE IN LANE
C       LEADER  VEHICLE SPECIFIC ARRAY - VEH. IN FRONT OF THIS VEHICLE
C       SPDLN   VEHICLE SPECIFIC ARRAY - STOP CODE
C       STOP    LINK SPECIFIC ARRAY - NUMBER OF VEHICLES FORCED TO STOP
C               AT LEAST ONCE
C       STOPL   LINK SPECIFIC ARRAY - NO. OF LEFT TURN VEH FORCED TO STOP
C       STOPR   LINK SPECIFIC ARRAY - NO. OF RIGHT TURN VEH FORCED TO STOP
C       TRNCD   CODE (0,1) IF MVEMENT-SPECIFIC MOE (ARE NOT,ARE) REQUESTED
C       TRVLL   LINK SPECIFIC ARRAY - TTL LEFT TURN VEH TRVL TIME, SEC
C       TRVLR   LINK SPECIFIC ARRAY - TTL RIGHT TURN TRVL TIME, SEC
C       TRVLTM  LINK SPECIFIC ARRAY - TOTAL TRAVEL TIME OF ALL VEHICLES
C               TRAVERSING LINK, SEC
C       TTLILK  TOTAL NUMBER OF INTERMAL LINKS IN SUBNETWORK
C       VTYPE   VEHICLE TYPE ARRAY - VEHICLE TYPE CODES
C       VTYPLD  VEHICLE TYPE ARRAY - PERSON OCCUPANCY * 100
C       W       FLAG (T,F) IF MOVEMENT-SPECIFIC MOE (ARE,ARE NOT) DESIRED
C       WL      FLAG (T,F) IF TRVLL(IL) (IS,NOT) TO BE INCREMENTED
C       WR      FLAG (T,F) IF TRVLR(IL) (IS,NOT) TO BE INCREMENTED
C       WSTOP   FLAG (T,F) IF STOP COUNTERS (ARE,ARENT) TO BE INCREMENTED
C       XBSTRV  BUS ROUTE SPECIFIC ARRAY - TOTAL TRAVEL TIME OF BUSES ON
C               ROUTE, SECS
C       XPERS   LINK SPECIFIC ARRAY - CUM. PERSON TRIPS * 100
C
C ----------------------------------------------------------------------
C
      IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
      COMMON /SIN020/ BSTIME(1)
      COMMON /SIN021/ BUSES (1)
      COMMON /SIN011/ BUSRT (1)
      COMMON /SIN104/ CLOCK
      COMMON /SIN026/ CNTENT(1)
      COMMON /SIN003/ CODES (1)
      COMMON /SIN031/ CUMVEH(1)
      COMMON /SIN137/ CUMVL (1)
      COMMON /SIN138/ CUMVR (1)
      COMMON /SIN005/ ENTRTM(1)
      COMMON /SIN006/ FOLOWR(1)
```

```
      COMMON /SIN038/ LANEF (1)
      COMMON /SIN040/ LANEV (1)
      COMMON /SIN007/ LEADER(1)
      COMMON /SIN008/ SPDLN (1)
      COMMON /SIN055/ STOP  (1)
      COMMON /SIN143/ STOPL (1)
      COMMON /SIN144/ STOPR (1)
      COMMON /GLR102/ TRNCD
      COMMON /SIN149/ TRVLL (1)
      COMMON /SIN150/ TRVLR (1)
      COMMON /SIN060/ TRVLTM(1)
      COMMON /SIN113/ TTLILK
      COMMON /SIN133/ VTYPE (1)
      COMMON /SIN134/ VTYPLD(    16)
      COMMON /GLR021/ XBSTRV(1)
      COMMON /SIN166/ XPERS (1)
C
C -----   SET MOVEMENT SPECIFIC FLAGS, WR AND WT = .T. WHENEVER MOVEMENT-
C -----   SPECIFIC OUTPUT IS REQUESTED AND TRAVEL TIME ACCUMULATOR FOR
C         THE MOVEMENT HAS NOT OVERFLOWED.

      W = TRNCD .EQ. 1
      WR = W .AND. TRVLR(IL) .GE. 0
      WL = W .AND. TRVLL(IL) .GE. 0
C
C -----   UPDATE VEHICLE CHAIN TO REFLECT DISCHARGE.
C

      IFV = FOLOWR(IV)
      K = 7 * (IL - 1) + MOD (SPDLN(IV) / 2**8, 2**3)
      IF (IFV .NE. 0) LEADER(IFV) = 0
      IF (IFV .EQ. 0) LANEV(K) = 0
      LANEF(K) = IFV
C
C -----   UPDATE LINK SPECIFIC ARRAYS TO SHOW DISCHARGING OF VEHICLE.
C -----   INCREMENT STOP COUNTER IF STOP CODE IS SET.
C

      ITURN = MOD (CODES(IV), 2**3)
      IF (W .AND. ITURN .EQ. 0) CUMVL(IL) = CUMVL(IL) + 1
      IF (W .AND. ITURN .EQ. 2) CUMVR(IL) = CUMVR(IL) + 1
      CUMVEH(IL) = CUMVEH(IL) + 1
      IF (MOD(CODES(IV)/2**6,2**8) .GT. 0) BUSES(IL) = BUSES(IL) + 1
      IF (IL .GT. TTLILK)                                    GO TO 10
      ITYP = MOD (VTYPE(IV), 2**4) + 1
      XPERS(IL) = XPERS(IL) + VTYPLD(ITYP)
      CNTENT(IL) = MAX0(CNTENT(IL) - 1, 0)
      WSTOP = MOD (SPDLN(IV) / 2**7, 2) .EQ. 1
      IF (WSTOP) STOP(IL) = STOP(IL) + 1
      WSTOP = W .AND. WSTOP
      IF (WSTOP .AND. ITURN .EQ. 0) STOPL(IL) = STOPL(IL) + 1
      IF (WSTOP .AND. ITURN .EQ. 2) STOPR(IL) = STOPR(IL) + 1
C
C -----   CALCULATE LINK TRAVEL TIME FOR THIS VEHICLE ON
C -----   THIS LINK AND ADD TO CUMULATIVE LINK TRAVEL TIME.
C
```

```
      JTIME = CLOCK * 10 - ENTRTM(IV)
      JTIME = JTIME + ITIME
      JTIME = MAX0 (JTIME, 10)
      TRVLTM(IL) = TRVLTM(IL) + (JTIME + 5) / 10
      KTIME = (JTIME + 5) / 10
      IF (WL .AND. ITURN .EQ. 0) TRVLL(IL) = TRVLL(IL) + KTIME
      IF (WR .AND. ITURN .EQ. 2) TRVLR(IL) = TRVLR(IL) + KTIME
C
C -----  TRA IF NOT A BUS. ELSE, INCREMENT BUS COUNTER AND POINTER
C -----  TO MANUVR ARRAY REFLECTING ITS DISCHARGE FROM LINK, IL.
C -----  ADD LINK TRAVEL TIME TO CUMULATIVE BUS TRAVEL TIME.
C
      IF (MOD(CODES(IV)/2**6,2**8) .EQ. 0)                    GO TO 10
      BSTIME(IL) = BSTIME(IL) + JTIME
      IB = MOD (CODES(IV) / 2**6, 2**8)
      IBR = BUSRT(IB)
      XBSTRV(IBR) = XBSTRV(IBR) + (JTIME + 5) / 10
   10 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE LINKST (IV, IL, ITIME)
C
C
C --- CODED    11-29-79 BY M. BURNS
C --- REVISED   3-26-88 BY O. SHARAF-ELDIEN TO REMOVE REDUNDANT ARRAYS
C --- REVISED   4-30-88 BY O. SHARAF-ELDIEN TO FIX REF.TO CODES ARRAY
C --- REVISED  12-13-88 BY A. KANAAN TO REMOVE SPLIT OF ENTRTM & TRVLTM
C
C --- TITLE - UPDATE LINK STATISTICS FOR DISCHARGING VEHICLE
C ---         - MODULE 3232.3.6
C
C --- FUNCTION - THIS MODULE UPDATES THE LINK STATISTICS FOR THE
C ---            LINK THE SUBJECT VEHICLE IS DISCHARGING FROM.
C --- ARGUMENTS - IV     = VEHICLE DISCHARGING FROM LINK, FROM CALLING
C ---                      ROUTINE
C ---               IL   = LINK NUMBER, FROM CALLING ROUTINE
C ---               ITIME = TIME USED TO DISCHARGE VEHICLE, FROM
C                          CALLING ROUTINE
C -------------------------  DESCRIPTION  ---------------------------
C
C     THIS MODULE UPDATES THE LINK SPECIFIC DATA FOR LINK, IL, WHICH
C     VEHCILE, IV, IS DISCHARGING FROM. THE LINKAGE IS UPDATED TO
C     REMOVE THE DISCHARGING VEHICLE FROM THIS LINK.
C
C -------------------  THIS ROUTINE CALLED BY  ----------------------
C
C
C                    GOQ    - MODULE 3232.3
C
C --------------------  THIS ROUTINE CALLS  ------------------------
C
C
C                              NONE
C
C --------------  GLOSSARY OF VARIABLE NAMES  --------------------
C
C     BSTIME  LINK SPECIFIC ARRAY - TOTAL TRAVEL TIME ON LINK FOR BUS,
C             SEC * 10
C     BUSES   BUS SPECIFIC ARRAY - TOTAL NO. BUSES TRAVERSING THIS LINK
C     BUSRT   BUS SPECIFIC ARRAY - BUS ROUTE NUMBER
C     CLOCK   ELAPSED TIME SINCE BEGINNING OF SIMULATION, SEC
C     CNTENT  LINK SPECIFIC ARRAY - NO. OF VEHICLES CURRENTLY ON LINK
C     CODES   LINK SPECIFIC ARRAY - TURN CODE, BUS VEH. NUMBER
C     CUMVEH  LINK SPECIFIC ARRAY - NO. OF VEHICLES DISCHARGED FROM
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C                LINK SINCE BEGINNING OF SIMULATION
C       CUMVL    LINK SPECIFIC ARRAY - COUNT OF LEFT TURN DSCHG VEHS.
C       CUMVR    LINK SPECIFIC ARRAY - COUNT OF RIGHT TURN DSCHG VEHS.
C       ENTRTM   VEHICLE SPECIFIC ARRAY - TIME VEH. ENTERED CURRENT LINK,
C                SEC * 10
C       FOLOWR   VEHICLE SPECIFIC ARRAY - VEHICLE BEHIND SUBJECT VEHICLE
C       IB       BUS VEHICLE NUMBER
C       IBR      BUS ROUTE NUMBER
C       IFV      VEHICLE FOLLOWING SUBJECT VEHICLE
C       ITURN    TURN CODE (0,1,2,3,4) FOR (LT,TH,RT,LD,RD) MOVEMENTS
C       ITYP     VEHICLE TYPE CODE + 1
C       JTIME    TRAVEL TIME OF VEHICLE, IV, ON LINK, IL, SEC * 10
C       K        INDEX TO LANEV AND LANEF ARRAYS
C       KTIME    TRAVEL TIME OF VEHICLE, IV, ON LINK, IL, (SECONDS)
C       LANEF    LINK SPECIFIC ARRAY - FIRST VEHICLE IN LANE
C       LANEV    LINK SPECIFIC ARRAY - LAST VEHICLE IN LANE
C       LEADER   VEHICLE SPECIFIC ARRAY - VEH. IN FRONT OF THIS VEHICLE
C       SPDLN    VEHICLE SPECIFIC ARRAY - STOP CODE
C       STOP     LINK SPECIFIC ARRAY - NUMBER OF VEHICLES FORCED TO STOP
C                AT LEAST ONCE
C       STOPL    LINK SPECIFIC ARRAY - NO. OF LEFT TURN VEH FORCED TO STOP
C       STOPR    LINK SPECIFIC ARRAY - NO. OF RIGHT TURN VEH FORCED TO STOP
C       TRNCD    CODE (0,1) IF MVEMENT-SPECIFIC MOE (ARE NOT,ARE) REQUESTED
C       TRVLL    LINK SPECIFIC ARRAY - TTL LEFT TURN VEH TRVL TIME, SEC
C       TRVLR    LINK SPECIFIC ARRAY - TTL RIGHT TURN TRVL TIME, SEC
C       TRVLTM   LINK SPECIFIC ARRAY - TOTAL TRAVEL TIME OF ALL VEHICLES
C                TRAVERSING LINK, SEC
C       TTLILK   TOTAL NUMBER OF INTERMAL LINKS IN SUBNETWORK
C       VTYPE    VEHICLE TYPE ARRAY - VEHICLE TYPE CODES
C       VTYPLD   VEHICLE TYPE ARRAY - PERSON OCCUPANCY * 100
C       W        FLAG (T,F) IF MOVEMENT-SPECIFIC MOE (ARE,ARE NOT) DESIRED
C       WL       FLAG (T,F) IF TRVLL(IL) (IS,NOT) TO BE INCREMENTED
C       WR       FLAG (T,F) IF TRVLR(IL) (IS,NOT) TO BE INCREMENTED
C       WSTOP    FLAG (T,F) IF STOP COUNTERS (ARE,ARENT) TO BE INCREMENTED
C       XBSTRV   BUS ROUTE SPECIFIC ARRAY - TOTAL TRAVEL TIME OF BUSES ON
C                ROUTE, SECS
C       XPERS    LINK SPECIFIC ARRAY - CUM. PERSON TRIPS * 100
C
C ------------------------------------------------------------------------
C
        IMPLICIT INTEGER (A-Q, S-V, X), REAL (R, Z), LOGICAL (W, Y)
C
        COMMON /SIN020/ BSTIME(1)
        COMMON /SIN021/ BUSES (1)
        COMMON /SIN011/ BUSRT (1)
        COMMON /SIN104/ CLOCK
        COMMON /SIN026/ CNTENT(1)
        COMMON /SIN003/ CODES (1)
        COMMON /SIN031/ CUMVEH(1)
        COMMON /SIN137/ CUMVL (1)
        COMMON /SIN138/ CUMVR (1)
        COMMON /SIN005/ ENTRTM(1)
        COMMON /SIN006/ FOLOWR(1)
        COMMON /SIN038/ LANEF (1)
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```
      COMMON /SIN040/ LANEV (1)
      COMMON /SIN007/ LEADER(1)
      COMMON /SIN008/ SPDLN (1)
      COMMON /SIN055/ STOP  (1)
      COMMON /SIN143/ STOPL (1)
      COMMON /SIN144/ STOPR (1)
      COMMON /GLR102/ TRNCD
      COMMON /SIN149/ TRVLL (1)
      COMMON /SIN150/ TRVLR (1)
      COMMON /SIN060/ TRVLTM(1)
      COMMON /SIN113/ TTLILK
      COMMON /SIN133/ VTYPE (1)
      COMMON /SIN134/ VTYPLD(   16)
      COMMON /GLR021/ XBSTRV(1)
      COMMON /SIN166/ XPERS (1)
C
C -----  SET MOVEMENT SPECIFIC FLAGS, WR AND WT = .T. WHENEVER MOVEMENT-
C -----  SPECIFIC OUTPUT IS REQUESTED AND TRAVEL TIME ACCUMULATOR FOR
C -----  THE MOVEMENT HAS NOT OVERFLOWED.
C
      W = TRNCD .EQ. 1
      WR = W .AND. TRVLR(IL) .GE. 0
      WL = W .AND. TRVLL(IL) .GE. 0
C
C -----  UPDATE VEHICLE CHAIN TO REFLECT DISCHARGE.
C
      IFV = FOLOWR(IV)
      K = 7 * (IL - 1) + MOD (SPDLN(IV) / 2**8, 2**3)
      IF (IFV .NE. 0) LEADER(IFV) = 0
      IF (IFV .EQ. 0) LANEV(K) = 0
      LANEF(K) = IFV
C
C -----  UPDATE LINK SPECIFIC ARRAYS TO SHOW DISCHARGING OF VEHICLE.
C -----  INCREMENT STOP COUNTER IF STOP CODE IS SET.
C
      ITURN = MOD (CODES(IV), 2**3)
      IF (W .AND. ITURN .EQ. 0) CUMVL(IL) = CUMVL(IL) + 1
      IF (W .AND. ITURN .EQ. 2) CUMVR(IL) = CUMVR(IL) + 1
      CUMVEH(IL) = CUMVEH(IL) + 1
      IF (MOD(CODES(IV)/2**6,2**8) .GT. 0) BUSES(IL) = BUSES(IL) + 1
      IF (IL .GT. TTLILK)                                    GO TO 10
      ITYP = MOD (VTYPE(IV), 2**4) + 1
      XPERS(IL) = XPERS(IL) + VTYPLD(ITYP)
      CNTENT(IL) = MAX0(CNTENT(IL) - 1, 0)
      WSTOP = MOD (SPDLN(IV) / 2**7, 2) .EQ. 1
      IF (WSTOP) STOP(IL) = STOP(IL) + 1
      WSTOP = W .AND. WSTOP
      IF (WSTOP .AND. ITURN .EQ. 0) STOPL(IL) = STOPL(IL) + 1
      IF (WSTOP .AND. ITURN .EQ. 2) STOPR(IL) = STOPR(IL) + 1
C
C -----  CALCULATE LINK TRAVEL TIME FOR THIS VEHICLE ON
C -----  THIS LINK AND ADD TO CUMULATIVE LINK TRAVEL TIME.
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```
C -----  TRA IF THE TRAVEL TIME OF AUTO IS NOT CONSIDERED.
      IF (ITYP .EQ. 1)                                          GO TO 10
C
C -----  TRA IF THE TRAVEL TIME OF CARPOOL IS NOT CONSIDERED.
C
      IF (ITYP .EQ. 3)                                          GO TO 10
C
C -----  TRA IF THE TRAVEL TIME OF BUS IS NOT CONSIDERED.
      IF (ITYP .EQ. 4)                                          GO TO 10
C
      JTIME = CLOCK * 10 - ENTRTM(IV)
      JTIME = JTIME + ITIME
      JTIME = MAX0 (JTIME, 10)
      TRVLTM(IL) = TRVLTM(IL) + (JTIME + 5) / 10
C
C -----  TOTAL VEHICLES CONSIDERED IN LINK TRAVEL TIME CALCULATION
C
      NOVEH (IL) = NOVEH (IL) + 1
C
      KTIME = (JTIME + 5) / 10
      IF (WL .AND. ITURN .EQ. 0) TRVLL(IL) = TRVLL(IL) + KTIME
      IF (WR .AND. ITURN .EQ. 2) TRVLR(IL) = TRVLR(IL) + KTIME
C
C -----  TRA IF NOT A BUS. ELSE, INCREMENT BUS COUNTER AND POINTER
C -----  TO MANUVR ARRAY REFLECTING ITS DISCHARGE FROM LINK, IL.
C -----  ADD LINK TRAVEL TIME TO CUMULATIVE BUS TRAVEL TIME.
C
      IF (MOD(CODES(IV)/2**6,2**8) .EQ. 0)                      GO TO 10
      BSTIME(IL) = BSTIME(IL) + JTIME
      IB = MOD (CODES(IV) / 2**6, 2**8)
      IBR = BUSRT(IB)
      XBSTRV(IBR) = XBSTRV(IBR) + (JTIME + 5) / 10
   10 CONTINUE
C
      RETURN
      END
```