Alternate Path Analysis Algorithm for Urban Freeway Corridor Evaluation

WILEY D. CUNAGIN AND RAMEY O. ROGNESS

Quick-response procedures and programmable calculator routines have been of increasing interest in transportation planning. As part of a continuing Highway Planning and Research Program study, the PASSER IV system of quick-response methodologies is being developed for analyzing urban freeway corridor alternatives. This will provide a practical and user-oriented tool to evaluate several classes of transportation system management alternatives. An algorithm is presented for estimating the levels of traffic flow on individual parallel facilities in an urban freeway corridor, based on equilibrium traffic assignments. A quick-response routine for the algorithm has been developed for use with a programmable calculator. The level of detail for the routine is ultramacroscopic and deterministic. The routine was designed to be modular to permit additional scenarios, extensions, and modifications to be easily appended. The routine as described is undergoing continuing revision and evolution.

Increased traffic demand and traffic congestion along freeway corridors in major Texas cities are making the effective management and use of existing facilities, as well as the implementation of minor geometric modifications for improving traffic flow, important functions of the various agencies involved. Existing analytical methods and related computer programs offer proven performance capabilities to address these problems, but most are seriously deficient in addressing analyses that require quick response:

1. They do not permit quick and simple analyses of problem areas to allow evaluation of several alternative improvements in a cost-effective manner,
2. They do not fully treat continuous frontage roads that are almost unique to Texas, and
3. They require a large amount of field data and computational effort to conduct the evaluation.

As a result, the use of quick-response procedures and programmable calculator routines has become of increasing interest and implementation.

Practical and user-oriented methods have been proposed. The Signal Operations Analysis Package (SOAP) programmable calculator routines can be used in the design, evaluation, and analysis of signal operation (1). The routines incorporate several computational techniques for analysis of a single approach to an intersection. Routines are available for calculation, analysis, and evaluation of signal settings and measures of effectiveness. Other procedures have been developed such as evaluation routines based on the PASSER II computer program (2) and critical movement analysis procedures (3).

Quick-response routines have been developed for travel-estimation procedures (4,5) and simplified methods have been developed for transportation analysis (6-8). Analysis techniques, including air quality evaluation (9) and energy impacts on travel (10), have been proposed. The development of simplified methods implementable on a programmable calculator has great interest.

The PASSER IV system of quick-response methodologies is now being developed for analyzing urban freeway corridor alternatives to provide transportation system analysts with useful tools to evaluate several classes of transportation systems management (TSM) feasible alternatives. This paper presents, as a part of the PASSER IV system, an algorithm for estimating the levels of traffic flow on individual parallel facilities in an urban freeway corridor, based on equilibrium traffic assignment. The algorithm can be applied to multiple parallel facilities quickly and efficiently. A quick-response routine for the algorithm has been developed for use with a programmable calculator.

SITUATION

The urban freeway corridors are the existing transportation backbone of every major city in Texas. The potential operational capacity of the freeway frontage roads and adjacent parallel arterial streets are major factors in the urban area. In order to manage and improve these critical transportation facilities, several situations and problems must be addressed.

Several of these problems have already been identified, regarding the effective transportation analysis of urban freeway corridor traffic management strategies and the application of TSM improvements to Texas freeways and parallel facilities. The analysis of these available alternative strategies can be time-consuming, costly, and data intensive.

Simplified methods (quick-response techniques) were needed to permit the transportation engineer or planner to expeditiously evaluate a wide range of TSM-based alternatives by using a minimum of data complexity and effort. As part of the Texas Highway Planning and Research Program (HPR) continuing study on development of freeway corridor evaluation system, PASSER IV, a quick-response analysis methodology for expedient evaluation of several classes of TSM-based feasibility studies from an operational viewpoint has been derived. The PASSER IV concept is to permit the decisionmaker the option of efficiently obtaining credible performance measures for various proposed scenarios. The algorithm presented here is based on equilibrium traffic assignment. It estimates the traffic flow levels (and measures of effectiveness) on parallel facilities in an urban freeway corridor.

The algorithm assumes that

1. Travelers behave in a manner that minimizes their travel time,
2. Travel time versus volume/capacity (v/c) ratio curves that describe the parallel paths may be determined, and
3. Piecewise linear approximations of these curves may be computed.

The algorithm is limited by the accuracy of origin-destination estimates, corridor volume estimates, and the travel time versus v/c curves.

The level of detail for the calculator procedure is ultramacroscopic and deterministic in design. Simplicity and user-oriented operation were emphasized. The routine was designed to be modular in design to permit additional TSM alternative scenarios to be addressed by subsequent additions and subroutines.

Algorithm Background

The algorithmic approach to the three alternate-path traffic-assignment problems is based on Wardrop's

Figure 1. Alternate urban freeway corridor paths.

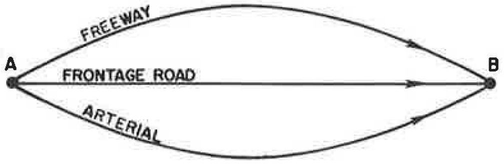
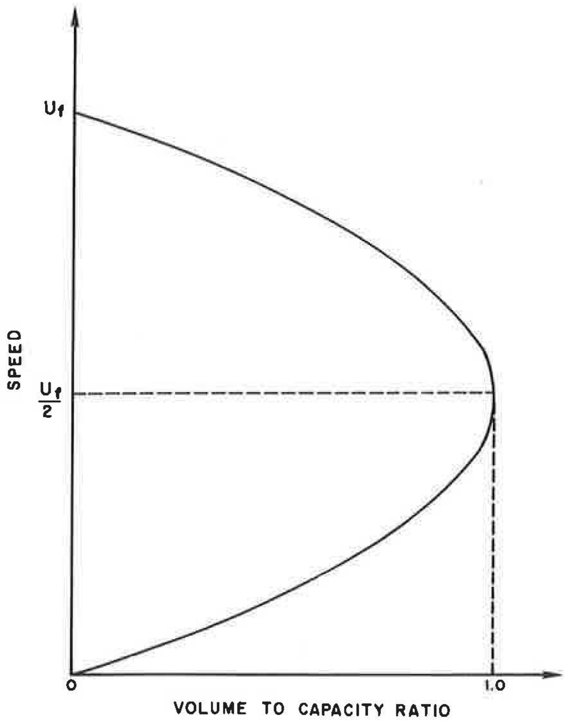


Figure 2. Urban freeway speed versus v/c.



first principle (user optimization) of equilibrium flows (11). The original corridor scenario for the three alternate paths was freeway, frontage road, and a parallel arterial street. The algorithm uses travel time relations for allocating the traffic to the three paths.

The freeway travel time is based on the relation between average freeway speed and v/c ratio as developed by Texas Transportation Institute (TTI). The frontage road travel time and the arterial street travel time is based on speed, volume, capacity, and signal density. These relations are developed as a piecewise linear function of travel time to v/c ratio for each alternate path.

The procedure allocates corridor travel demand to the facilities based on travel times. As these volumes are added to each facility, the travel time on the facility is increased. The procedure iteratively determines the allocation of the demand to provide equal travel times for all facilities by using piecewise linear representations of the travel time curves.

Algorithm Development

Traffic flows on three parallel paths are illustrated in Figure 1. Travelers wish to go from point A to B. Point A might be a suburban community and point B could be a central business district. These travelers may choose among paths 1, 2, and 3 for their trip. Each path has its own distances, speed, and capacity attributes. For a typical urban freeway corridor in Texas, path 1 is the freeway main lanes, path 2 is the frontage road, and path 3 is a parallel arterial street.

The solution approach presented here for allocating traffic among these competing paths is based on Wardrop's first principle of equilibrium flows in a transportation network (11). This principle states that each individual traveler will choose a path that gives him or her minimum travel time under the perceived operating condition. This assumption is known as user optimization and is in general agreement with observed behavior. The driver perceives (or anticipates) the operating conditions on each path and then chooses the path that he or she thinks will minimize travel time from point A to point B.

Traditional nonequilibrium traffic assignment techniques have not addressed allocation of traffic explicitly so that this condition is met. For example, in an all-or-nothing assignment, the technique finds the minimum travel time between two zones under specific conditions. All traffic is then assigned to the path that has that minimum time. The presence of this traffic causes the resulting travel time on that path to become much greater than the calculated value and, if minimum travel times were again computed, another path between the two zones would probably be chosen. This diversion of traffic is addressed in capacity-restraint assignment, yet travelers may still not be on a path that gives them minimum travel time. A number of methods are now used to redistribute assigned traffic more realistically in a corridor following a traffic assignment for the urban area. Many of these methods, however, require substantial effort and time to use and are not amenable to quick and simple analysis to evaluate several alternatives for TSM strategies in the corridor.

The algorithm presented in this paper explicitly treats the perceptions of path choice of the individual traveler and is sensitive to TSM actions that may be applied in the corridor.

TRAVEL TIME FUNCTIONS

In modeling the path choices of individual drivers, it is first necessary to model the variation of travel time on a path with increasing traffic on that path.

For a typical urban freeway corridor in Texas, as depicted in Figure 1, path 1 is the freeway main lanes, path 2 is the frontage road, and path 3 is a parallel arterial street. In order to compare travel times along each of these paths to satisfy the equal travel time condition (user optimization), travel times along each path must be determined as a function of the volume and capacity on that path. For freeways, speed has been related to v/c ratio by the relation shown in Figure 2 (12). The quantity u_f is the free speed for the facility.

Creighton, Hamburg, Inc., in work for the Federal Highway Administration (FHWA), propose modification of the relation shown in Figure 2 to that shown in Figure 3 to model reduction in speed due to congestion for the FHWA micro assignment model (13). For v/c values in the range (0, 0.8), this curve is the same as the Highway Capacity Manual curves shown in Figure 2 (12). For values of v/c greater than 0.8, the curve drops linearly to a value of 0 when v/c = 1.0, as shown in Figure 3.

The monotonically decreasing form of the function in Figure 3 agrees with the observed condition that average speed decreases as the v/c ratio increases. One logical difficulty, however, is that the speed in Figure 3 decreases to zero at a volume equal to

Figure 3. FHWA freeway speed versus v/c for freeway arterial vehicle mile per hour splitter.

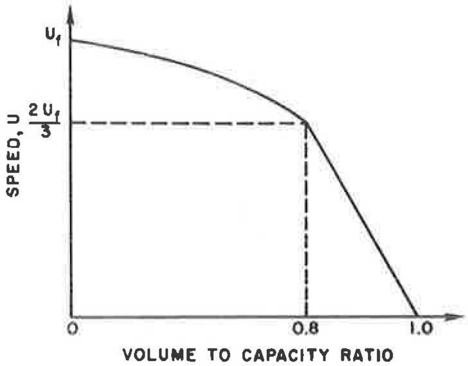


Figure 4. TTI urban freeway speed versus v/c.

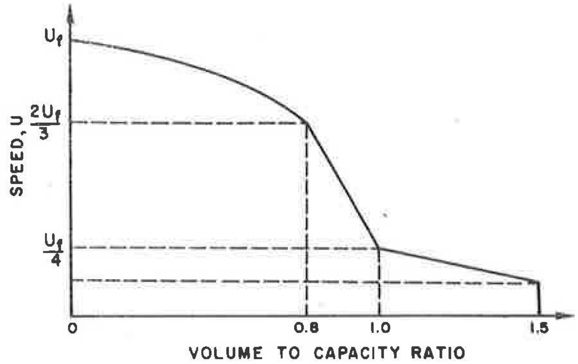


Figure 5. TTI urban freeway travel time versus v/c.

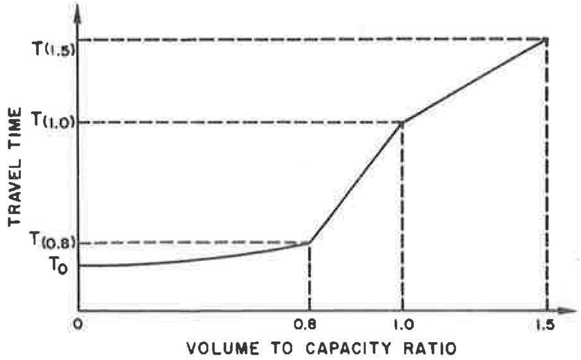
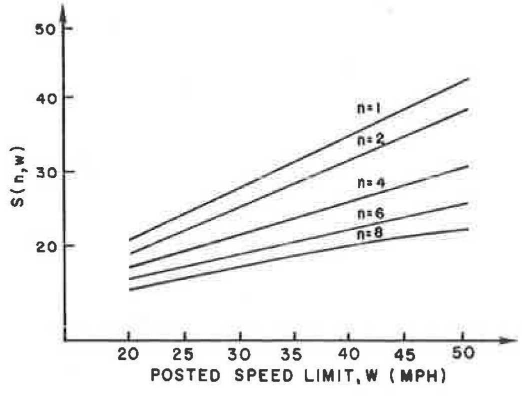


Figure 6. Free flow versus posted speed w and signal density n.



capacity, especially since Figure 2 shows a speed of $u_f/2$ when volume is equal to capacity.

For the freeway speed model used in this algorithm, speed at capacity was set at $u_f/4$ to approximate average actual speed. In addition, because volumes greater than estimated capacity are sometimes observed (e.g., when level of service C volumes and capacities are used), the freeway speed curve was extended in this research to a speed value of 10 mph when v/c = 1.5. The freeway speed curve developed by TTI is shown in Figure 4.

The relation shown in Figure 4 is piecewise linear for v/c > 0.8, so that mathematically the relation can be expressed as follows:

$$S_{fwy} = \begin{cases} 0.5\ S_0 + (S_0^2 - 2v)^{1/2} & v/c \leqslant 0.8 \\ S_1 + [(S_2 - S_1)/0.2](v/c) - 0.8 & 0.8 < v/c < 1.0 \\ S_2 + [(10 - S_2)/0.5](v/c) - 1.0 & 1.0 < v/c < 1.5 \\ 10 \quad v/c > 1.5 \end{cases} \tag{1}$$

where

S_{fwy} = speed on freeway at volume v per lane (mph),
v = freeway volume per lane (vehicles/h),
c = capacity per lane (vehicles/h),
S_0 = free flow speed on freeway (mph),
S_1 = speed on freeway when v/c = 0.8 (mph), and
S_2 = speed on freeway when v/c = 1.0 (mph).

This model provides a determinable relation between speed and volume for the freeway situation.

From the speed versus v/c relation shown in Figure 4, a travel time relation may be constructed by using

$$T(v/c) = \text{Travel time} = \text{Distance/Speed} \tag{2}$$

for each continuous interval. The resulting travel time relation is shown in Figure 5. This relation shows that, as the volume (or v/c) on the freeway increases, the travel time increases. This developed relation agrees with expected results. The piecewise linear nature of the travel time curves makes possible the evaluation of successive critical points on the curves for parallel facilities rather than the solution of a set of mathematical equations. Although modification of the FHWA's freeway-surface arterial VMT splitter speed versus v/c curves were used here to derive travel time curves, other curves, such as those of Davidson (<u>14</u>), or FHWA (<u>15</u>), may be used as long as they are modified to a piecewise linear form.

For signalized roadways, the relation between speed and capacity is complicated by the presence of the signals along the roadway, which provide a further component of delay. The effect of this delay can be correlated to the signal density and signal timings. The relation developed is a modified version of that in FHWA's micro assignment model (<u>13</u>). This relation provides for travel time to be dependent on volume and signal density. For signalized roadways the equations are

$$S = \begin{cases} S_0(n,w) + (v/c)f(n) & v/c < 0.8 \\ S_1 + [(S_2 - S_1)/0.2]\,(v/c) - 0.8 & 0.8 < v/c \leqslant 1.0 \\ S_2 + [(5 - S_2)/0.5]\,(v/c) - 1.0 & 1.0 < v/c \leqslant 1.5 \\ 5 \quad v/c > 1.5 \end{cases} \tag{3}$$

where

S = speed on signalized roadway at volume v per lane (mph),
v = roadway volume per lane (vehicles/h),
c = capacity per lane (vehicles/h),

n = signal density (signals/mile),
w = posted speed (mph),
$f(n)$ = speed reduction with unit increase in v/c,
$S_0(n,w)$ = free-flow speed for signalized roadway with signal density n and posted speed w,
S_1 = speed when v/c = 0.8,
S_2 = speed when v/c = 1.0, and
$S_0(n,w) = 3600/(3600/w) + 12.5n$.

$$f(n) = -0.0672n^3 + 0.781n^2 - 3.2232n \qquad n < 5.5 \tag{4a}$$

$$f(n) = 0.138n - 6.028 \qquad n \geqslant 5.5 \tag{4b}$$

A family of curves that relate free-flow speed to posted speed and signal density is shown in Figure 6. A family of curves that show average speed for varying values of signal density (n), posted speed, and values of v/c is illustrated in Figure 7.

Travel time curves may be constructed by using the speed curves shown in Figure 7 and Equation 2. The travel time curves developed are illustrated in Figure 8.

Figure 8 shows that, although the effect of signal density is somewhat masked, the travel time relation behaves as would be expected.

ALGORITHM

Once the travel time functions have been defined for each of the three paths in Figure 1, the problem remains to determine how the travel demand from A to B will be distributed among paths 1, 2, and 3. Obviously, if all that is considered is the free-flow travel time, all of the drivers will choose path 1 (the freeway path) as in an all-or-nothing assignment. But, the actual travel time increases as each motorist enters the facility, so that eventually the path 1 travel time for an additional motorist is increased such that, if that motorist enters path 1, then path 2 or path 3 will have lower free-flow travel times than the travel time on path 1 under the existing conditions. Since this is contrary to Wardrop's first principle, the motorist selects the minimum travel time path.

The travel time curve for each path, due to its piecewise linear nature, contains a series of inflection points (discontinuities). The successive evaluation of these critical points is the basis for this algorithm. The free-flow travel time of each path (the intercept with the travel time axis) is considered to be a critical point. The remaining critical points (discontinuities) on the curves project onto the travel time axis to define the intervals of travel time for which the slopes of all of the travel time curves are simultaneously constant. The total assigned volume is computed at the upper limit of each of these travel time intervals. When this assigned value exceeds the total demand, the volumes on each path are backed off simultaneously, proportional to the slopes of the piecewise linear travel time curves on that interval.

Figure 7. FHWA signalized roadway speed versus v/c.

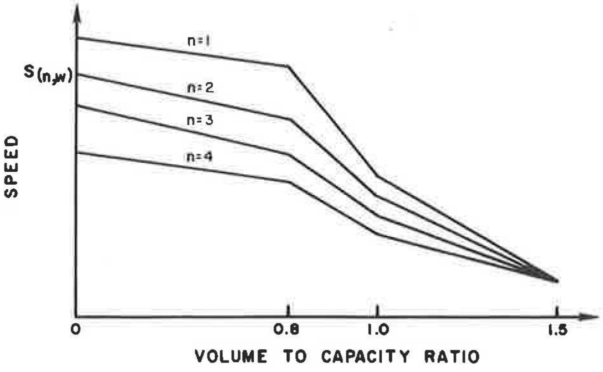
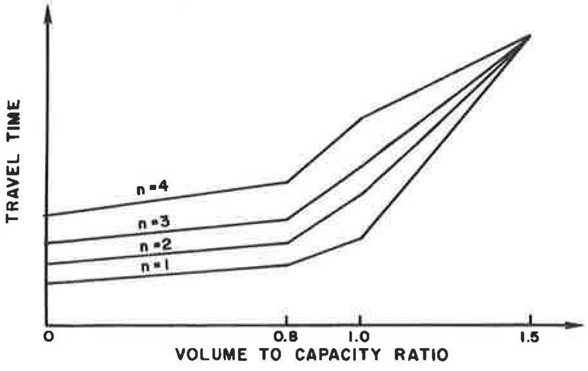


Figure 8. TTI signalized roadway travel time versus v/c.



CALCULATOR ROUTINE FEATURES AND CAPABILITY

The routine has undergone several revisions in its development. The addition of enhancements and modifications to the original routine is an evolutionary process. Improvements in run time, program structure, and number of steps and memories have been accomplished to increase the efficiency and applicability of the procedure.

Original Procedure

The original procedure was developed for the algorithm just described to consider a typical urban freeway corridor in Texas. The three parallel paths available were established as the freeway main lanes, frontage roads, and a parallel arterial street. The input data are given in the table below.

Input Data	Freeway	Frontage Road	Arterial
No. of lane	X	X	X
Distance	X	X	X
Speed	X	X	X
Capacity	X	X	X
Signal density		X	X
Total demand			

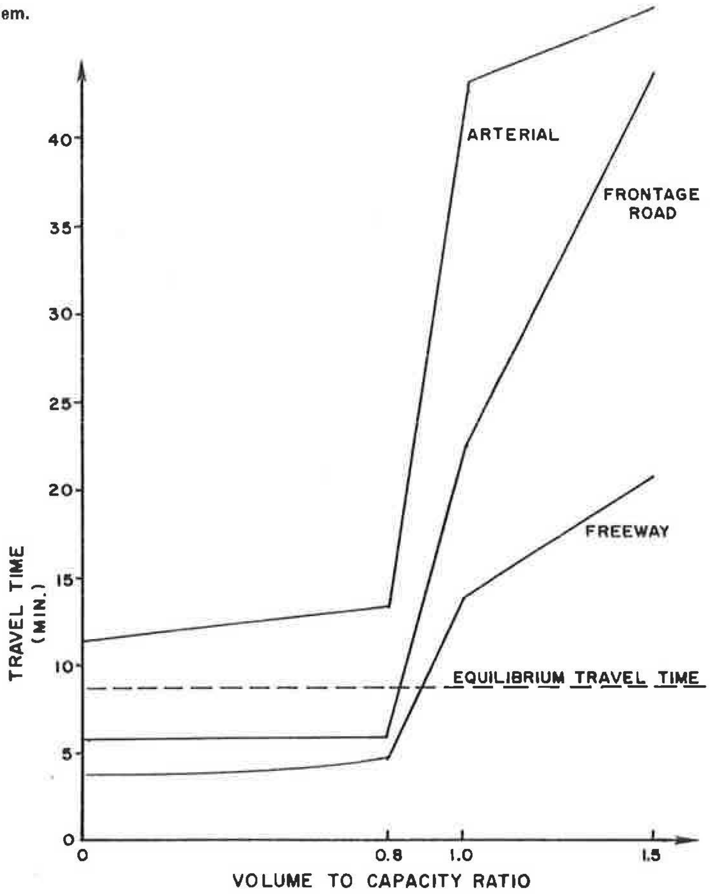
The input data along with embedded data in the routine provide the characteristics of the facility and demand volume. The piecewise linear segment of each travel time curve is established at v/c of 0, 0.8, 1.0, and 1.5. A representative series of travel time curves are illustrated in Figure 9. The free-flow speed is the only variable (and number of signals for nonfreeway paths) that the user can input to describe the curve. The corresponding speeds for v/c of 0.8, 1.0, and 1.5 are fixed internally. The output for the original routine are system travel time (at equilibrium), traffic volumes on each path, and v/c for each path.

The original routine satisfied the objectives of the study. During its development, certain structural and design limitations were recognized. Also, several enhancements, modifications, and variables input were recognized as desirable for incorporation in the procedure.

Procedure Extensions

The original procedure was revised. The revised

Figure 9. Travel time functions for example problem.



procedure still retained the basic three alternate path algorithms. It used fewer program steps, less input cards, and fewer memory locations. The use of indirect addressing and skip on zero routines improved computational efficiency.

One improvement in the program structure is that any number of freeways, frontage roads, or arterial streets may be used to a maximum of three total paths. Input of these path data may be in any order.

To provide greater flexibility and utility of the procedure, three variables were added--quality of progression factor, variable overcapacity limit, and variable overcapacity speed. The quality of progression factor (range of 0-1) provides a means to model the progressive quality along an arterial street or the frontage road to match existing or future operational characteristics more closely. The default value is one.

The overcapacity limit and the overcapacity speed are related. The overcapacity limit is the v/c for the final reference point on the travel time curve. The default value is 1.5. The input is 0 for the default value or a value greater than 1.0. The overcapacity speed is the corresponding speed at the overcapacity limit used. The default value is 10 mph for freeways and 5 mph for signalized facilities. These three new variable inputs provide great flexibility for the user to model the problem to be analyzed. This flexibility provides increased ability to model real-world conditions in a corridor. However, this flexibility requires that additional user instructions be provided to aid in proper selection of the variable values.

To increase the capability of the procedure to better model greater complexity and provide additional path alternative analysis, two features were added to the program. The first addition is the ability to handle more than one speed along a path. This corresponds to be the ability to analyze different travel times on segments of a path. An example would be different posted speed limits along an arterial street. The second feature is the capability to analyze more than three alternate paths or a combination of parallel streets. This feature is directed toward providing the capability of analyzing freeway main lanes, frontage roads, and three parallel arterial streets as alternate paths. The multiple alternate paths for the facility type are preprocessed to provide a composite representation of the facilities before input to the main algorithm. The algorithm output for those facilities is then fed into a postprocessor to provide the estimated traffic assignment to those paths. Extensions to multiple paths or three representations of corridor facilities could be analyzed similarly by the procedure.

SUMMARY

The application of programmable calculator routines and simplified methodologies to analyze TSM alternative improvements in a freeway corridor is shown. The ability of the calculator routine to analyze more than the basic three-path situation is indicated for corridor traffic assignment.

The routine is part of a continuing HPR research study. The procedure is undergoing continuing revision and evolution to increase the efficiency and widen the applicability of the procedure to corridor evaluations.

ACKNOWLEDGMENT

This paper presents the quick-response technique portion of a continuing Texas HPR study, Development of Freeway Corridor Evaluation System--PASSER IV, sponsored by the Texas State Department of Highways and Public Transportation and FHWA and conducted by TTI. Carroll J. Messer is acknowledged for his assistance in the development of the basic algorithm. Herman E. Haenel, Blair G. Marsden, and Pete Osburn of the Texas State Department of Highways and Public Transportation are acknowledged for their guidance and assistance in all phases of the study. The contents of this paper reflect our views, and we are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas State Department of Highways and Public Transportation or FHWA. This report does not constitute a standard, specification, or regulation. As part of a continuing HPR study, this paper has not been subject to a final review process or acceptance by the sponsor.

REFERENCES

1. Signal Operations Analysis Package, Volume 4--Programmable Calculator Routines. Federal Highway Administration, Implementation Package 79-9, 1979.
2. Signal Timing Optimization to Maximize Traffic Flow, A 3-Day Workshop. Texas Transportation Institute, Texas A&M Univ., College Station, 1981.
3. Critical Movement Analysis. Univ. of Florida, Gainesville, Sept. 1980.
4. A.B. Sosslau, A.B. Hassam, M.M. Carter, and G.V. Wickstrom. Travel Estimation Procedures for Quick Response to Urban Policy Issues. NCHRP, Rept. 186, 1978, 70 pp.
5. A.B. Sosslau, A.B. Hassam, M.M. Carter, and G.V. Wickstrom. Quick-Response Urban Travel Estimation Techniques and Transferable Parameters, User's Guide. NCHRP, Rept. 187, 1978, 229 pp.
6. I. Salomon. Application of Simplified Analysis Methods: A Case Study of Boston's Southeast Expressway Carpool and Bus Lane. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, 1979.
7. K.H. Karash, A. Baver, and M.L. Manheim. Workshops in Simplified Methods, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Aug. 1979.
8. M.L. Manheim, P. Furth, and I. Salomon. Examples of Transportation Analysis Using Pocket Calculators. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, 1979.
9. K.K. Karash and E. Hollingshead. A Case Study of the Use of Pocket Calculator and Workshop Methods for Analyzing Air Quality Related Transportation Control Strategies. Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Working Paper 80-5, 1980.
10. T.J. Tardiff and J.L. Benham. Quick-Response Methodology for Analyzing the Travel Impacts of Fuel-Supply Limitations. Paper presented at 60th Annual Meeting, TRB, 1981.

Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting

---

Consideration of Alternative Access, Egress, and Line-Haul Travel Choices Within UTPS Framework

ASHOK KUMAR AND YEHUDA GUR

In many large metropolitan areas more than one line-haul transit service is often available in some travel corridors. Examples include express bus and rail rapid transit, commuter rail and rail rapid transit, private suburban bus lines and competing service provided by regional transit operator. This is especially true as one moves away from the core area and corridors become wider. Coupled with the choice of line-haul modes are several choices of accessing these modes such as walk, feeder bus, park-and-ride, and kiss-and-ride. This paper addresses these issues and describes a systematic procedure for analyzing such mode choices. It is argued that straightforward use of urban transportation planning system (UTPS) programs prevents meaningful analysis of important policy issues due to their all-or-nothing assignment principle, when real access-egress and line-haul choices have to be considered.

Much progress has been made in the last two decades in quantitative aspects of long-range planning of highway and mass transportation facilities. The forecasting of travel demand along highway links and transit lines that comprise the transportation network of a metropolitan area has been greatly facilitated by the availability of two software packages, PLANPAC (1) and Urban Transportation Planning System (UTPS) (2), developed by the U.S. Department of Transportation. Several publications (3,4) describe the sequence of trip generation, trip distribution, mode choice, and route-assignment models used to simulate the traffic flow by using these packages. This paper addresses the problems associated with application of computer programs UNET, UPATH, UPSUM, UMODEL, and ULOAD (2) if alternative access, egress, and line-haul choices are available between an origin-destination (O-D) pair. Briefly, UNET is used to prepare the computerized description of a transit system that serves the study area. UPATH finds the minimum impedance (travel time, travel cost, or both) path between any O-D pair in the system and zone-to-zone fare matrix. UPSUM computes the travel time along minimum impedance path and can store the time spent walking, waiting, transferring, and in-motion along various travel modes (walk, automobile, bus, or rail) used between an O-D pair. UMODEL computes the share of transit trips (mode split) given the transit level-of-service data prepared by UPATH and UPSUM, highway level-of-service data prepared by either PLANPAC programs BUILDHR (1) and BUILDVN (1), or UTPS programs HR (2) and UROAD (2). It computes total person trips between an O-D pair by using a