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16. Abstract  The report describes and presents a user's guide for the PASSER IV quick response procedures for analyzing urban freeway corridor alternatives. Estimates of traffic flow levels on individual parallel facilities in an urban freeway corridor are obtained, based on equilibrium traffic assignments. System travel time also is computed. The algorithm includes special features to handle route changing and nonhomogeneous routes. A FORTRAN computer program based on the procedures is provided.			
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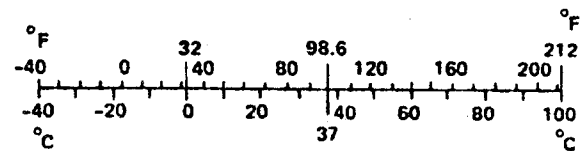
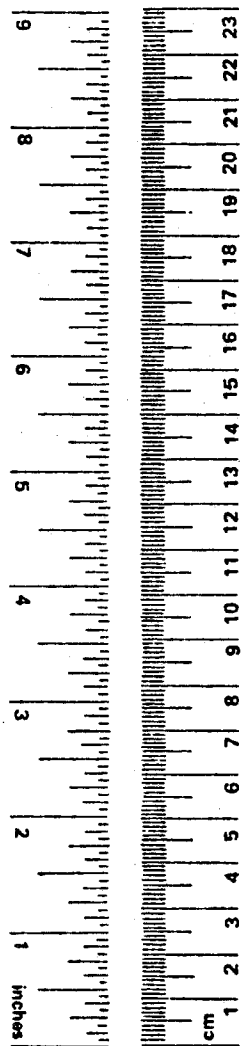
## METRIC CONVERSION FACTORS

### Approximate Conversions to Metric Measures

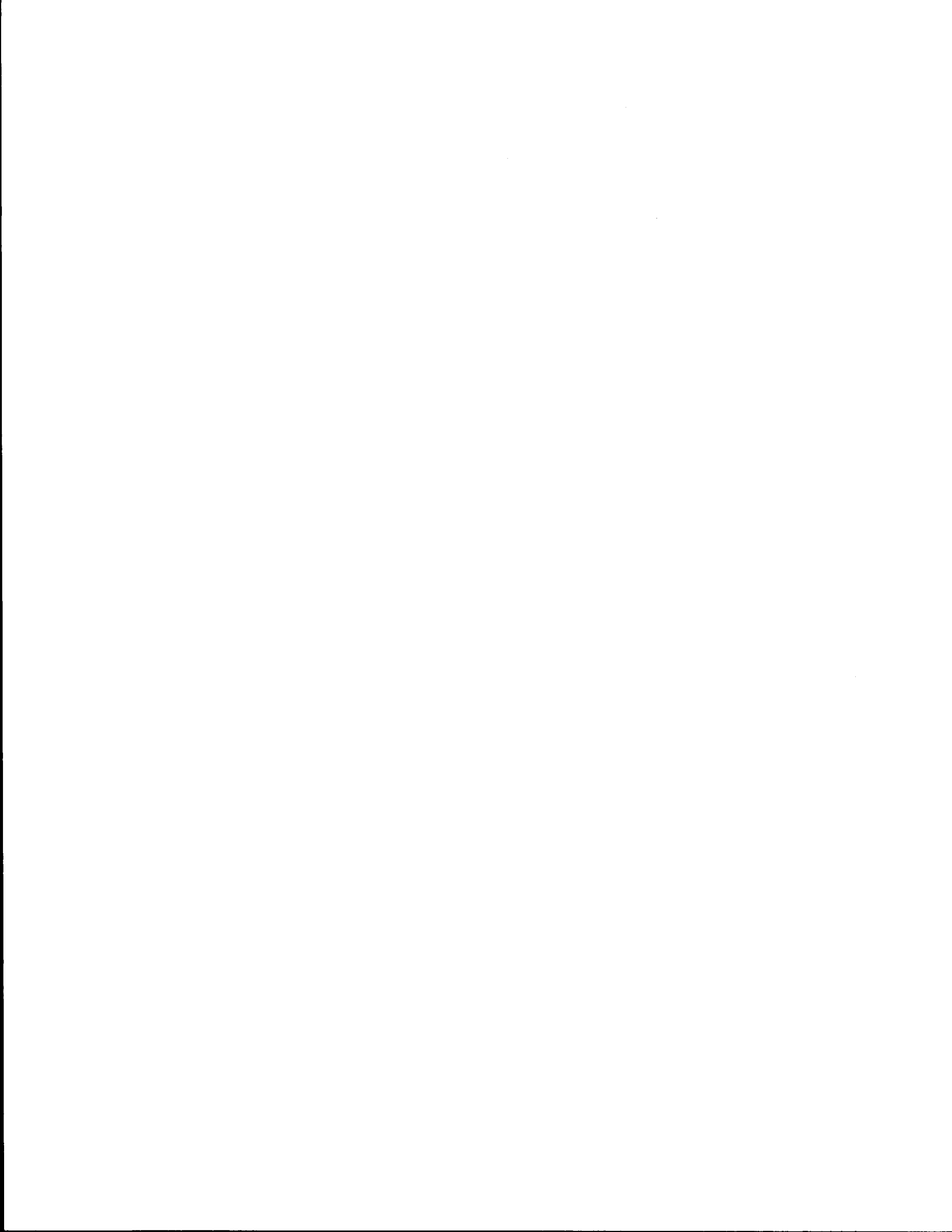
Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

### Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



\* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10:286.



**PASSER IV QUICK RESPONSE PROCEDURES**

by

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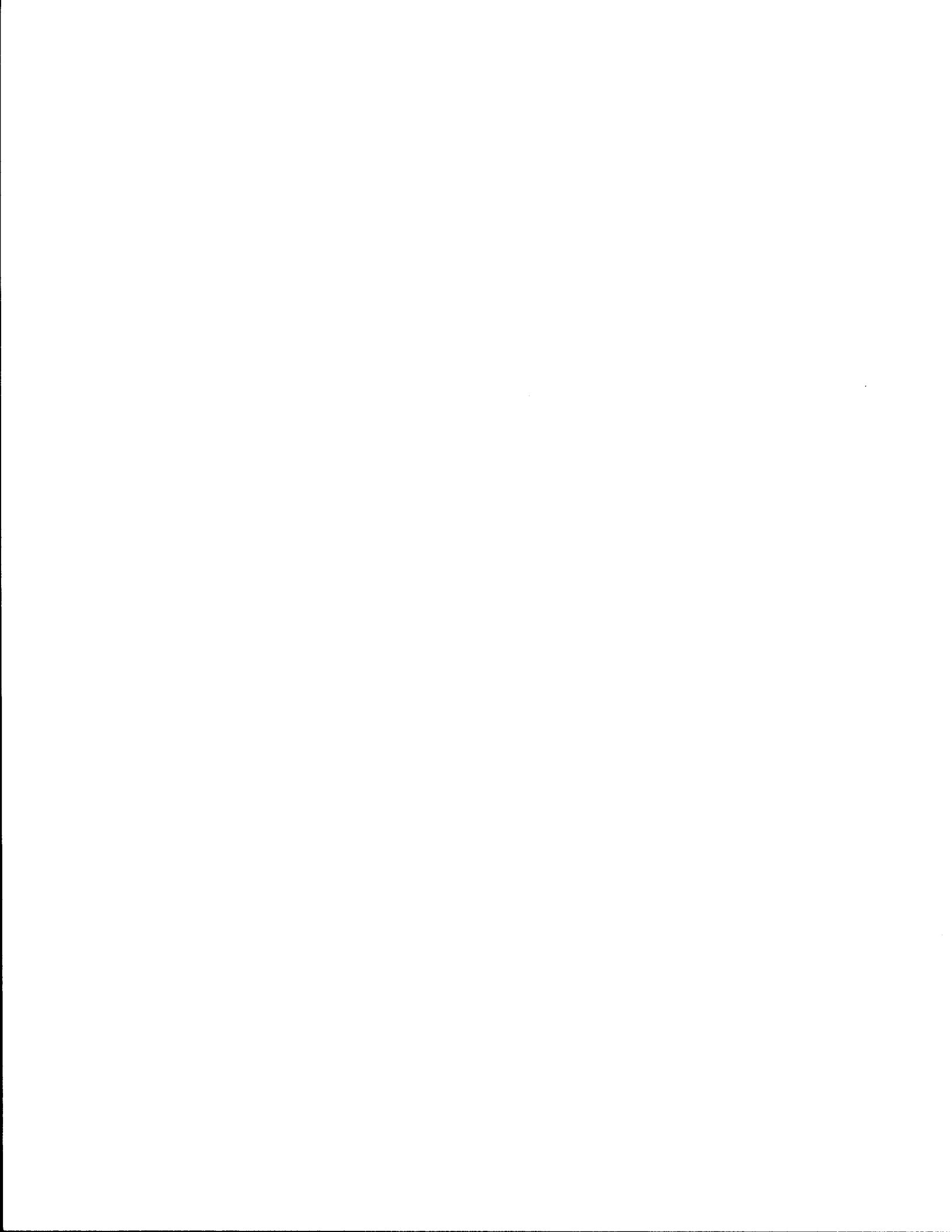
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B. G. Marsden

C. M. Mao

A. B. Osburn

E. A. Koeppe

The numerous attendees of the PASSER IV workshop sessions in Dallas/Fort Worth, San Antonio, and Houston contributed important ideas and evaluations which were used in the final formulation of the PASSER IV Quick Response Procedures.

## ABSTRACT

This report describes and presents a user's guide for the PASSER IV quick response procedures for analyzing urban freeway corridor alternatives. Estimates of traffic flow levels on individual parallel facilities in an urban freeway corridor are obtained, based on equilibrium traffic assignments. System travel time also is computed. The algorithm includes special features to handle route changing and nonhomogeneous routes. A FORTRAN computer program based on the procedures is provided.

KEY WORDS: Traffic Assignment, Equilibrium Assignment, Traffic Diversion



## SUMMARY

The PASSER IV Quick Response Procedures described in this report are designed to provide the user with an effective tool for performing quick and simple analyses of traffic flow conditions in a freeway corridor. Alternative approaches for improving traffic movement in the freeway corridor can be evaluated with reasonable amounts of easily obtained data, most of which already exists. For a defined set of conditions, the resulting traffic flow levels and operating conditions can be obtained for each parallel arterial, frontage road, or freeway in the corridor.

A computer program is described and a program listing is provided to assist in using the quick response procedure.

## **IMPLEMENTATION**

The Passer IV Quick Response Procedures and computer program should be useful to traffic engineers and planners who need an effective tool to quickly evaluate a wide range of possible projects to improve traffic flow conditions in a freeway corridor.

## **DISCLAIMER**

The contents of this report reflect the views of the authors who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

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## PASSER IV QUICK RESPONSE PROCEDURES

Problems of increasing traffic demand and traffic congestion along freeway corridors in major Texas cities have made the effective management and utilization of existing facilities, as well as the implementation of minor geometric modifications for improving traffic flow, important functions of the various agencies (State Department of Highways and Public Transportation, Cities, Counties, etc) involved. Existing analytical methods and related computer programs offer proven performance capabilities in addressing these problems; however, most are seriously deficient in addressing analyses which require quick response. That is: they do not permit quick and simple analyses of problem areas to allow evaluation of several alternative improvements in a cost-effective manner; they do not fully treat continuous frontage roads that are virtually unique to Texas; and they require a large amount of field data and computational effort to conduct the evaluation. As a result, the use of quick response procedures, microcomputer programs, and programmable calculator routines has become the subject of increasing interest and implementation.

Practical and user-oriented methods have been proposed. The SOAP programmable calculator routines can be used in the design, evaluation and analysis of signal operations (1). These routines incorporate several computational techniques for analysis of a single approach to an intersection. Routines also are available for calculation, analysis and evaluation of signal settings and measures of effectiveness. Other procedures which have been developed include evaluation routines based on the trademarked PASSER II-84 computer program (2) and the 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, 7, 8). Analysis techniques including air quality

evaluation (9) and energy impacts on travel (10) have been proposed. Increasing applications have become the norm. The development of simplified methods for implementation on programmable calculators or microcomputers has elicited great interest.

The PASSER IV system of quick response methodologies for analyzing urban freeway corridor alternatives is intended to provide transportation system analysts with useful tools to expediently evaluate several classes of Transportation Systems Management (TSM) feasible alternatives. This report presents, as a part of the PASSER IV system, a procedure for estimating traffic flow levels on individual parallel facilities in an urban freeway corridor, based on equilibrium traffic assignment. The algorithm can be applied quickly and efficiently to multiple parallel facilities. A quick response routine for the procedure has been developed.

The main body of this report describes the basis and development of this algorithm. A concise user's manual is attached as Appendix A. The program listing is Appendix B.

## The Procedure

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

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

It was recognized that simplified methods (quick response techniques) were needed to permit the transportation engineer or planner to expeditiously evaluate a wide range of TSM-based alternatives using a minimum of data complexity and effort. As part of the Texas Highway Planning and Research (HP&R) continuing study, "Development of Freeway Corridor Evaluation System - PASSER IV," a quick response analysis methodology has been derived for expediently evaluating several classes of TSM-based feasibility studies from an operational viewpoint. The PASSER IV concept provides the decision maker with the option of efficiently obtaining credible performance measures for various proposed scenarios.

The algorithm presented herein is based on equilibrium traffic assignment. It provides estimates of 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 which minimizes their travel time.

Implicit in this assumption is the driver's perception of his travel time. Since this algorithm is based on computations of actual travel times, its accuracy is affected by differences between the driver's perceived travel time and his actual travel time.

2. Speed versus volume/capacity ( $v/c$ ) ratio curves describing the parallel paths may be determined.
3. Piecewise linear approximations of these curves can be computed.
4. The speed at density is deterministic.
5. The freeway is not metered, or the capacity has been adjusted to reflect its presence.
6. Demand in excess of capacity can be accommodated.

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

The procedure is microscopic and deterministic. Simplicity and user-oriented operation have been emphasized. The routine is modular in design, permitting other TSM-type alternative scenarios to be addressed by subsequent additions and subroutines.



## PROCEDURE BACKGROUND

The algorithmic approach to the alternate path traffic assignment problem is based upon Wardrop's first principle (user optimization) of equilibrium flows (11). The original corridor scenario for three alternate paths included a freeway, a frontage road, and a parallel arterial street. The algorithm initially used travel time relationships for allocating traffic to the three paths; however, this has been extended to include up to ten alternative parallel facilities.

Freeway travel time is based on the relationship between average freeway speed and volume/capacity ratio as developed by the Texas Transportation Institute (TTI). Frontage road travel time and arterial street travel time are based on speed, volume, capacity, and signal density. These relationships are developed as a piecewise linear function of travel time to volume to capacity 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, travel time on the facility is increased. The procedure iteratively determines the allocation of the demand to provide equal travel times for all facilities utilizing 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 point B. Point A might be a suburban community while point B could be a central business district. These travelers may choose from among paths 1, 2 and 3 for their trip. Each of these paths has its own distance, speed and capacity attributes. For a typical urban freeway corridor in Texas, path 1 is the freeway mainlanes, path 2 is the frontage road, and path 3 is a parallel arterial street.

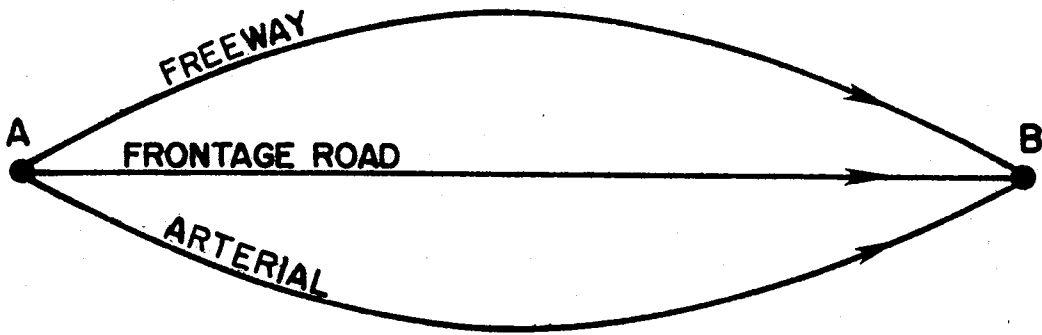


Figure 1. Alternate Urban Freeway Corridor Paths

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 individual travelers will choose a path that enables minimum travel time under the perceived operating conditions. This assumption of the behavior of the user of the transportation system is known as "user optimization" and is in general agreement with observed behavior. The driver perceives (or anticipates) certain operating conditions on each path and then chooses the path which he thinks will minimize travel time from point A to point B. Traditional nonequilibrium traffic assignment techniques have not explicitly addressed the allocation of traffic to meet this condition. For example, in an all-or-nothing assignment, the technique finds the minimum travel time between two zones under specific conditions; all traffic then is 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 initial value, and if minimum travel times were to be computed again, another path between the two zones probably would be chosen. This diversion of traffic is addressed in capacity restraint assignment, yet travelers still may not be on a path that gives them minimum travel time. A number of methods now are 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 analyses to evaluate several alternatives for TSM strategies in the corridor.

The algorithm presented in this paper explicitly treats the path choice perceptions 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.

### FREEWAY TRAVEL TIME FUNCTIONS

For a typical urban freeway corridor in Texas, as depicted in Figure 1, path 1 includes the freeway mainlanes, 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 volume/capacity ( $v/c$ ) ratio by the relationship similar to that shown in Figure 2 (12), taken from the 1965 Highway Capacity Manual (HCM) (13). The quantity  $u_f$  is the free-flow speed for the facility.

In work for the Federal Highway Administration (FHWA) on the "Freeway-Surface Arterial VMT Splitter" project, Creighton, Hamburg, Inc. proposed 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 (14). For  $v/c$  values in the range (0, 0.8), this curve is the same as the HCM citation curves shown in Figure 2. 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 capacity, especially since Figure 2 shows a speed of  $u_f/2$  when volume is equal to capacity.

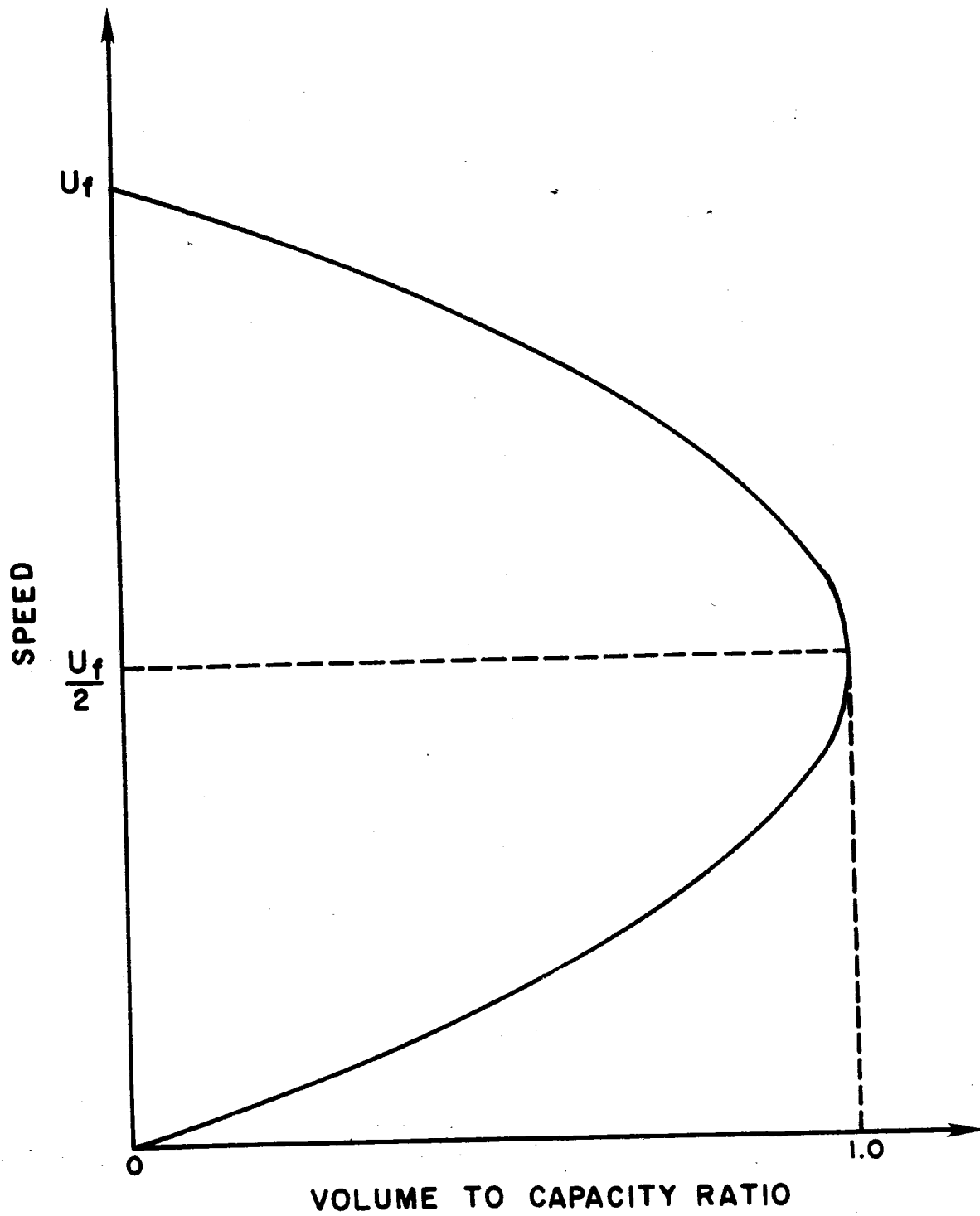


Figure 2. Urban Freeway Speed Versus v/c Ratio (13)

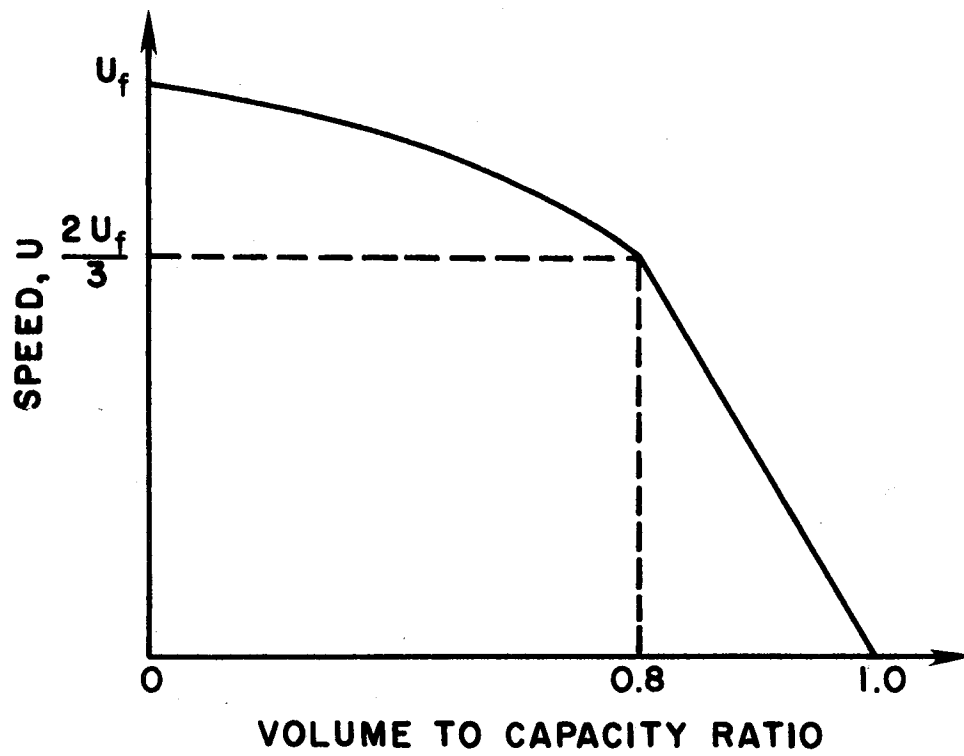


Figure 3. FHWA Freeway Speed Versus v/c Ratio for Freeway-Arterial VMT

For the freeway speed model used in this algorithm, speed at capacity was set at  $u_f/2$ , to approximate average actual speed. In addition, since volumes greater than estimated capacity sometimes are observed, the freeway speed curve was extended in this research to a speed value of 10 miles per hour 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 relationship can be expressed as:

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

where  $S_{fwy}$  = speed on freeway at volume  $v$  per lane (mph)

$v$  = freeway volume per lane (vph)

$c$  = capacity per lane (vph)

$S_0$  = free flow speed on freeway (mph)

$S_1$  = speed on freeway when  $v/c = 0.8$  (mph)

$S_2$  = speed on freeway when  $v/c = 1.0$  (mph)

This model provides a determinable relationship 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 using

$$T(v/c) = \text{Travel Time} = \frac{\text{Distance}}{\text{Speed}}$$

for each continuous interval. The resulting travel time relation is shown in

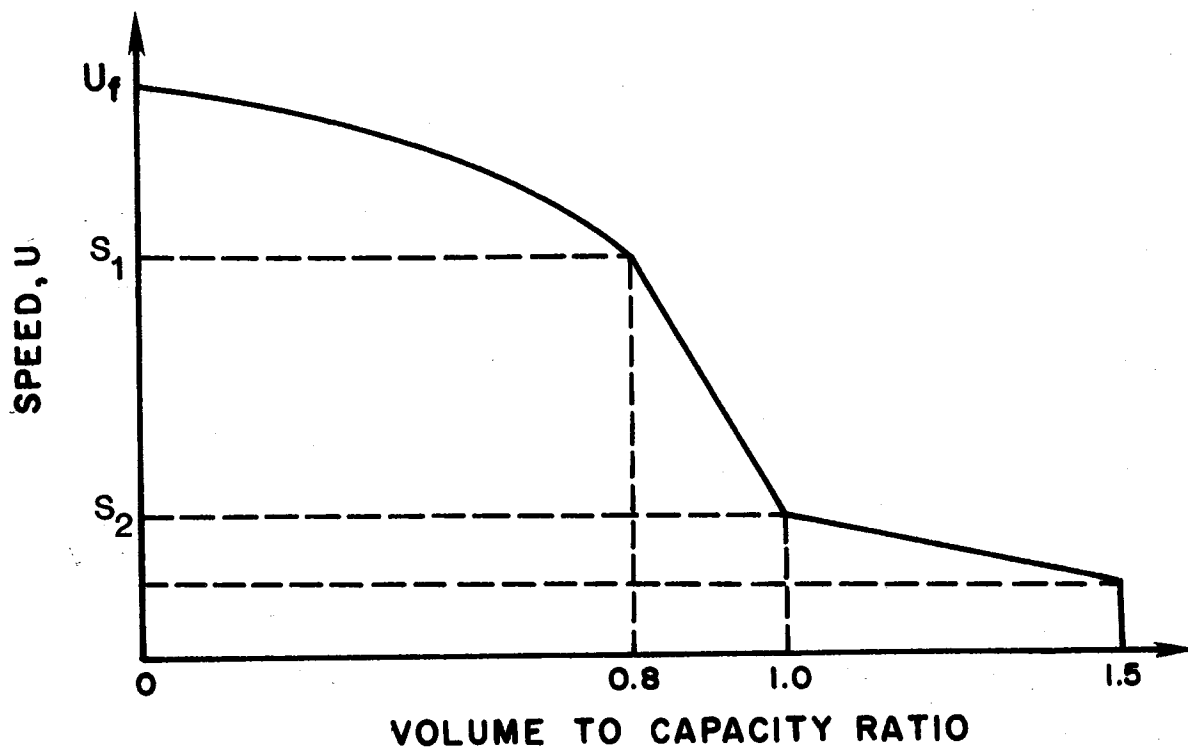


Figure 4. TTI Urban Freeway Speed Versus v/c Ratio



Figure 5. This relationship shows, as would be expected, that as the volume (or volume/capacity ratio) on the freeway increases, travel time increases. This developed relationship 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 or the FHWA, may be used as long as they are modified to a piecewise linear form.

#### SIGNALIZED ROADWAY TRAVEL TIME FUNCTIONS

For signalized roadways, the relationship between speed and capacity is complicated by the signals along the roadway, which provide a component of delay in addition to that attributable to vehicles. The effect of this delay can be correlated to the signal density and signal timings. The relationship developed in this report is a modified version of that in the FHWA's Micro Assignment Model (14). This relationship provides for travel time to be dependent on volume and signal density. For signalized roadways the equations are:

$$S_{art} = \begin{cases} S_0 (n,w) + \frac{v}{c} f(n) & \frac{v}{c} \leq 0.8 \\ S_1 + \left[ \frac{S_2 - S_1}{0.2} \right] \left[ \frac{v}{c} - 0.8 \right] & 0.8 < \frac{v}{c} \leq 1.0 \\ S_2 + \left[ \frac{5 - S_2}{0.5} \right] \left[ \frac{v}{c} - 1.0 \right] & 1.0 < \frac{v}{c} \leq 1.5 \\ 5 & \frac{v}{c} > 1.5 \end{cases}$$

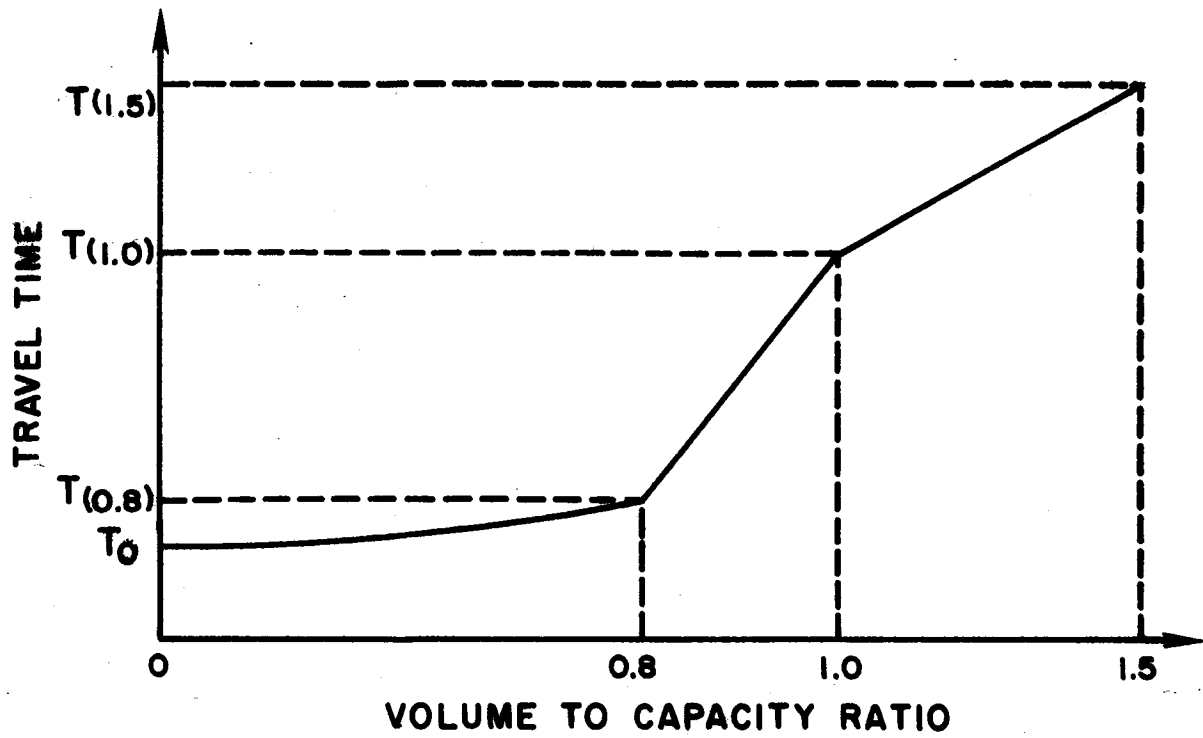


Figure 5. TTI Urban Freeway Travel Time Versus v/c Ratio

where  $S_{art}$  = speed on signalized roadway at volume  $v$  per lane (mph)

$v$  = roadway volume per lane (vph)

$c$  = capacity per lane (vph)

$n$  = 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  $S_0(n,w) = 3600/[3600/w + 12.5n]$

and  $f(n) = \begin{matrix} -0.0672n^3 + 0.781n^2 - 3.2232n & n < 5.5 \\ 0.138n - 6.028 & n \geq 5.5 \end{matrix}$

A family of curves relating free flow speed to posted speed and signal density is shown in Figure 6. A family of curves showing 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 using the speed curves shown in Figure 7 and the relation

$$T(v/c) = \text{Total Travel Time} = \frac{\text{Distance}}{\text{Speed}}$$

The travel time curves developed are illustrated in Figure 8.

Looking at Figure 8, it can be seen that while the effect of signal density is somewhat diminished the travel time relationship behaves as would be expected.

For example, consider the three-path travel time curves illustrated in Figure 9. Path 1 is a freeway, path 2 is a frontage road, and path 3 is a parallel arterial street.

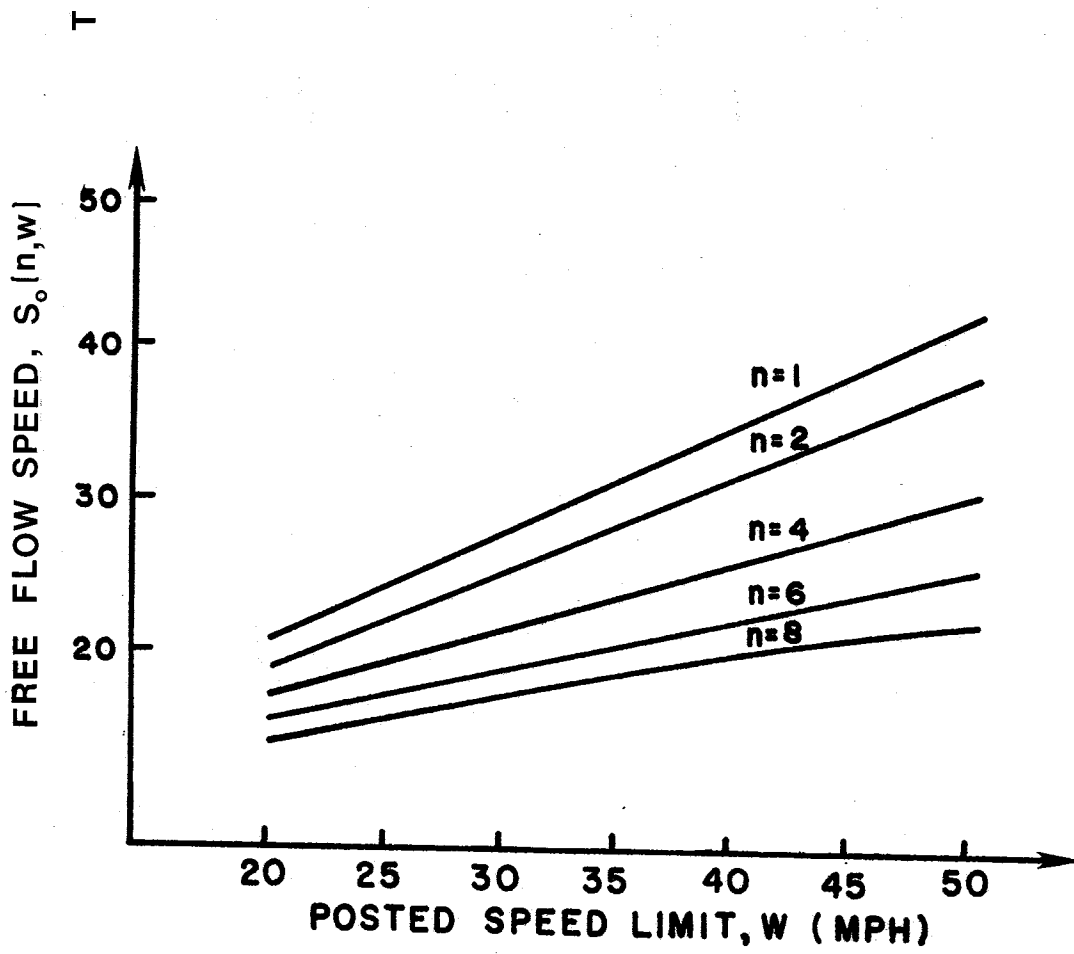


Figure 6. Free Flow Speed Versus Posted Speed  $w$  and Signal Density  $n$

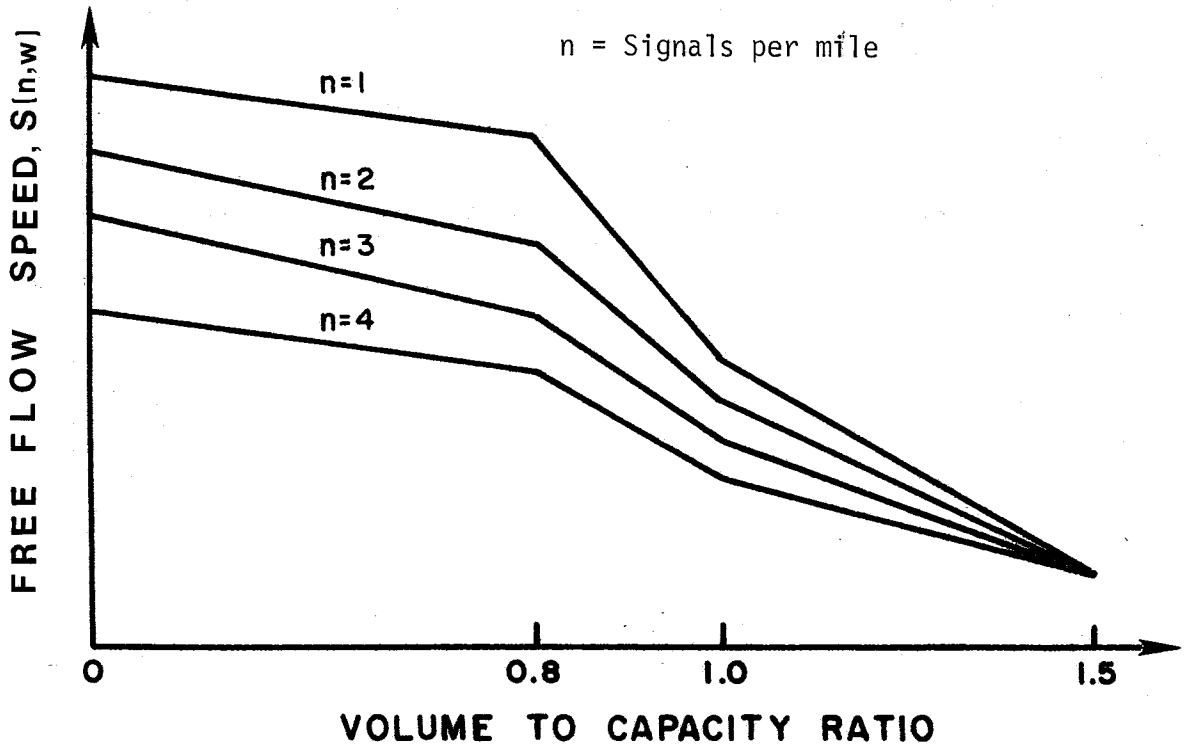


Figure 7. FHWA Signalized Roadway Speed Versus v/c Ratio

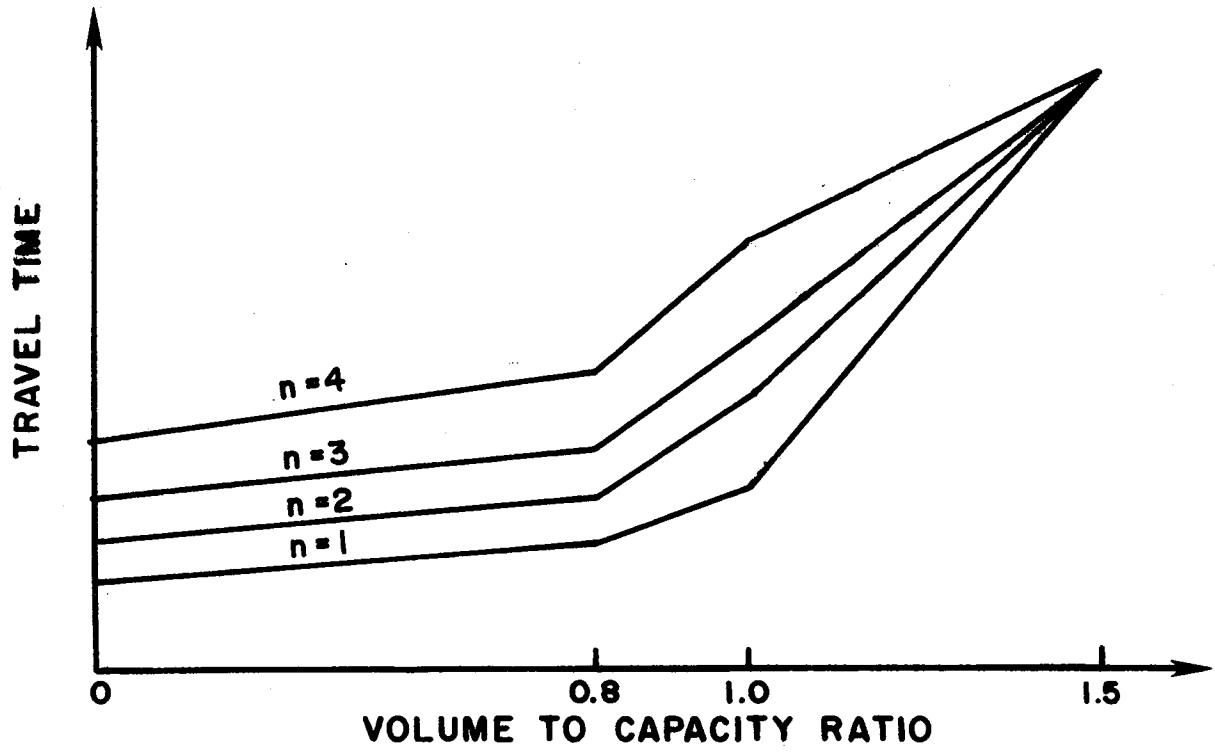


Figure 8. TTI Signalized Roadway Speed Versus v/c Ratio

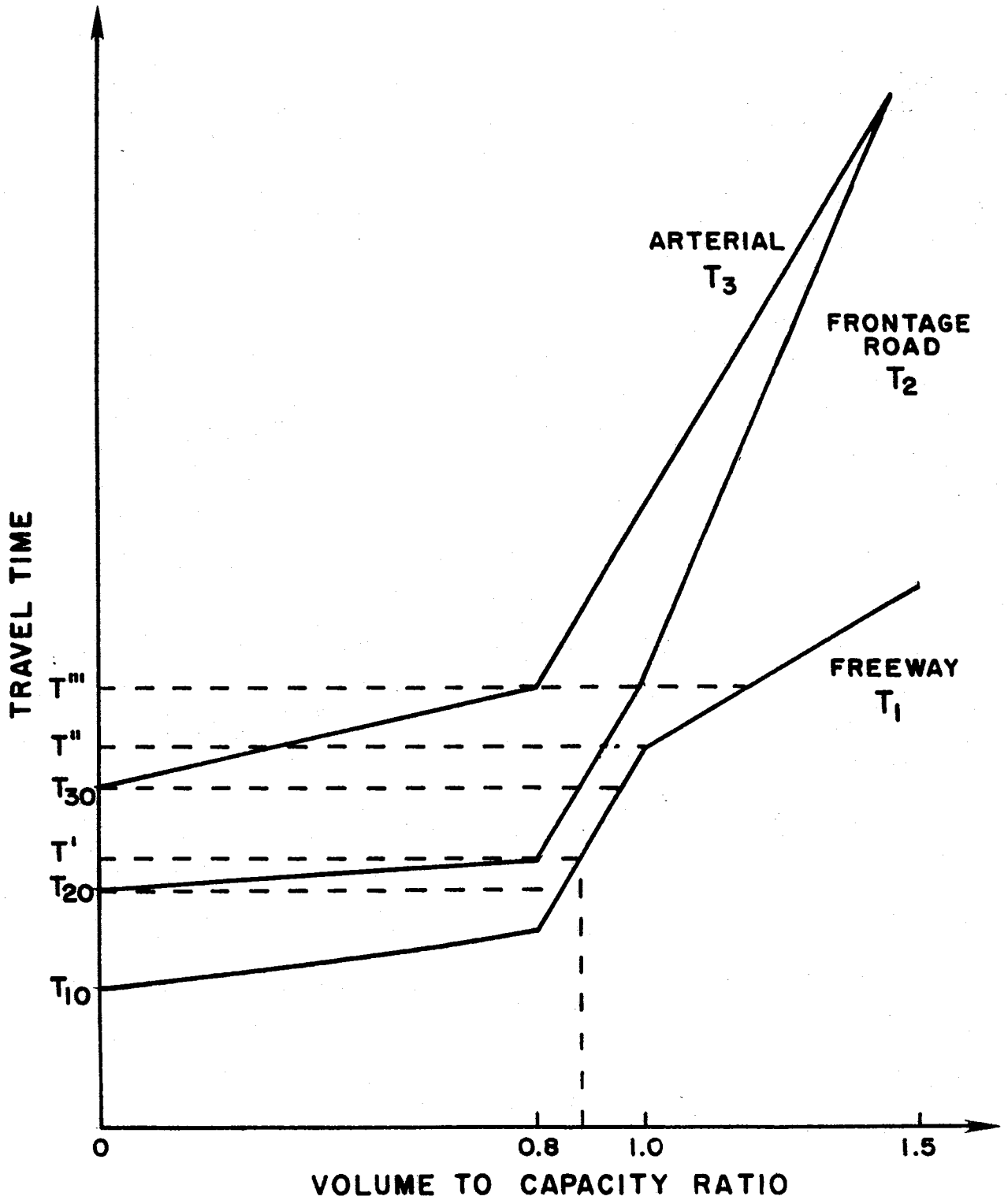


Figure 9. Urban Freeway Corridor Travel Time Functions for a Freeway, a Frontage Road and an Arterial Street

When there is no traffic on any facility, an individual traveler will choose the path which gives him the least travel time. In this example (Figure 9), the freeway free flow travel time  $T_{10}$  is least, so the first traveler chooses path 1 (the freeway). Subsequent entering travelers also choose path 1, so long as the loaded travel time on path 1 is less than the free flow travel time on path 2,  $T_{20}$ . Indeed, no traffic will use the frontage road (path 2) until the v/c ratio on the freeway is 0.85, at which point the (loaded) freeway travel time is the same as the free flow travel time on the frontage road.

As still more travelers desire to go from A to B, they will choose either path 1 (the freeway) or path 2 (the frontage road), but by Wardrop's first principle they must proportion themselves so that travel time on the frontage road remains the same as the travel time on the freeway. The proportions are determined by the slopes of the travel time curves at this point. As shown in Figure 9, when travel time is in the interval  $[T_{20}, T']$ , the slope of the freeway curve is

$$\frac{T_1 (1.0) - T_1 (0.8)}{0.2}$$

while the slope of the frontage road curve is

$$\frac{T_2 (0.8) - T_{20}}{0.8}$$

The change in travel time ( $T_1$ ) along the freeway is:

$$T_1 = \left[ \frac{\Delta T_1 (1.0) - T_1 (0.8)}{0.2} \right] \left[ \frac{\Delta V_1}{C_1} \right]$$

and the change in travel time along the frontage road is:

$$\Delta T_2 = \left[ \frac{T_2 (0.8) - T_{20}}{0.8} \right] \left[ \frac{\Delta V_2}{C_2} \right]$$



But since  $\Delta T_1 = \Delta T_2$

$$\Delta V_2 = \left[ \frac{4C_2}{C_1} \right] \left[ \frac{T_1 (1.0) - T_1 (0.8)}{T_2 (0.8) - T_{20}} \right] \left[ \Delta V_1 \right]$$

Therefore, unless all of the travel demand between A and B has been satisfied, for every vehicle added to path 1,

$$\left[ \frac{4C_2}{C_1} \right] \left[ \frac{T_1 (1.0) - T_1 (0.8)}{T_2 (0.8) - T_2 (0.0)} \right]$$

vehicles will be added to path 2. This relationship continues until the travel time on both paths 1 and 2 is equal to  $T'$  as shown in Figure 9.

Looking at the next interval on the travel time axis,  $[T', T_{30}]$ , the change in travel time along the freeway is

$$\Delta T_1 = \left[ \frac{T_1 (1.0) - T_1 (0.8)}{0.2} \right] \left[ \frac{\Delta V_1}{C_1} \right]$$

and the change in travel time on the frontage road is

$$\Delta T_2 = \left[ \frac{T_2 (1.0) - T_2 (0.8)}{0.2} \right] \left[ \frac{\Delta V_2}{C_2} \right]$$

so that, unless all of the travel demand between A and B has been satisfied, for every vehicle that is added to path 1,

$$\left[ \frac{C_2}{C_1} \right] \left[ \frac{T_1 (1.0) - T_2 (0.8)}{T_2 (1.0) - T_2 (0.8)} \right]$$

vehicles will be added to path 2.

$$\Delta T_1 = \left[ \frac{T_1 (1.0) - T_1 (0.8)}{0.2} \right] \left[ \frac{\Delta V_1}{C_1} \right]$$

$$\Delta T_2 = \left[ \frac{T_2 (1.0) - T_2 (0.8)}{0.2} \right] \left[ \frac{\Delta V_2}{C_2} \right]$$

and

$$\Delta T_3 = \left[ \frac{T_3(0.8) - T_{30}}{0.8} \right] \left[ \frac{V_3}{C_3} \right]$$

Unless the travel demand between point A and point B has been satisfied, for every vehicle added to path 1 (the freeway),

$$\left[ \frac{4C_3}{C_1} \right] \left[ \frac{T_1(1.0) - T_1(0.8)}{T_3(0.8) - T_{30}} \right]$$

vehicles are added to path 3.

This procedure continues for subsequent intervals along the travel time axis in Figure 9 until the travel demand from A to B has been satisfied. The relative proportions of vehicles using each path are recalculated for each new interval, as defined by the points of inflection of the piecewise linear curves, and interval volumes are accumulated for each path. The limits of each of the travel time intervals are defined by two points of discontinuity on one curve or one point of discontinuity on each of two curves.



## Procedure Features and Capabilities

The routine has undergone several revisions during 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 memory utilization 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. A TI-59 programmable calculator was used. Due to memory constraints, only three alternate paths were allowed. The three parallel paths available could be the freeway mainlanes, frontage roads, and a parallel arterial street. The input data, shown in Table 1, along with embedded data in the routine provide the characteristics of the facility and demand volume. The piecewise linear segments of each travel time curve are established at volume to capacity ratios of .8, 1.0, and 1.5. A representative series of travel time curves is illustrated in Figure 10. The free flow speed (or travel time) is the only variable (add number of signals for non-freeway paths) that the user must input to describe the curve. The corresponding speeds for v/c ratios of .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 volume-to-capacity ratio for each path.

TABLE 1. ROUTINE INPUT DATA

	Freeway	Frontage Road	Arterial
Number of lanes	X	X	X
Distance	X	X	X
Speed	X	X	X
Capacity	X	X	X
Signal Density		X	X
Total Density		X	X
Total Demand			

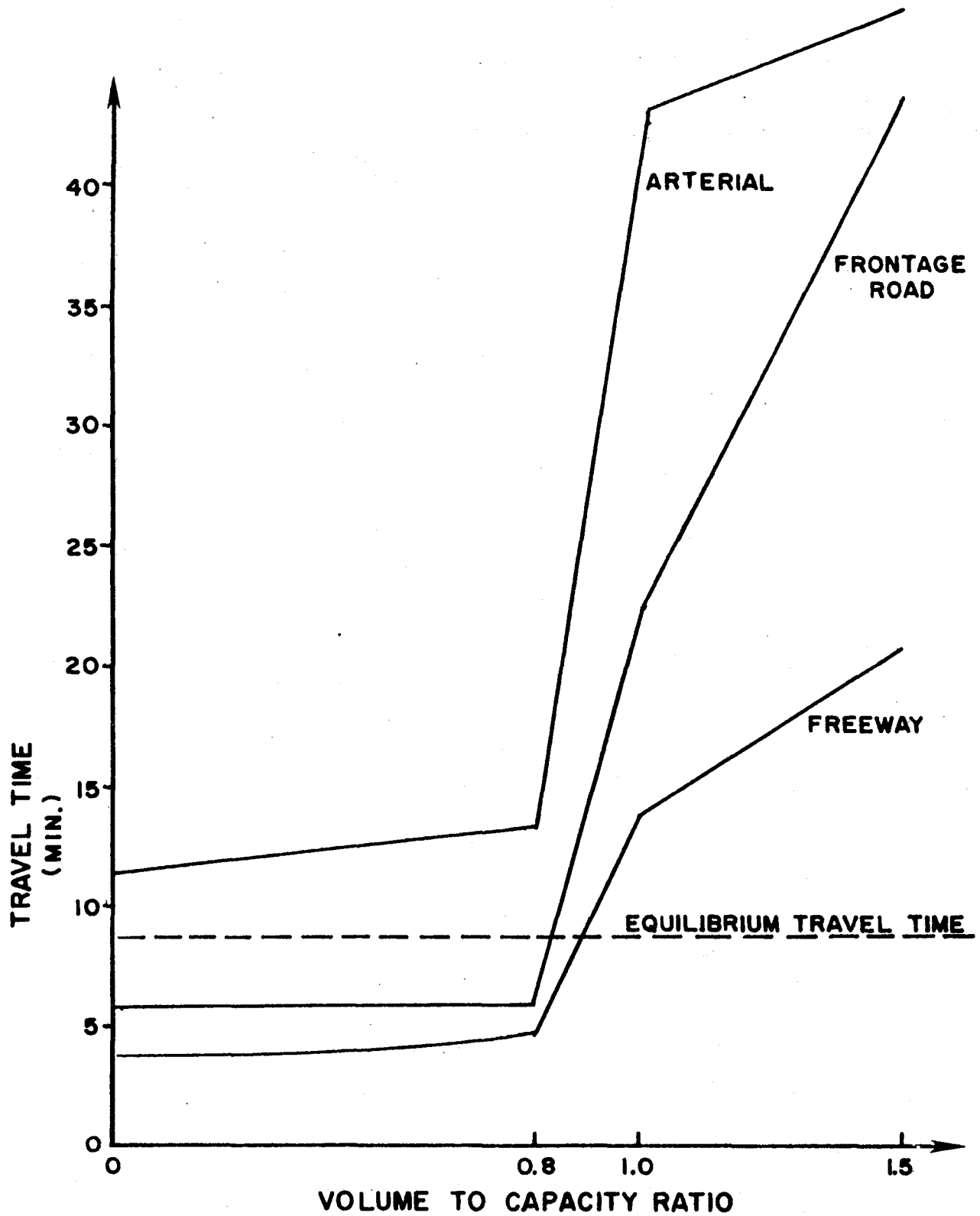


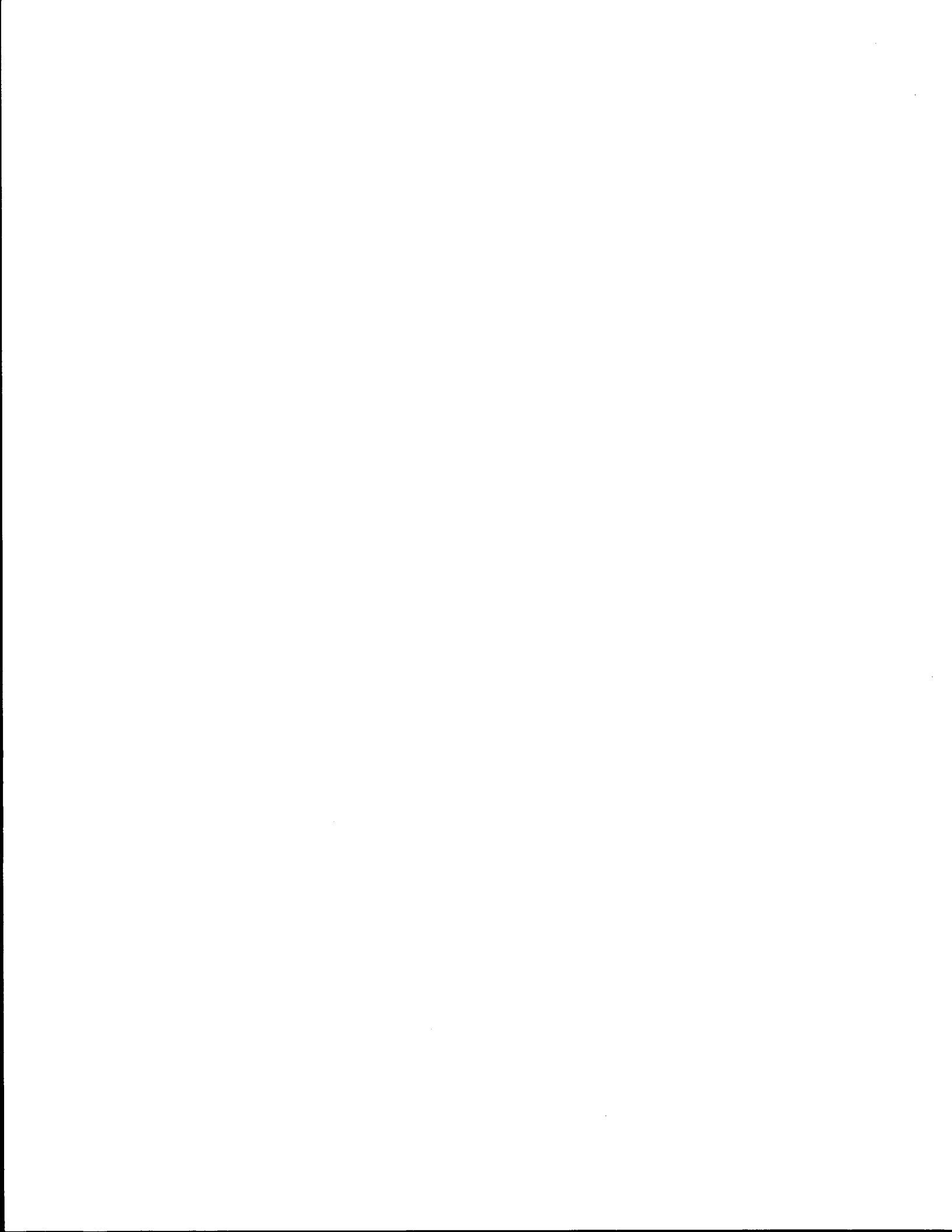
Figure 10. Travel Time Functions for Example Problem

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APPENDIX A





## FORTTRAN Program

Given the initial roadway characteristics and the system demand volume, this program can be used to determine the required travel time and volumes assigned to each roadway. It can be used in three different ways in calculating the travel time and the volume on each roadway.

First, it can be used to compute single travel time and volumes on each roadway. The user may input the current characteristics of roads and calculate the system travel time for any number of vehicles to pass through the system. Second, the program can be used to calculate travel time and volume on each roadway while varying one of the parameters, i.e., speed, capacity, number of lanes or signal density. This option can be used to determine the effects of changes in one parameter to the entire system traffic flow. Finally, it can be used to determine the travel time and volume on each roadway while varying the system demand volume. This option can be used to study the effects of an increase in system demand volume to the entire system traffic flow.

### ALGORITHM DEVELOPMENT

The program is designed in a modular structured format to allow for efficient coding and execution by selecting only the necessary modules during the execution period. Input to the program is effected through the subroutine INDATA, which reads the initial data, checks for any fatal errors, and echo prints the input data for user verification. After subroutine INDATA is executed, the program has the necessary roadway characteristics for the actual calculation of system travel time.

A bisectional algorithm is used by subroutine CALTT to search for and to calculate the required system travel time. The initial travel time,  $T_j$ , is calculated based on the average of the maximum and minimum travel times. The

maximum travel time,  $T_{max}$ , is based on free flow speed, while the minimum travel time,  $T_{min}$ , is based on a crawl speed. Both the free flow and crawl speeds are based on roadway characteristics.

Given the initial travel time,  $T_i$ , subroutine RMODEL calculates the maximum volume,  $V_{max}$ , which the roadway system can accommodate. This  $V_{max}$  is compared with the system demand volume,  $V_{dem}$ , to determine the next travel time,  $T_{i+1}$ . If  $V_{max}$  is greater than  $V_{dem}$  (i.e., actual travel time should be less than  $T_i$ ), then  $T_i$  becomes the new value for  $T_{max}$ . If  $V_{max}$  is less than  $V_{dem}$  (i.e., actual travel time should be greater than  $T_i$ ), then  $T_i$  becomes the new value for  $T_{min}$ . The next estimated travel time,  $T_{i+1}$ , is calculated as the average of  $T_{max}$  and  $T_{min}$ . This bisectional search method is repeated until the difference between the two volumes is less than one tenth of one percent of the system demand volume. The final estimated travel time determined during the search then is used as the system travel time to calculate the volume on each roadway.

The subroutine OTDATA outputs the final system travel time and the volume on each roadway. It also calculates the volume-to-capacity ratio for each roadway as well as the entire system.

#### INPUT CODING

Input data is normally instream and attached to the end of the program. Since most of the data are input column dependent, the user must be careful to code all of the input values into their appropriate columns.

The first card is used as a header card, which may contain up to 80 characters to describe the data set. Example coding forms are included in this report to aid the user in the actual input data coding. The second card contains the values for six variables--INDEX1, CHOICE, RDNUM, MIN, MAX and INC. These values must be right justified in their proper fields.

- Columns 8 - 10     INDEX1.   The parameter to determine which of the three options to execute.
1. Single travel time calculation
  2. Allows the user to vary geometric inputs, i.e. speed, capacity, signal density, and number of lanes
  3. Provides for a systematic variation among the system demand volume.
- Columns 18 - 20    CHOICE.   The variable to determine which parameter is to be varied during the program execution.
1. Number of lanes
  2. Not used
  3. Speed limit
  4. Per lane capacity
  5. Signal density per mile
- Columns 28 - 30    RDNUM. Selection of the specific roadway which is to be analyzed throughout execution. parameterized during the execution.
- Columns 38 - 40    MIN.    The minimum value for the parameter looping during the execution period.
- Columns 48 - 50    MAX.    The maximum value for the parameter looping during the execution period.
- Columns 58 - 60    INC.    Increment step size for parameter looping from MIN to MAX.

The third card contains the initial values for MINVOL, MAXVOL, and STEP. These values are necessary if the user desires to vary the system demand volume. If the system demand volume is to be systematically increased the user must specify this by setting the value of INDEX1 to three and inputting the range of volumes and the increment step size during the program execution. by setting the value of INDEX1 to three and inputting the range of volumes and the increment step size during the program execution.

- Columns 11 - 15    MINVOL.   The initial system demand volume to be assigned is minimum value for volume variation during the program execution.

Columns 26 - 30    MAXVOL.    The maximum system demand volume to be used during the program execution. Program terminates after the maximum demand volume is reached.

Columns 41 - 45    STEP.    The increment step size used to systematically increase the system demand volume from MINVOL to MAXVOL.

Card four contains the value for DEMAND in columns 21-30. DEMAND is the initial system demand volume to be processed independently of any systematic volume variations.

Card five contains the value for NUMRD in columns 21-23. NUMRD is the number of roadways in the system. This program can accommodate a maximum of ten roadways. Any number greater than ten will be treated as a fatal error in input data and will cause the program to terminate.

Card six is skipped during the data input. It is used only to specify the fields width for LANES, DISTANCE, SPEED, CAPACITY and SIGNAL. Card six may be used as a comment card or left blank.

The remaining cards contain the actual roadway characteristics for each of the roads within the system. A maximum of two cards per roadway are required to input these characteristics.

Columns 11 - 20    LANES.    The number of lanes in the roadway is entered.

Columns 21 - 30    DISTANCE.    The distance in miles between the origin and the terminal nodes is entered.

Columns 31 - 40    SPEED.    The posted speed limit for the roadway is entered. If the roadway has multiple speed limits, the user may input multiple speed limits. If the user wishes to input multiple speed limits, the value of SPEED must be set to -1.

Columns 41 - 50    CAPACITY.    The per-lane capacity volume for the roadway is entered.

Columns 51 - 60     SIGNAL.   The signal density per mile for the roadway is entered. If the roadway is a freeway, the signal density must be set to zero.

If the option to input multiple speed limits is selected, i.e., SPEED=-1, an additional card must follow the roadway characteristics card. This card will contain each of the speed limits and their corresponding distances. A maximum of five different speed limits and distances may be input for each roadway. If only one speed limit is to be used for a roadway, this card is omitted.

To code the multiple speed and distances, each value must be coded within six columns.

Columns 1 - 6     SPEED1. The posted speed limit for the first segment of the roadway is entered.

Columns 7 - 12    DIST1. The distance in miles covered by SPEED1 is entered.

Columns 13 - 18   SPEED2. The posted speed limit for the second segment of the roadway is entered.

Columns 19 - 24   DIST2. The distance in miles covered by SPEED2 is entered.

Columns 25 - 30   SPEED3. The posted speed limit for the third segment of the roadway is entered.

Columns 31 - 36   DIST3. The distance in miles covered by SPEED3 is entered.

Columns 37 - 42   SPEED4. The posted speed limit for the fourth segment of the roadway is entered.

Columns 43 - 48   DIST4. The distance in miles covered by SPEED4 is entered.

Columns 49 - 54   SPEED5. The posted speed limit for the fifth segment of the roadway is entered.

Columns 55 - 60   DIST5. The distance in miles covered by SPEED5 is entered.

If any of the above fields are left blank, they will be considered as zero, and the program will calculate the average speed accordingly. This Calculated, weighted average speed will be used as the speed for the entire roadway. The SPEED1-SPEED5 must lie within the range,  $0 < \text{SPEED} \leq 55$ .

In the following Figures 11 - 16, the general block diagrams of the main program execution is described. The program can select one of the three paths to calculate a single travel time or vary one of the parameters or vary the system demand volume. The example coding from and a blank coding sheet is included for user to make copies for further coding activities.

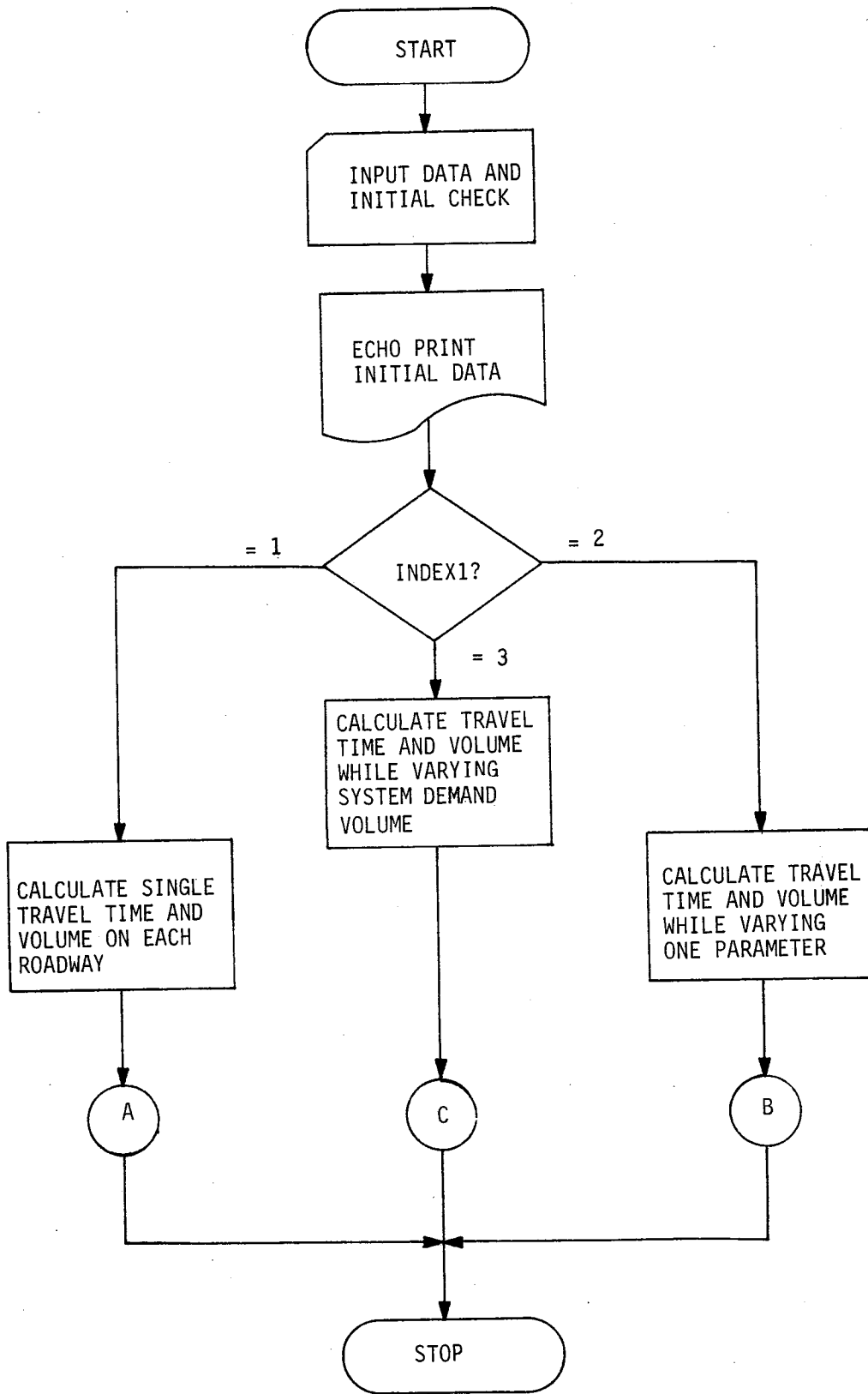


Figure 11. General Block Diagram



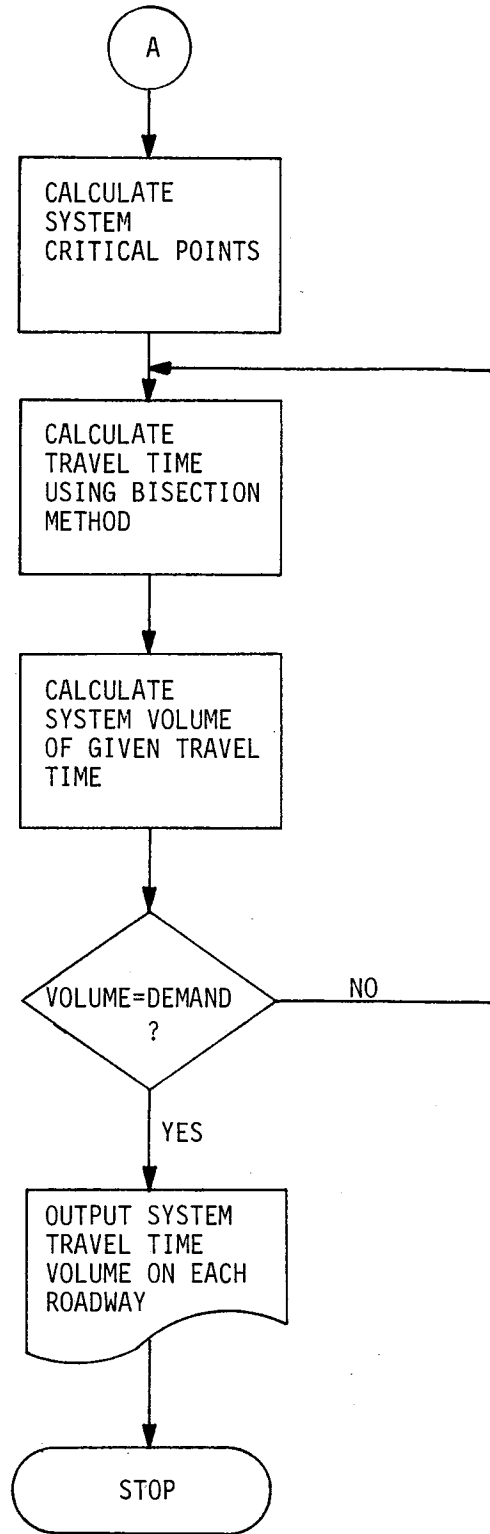


Figure 12. Single Calculation Flowchart

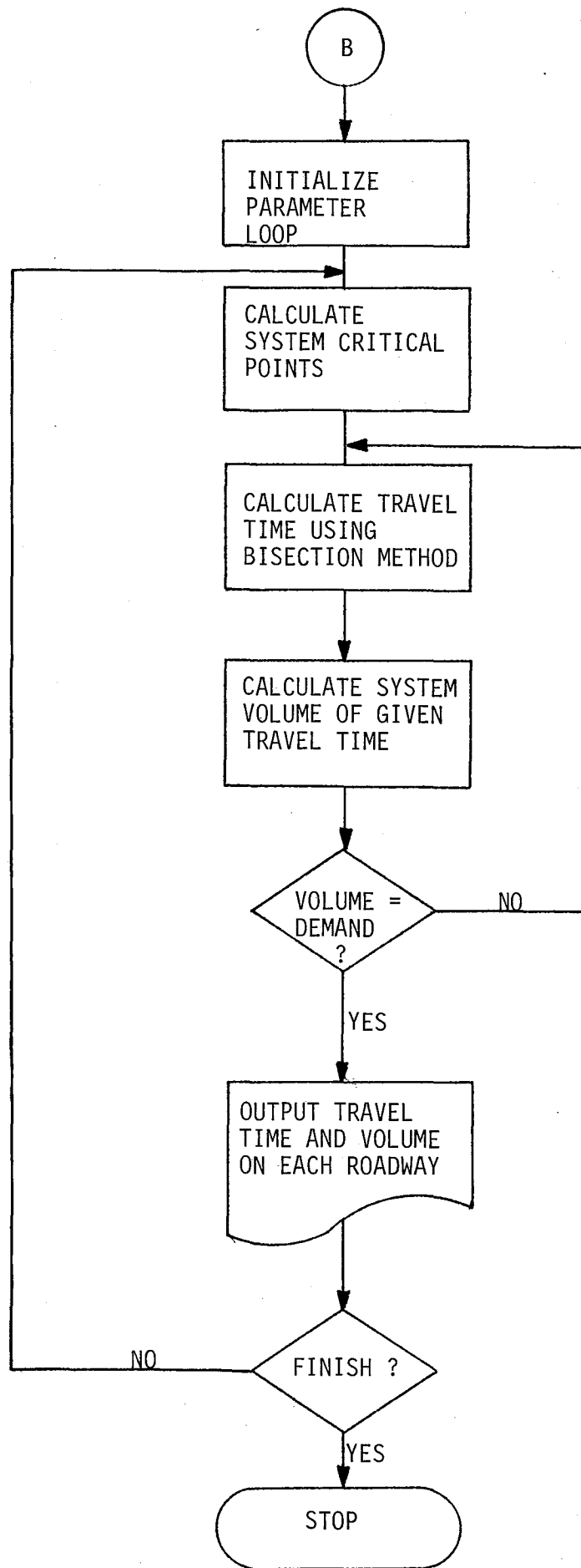


Figure 13. Delineate Flowchart of Variables

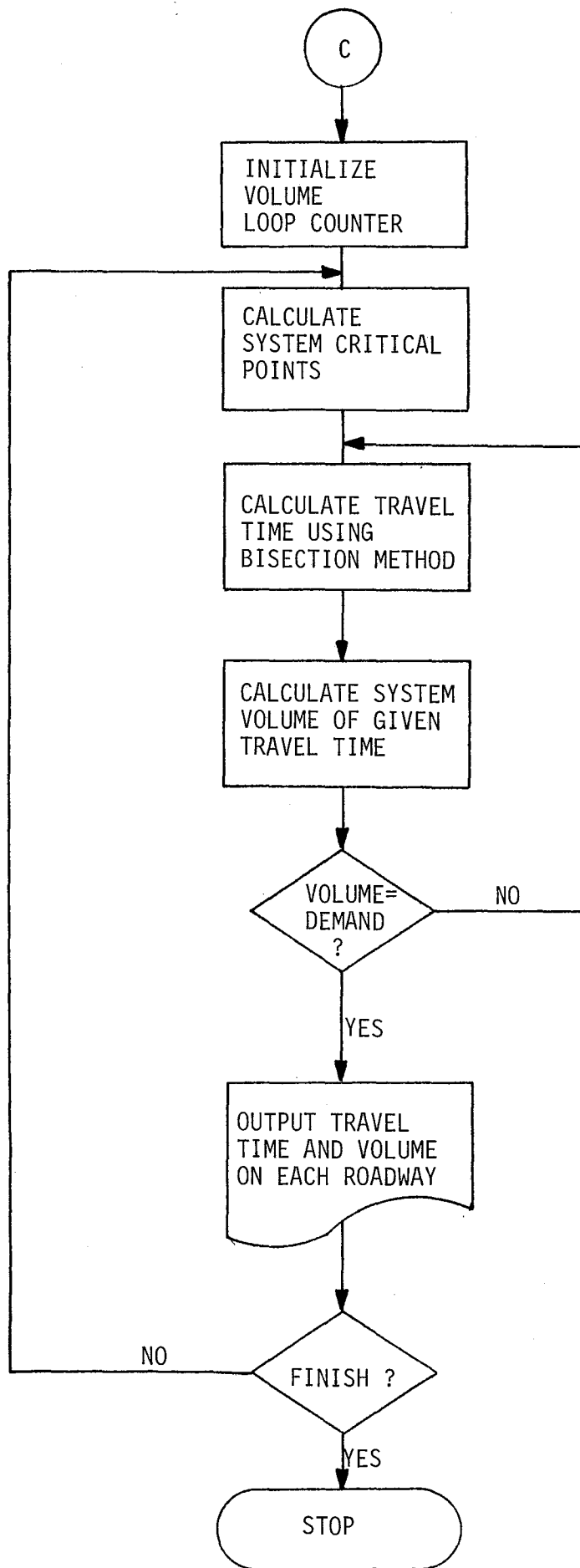


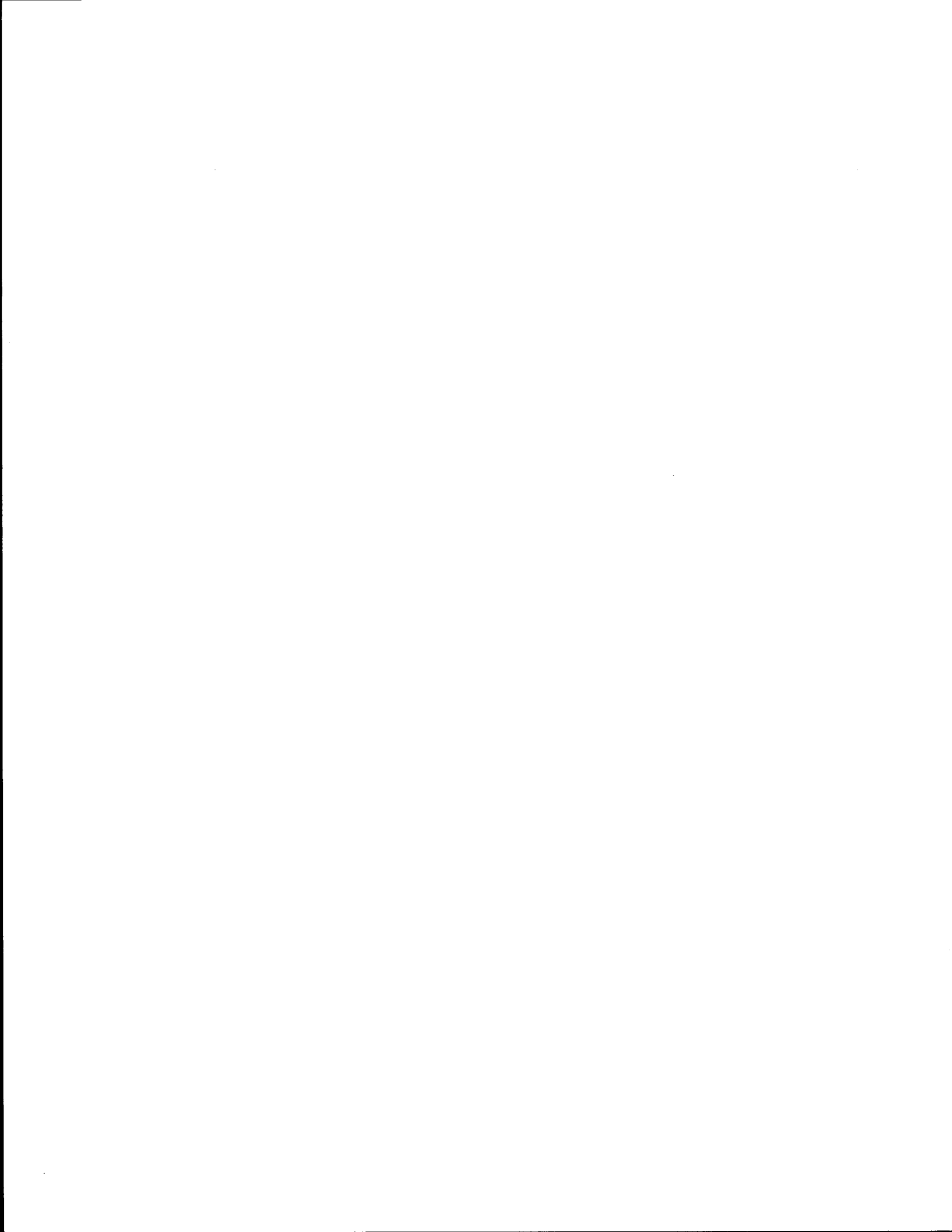
Figure 14. Flowchart of Volume Variability



10										20										30										40										50										60																						
																				... INPUT DATA ...																																																				
INDEX1 :	N									CHOICE :	N									RDNUM :	N									MIN :	N									MAX :	N									INC :	N																					
MINVOL :	NNNNN									MAXVOL :	NNNNN									STEP :	NNNNN																																																			
TOTAL DEMAND VOLUME :	X																																																																							
NUMBER OF ROADS :	N																																																																							
										LANES										DISTANCE										SPEED										CAPACITY										SIGNAL																						
RDWY1	X									X									X									X									X									X																										
RDWY2	X									X									X									X									X									X																										
RDWY3	X									X									X									X									X									X																										
.	.									.									.									.									.									.																										
.	.									.									.									.									.									.									.																	
.	.									.									.									.									.									.									.																	
RDWY7	X									X									X									X									X									X																										
SPD1	DIST1									SPD2	DIST2									SPD3	DIST3									SPD4	DIST4									SPD5	DIST5																															
.	.									.									.									.									.									.									.																	
.	.									.									.									.									.									.									.									.								
RDWY10	X									X									X									X									X									X																										

Figure 16. Sample Data Form

APPENDIX B



```

C*****
C*
C*   THIS PROGRAM IS DEVELOPED BASED ON THE REPORT TITLED   *
C*   "AN ALTERNATE PATH ANALYSIS ALGORITHM FOR URBAN     *
C*   FREEWAY CORRIDOR EVALUATION".  THIS PROGRAM WILL     *
C*   UTILIZE THE QUICK RESPONSE ALGORITHM DESCRIBED IN THE *
C*   ABOVE REPORT.  IT CALCULATES THE TRAVEL TIME REQUIRED  *
C*   FOR A GIVEN SYSTEM VOLUME OF CARS TO TRAVEL THROUGH A *
C*   SYSTEM OF ROADWAYS.  PROGRAM WILL ALSO CALCULATE THE *
C*   VOLUME OF CARS ASSIGNED TO EACH ROADWAY.             *
C*
C*****
C
C
C
C
C
C
COMMON DEMAND,NUMRD,RDWDY(10,5),SI(10,4),VOLROD(10)
COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
REAL DEMAND,RDWDY,SI
INTEGER NUMRD,MINVOL,MAXVOL,STEP,CHOICE,RDNUM
INTEGER MIN,MAX,INC,INDEX1
C
C*****
C*
C*   THE INPUT VARIABLES FOR THIS PROGRAM ARE DESCRIBED  *
C*   IN THIS SECTION.                                     *
C*
C*****
C*
C*   1) INDEX1 - PARAMETER TO DETERMINE WHICH OF THREE   *
C*   SEGMENT TO EXECUTE.                                  *
C*   1 - SINGLE CALCULATION                               *
C*   2 - PARAMETERIZE A VARIABLE                          *
C*   3 - PARAMETERIZE VOLUME DEMAND                       *
C*
C*-----*
C*
C*   2) CHOICE - VARIABLE TO DETERMINE WHICH PARAMETER IS *
C*   TO BE PARAMETERIZED DURING EXECUTION                *
C*
C*   1 - LANE                                             *
C*   2 - NOT USED                                         *
C*   3 - SPEED                                             *
C*   4 - CAPACITY                                         *
C*   5 - SIGNAL DENSITY                                    *
C*
C*-----*
C*
C*   3) RDNUM - SELECT THE ROADWAY TO BE PARAMETERIZED  *
C*
C*-----*
C*
C*   4) MIN - MINIMUM VALUE IN WHICH THE PARAMETER IS   *
C*   BE ASSIGNED DURING EXECUTION                        *
C*
C*-----*
C*

```





```

C*****
C
1000  CALL CALSI (IFLAG)
      IF (IFLAG .EQ. 1) GOTO 999
C
      CALL CALTT (VOLSYS,TRDWY,IFLAG)
C
      IF (IFLAG .EQ. 1) GOTO 999
C
      CALL OTDATA (TRDWY)
C
      GOTO 998
C
C*****
C*
C*   INDEX1 = 2:  THIS SEGMENT WILL CALCULATE TRAVEL *
C*                 TIME AND THE VOLUME ON EACH ROAD *
C*                 WHILE VARYING THE PARAMETER VALUE *
C*
C*****
C
C
2000  DO 100 I = MIN,MAX,INC
C
C   INITIALIZE THE PARAMETER VALUE TO BE USED THRU EACH LOOP
C
      RDWY (RDNUM,CHOICE) = I
C
      CALL CALSI (IFLAG)
C
      IF (IFLAG .EQ. 1) GOTO 999
C
      CALL CALTT (VOLSYS,TRDWY,IFLAG)
C
      IF (IFLAG .EQ. 1) GOTO 999
C
      CALL OTDATA(TRDWY)
100   CONTINUE
      GOTO 998
C
C*****
C*
C*   INDEX1 = 3:  THIS SEGMENT CALCULATE THE TRAVEL *
C*                 TIME AND VOLUME ON EACH ROADWAY *
C*                 WHILE VARYING THE SYSTEM DEMAND *
C*
C*****
C
C
3000  CALL CALSI (IFLAG)
C
      IF (IFLAG .EQ. 1) GOTO 999
C
C   INITIALIZE NEW SYSTEM DEMAND VOLUME THRU EACH LOOP
C
      DO 200 I = MINVOL,MAXVOL,STEP
      VOLSYS = I
      DEMAND=VOLSYS
C
      CALL CALTT (VOLSYS,TRDWY,IFLAG)

```

```

C
      IF (IFLAG .EQ. 1) GOTO 999
      CALL OTDATA(TRDWY)
200  CONTINUE
      WRITE (6,30)

C
C
      STOP

C
999  WRITE(6,40)
40   FORMAT (//,30X,'PROGRAM ABORTED DUE TO ERROR')
998  WRITE(6,30)
30   FORMAT('1')
      STOP
      END

C
C
C*****
C*
C   SUBROUTINES WILL BE HERE.
C
C       CALTT
C       INDATA
C       CALSI
C       TRIAL
C       RMODEL
C
C*****
C*
C*       ***SUBROUTINE CALTT***
C*
C*****
C*
C*   THIS SUBROUTINE WILL CALCULATE THE SYSTEM
C*   TRAVEL TIME FOR A GIVEN TOTAL DEMAND.
C*
C*****
C
      SUBROUTINE CALTT(VOLSYS,SYSTT,IFLAG)
      COMMON DEMAND, NUMRD, RDWY(10,5), SI(10,4),VOLROD(10)
      COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
      REAL DEMAND, RDWY, SI
      INTEGER NUMRD,MINVOL,MAXVOL,STEP

C
C
C
C   FIND MINIMUM AND MAXIMUM TRAVEL TIME OF THIS SYSTEM
      TMIN = 1000
      TMAX = 0
      DO 10 I = 1,NUMRD
      TTO = RDWY(I,2)/SI(I,1)
      TT3 = RDWY(I,2)/SI(I,4)
      IF (TMIN .GT. TTO) TMIN = TTO
      IF (TMAX .LT. TT3) TMAX = TT3
10  CONTINUE

C
C*****
C*

```

```

C* FIND SYSTEM TRAVEL TIME FOR THE GIVEN DEMAND. *
C* IF THE DEMAND IS LARGER THAN 1.5*TOTAL CAPACITY *
C* WRITE A MESSAGE. *
C* *
C* *
C*****
C
      VSUM = 0
      DO 20 I=1,NUMRD
      VSUM = VSUM + 1.5*RDWY(I,1)*RDWY(I,4)
20  CONTINUE
      IF (DEMAND .GT. VSUM) GO TO 910
C
C*****
C* FIND SYSTEM TRAVEL TIME BY USING BINARY SEARCH *
C* METHOD. *
C* *
C*****
C
      TLOW = TMIN
      THIGH = TMAX
      TEST = (THIGH + TLOW)/2
      EPSLON = 0.01 * DEMAND
30  CALL TRIAL(TEST,VOLUME)
      DIFF = ABS(DEMAND-VOLUME)
      IF(DIFF .LT. EPSLON) GO TO 35
      IF(VOLUME .LT. DEMAND) GO TO 31
      THIGH = TEST
      GO TO 32
31  TLOW = TEST
32  TEST = (THIGH + TLOW)/2
C
C
C
C
C
C
C
C
C
      GO TO 30
35  SYSTT = TEST
C
C
C
C
C
C
C
C
      RETURN
C
C  ERROR MESSAGE
910 WRITE(6,911)
911 FORMAT(//,5X,'ERROR: DEMAND IS LARGE THAN 1.5*SYSTEM CAPACITY')
      IFLAG = 1
C
      RETURN
C
      END

```

```

C
C
C*****
C*
C*          ***SUBROUTINE TRIAL***
C*
C*****
C*
C* CALCULATE TOTAL SYSTEM VOLUME FOR THE GIVEN SYSTEM
C* TRAVEL TIME (TEST).
C*
C*****
C
      SUBROUTINE TRIAL (TEST,VOLUME)
      COMMON DEMAND, NUMRD, RDWY(10,5), SI(10,4),VOLROD(10)
      COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
      REAL DEMAND, RDWY, SI, TEST, VOLUME, VTEMP
      INTEGER NUMRD,MINVOL,MAXVOL,STEP

C
      VTEMP = 0
      DO 100 I=1,NUMRD
      CALL RMODEL (I,TEST,VROAD)
      VOLROD(I) = VROAD
      VTEMP = VTEMP + VROAD
100 CONTINUE
      VOLUME = VTEMP
      RETURN
      END

C
C*****
C*
C*          ***SUBROUTINE RMODEL***
C*
C*****
C*
C* FOR A GIVEN TRAVEL TIME(TEST), THIS SUBROUTINE
C* WILL RETURN VOLUME OF THE ROAD(I).
C*
C*****
C
      SUBROUTINE RMODEL(I,TEST,VROAD)
      COMMON DEMAND, NUMRD, RDWY(10,5), SI(10,4),VOLROD(10)
      COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
      REAL DEMAND, RDWY, SI, LANES
      INTEGER NUMRD,MINVOL,MAXVOL,STEP

C
C*****
C* ASSIGN THE COEFFICIENT OF THE ROAD EQUATION
C*****
C
      S0 = SI(I,1)
      S1 = SI(I,2)
      S2 = SI(I,3)
      S3 = SI(I,4)
      LANES = RDWY(I,1)
      DIST = RDWY(I,2)
      SPEED = RDWY(I,3)
      C = RDWY(I,4)
      SIGNAL = RDWY(I,5)
C

```

```

C     CHECK SIGNALIZED OR UNSIGNALIZED ROADWAY.
C
C     IF (RDWY(I,5) .EQ. 0) GO TO 100
C     IF (RDWY(I,5) .GT. 0) GO TO 200
C
C*****
C*
C*     IF THE SIGNAL DENSITY IS A NEGATIVE VALUE,
C*     WRITE AN ERROR MESSAGE.
C*
C*****
C*
C     GO TO 910
C
C
C*****
C*
C*     ***FREEWAY MODEL***
C*
C*****
C*
C*     CHOOSE AN EQUATION ACCORDING TO THE GIVEN
C*     TRAVEL TIME, AND CALCULATE VOLUME OF THE
C*     ROAD WAY.
C*
C*****
C
C     100 T1 = DIST/S1
C         T2 = DIST/S2
C         IF (TEST .LE. T1) GO TO 110
C         IF (TEST .LE. T2) GO TO 120
C         GO TO 130
C
C     TEST = TRAVEL TIME AT V/C=0.8
C     110 VROAD = ( SO**2 - (2*(DIST/TEST) - SO)**2)/2
C         IF (VROAD .LT. 0) VROAD = 0
C         VROAD = LANES*VROAD
C         RETURN
C
C     TRAVEL TIME AT V/C=0.8 TEST = TRAVEL TIME AT V/C=1
C
C     120 VROAD = C*(0.8 + 0.2*(DIST/TEST - S1)/(S2 - S1))
C         VROAD = LANES*VROAD
C         RETURN
C
C     TRAVEL TIME AT V/C=1 TEST
C
C     130 VROAD = C*(1.0 + 0.5*(DIST/TEST - S2)/(10 - S2))
C         VOLMAX = 1.5 * C
C         IF (VROAD .GT. VOLMAX) VROAD = VOLMAX
C         VROAD = LANES*VROAD
C         RETURN
C
C*****
C*
C*     ***SIGNALIZED ROADWAY MODEL***
C*
C*****
C*

```

```

C*   CHOOSE AN EQUATION ACCORDING TO THE GIVEN          *
C*   TRAVEL TIME, AND CALCULATE VOLUME OF THE ROAD.    *
C*                                                     *
C*****
C
200 IF (SIGNAL .GE. 5.5) GO TO 201
    FN = -0.067*SIGNAL**3 + 0.781*SIGNAL**2 - 3.2232*SIGNAL
    GO TO 202
201 FN = 0.138*SIGNAL - 6.028
202 CONTINUE

C
    T1 = DIST/S1
    T2 = DIST/S2
    IF (TEST .LE. T1) GO TO 210
    IF (TEST .LE. T2) GO TO 220
    GO TO 230

C
    TEST   TRAVEL TIME AT V/C=0.8

C
210 VROAD = C/FN*(DIST/TEST - S0)
    IF (VROAD .LT. 0) VROAD = 0
    VROAD = LANES*VROAD
    RETURN

C
    TRAVEL TIME AT V/C=0.8   TEST = TRAVEL TIME AT V/C=1.0

C
220 VROAD = C*(0.8 + 0.2*(DIST/TEST - S1)/(S2 - S1))
    VROAD = LANES*VROAD
    RETURN

C
    TRAVEL TIME AT V/C=1.0   TEST

C
230 VROAD = C*(1.0 + 0.5*(DIST/TEST - S2)/(S2 - S1))
    VOLMAX = 1.5*C
    IF (VROAD .GT. VOLMAX) VROAD = VOLMAX
    VROAD = LANES*VROAD
    RETURN

C
    ERROR MESSAGE
910 WRITE (6,911)
911 FORMAT (' ', 'ERROR: SIGNAL DENSITY IS NEGATIVE')
    RETURN

C
    END

C
C*****
C*
C*   *** SUBROUTINE OTDATA ***
C*
C*****
C*
C*   THIS SUBROUTIEN WILL WRITE THE SYSTEM
C*   TRAVEL TIME, VOLUME OF EACH ROAD, AND
C*   VOLUME TO CAPACITY RATIOS.
C*
C*****
C
C
C
C
SUBROUTINE OTDATA (SYST)

```

```

COMMON DEMAND, NUMRD, RDWY(10,5), SI(10,4),VOLROD(10)
COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
REAL DEMAND,RDWY,SI,SYSTT
REAL VRATIO(10),CAPCTY(10)
INTEGER NUMRD,MINVOL,MAXVOL,STEP

C
WRITE(6,10)
10 FORMAT('1',20X,'***** OUTPUT OF SIMULATION *****')
C
C   CLCULATE VOLUME TO CAPACITY RATIO OF SYSTEM
C   C = 0
C   DO 100 I = 1,NUMRD
C   C = C + RDWY(I,4)*RDWY(I,1)
100 CONTINUE
RATIO = DEMAND/C
VOLSYS=DEMAND

C
WRITE(6,20) VOLSYS,RATIO
20 FORMAT('0',10X,'SYSTEM VOLUME=',F10.0,
*         10X,'SYSTEM V/C RATIO=',F6.2)
C
SYSMIN = 60*SYSTT
WRITE(6,30) SYSMIN
30 FORMAT ('0',10X,'SYSTEM TRAVEL TIME=',F7.2)
C
WRITE(6,40)
40 FORMAT('0',20X,'VOLUME',T40,'CAPACITY',
*         T60,'VOLUME TO CAPACITY RATIO')
C
C   CALCULATE V/C RATIO OF EACH ROADWAY.
C
C
RODMAX = 0.0
SYSVOL = 0.0
C
DO 200 I = 1,NUMRD
CAPCTY(I) = RDWY(I,4) * RDWY(I,1)
VRATIO(I) = VOLROD(I)/CAPCTY(I)
SYSVOL = SYSVOL + VOLROD(I)
C
C
IF (VOLROD(I) .LE. RODMAX) GOTO 200
RODMAX = VOLROD(I)
INDEX = I
C
C
200 CONTINUE
C
C
DIFF = SYSVOL - DEMAND
VOLROD(INDEX) = VOLROD(INDEX) - DIFF
VRATIO(INDEX) = VOLROD(INDEX) / CAPCTY(INDEX)
C
C
DO 222 J = 1,NUMRD
WRITE(6,50) J,VOLROD(J),CAPCTY(J),VRATIO(J)
222 CONTINUE
C
C
50 FORMAT('0',7X,'ROAD(',I2,')',T20,F6.0,T40,F6.0,T60,F6.2)

```



RETURN  
END

```
C
C
C*****
C*
C*          ***SUBROUTINE INDATA***
C*
C*****
C*
C*  THIS SUBROUTINE READS INPUT DATA USING THE
C*  FOLLOWING FORMAT.
C*
C*****
C-----
C          **** INPUT DATA FILE ****
C INDEX= N CHOICE= N RDNUM= N MIN = N MAX = N INC = N
C MINVOL = N MAXVOL = N STEP = N
C TOTAL DEMAND VOLUME=XXXXXXXXXX
C NUMBER OF ROADS =XXX
C          LANES      DISTANCE  SPEED      CAPACITY  SIGNAL
C RDWY1      X          X          X          X          X
C RDWY2      X          X          X          X          X
C SPEED1  DIST1  SPEED2  DIST2  SPEED3  DISTSPEED4  DIST4  SPEED5  DIST5
C -          -          -          -          -          -          -          -
C -          -          -          -          -          -          -          -
C RDWYN      X          X          X          X          X
C-----
C
C          SUBROUTINE INDATA(IFLAG,INDEX1)
C          COMMON DEMAND,NUMRD,RDWH(10,5),SI(10,4),VOLROD(10)
C          COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP
C          REAL DEMAND,RDWH,SI,SPEEDS(5),DISTS(5)
C          INTEGER NUMRD,MINVOL,MAXVOL,STEP,CHOICE,RDNUM
C          INTEGER MIN,MAX,INC,INDEX1
C
C
C          READ(5,15,END=110) INDEX1,CHOICE,RDNUM,MIN,MAX,INC
15  FORMAT(/6(8X,12))
C
C          READ(5,60) MINVOL,MAXVOL,STEP
60  FORMAT(3(10X,15))
C
C          WRITE(6,16) INDEX1,CHOICE,RDNUM,MIN,MAX,INC,
*          MINVOL,MAXVOL,STEP
16  FORMAT(//,T25,'INDEX = ',T35,I10,/,T25,'CHOICE = ',T35,
*          I10,/,T25,'RDNUM = ',T35,I10,/,T25,'MIN = ',T35,
*          I10,/,T25,'MAX = ',T35,I10,/,T25,'INC = ',T35,
*          I10,/,T25,'MINVOL = ',T35,
*          I10,/,T25,'MAXVOL = ',T35,I10,/,T25,'STEP = ',T35,
*          I10,///)
C
C
C          READ(5,10,END=110) DEMAND
10  FORMAT (20X,F10.0)
          READ(5,20,END=110) NUMRD
```

```

20 FORMAT (20X,I3/)
WRITE(6,21) DEMAND,NUMRD
21 FORMAT(//10X,'DEMAND=',F10.0,10X,'NUMBER OF ROADWAYS=',I3)
C*
IF(NUMRD .GT. 10) GOTO 110
C*
C
WRITE(6,35)
35 FORMAT('0',T25,' LANES',T35,'DISTANCE',T45,' SPEED',T55,
* 'CAPACITY',T65,' SIGNAL')
C
C
DO 100 I = 1,NUMRD
TLENTH = 0.0
TSPEED = 0.0
C
READ (5,40,END=120) (RDWY(I,J),J=1,5)
IF (RDWY(I,3) .GT. 0.0) GOTO 65
READ (5,70) (SPEEDS(J),DISTS(J), J=1,5)
C
DO 200 J=1,5
IF (DISTS(J) .LE. 0.0) GOTO 110
IF (SPEEDS(J) .LE. 0.0) GOTO 110
C
TLENTH = TLENTH + DISTS(J)
TSPEED = TSPEED + SPEEDS(J)*DISTS(J)
200 CONTINUE
C
RDWY(I,3) = TSPEED / TLENTH
WRITE(6,30) I, (RDWY(I,J),J=1,5)
GOTO 100
65 WRITE(6,30) I, (RDWY(I,J),J=1,5)
100 CONTINUE
40 FORMAT(10X,F10.0,F10.2,2F10.0,F10.0)
30 FORMAT(10X,'ROAD(',I3,')',T20,F10.0,F10.2,3F10.0)
70 FORMAT(10F6.1)
120 RETURN
C
110 WRITE(6,111)
111 FORMAT('0',5X,'ERROR: ERROR IN INPUT DATA')
IFLAG = 1
RETURN
C
C
END
C
C*****
C*
C* ***SUBROUTINE CALSI***
C*
C*****
C*
C* CALCULATE CRITICAL SPEEDS OF THE SPEED VERSUS
C* V/C RELATION. ASSIGN THOSE VALUES TO
C* ARRAY SI(10,4).
C*
C*****
C
SUBROUTINE CALSI(IFLAG)
COMMON DEMAND,NUMRD,RDWY(10,5),SI(10,4),VOLROD(10)

```

COMMON MINVOL,MAXVOL,CHOICE,RDNUM,MIN,MAX,INC,STEP  
REAL DEMAND,RDWY,SI  
INTEGER NUMRD,MINVOL,MAXVOL,STEP

C

DO 100 I=1,NUMRD

C

C

CHECK SIGNALIZED OR UNSIGNALIZED ROADWAY.

C

IF (RDWY(I,5) .EQ. 0) GO TO 10

IF (RDWY(I,5) .GT. 0) GO TO 20

GO TO 910

C

C

UNSIGNALIZED ROADWAY

C

10 SI(I,1) = RDWY(I,3)

SI(I,2) = 0.5\*( SI(I,1)+( SI(I,1)\*\*2 - 2\*0.8\*RDWY(I,4))\*\*(1/2))

SI(I,3) = SI(I,1)/2

SI(I,4) = 10

C

GO TO 100

C

C

SIGNALIZED ROADWAYS

C

20 SO = 3600/(3600/RDWY(I,3) + 12.5\*RDWY(I,5))

SIGNAL = RDWY(I,5)

IF (SIGNAL .GE. 5.5) GO TO 40

FN = -0.067\*SIGNAL\*\*3 + 0.781\*SIGNAL\*\*2 - 3.2232\*SIGNAL

GO TO 50

40 FN = 0.138\*SIGNAL - 6.028

50 CONTINUE

SI(I,1) = SO

SI(I,2) = SO + 0.8\*FN

SI(I,3) = SO/2

SI(I,4) = 5

C

100 CONTINUE

RETURN

C

C

WRITE ERROR MESSAGE

C

910 WRITE (6,30)

30 FORMAT ('1',20X,'ERROR: SIGNAL DENSITY IS NEGATIVE')

IFLAG = 1

RETURN

C

END

C

C

C

C

C

C

C

C

//\$DATA

\*\*\* INPUT DATA FILE \*\*\*

INDEX1= 3 CHOICE= 1 RDNUM= 3 MIN = 1 MAX= 3 INC= 1

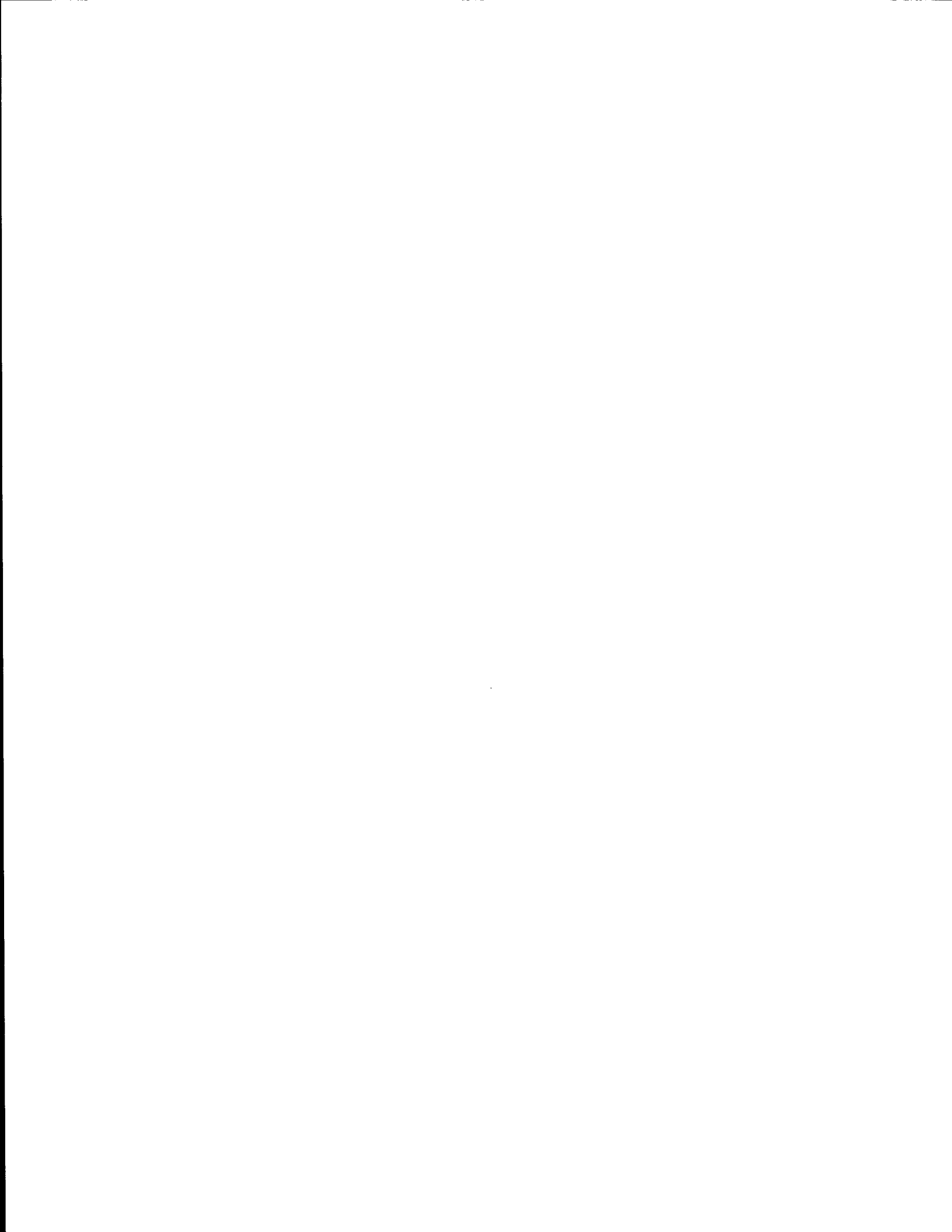
MINVOL = 1000 MAXVOL = 15000 STEP = 2000

TOTAL DEMAND VOLUME= 2000.0

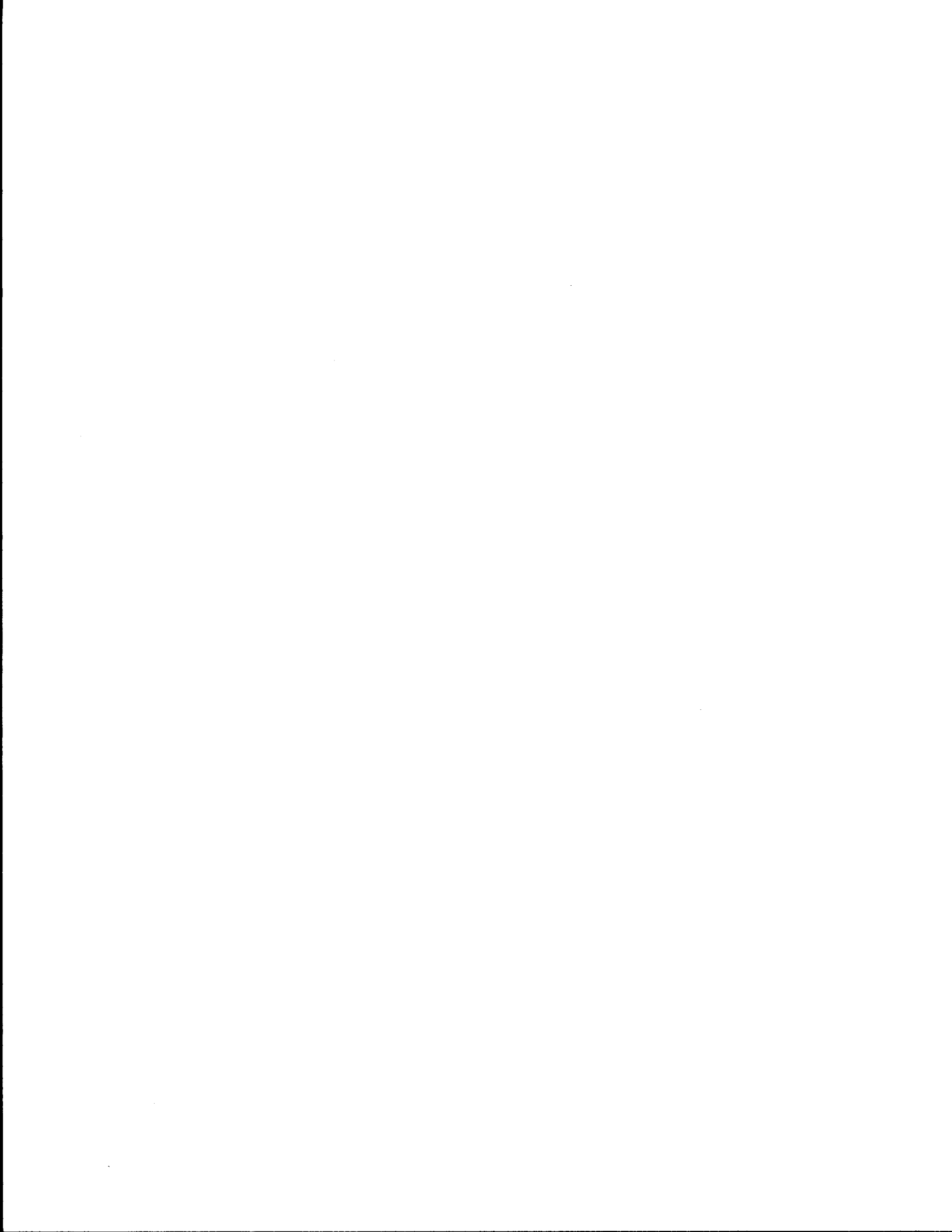
NUMBER OF RDWYS = 3

RDWY1	LANES	DISTANCE	SPEED	CAPACITY	SIGNAL
	3.	6.0	35.	400.	2.

RDWY2	2.	5.0	30.	600.	5.
RDWY3	4.	4.0	55.	900.	0
//*END					



APPENDIX C



\*\*\* INPUT DATA \*\*\*

INDEX = 1  
CHOICE = 1  
RDNUM = 3  
MIN = 1  
MAX = 1  
INC = 1  
MINVOL = 1000  
MAXVOL = 5000  
STEP = 100

DEMAND= 2000. NUMBER OF ROADWAYS= 3

	LANES	DISTANCE	SPEED	CAPACITY	SIGNAL
ROAD( 1)	3.	6.00	35.	400.	2.
ROAD( 2)	2.	5.00	30.	600.	5.
ROAD( 3)	4.	4.00	55.	900.	0.

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 2000. SYSTEM V/C RATIO= 0.33

SYSTEM TRAVEL TIME= 4.80

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	2000.	3600.	0.56



\*\*\* INPUT DATA \*\*\*

INDEX = 2  
CHOICE = 1  
RDNUM = 3  
MIN = 1  
MAX = 3  
INC = 1  
MINVOL = 1000  
MAXVOL = 5000  
STEP = 100

DEMAND= 2000.

NUMBER OF ROADWAYS= 3

	LANES	DISTANCE	SPEED	CAPACITY	SIGNAL
ROAD( 1)	3.	6.00	35.	400.	2.
ROAD( 2)	2.	5.00	30.	600.	5.
ROAD( 3)	4.	4.00	55.	900.	0.

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 2000. SYSTEM V/C RATIO= 0.61

SYSTEM TRAVEL TIME= 14.14

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	838.	1200.	0.70
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	1162.	900.	1.29

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 2000. SYSTEM V/C RATIO= 0.48

SYSTEM TRAVEL TIME= 10.18

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	2000.	1800.	1.11

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 2000. SYSTEM V/C RATIO= 0.39

SYSTEM TRAVEL TIME= 4.99

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	2000.	2700.	0.74

\*\*\* INPUT DATA FILE \*\*\*

INDEX = 3  
CHOICE = 1  
RDNUM = 3  
MIN = 1  
MAX = 1  
INC = 1  
MINVOL = 1000  
MAXVOL = 15000  
STEP = 2000

DEMAND= 2000.

NUMBER OF ROADWAYS= 5

	LANES	DISTANCE	SPEED	CAPACITY	SIGNAL
ROAD( 1)	3.	6.00	35.	400.	2.00
ROAD( 2)	2.	5.00	30.	600.	5.00
ROAD( 3)	4.	4.00	55.	900.	0.00
ROAD( 4)	4.	5.50	45.	800.	3.00
ROAD( 5)	3.	5.00	50.	900.	2.00

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 1000. SYSTEM V/C RATIO= 0.08  
SYSTEM TRAVEL TIME= 4.56

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	1000.	3600.	0.28
ROAD( 4)	0.	3200.	0.00
ROAD( 5)	0.	2700.	0.00

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 3000. SYSTEM V/C RATIO= 0.25  
SYSTEM TRAVEL TIME= 5.10

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	3000.	3600.	0.83
ROAD( 4)	0.	3200.	0.00
ROAD( 5)	0.	2700.	0.00

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 5000. SYSTEM V/C RATIO= 0.42

SYSTEM TRAVEL TIME= 8.66

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	3279.	3600.	0.91
ROAD( 4)	0.	3200.	0.00
ROAD( 5)	1721.	2700.	0.64

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 7000. SYSTEM V/C RATIO= 0.59

SYSTEM TRAVEL TIME= 10.98

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	4181.	3600.	1.16
ROAD( 4)	425.	3200.	0.13
ROAD( 5)	2394.	2700.	0.89

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 9000.                    SYSTEM V/C RATIO= 0.76  
SYSTEM TRAVEL TIME= 11.95

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	0.	1200.	0.00
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	4362.	3600.	1.21
ROAD( 4)	2167.	3200.	0.68
ROAD( 5)	2471.	2700.	0.92

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 11000.                    SYSTEM V/C RATIO= 0.92  
SYSTEM TRAVEL TIME= 14.27

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	912.	1200.	0.76
ROAD( 2)	0.	1200.	0.00
ROAD( 3)	4699.	3600.	1.31
ROAD( 4)	2775.	3200.	0.87
ROAD( 5)	2614.	2700.	0.97

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 13000. SYSTEM V/C RATIO= 1.09

SYSTEM TRAVEL TIME= 18.45

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	1081.	1200.	0.90
ROAD( 2)	838.	1200.	0.70
ROAD( 3)	5091.	3600.	1.41
ROAD( 4)	3060.	3200.	0.96
ROAD( 5)	2929.	2700.	1.08

\*\*\*\*\* OUTPUT OF SIMULATION \*\*\*\*\*

SYSTEM VOLUME= 15000. SYSTEM V/C RATIO= 1.26

SYSTEM TRAVEL TIME= 27.51

	VOLUME	CAPACITY	VOLUME TO CAPACITY RATIO
ROAD( 1)	1265.	1200.	1.05
ROAD( 2)	1158.	1200.	0.96
ROAD( 3)	5400.	3600.	1.50
ROAD( 4)	3715.	3200.	1.16
ROAD( 5)	3462.	2700.	1.28

APPENDIX D





## Main Program

- CHOICE - Variable to Select the parameter to be varied during program execution.
- DEMAND - System demand volume to be assigned to the system of roadways.
- INC - Increment step size to vary the parameter values from 'MIN' to 'MAX'.
- IFLAG - Flag variable to be set whenever an error condition exists during program execution.
- INDEX1 - Variable to determine which of the three program segments to be executed.
- MAX - Maximum limit for parameter variation during program execution.
- MAXVOL - Maximum limit for volume demand variation during program execution.
- MIN - Minimum initial value for the selected parameter during program execution.
- MINVOL - Minimum initial volume for volume demand variation during program execution.
- NUMRD - Number of roadways in the given system. Maximum number of roadways is set to 10.
- RDNUM - Variable to select a particular roadway to be analyzed during program execution.
- RDWY - Double dimensioned array of the size (10,5), which contains all of the characteristics of the system of roadways.
- SI - Double dimensioned array of the size (10,4), which contains all of the system inflection points of individual roadways in the system. Each roadway has 4 critical inflection points.
- STEP - Increment step size to be used while varying system volume from 'MINVOL' to 'MAXVOL'.
- TRDWY - Variable to hold system travel time calculated by the subroutine CALTT.
- VOLROD - Single dimensioned array of 10 elements to hold the volume assigned to each roadway calculated by subroutine RMODEL.
- VOLSYS - Copy of variable DEMAND to be used as a temporary variable.

## Subroutine CALTT

### PARAMETERS USED ARE:

- IFLAG - Variable set to notify error condition to the main program.
- SYSTT - Holds the system travel time calculated in this subroutine.
- VOLSYS - Holds the value for system demand volume for either single travel time calculation on demand volume variation.

### VARIABLES USED ARE:

- DIFF - Difference between system demand volume and total volume allowed with given system travel time.
- EPSILON - 1% of the system demand volume used to terminate binary search of system travel time.
- NUMRD - Contains the number of roadways in the system.
- TEST - Mid-point of THIGH and TLOW used as an intermediate system travel time to calculate the system volume.
- THIGH - Extra copy of TMAX used during the binary search of SYSTT.
- TMAX - Initial minimum system travel time set to 0 seconds for SYSTT calculation.
- TIMIN - Initial maximum system travel time set to 1000 seconds for SYSTT calculations.
- TT0 - Initial system travel time calculated by using the crawl speed of the roadway.
- TT3 - Initial system travel time calculated by using the lowest v/c ratio of the system.
- VOLUME - Contains the maximum roadway volume allowed given the system travel time. VOLUME is calculated in the subroutine TRIAL.
- VSUM - Maximum system volume allowed the given roadway system. VSUM is calculated as 1.5\* capacity volume of the system.

## Subroutine TRIAL

### PARAMETERS USED ARE :

- TEST - Given system travel time to be used to calculate the system volume.
- VOLUME - System volume calculated by using the given system travel time TEST.

### VARIABLES USED ARE :

- VOLROD - Array of 10 elements to hold the volume on each roadway given the system travel time.
- VROAD - Contains the volume on the selected roadway calculated by the subroutine RMODEL.
- VTEMP - Temporary accumulation variable to sum the volume on each roadway to obtain the entire system volume.
- VROAD - Parameter used to pass the volume of a particular roadway calculated using the given travel time.

## Subroutine RMODEL

### PARAMETERS USED ARE:

- I - Parameter to select the particular roadway from the system of roadways.
- TEST - Parameter used to pass the given system travel time for volume calculation.
- VRoad - Parameter used to pass the volume of a particular roadway calculated using the given travel time.

### VARIABLES USED ARE:

- C - Input per lane capacity value of a roadway system.
- DIST - Input distance between the origin and destination points for the selected roadway.
- FN - Coefficient used for signalized roadway to calculate volume on the selected roadway.
- LANES - Number of lanes on the roadway.
- S0 - Coefficient used when  $v/c < 0.8$ .
- S1 - Coefficient used when  $0.8 < v/c \leq 1.0$ .
- S2 - Coefficient used when  $1.0 < v/c \leq 1.5$ .
- S3 - Coefficient used at crawl speed.
- SIGNAL - Signal density per mile of the selected roadway.
- SPEED - Posted speed on the selected roadway.
- T1 - Coefficient used to select the different equations to calculate the roadway volume.
- T2 - Coefficient used to select the different equations to calculate the roadway volumes.
- VOLMAX -  $1.5 * \text{CAPACITY}$  of the roadway used to guard against overflow of the roadway.

## Subroutine OTDATA

### PARAMETER USED:

SYSTT - Parameter used to transfer system travel time used to calculate volume.

### VARIABLES USED ARE:

C - Capacity of the selected roadway.

CAPACITY - Array of 10 elements to contain capacities of each roadway in the system.

NUMRD - Number of roadways in the system.

RATIO - Ratio of demand and the capacity.

RODMAX - Temporary variable to hold value of roadway volume during execution, initially set to zero.

SYSMIN - System travel time expressed in minutes.

SYSVOL - Accumulator variable used to sum up all of the roadway system volume.

VRATIO - Array of 10 elements to contain v/c ratio of all the roadways in the system.

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Subroutine INDATA

PARAMETERS USED ARE :

- IFLAG - Used to indicate error condition in the input data.
- INDEX1 - Used to transfer the value of INDEX1 back to the main program.

VARIABLES USED ARE :

- CHOICE - Variable to select the parameter to be varied during program execution.
- INC - Increment step size to vary the parameter values from 'MIN' to 'MAX'.
- MAX - Maximum limit for parameter variation during program execution.
- MAXVOL - Maximum limit for volume demand variation during program execution.
- MIN - Minimum initial values for the selected parameter during program execution.
- MINVOL - MINIMUM initial volume for volume demand variation during program execution.
- NUMRD - Number limit for volume demand variation during program execution.
- RDNUM - Select a particular roadway to be analysed during program execution.
- STEP - Increment step size to be used when varying system volume from 'MINVOL' to 'MAXVOL'.
- TLENGTH - Total length of the roadway system used to calculate the average speed for the entire system.
- TSPEED - Total speed of the system to be used to calculate the average speed for the entire system.

## Subroutine CALSI

### PARAMETER USED:

IFLAG - Used to indicate an error condition, i.e., negative signal density.

### VARIABLES USED ARE:

- FN - Coefficient used for signalized roadway to calculate volume on the selected roadway.
- NUMRD - Number of roadways in the system used as upper limit for loop iterations.
- RDWY - Double dimensioned array of the size (10,5), which contains all of the system roadway characteristics.
- SI - Double dimensional array of the size (10,4), which contains all of the system inflection points of individual roadways in the system.