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Transit Action Performance Model (TAPM)

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16. Abstract

   TAPM is a program package designed to help a traffic engineer or transit planner evaluate the impacts of actions intended to improve the movement of people on urban roads. At the present time TAPM contains four models.

   The signal-preemption model permits the user to evaluate different bus preemption signal strategies at an isolated intersection with no nearside bus stop. The bus-stop-spacing model helps the user to determine the optimum bus stop spacing for a bus route along a straight road with bus stops spaced equally apart. The signal-setting model is used for finding a fixed cycle length which minimizes total person delay at a simple crossing intersection. The HOV model is intended for the analysis of impacts of a proposed high-occupancy-vehicle lane of a freeway.

   This final report contains the list of necessary equipment, diskettes, and the basic instructions of how to get started, as well as a short description of the models.

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CHAPTER I

INTRODUCTION

TAPM is a program package designed to help a traffic engineer or transit planner evaluate the impacts of actions intended to improve the movement of people on urban roads. It has been prepared with the aid of the grant from UMTA (MI-11-0008), additional assistance from UMTA, and the University of Michigan. At the present time TAPM contains models capable of calculating the effects of the following actions:

1. Bus Signal-Preemption, PREEMPT

2. Bus-Stop-Spacing, BUSTOP

3. Isolated Intersection Signal Setting, BEAST

4. High-Occupancy-Vehicle Exclusive-Lane, HOVEL, (IBM and Compatibles only).

The Bus Signal-Preemption model permits the user to evaluate different bus preemption signal strategies at an isolated intersection with no nearside bus stop. It is assumed that the signal controller has green phase extension and red phase truncation capabilities, and that passenger cars and buses arrive randomly.

The Bus-Stop-Spacing model helps the user to determine the optimum bus stop spacing for a bus route along a straight road with bus stops spaced equally apart. It is assumed that each stop is surrounded by a circular catchment area, and that the land use within the catchment area is homogeneous and generates passenger trips at a constant rate.

The Isolated Intersection Signal Setting model is used for finding a fixed cycle length which minimizes total person delay at a simple crossing intersection. It is assumed that the signal controller has two phases (green and red) and yellow time is included in the green phase. The model also assumes that traffic flow does not exceed the intersection's capacity.

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The High-Occupancy-Vehicle Exclusive-Lane model is intended for the analysis of impacts of a proposed high-occupancy-vehicle lane of a freeway. The model assumes the freeway has at least six lanes in both directions.

The first three models were used in a short course, "The Essentials of Traffic Engineering for Transit Managers", held at the University of Michigan Transportation Research Institute in Ann Arbor, Michigan, September, 1984. The students, practicing transportation professionals, used the models to solve illustrative problems. Professor L. P. Kostyniuk demonstrated and used the package in a transportation engineering course at the Michigan State University, in E. Lansing, in the 1985 Winter term. Several comments and suggestions received from the students were reviewed and incorporated in the programs.

In general, an analytic approach is taken in TAPM. TAPM emphasizes the methodology to solve problems rather than the solutions to specific problems. Users can modify the models according to their specific needs. TAPM is user friendly, and the diskettes contain all explanations and operating instructions. The diskettes also contain the bibliographic references of the models.

This report contains the list of necessary equipment, diskettes, and the basic instructions of how to get started, as well as a short description of the models. The appendix presents examples of screen displays of program menus and output.

CHAPTER II

INSTRUCTIONS FOR USE OF TAPM

Microcomputer Equipment

TAPM can presently be run on APPLE II+, IIe, IBM PC, IBM PC/XT/AT, and IBM PC compatibles. The following requirements for the microcomputer equipment apply:

APPLE II+, IIe

1. 64K RAM

2. PASCAL language card

3. 2 Disk Drives

4. Printer

5. Monitor

IBM PC, PC/XT/AT, and IBM PC compatibles

1. 128K RAM

2. DOS 2.0

3. At least one disk drive

4. Printer

5. Monitor

Note: DOS 1.0 can also be used. In this case, copy the files first separately from the DOS 2.0 diskettes using a DOS 2.0 system to formatted DOS 1.0 diskettes, then run the models by using the file names of the disk directory.

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Programs and Diskettes

The source programs of TAPM were written originally for the Apple in Apple Pascal. Later, to make the programs transportable, the original Apple versions were modified and partly rewritten to meet the requirements of Standard Pascal. Because of this, the IBM version does not include the graphics output capability. The IBM version was compiled with the Turbo-Pascal compiler of Borland International, version 2.00B PC-DOS. Figures 2.1 and 2.2 present the program structures of Apple Pascal and Standard Pascal versions, respectively. In the Apple version, the model, explanation routines, and functions are stored in separate files. When the programs were compiled the routines were chained to one program package. On the IBM PC version each model is a "stand-alone" program package. This permits the copying of any of the programs to another diskette or directory, and running it independently of other programs, including the menu program, MENU.COM, and the introductory program, TAPM.COM. However, no knowledge of the program structures is needed to run the programs. The programs are user friendly and prompt the instructions on the screen when they are run.

TAPM on Apple - Two diskettes are required to use TAPM. A third is necessary if one wishes to store input data for later reference and use. TAPM1 and TAPM3 are the diskettes on which the models are stored. TAPM1 contains the models Signal-Preemption (PREEMPT) and Bus-Stop-Spacing (BUSTOP). TAPM3 contains the model Signal Timing (BEAST). The program High-Occupancy-Vehicle Exclusive-Lane (HOVEL) is not available in the Apple-TAPM version. TAPM2 is a user provided diskette on which data can be stored. This diskette must be formatted in Apple Pascal and must be labeled TAPM2. For instructions on labeling and formatting diskettes see an Apple disk operating manual.

Operation of TAPM on an Apple Computer

- Insert either TAPM1: or TAPM3: into disk drive 1.

- Insert TAPM2: into drive 2 if you wish to store data on a file.

- Turn on the computer (or press RESET). The computer will take

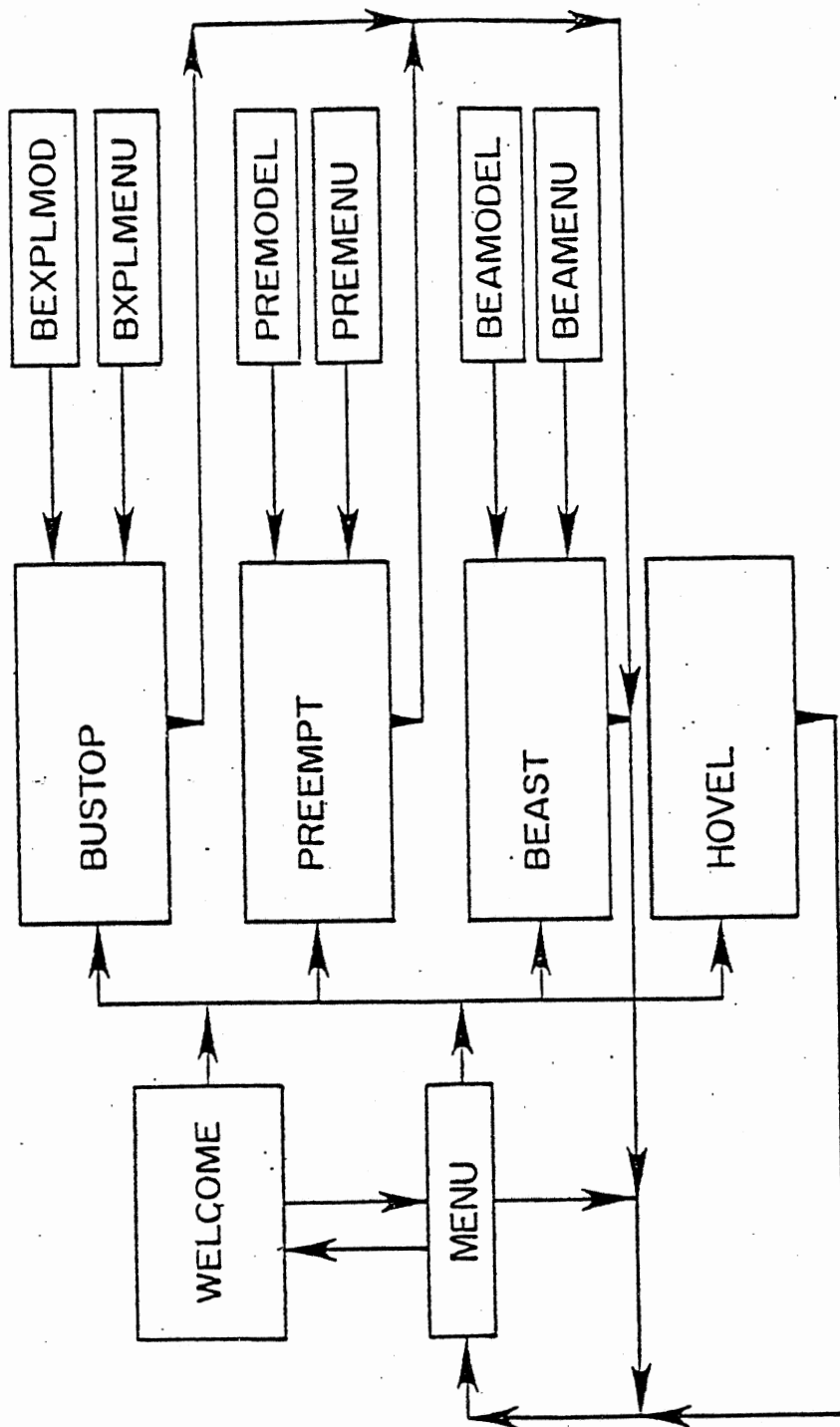Figure 2.1: Program Structure TAPM in APPLE II+/IIe
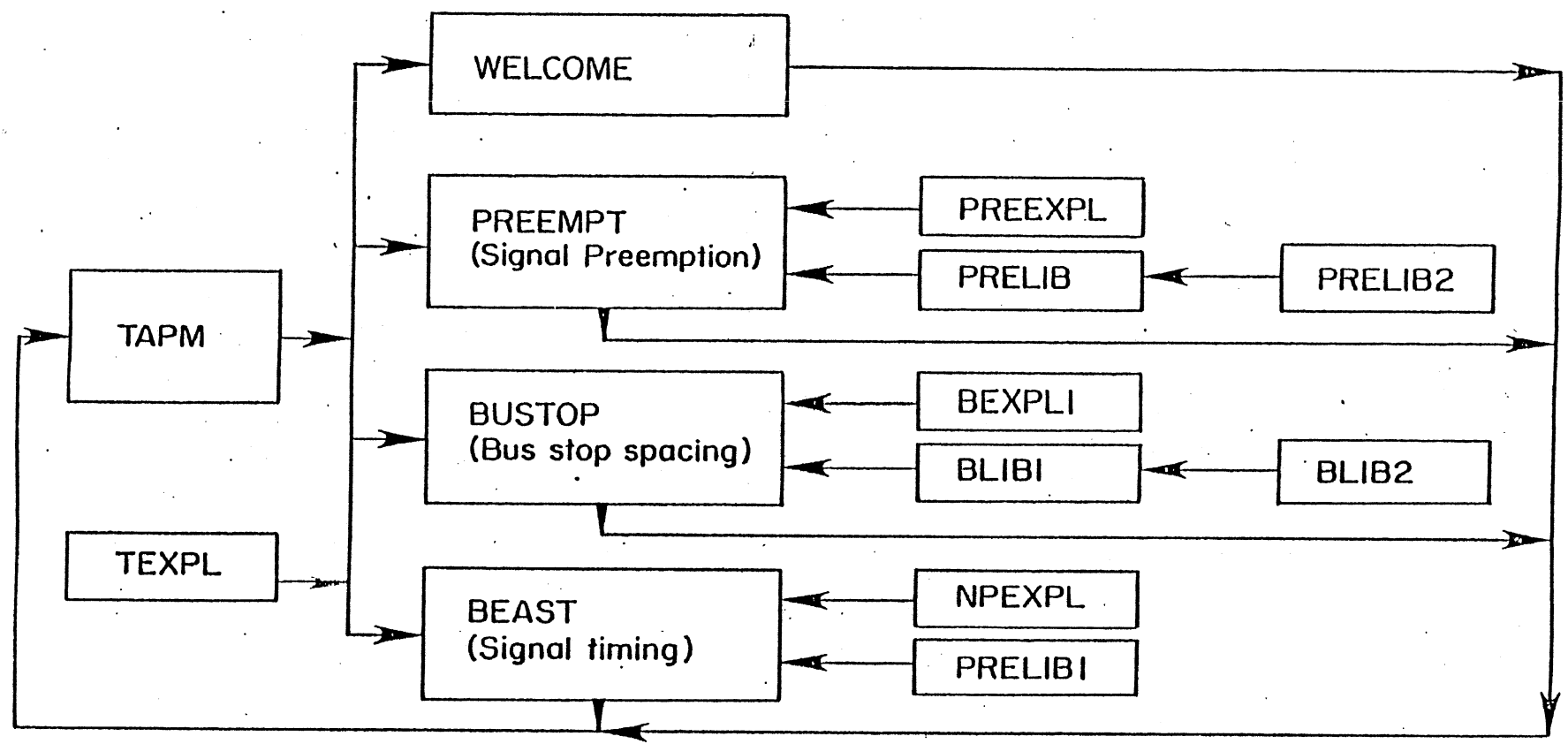
Figure 2.2: Program Structure TAPM in IBM PC & compatibles

approximately 10 seconds to 'boot' before the TAPM title appears on the screen.

- Follow the directions and select the model you wish to exercise. Since some of the models are stored on TAPM1: and others on TAPM3:, the computer will prompt you with a question to check and to put the appropriate diskette into the default drive. After you are done with TAPM, pull out the diskettes and turn off the machine.

TAPM on IBM and Compatibles - One diskette is required to use TAPM. TAPM, Transit Action Performance Model, is the diskette on which the models are stored. The diskette contains all the models: Signal-Preemption (PREEMPT), Bus-Stop-Spacing (BUSTOP), Signal Timing (BEAST) and High-Occupancy-Vehicle Exclusive-Lane (HOVEL).

Operation of TAPM on an IBM PC

- Insert TAPM diskette into the default disk drive, (A or B).

- Turn on the computer (or reset the computer by pressing the keys Ctrl+Alt+Del at the same time). It will take approximately 10 seconds to 'boot' before the TAPM title appears on the screen.

- Follow the directions and select the model you wish to exercise. Since the models are separate programs in separate files, they can be run directly from the directory by typing in a single number and pressing the RETURN-key, denoted <ret> below, (called ENTER in some computers), as follows:

Signal-Preemption   - type in: 1 <ret>

Bus-Stop-Spacing   - type in: 2 <ret>

Optimal-Signal-Timing   - type in: 3 <ret>

High-Occupancy-Vehicle Lane - type in: 4 <ret>

The TAPM menu is in a file called MENU.COM. You can get the menu any time while in the operating system command mode, (prompt C>), by typing in MENU and pressing the RETURN key. After you are done with TAPM, pull out the diskette and turn off the machine.

CHAPTER III

TAPM MODELS

Signal-Preemption Model (PREEMPT)

The signal-preemption model employed in TAPM was published by Radwan and Hurley in 1982. This macroscopic model applies a stochastic procedure to evaluate different bus-preemption-signal strategies at an isolated intersection with no nearside bus stop. The model permits the user to evaluate certain operation strategies for both main street and cross street bus traffic. It is assumed that the signal controller has green-phase extension and red-phase truncation capabilities. Webster's delay formula is used in delay calculations. See the appendix for example screen display of the program menus and output.

The basic concept of the model is to investigate all possible cases in which any bus detection event may result in signal preemption, either green extension or red truncation. The probabilities of these preemption events and the corresponding signal cycle lengths and signal splits are listed. The cycle lengths, proportions of the cycle which are effectively green, degree of saturation, and flow rates are substituted in Webster's delay formula to determine the average delays per approaching vehicle for individual cases. These average delays and their probabilities are used to determine the expected delay for each vehicle.

Appropriate adjustments and assumptions are made to calculate passenger car delays and bus delays, which are divided into stop-time delay and delay due to acceleration and deceleration. The time lost due to a stop is assumed to be 5.56 seconds per passenger car and 13.78 seconds per bus, assuming an average speed of 25 mph for heavily traveled urban streets. The total person delays for passenger cars and buses are obtained accordingly by assuming a certain vehicle occupancy.


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Model Assumptions - The following are the assumptions made to formulate the analytical model:

1. An isolated intersection with two critical one-way approaches. Random arrivals of passenger cars and buses are assumed.

2. A pretimed signal controller with a two-phase plan and a cycle determined from Webster's optimum cycle formula for vehicular delay. A lost time of 5 seconds is used for both streets.

3. The minimum red phase durations for both streets are determined from Webster's minimum cycle formula with a minimum of 15 seconds.

4. The absolute minimum cycle length is 35 seconds and the absolute maximum cycle length is 280 seconds.

5. A detector is located about 250 feet upstream from the intersection with an average time of 7 seconds needed for a bus to clear the intersection from that point. The location of the detectors does not allow for nearside bus stops.

6. A saturation flow rate of 1700 passenger car equivalents per hour per lane is used.

7. A bus capacity weighting of 2.25 passenger car equivalents, PCU, is used.

8. An average car occupancy of 1.4 passengers is used.

Some of the above parameters can be varied in a sensitivity analysis.

Model Development - The determination of the minimum red phases for both streets is based on the minimized red phase constraints estimated from Webster's minimum cycle formula, or the absolute minimum phase of 15 seconds, whichever is greater. These minimum red phase durations, combined with the bus detection time periods within which green extension may be granted, create four possible operational scenarios as shown in Figure 3.1. The four scenarios are:

SCENARIO 1
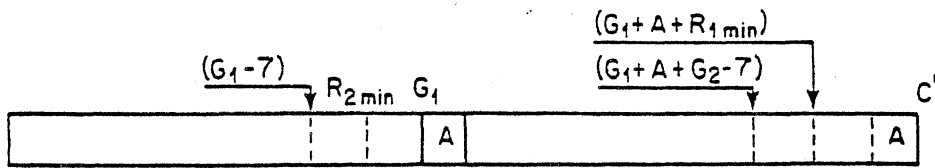
SCENARIO 2
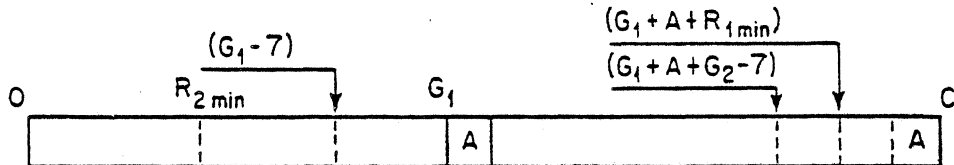
SCENARIO 3

SCENARIO 4

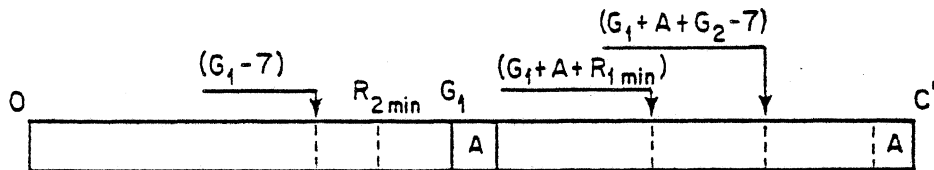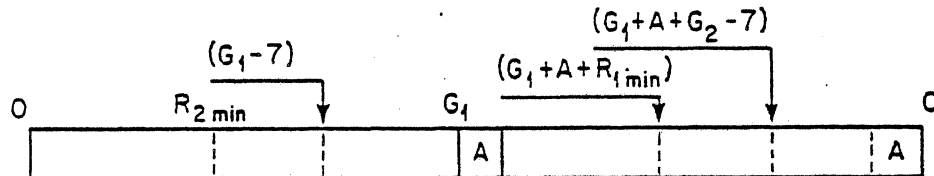Where: G_1 = Green phase on main street

G_2 = Green phase on cross street

A = Amber phase

$R_{1\,min}$ = Minimum red phase on main street

$R_{2\,min}$ = Minimum red phase on cross street

C' = Webster's optimum cycle duration

Figure 3.1: Four Possible Signal Operation Scenarios

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1. $R_{1\ min} - A > G_2 - 7$ and $R_{2\ min} - A > G_1 - 7$

2. $R_{1\ min} - A > G_2 - 7$ and $R_{2\ min} - A < G_1 - 7$

3. $R_{1\ min} - A < G_2 - 7$ and $R_{2\ min} - A > G_1 - 7$

4. $R_{1\ min} - A < G_2 - 7$ and $R_{2\ min} - A < G_1 - 7$

where

G_1 = green phase on street 1

G_2 = green phase on street 2

$R_{1\ min}$ = minimum red phase on street 1

$R_{2\ min}$ = minimum red phase on street 2

A = amber phase

In general, there are a total of ten operational cases for any cycle:

Case 1: No buses in a cycle

Case 2: Buses arrive, but there is no preemption

Case 3: Street 1 green extension

Case 4: Street 2 green extension

Case 5: Street 1 red truncation with red phase equal to $R_{1\ min}$

Case 6: Street 1 red truncation between $G_1 + A + R_{1\ min}$ and $G_1 + A + G_2 - 7 + A$

Case 7: Street 1 red truncation after $G_1 + A + G_2 - 7 + A$

Case 8: Street 2 red truncation with red phase equal to $R_{2\ min}$

Case 9: Street 2 red truncation between $R_{2\ min}$ and $G_1 - 7 + A$

Case 10: Street 2 red truncation between $G_1 - 7 + A$ and $G_1 + A$

Examination of Figure 3.1 reveals that the number of cases for scenarios 1, 2, 3, and 4 are 8, 9, 9, and 10 cases, respectively.

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The cycle interval is divided into six appropriate intervals:

Interval 1: from $C'-A$ to C', and from 0 to $R_{2\ min}-A$

Interval 2: from $R_{2\ min}-A$ to G_1-7

Interval 3: from G_1-7 to G_1

Interval 4: from G_1 to $G_1+A+R_{1\ min}-A$

Interval 5: from $G_1+A+R_{1\ min}-A$ to G_1+A+G_2-7

Interval 6: from G_1+A+G_2-7 to $C'-A$

where C' = Webster's optimum cycle duration

The probability of no bus arrivals during each of the 6 intervals is presented in a matrix format, Table 3.1, with the element X_{ij} being the probability of interval i from street j. For some cases with $R_{2\ min}-A>G_1-7$ or $R_{1\ min}-A>G_2-7$, intervals 2 and 3 or intervals 5 and 6 are replaced by interval 2A (from $R_{2\ min}-A$ to G_1) or interval 5A (from $G_1+A+R_{1\ min}-A$ to $C'-A$). The probability expressions are shown in Table 3.2 (a) and 3.2 (b); the probabilities for cases 5, 6, and 7 or cases 8, 9, and 10 corresponding to interval 2A or 5A have to be modified accordingly.

The cycle lengths that correspond to the 10 operational cases are shown in Table 3.3. The cycle length expression of cases 3 and 4 is obtained by adding the expected green extension to Webster's optimum cycle length. It is assumed that no more than 3 buses request green extensions in any cycle. The expected green extension period is calculated by summing· the product of the probability of exactly n arrivals to produce one headway greater than 7 seconds times. the expected extensions of n arrivals.

In the delay calculation, it is assumed that Webster's formula applies to the delay estimation for passenger cars, and that the benefit from signal preemption is reflected in the (G/C) term. The delay terms for buses for all possible signal cases are shown in Tables 3.4 and 3.5.

Inputs to the coded program are bus volumes on streets 1 and 2,

Table 3.1: The Probability of No Bus Arrival Matrix

Probability expressions		Comments
$X_{11} = \exp\left[\dfrac{-B_1 R_{2\,min}}{3600}\right]$	$X_{12} = \exp\left[\dfrac{-B_2 R_{2\,min}}{3600}\right]$	Where for all: B_1, B_2 bus flow rates for main and cross street.
$X_{21} = \exp\left[\dfrac{-B_1(G_1 - R_{2\,min} + A - 7)}{3600}\right]$	$X_{22} = \exp\left[\dfrac{-B_2(G_1 - R_{2\,min} + A - 7)}{3600}\right]$	exp is the Napierian exponent
$X_{31} = \exp\left[\dfrac{-7B_1}{3600}\right]$	$X_{32} = \exp\left[\dfrac{-7B_2}{3600}\right]$	
$X_{41} = \exp\left[\dfrac{-B_1 R_{1\,min}}{3600}\right]$	$X_{42} = \exp\left[\dfrac{-B_2 R_{1\,min}}{3600}\right]$	
$X_{51} = \exp\left[\dfrac{-B_1(c' - G_1 - A - R_{1\,min} - 7)}{3600}\right]$	$X_{52} = \exp\left[\dfrac{-B_2(c' - G_1 - A - R_{1\,min} - 7)}{3600}\right]$	
$X_{61} = \exp\left[\dfrac{-7B_1}{3600}\right]$	$X_{62} = \exp\left[\dfrac{-7B_2}{3600}\right]$	

Table 3.2 (a)

General Probability Expressions
for Scenarios 1 and 2

Case Number	Scenario Number	
	1	2
P_1	-	*
P_2	-	**
P_3	$(1-X_{31})$	$(1-X_{31})X_{12}X_{22}$
P_4	$(1-X_{62})X_{31}$	$(1-X_{62})a$
P_5	$(1-X_{41})X_{31}X_{62}$	$(1-X_{41})X_{62}a$
P_6	$(1-X_{51}X_{61})X_{41}X_{31}X_{62}$	$(1-X_{51}X_{61})X_{41}X_{62}a$
P_7	-	-
P_8	$(1-X_{12})X_{62}X_{31}X_{41}X_{51}X_{61}$	$(1-X_{12})$
P_9	$(1-X_{22}X_{32})X_{62}X_{12}X_{31}X_{41}X_{51}X_{61}$	$(1-X_{22})X_{12}$
P_{10}	-	$(1-X_{32})X_{12}X_{22}X_{31}$

where * $- \exp\left[\dfrac{-(B_1+B_2)C'}{3600}\right]$

** $- \exp\left[\dfrac{-(-7(B_1+B_2)+B_2(G_1+A)+B_1(C'-G_1-A))}{3600}\right] -\exp\left[\dfrac{-(B_1+B_2)C'}{3600}\right]$

exp - Napierian exponent

$a = X_{12}X_{22}X_{31}X_{32}$

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Table 3.2 (b)

General Probability Expressions
for Scenarios 3 and 4

Case Number	Scenario Number	
	3	4
P_1	–	–
P_2	–	–
P_3	$(1-X_{31})$	$(1-X_{31})X_1 2X_2 2$
P_4	$(1-X_{62})X_{31}X_{41}X_{51}$	$(1-X_{62})X_{41}X_{51}a$
P_5	$(1-X_{41})X_{31}$	$(1-X_{41})a$
P_6	$(1-X_{51})X_{41}X_{31}$	$(1-X_{51})X_{41}a$
P_7	$(1-X_{61})X_{41}X_{51}X_{62}X_{31}$	$(1-X_{61})X_{41}X_{51}X_{62}a$
P_8	$(1-X_{12})X_{62}X_{31}X_{41}X_{51}X_{61}$	$(1-X_{12})$
P_9	$(1-X_{22}X_{32})X_{62}X_{12}X_{31}X_{41}X_{51}X_{61}$	$(1-X_{22})X_{12}$
P_{10}	–	$(1-X_{32})X_{12}X_{22}X_{31}$

where exp – Napierian exponent
$a = X_{12}X_{22}X_{31}X_{32}$

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Table 3.3: Signal Cycle Lengths

Case Number	Corresponding Cycle length	Comments
1	$C=C'$	where for all
2	$C=C'$	$C'=$ Webster's optimum
3	$C= \sum\limits_{n=1}^{3} (p_1 q_1^{n-1} Y + C')$	$p_1 = \exp\left[\dfrac{-7B_1}{3600}\right]$
4	$C= \sum\limits_{n=1}^{3} (p_2 q_2^{n-1} Y + C')$	$q_1 = 1 - p_1$
5	$C=G_1 + A + R_{1\ min}$	$p_2 = \exp\left[\dfrac{-7B_2}{3600}\right]$
6	$C=G_1 + A + R_{1\ min} + \left[\dfrac{(G_2 - R_{1\ min} - 7 + A)}{2}\right]$	$q_2 = 1 - p_2$
7	$C=G_1 + A + G_2 - 7/2 + A$	
8	$C=G_2 + A + R_{2\ min}$	
9	$C=G_2 + A + R_{2\ min} + \left[\dfrac{(G_1 - R_{2\ min} - 7 + A)}{2}\right]$	
10	$C=G_2 + A + G_1 - 7/2 + A$	

Where:

$$Y = (n-1)\left[\left[\dfrac{3600}{B_1}\right] - 7\exp\left[\dfrac{-7B_1}{3600}\right] - \left[\dfrac{3600}{B_1}\right]\exp\left[\dfrac{-7B_1}{3600}\right]\right] + 7$$

$$Z = (n-1)\left[\left[\dfrac{3600}{B_2}\right] - 7\exp\left[\dfrac{-7B_2}{3600}\right] - \left[\dfrac{3600}{B_2}\right]\exp\left[\dfrac{-7B_2}{3600}\right]\right] + 7$$
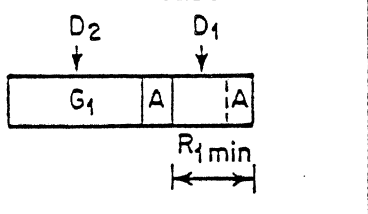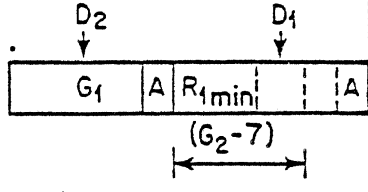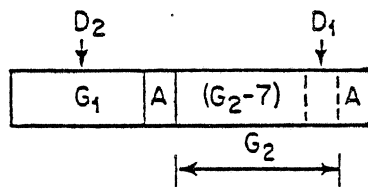
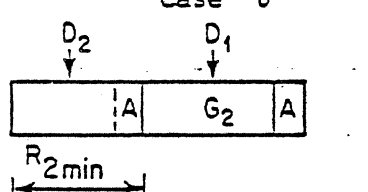exp - Napierian exponent

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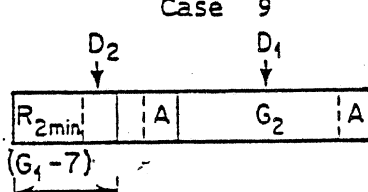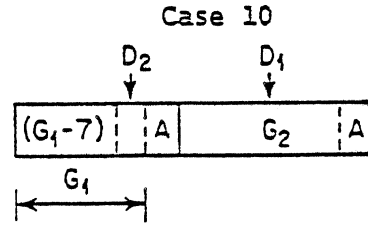
Table 3.4: Bus Delay Terms Used in the Model

Case Number	Main Street	Cross Street
1. No buses in a cycle	Webster (S is adjusted for no bus arrivals)	Webster (S is adjusted for no bus arrivals)
2. Buses arrive, no preemption	Webster	Webster
3. Main street green extension	Webster	Webster
4. Cross street green extension	Webster	Webster
5. Main street red truncation $(R = R_1$ min$)$	Compound delay model 1*	Webster
6. Main street red truncation $(G_1+R_1$ min $<R<G_1+A+G_2-7+A)$	Compound delay model 2*	Webster
7. Main street red truncation $(G_1+A+G_2-7+A<R<C')$	Compound delay model 3*	Webster
8. Cross street red truncation $(R = R_2$ min$)$	Webster	Compound delay model 4*
9. Cross street red truncation $(R_2$ min $<R<G_1-7+A))$	Webster	Compound delay model 5*
10. Cross street red truncation $(G_1-7+A<R<G_1+A)$	Webster	Compound delay model 6*

Shown in detail in Table 3.5

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Case 5

$$D_1 = \left[\frac{B_1}{3600}\right]\frac{(R_{1\,min})^2}{2}N_c + p(Stop)(13.78\,B_1)$$

D_2 from Webster with $C = G_1 + A$

Case 6

$$D_1 = \left[\frac{B_1}{3600}\right]\left[\frac{(G_2 - R_{1\,min} - 7 + A)^2}{2}\right]N_c + p(Stop)(13.78\,B_1)$$

D_2 from Webster with $C = G_1 + A + R_{1\,min}$

Case 7

$$D_1 = \left[\frac{B_1}{3600}\right]\left[\frac{7^2}{2}\right]N_c + p(Stop)(13.78\,B_1)$$

D_2 from Webster $C = G_1 + A + G_2 - 7 + A$

Case 8

D_1 from Webster with $C = G_2 + A$

$$D_2 = \left[\frac{B_2}{3600}\right]\frac{(R_{2\,min})^2}{2}N_c + p(Stop)(13.78\,B_2)$$

Case 9

D_1 from Webster with $C = G_2 + A + R_{2\,min}$

$$D_2 = \left[\frac{B_2}{3600}\right]\left[\frac{(G_1 - R_{2\,min} - 7 + A)^2}{2}\right]N_c + p(Stop)(13.78\,B_2)$$

Case 10

D_1 from Webster with $C = G_2 + A + G_1 - 7 + A$

$$D_2 = \left[\frac{B_2}{3600}\right]\left[\frac{7^2}{2}\right]N_c + p(Stop)(13.78\,B_2)$$

Where: D_1 and D_2 are delays of buses arriving during the time periods indicated by arrows. Total bus delay $= D_1 + D_2$.

N_c = Number of cycles per hour.

passenger car volumes on streets 1 and 2, passenger car and bus occupancies, number of approaching lanes on streets 1 and 2, lost times for streets 1 and 2, minimum red times for streets 1 and 2, and the saturation flow. The program internally calculates the total delays for passenger cars and buses under the preemption and non-preemption strategies, and provides the total delay savings (or losses) attributable to the signal preemption.

Input variables are:

1. Bus volume on street 1, bus/lane and hr

2. Bus volume on street 2, bus/lane and hr

3. Car volume on street 1, veh/lane and hr

4. Car volume on street 2, veh/lane and hr

5. Average number of passengers per car

6. Average number of passengers per bus

7. Number of approach lanes, street 1

8. Number of approach lanes, street 2

9. Lost time, street 1, in seconds

10. Lost time, street 2, in seconds

11. Minimum red time, street 1, in seconds

12. Minimum red time, street 2, in seconds

13. Saturation flow, veh/lane and hour

The output includes optimal cycle length and G/C ratio for street 1, total person delay without preemption, person time saved for cars and for buses, person time saved for street 1 and for street 2, and total person time saved with preemption.

The model can calculate the following outputs:

1. Optimal cycle length, street 1, in seconds

2. Green time - cycle length ratio, street 1, G/C

3. Total person delay without preemption, in seconds

4. Person time saved through preemption for cars, in seconds

5. Person time saved through preemption for buses, in seconds

6. Person time saved through preemption, street 1, in seconds

7. Person time saved through preemption, street 2, in seconds

8. Total Person time saved through preemption, in seconds.

Bus-Stop-Spacing Model (BUSTOP)

Model Assumptions - The Bus-Stop-Spacing model used in TAPM is a modification of a model developed by Lesley in 1976. The model considers a bus route along a straight road with bus stops spaced equally. Surrounding each stop is a circular catchment area with a radius, r, of half of the bus stop spacing distance. It is assumed that the land use within the catchment area is homogeneous and generates passenger journeys at a constant rate, g, per unit area per unit time. The model assumes that a grid walking pattern is followed in the passenger's walk to the bus stop and thus uses the Euler distance for the average walking distance from the catchment area to the bus stop. See the appendix for an illustrative screen display of the program menus and output.

Model Development - The bus acceleration and deceleration characteristics are built into the model. A nonlinear acceleration model developed from performance values of urban buses presented by Vuchic is used in the model, see Table 3.6. A constant value of 3 mphps is used for deceleration.

Average speed from start to start is obtained by calculating first the average start-to-start time, τ, required by the bus. τ is calculated using the following formula 3.1.

$$\tau = t_1(2r, v_{max}) + t_{door} + t_{board} fg\pi r^2 \qquad (3.1)$$

where

t_1 = the time the bus is in movement, determined as a function of bus-stop spacing and maximum running speed using Table 3.6

t_{door} = door time loss at each stop

t_{board} = boarding time per passenger

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Table 3.6

Performance Values of Urban Buses

Bus Stop Spacing (ft)	Time Required from Start to Stop (sec)	Maximum Running Speed (ft/sec)
67	8.4	10.2
97	10.2	12.5
131	11.9	14.7
169	13.6	16.6
210	15.1	18.4
252	16.7	20.0
298	18.1	21.4
344	19.6	22.7
391	20.9	23.8
436	22.2	24.7
483	23.5	25.5
531	24.8	26.3
581	26.0	27.1
632	27.3	27.9
685	28.6	28.7
739	29.8	29.5

The average operating speed, v_1, becomes then

$$v_1 = \frac{2r}{\tau} \qquad (3.2)$$

The average in-vehicle time, T, is determined using the average in-vehicle trip length, l, and the average operating speed, v_1.

$$T = \frac{l}{v_1} \qquad (3.3)$$

The average out-of-vehicle time, E, is a function of the average waiting time, approximated by $f/2$, the average walking distance, using the Eulerian distance, and the average walking speed for both origin and destination of the trip as shown in equation 3.4.

$$E = \frac{f}{2} + 8\left(\frac{2r}{6\pi w}\right) \qquad (3.4)$$

The average total travel time, T_{tot} becomes then

$$T_{tot} = T + E \qquad (3.5)$$

The average weighted travel time is an average travel time where the out-of-vehicle time component is weighted by an out-of-vehicle time factor, because the in-vehicle time and out-of-vehicle time may be valued differently by the passengers. The out-of-vehicle time factor is initially set to a default value of 1.00. The out-of-vehicle time factor can be changed using the appropriate program menu item.

The average total number of trips, G, from a catchment area is calculated using the rate, g, of trips generated per unit area and unit time, the area of the catchment area, and the time headway, f, of service as shown in equation 3.6.

$$G = g\pi r^2 f \qquad (3.6)$$

The average bus occupancy, BO, is determined as a function of the average passenger in-vehicle trip length, l, bus-stop spacing, 2r, and the average total number of trips, G, from a catchment area using the relationship 3.7.

$$BO = \frac{l}{2r} G \qquad (3.7)$$

The route fleet size, NUMBUS, is obtained using 3.8 as a function of the total route length, L, average operating speed, v_1, and time headway, f, of the service.

$$NUMBUS = \frac{2L}{v_1 f}$$ (3.8)

The generalized cost of each trip includes the bus operating cost, C_1, per trip, the administrative cost, C_2, per trip, and the value of passengers total travel time, C_3. Since the administrative cost is assumed in the program to be an annual cost, the average total number of trips, N, per year has to be determined first, using 3.9.

$$N = .5 \ L \ BHR \ g\pi r$$ (3.9)

where

L = total length of route

BHR = annual bus operation time

g = trips generated per unit area and unit time

r = radius of catchment area

The bus operation cost per trip, C_1, is then obtained from

$$C_1 = \frac{BOC \ NUMBUS \ BHR}{N}$$ (3.10)

where

BOC = hourly bus operation cost

NUMBUS = fleet size

BHR = annual bus operation time

N = average total number of trips per year

The administrative cost, C_2, per trip is a function of the annual administrative cost, AC, and the average total number of trips N as shown in 3.11.

$$C_2 = \frac{AC}{N}$$ (3.11)

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The value of passengers total trip time, C_3, is determined using the value of passenger time, VPT, and the sum of the in- and out-of-vehicle time, T+E. Hence

$$C_3 = VPT(T+E) \qquad (3.12)$$

The generalized cost, GC, of each trip becomes then clearly

$$GC = C_1 + C_2 + C_3 \qquad (3.13)$$

Input variables are:

1. Bus stop spacing, 2r, in feet

2. Time headway of service, f, in minutes

3. Trips generated per sq. mile per hour, g, trips/mi^2 and hour

4. Maximum running speed, v_{max}, in mph

5. Route length, L, in miles

6. Door time loss at each stop, t_{door}, in seconds

7. Boarding time per passenger, t_{board}, in seconds

8. Administrative costs of route, AC, in $/year

9. Hourly bus operation cost, BOC, in $/hr/bus

10. Average annual bus operating time, BHR, in hours/year

11. Passenger in-vehicle trip length, l, in miles

12. Passenger walking speed, w, in feet/sec

13. Value of passenger time, VPT, in $/hr

14. Out-of-vehicle time factor

The model can calculate the following outputs:

1. The average in-vehicle time of each trip, T

2. The average out-of-vehicle time of each trip, including the walking and waiting times, E

3. The average total travel time, T_{tot}

4. The average weighted travel time. This is the sum of the average in-vehicle time and the product of the out-of-vehicle time multiplied by the out-of-vehicle time factor. This is calculated for easy input into the modal choice analyses.

5. Bus and passenger cost per trip, GC. This is a generalized cost of each trip. It includes the bus operating cost per trip, the administrative cost per trip, and the value of passenger's total trip time.

6. Route fleet size, NUMBUS

7. Average bus occupancy, BO

8. Overall speed of the bus, average operating speed, v_1.

Optimal-Signal-Timing Model (BEAST)

Model Development - An iterative procedure for finding a fixed cycle length which minimizes total person delay at individual intersections has been developed. (See the appendix for example screen display of the program menus and output.) The delay formula of Miller, 1963 and 1964, is used for calculating the average delay for each vehicle on each approach. The formula can be stated as follows:

$$\bar{d} = \frac{c-g}{2c(1-y)} \left[\frac{I(2x-1)}{q(1-x)} + (c-g) + \frac{I-1+y}{s} \right]$$

(3.14)

where

$\bar{d}$ = the average delay per vehicle on one approach in (sec/veh)

c = cycle time (sec)

g = effective green on one approach (sec)

I = dispersion index, variance/mean ratio of counts of arrivals per cycle on one approach, (Poisson=1.0)

q = arrival on one approach (vps)

s = saturation flow on one approach (vps)

y = q/s, the ratio of arrival to saturation flow on one approach

x = $qc/(sg)$, the ratio of arrival to capacity on one approach.

During each change of phase a certain amount of time is lost while the intersection is being cleared, and while the first vehicles accelerate from the stop line. Therefore, instead of the available green time, the effective green time is used in the delay formula. The effective green time, g, accounts for the total lost time, L, per cycle. In 3.14 the effective green time, g_i, is

$$g_i = \pi_i(c-L) \qquad \text{for approach } i$$

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where

π_i = proportion of the available green time allocated to approach i, or "split"

L = total lost time per cycle

When the average delay for each vehicle type is weighted by its occupancy, the result is the person delay. If $\bar{d}_i$ is the average delay per vehicle on approach i, then the rate of delay, R_i, in vehicle hours per hour is

$$R_i = q_i \bar{d}_i \tag{3.15}$$

and the total rate of delay for all approaches of the intersection is

$$R = \sum_i q_i \bar{d}_i \tag{3.16}$$

When, in the equation 3.16, the weighted delay, or person delay, is used instead of average delay the total person delay at the intersection is obtained.

The proportion of the available green time allocated to approach i, π_i, or "split", is calculated using the equation 3.17.

$$\pi_i = \frac{\sqrt{y_i I_i} + \beta_r \sqrt{y_i y_j}\left[\sqrt{y_i I_j} - \sqrt{y_j I_i}\right]}{\sqrt{y_i I_i} + \sqrt{y_j I_j}} \tag{3.17}$$

At the initial setting, the "split", π_i, is determined for coefficient value $\beta_r = 1.2$. After a first calculation the value of π_i is recalculated using $\beta_r = c/(c-L)$. The cycle length is calculated for each π value using the equation 3.18.

$$c = \frac{L + 2\sqrt{\dfrac{\overline{I_i L}}{s_i}}}{1 - \dfrac{y_i}{\pi_i}}$$

(3.18)

where

L = total lost time per cycle

The values used for I, s, y, and π are those which give the longest cycle time for the selected direction of traffic.

The procedure implemented in the program BEAST is summarized below in four steps.

Step 1: Calculate the average delay, $\bar{d}$, per vehicle using 3.14 for each approach. Obtain the person delay by weighting the average vehicle delay $\bar{d}$ by vehicle occupancy. Obtain the total person delay using 3.16. Go to Step 2.

Step 2: Determine the proportion of the available green time allocated to approach i, the split π_i, using 3.17 with β_r=1.2, if r=1, and β_r=c/(c-L) if r>1. Note: r denotes here the rth repetition of Step 2. Go to Step 3.

Step 3: Determine the cycle length c using 3.18. Calculate c considering the direction of traffic with the highest y value. Go to Step 4.

Step 4: If $\Delta\beta < \epsilon$, where $\Delta\beta = \beta_r - \beta_{r-1}$ then terminate and conclude that the current cycle length minimizes the total person delay at the intersection. Otherwise go to Step 1. Note: ϵ is here a selected small number used in the program as termination criteria indicating that the change in β is smaller than ϵ at program termination.

The input of the program includes auto and bus arrivals on two approaches, auto and bus occupancies, number of approaching lanes on two approaches, and the saturation flow. The program output includes the optimum signal setting with total cycle length and the splits identified, total vehicle delays for cars and for buses, total bus

passenger delay, and total person delay at the intersection.

Input variables are:

1. Bus volume on street 1, bus/lane and hr

2. Bus volume on street 2, bus/lane and hr

3. Car volume on street 1, veh/lane and hr

4. Car volume on street 2, veh/lane and hr

5. Average number of passengers per car

6. Average number of passengers per bus

7. Number of approach lanes, street 1

8. Number of approach lanes, street 2

9. Dispersion index, street 1

10. Dispersion index, street 2

11. Lost time, street 1, in seconds

12. Lost time, street 2, in seconds

13. Minimum red time, street 1, in seconds

14. Minimum red time, street 2, in seconds

15. Saturation flow, veh/lane and hour

The model can calculate the following outputs:

1. Cycle length, optimum signal setting in terms of total person delay at an isolated intersection, in seconds

2. Proportion of the available green time allocated to each approach, called split, in %

3. Total vehicle delay for cars, in seconds

4. Total vehicle delay for buses, in seconds

5. Total delay for bus passengers, in seconds

6. Total person delay, in seconds

High-Occupancy-Vehicle Exclusive-Lane Model (HOVEL)

High-Occupancy-Vehicle Exclusive-Lane on Freeway: (HOVEL) - The purpose
of providing preferential treatment for high-occupancy vehicles is to
increase the person-carrying capacity of freeway, decrease traffic
congestion, decrease person delay, and consequently, reduce air
pollution and energy consumption by encouraging transit, van- and
carpool use. Establishing high-occupancy vehicle exclusive lanes on
freeways, or even on arterials, in urban areas is one of such priority
treatments. A high-occupancy vehicle exclusive lane can be established
in three ways: with-flow bus or HOV lane, contra-flow bus or HOV lane,
and separate bus or HOV facilities. Constraints resulting from road and
right-of-way geometry and limits, traffic conditions, and available
financing affect the type of high-occupancy vehicle lanes selected and
implemented.

Separate bus or HOV facilities have been successfully provided in
many cities such as Washington, D.C., (Shirley Highway), Los Angeles
(San Bernardino), Pittsburgh (South PATway), and San Francisco (I-580);
with-flow bus or HOV lanes in Boston (S.E. Expressway, I-93), Honolulu
(Moanalua Freeway), Portland (Banfield Freeway); and contra-flow bus or
HOV lanes in New Jersey (I-495, Lincoln Tunnel), New York city (Long
Island Expressway, Gowanas Expressway), Houston (North Freeway, I-45),
Seattle (I-5, SR520).

Some likely impacts are:

- Travel time savings of 0.4 to 1.2 min/mile for normal flow HOV
  lane, and 5.0 min/mile on bridge or tunnel approach

- Capacity increase of 6 to 14% in peak hour person volume.

Model Assumptions - This model is based on the q/k-curve model which is
used for traffic operations analysis in the New Highway Capacity Manual
(HCM), 1984. The purpose of developing the model is to help the analysis
of the impacts of a proposed HOV lane with respect to the level of

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service of a freeway.

Sixteen parameters representing highway geometrics, traffic characteristics, and environmental conditions are used as independent variables. The volume-capacity ratio, average travel speed, vehicle slowness, and person slowness (min/mi) are the dependent variables. These variables reflect the effects resulting from an installation of such an exclusive Bus/HOV Lane.

The program can be applied to freeways with at least six lanes in both directions. The procedure used will iterate until the user is satisfied with the results. It allows the comparison of at most four different strategies in one analysis session. See the appendix for example screen display of the program menus and output.

Model Development

Determine Adjustment Factors - Some adjustment factors are needed in the calculation. These factors include adjustment factor for lane width, (F_{wd}), which reflects the impact of lane width and lateral clearance on the lane capacity; Passenger Car Equivalents, (PCU), for heavy vehicles (such as trucks), (E_{tr}), for recreational vehicles, (R_{rv}), and buses, (E_{bs}); and adjustment factors for the character of the traffic stream (driver population), (F_{dp}). They will be determined automatically by the program. Corresponding to given geometric and/or traffic conditions a default value of an adjustment factor will be displayed on the screen. A table corresponding to the particular adjustment factor will appear on the screen at the same time. That gives the user an opportunity to choose the value of the adjustment factor which most appropriately fits the existing conditions, see Table 3.7.

At the same time, the following questions will be prompted on the screen: "For lane width 12 feet and lateral clearance 6 feet, the default value of F_{wd} is 1.00. Does this value correspond your case, y or n?" If the answer is negative, the program will ask the user to make an own choice by prompting "Select F_{wd} value from the table. New value=?".

The adjustment factors and their determinants are:

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Table 3.7

Adjustment Factor for Lane Width, F_{wd}

Lateral clearance (ft)	Lane Width (ft)			
	12	11	10	9
6	1.00	0.96	0.89	0.78
5	0.99	0.95	0.88	0.77
4	0.99	0.95	0.87	0.77
3	0.98	0.94	0.87	0.76
2	0.97	0.93	0.86	0.76
1	0.95	0.92	0.86	0.75
0	0.94	0.91	0.85	0.74

1) Adjustment factor for lane width, F_{wd}, -- lane width, lateral clearance

2) PCU equivalents for trucks, E_{tr}, -- grade and its length, percent of trucks

3) PCU equivalents for recreational vehicles, (RV), E_{rv}, -- grade and its length, percent of RV's

4) PCU equivalents for buses, E_{bs}, -- grade and its length, percent of buses

5) Adjustment factor for the character of the traffic stream, F_{dp}

The adjustment factor for heavy vehicles, including trucks, recreational vehicles RV, and buses is determined by the following formula.

$$F_{hv} = \frac{1}{1+P_t(E_{tr}-1)+P_r(E_{rv}-1)+P_b(E_{bs}-1)} \qquad (3.19)$$

Where

F_{hv} = adjustment factor for heavy vehicles

P_t = percent of trucks in the traffic stream

P_r = percent of RV's in the traffic stream

P_b = percent of buses in the traffic stream

E_{tr} = PC equivalent for trucks

E_{rv} = PC equivalent for recreational vehicles

E_{bs} = PC equivalent for buses

Using 3.20 the volume of traffic flow in peak hour is calculated.

$$q_{sv} = \frac{N_{pc}+N_{tr}+N_{rv}+N_{bs}}{phf} \qquad (3.20)$$

Where

q_{sv} = the maximum flow measured in peak 20 minutes

N_{tr} = the number of trucks

N_{rv} = the number of RV's

N_{bs} = the number of buses

phf = peak hour factor

The volume-capacity ratio is determined using the formula:

$$vc = \frac{q_{sv}}{cp\ N_1 F_{wd} F_{hv} F_{dp}}$$ (3.21)

Where

vc = volume capacity ratio

q_{sv} = the maximum flow

cp = capacity of freeway,veh/lane/hour

N_1 = the number of lanes

F_{wd} = factor for lane width

F_{hv} = factor for heavy vehicles

F_{dp} = factor for driver population

Using the volume-capacity ratio the level of service is determined. The corresponding travel speed is found with 3.22.

$$u = u_f e^{a + \beta vc^3}$$ (3.22)

Where

u = running speed in miles/hour

u_f = free-flow speed in miles/hour

vc = volume capacity ratio

a, β = constants

The vehicle concentration or density, in veh/mile, is calculated with the following relationship:

k = cp vc/u

Where

k = concentration, in veh/mile

cp = capacity, in veh/lane/hour

vc = volume capacity ratio
u = running speed, in miles/hour

Input variables are:

1. Number of lanes on freeway

2. Lane width, (ft)

3. Lateral clearance to closest obstruction, (ft)

4. Average grade, (%)

5. Length of the grade, (mi)

6. Lane capacity

7. Design speed, (mi/hr)

8. Passenger car volume, (veh/hour)

9. Passenger car occupancy, (persons/veh)

10. Truck volume, (trucks/hour)

11. Recreational vehicle volume, (RV/hour)

12. Bus volume, (buses/hour)

13. Bus occupancy, (passengers/hour)

14. Carpool volume, (veh/hour)

15. Carpool occupancy, (passengers/car)

16. Peak hour factor, phf

The model calculates the following output:

1. Volume-capacity ratio

2. Average travel speed, (mph)

3. Vehicle flow, (veh/hour)

4. Vehicle slowness, (minute/mile)

5. Person flow, (persons/hour)

6. Person slowness, (minute/mile).

When executing the program the user simply answers the questions prompted on the screen. The program reallocates traffic among the available lanes in accordance with the plan being studied.

Attention has to be paid to the following:

1) Check the default values of parameters listed and change them if necessary.

2) Check the default values of adjustment factors and change them if necessary.

When the difference between traffic volumes in the two directions on the freeway is big enough (for example, the level of service in the peak direction is D, but that in the non-peak direction is B as it is often the case during peak hours), it is advisable to consider reserving one of the lanes in non-peak direction for an exclusive bus or HOV lane, that is, installing a contra-flow bus/HOV lane.

Example: To install a contra-flow bus lane on an 8-lane freeway, the user needs to answer the following questions prompted on the screen:

```
"ESTABLISH AN EXCLUSIVE BUS LANE?"---------------------- Y
"HOW MANY PARAMETERS DO YOU WANT TO CHANGE?"------------ 1
```

Leave the number of lanes in peak direction as 4. Change the number of lanes in opposite direction to 3.

If the traffic in both directions is almost equally heavy, it is recommended to consider a separate bus or HOV lane. To install an extra median Bus/HOV Lane on a 6-lane freeway, the user has to press the Y-key to answer the "ESTABLISH?"-question, and leave the number of lanes for both directions in their initial values.

```
"ESTABLISH AN EXCLUSIVE BUS LANE?"---------------------- Y
"HOW MANY PARAMETERS DO YOU WANT TO CHANGE?"------------ 0
```

Leave the number of lanes for both directions as 3.

It is obvious that a bus/HOV lane can decrease travel time for both bus riders and car users. To make a final decision on whether an

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exclusive bus/HOV lane is to be installed, a benefit-cost analysis may be carried out.

APPENDIX

Examples of Screen Display of Program Menus and Output

SCREEN 1:

```
----------------------------------

        ***   TAPM MENU   ***

----------------------------------


        1) Explain this program
        2) Explain menu items..
        3) Display/select model
        4) Exit TAPM..........

        Select item of interest.
```


SCREEN 2:

```
----------------------------------------------

            TAPM Model Selection

----------------------------------------------


    1. Radwan & Hurley    Signal-Preemption
    2. L.J.S. Lesley      Bus-Stop-Spacing
    3. Miller A.J.        Signal Timimg
    4. HCM (1984)         High-Occupancy-Veh. Lane

To return to TAPM Menu, type in MENU.
Choose by number, or type in MENU, and press return.
```

SCREEN 3:

```
***          SIGNAL PREEMPTION        ***
1) Explain this model................
2) Explain the menu items............
3) Change independent variable 1.....
4) Change independent variable 2.....
5) Change independent constants......
6) Change dependent variable.........
7) View all variables and constants..
8) Generate output...................
9) Show tabular output...............
B) Printer ON/OFF....................
E) Return to TAPM MENU...............

Select item of interest.
```

SCREEN 4:

```
***         BUS STOP SPACING MENU      ***
1) Explain this model................
2) Explain the menu items............
3) Change independent variable 1.....
4) Change independent variable 2.....
5) Change independent constants......
6) Change dependent variable.........
7) View all variables and constants..
8) Generate output...................
9) Save output to a file.............
B) Printer ON/OFF....................
E) Return to TAPM MENU...............

Select item of interest.
```

SCREEN 5:

```
***        OPTIMAL SIGNAL TIMING       ***
1) Explain this model................
2) Explain the menu items............
3) Change independent variable 1.....
4) Change independent variable 2.....
5) Change independent constants......
6) Change dependent variable.........
7) View all variables and constants..
8) Generate output...................
9) Save output to a file.............
B) Printer ON/OFF....................
E) Return to TAPM MENU...............

Select item of interest.
```

SCREEN 6:

```
***  HIGH OCCUPANCY VEHICLE EXCLUSIVE LANE  ***
1) Explain this model........................
2) Explain the menu items...................
3) Generate output...........................
4) Printer ON/OFF............................
E) Return to TAPM MENU.......................

Select item of interest.
```

SCREEN 7:

```
            ***    SIGNAL PREEMPTION - RESULTS    ***

                         CYCLE.ST 1 G/C (SEC.%)
VARIABLE 1
BUS ST. 1           VARIABLE 2 BUS ST. 2 (B/LN-HR)
(B/LN-HR)
                 0.00      5.00     10.00     15.00     20.00

    0.00        68.50     70.50     71.50     73.49     75.49
    1.00        68.51     70.50     72.50     73.49     75.49
    2.00        69.51     70.50     72.50     74.49     75.49
    3.00        69.51     71.50     72.50     74.50     76.49
    4.00        69.51     71.50     73.50  .  74.50     76.49
    5.00        70.51     71.50     73.50     75.50     77.49
    6.00        70.51     72.51     73.50     75.50     77.49
    7.00        71.51     72.51     74.50     76.50     78.50
   10.00        71.51     73.51     75.50     77.50     79.50
   15.00        73.52     75.51     77.51     79.50     81.50
   20.00        75.52     77.52     79.51     81.51     83.50
   25.00        77.52     79.52     81.52     83.51     85.51
   30.00        79.53     81.52     83.52     85.52     88.51
   35.00        81.53     83.53     85.52     88.52     90.52
   40.00        83.54     85.53     88.53     90.52     93.52
   45.00        85.54     88.54     90.53     93.53     96.52
   50.00        88.54     90.54     93.54     96.53     99.53
```

SCREEN 8:

```
          ***     BUS STOP SPACING - RESULTS      ***

                         AVE IN-VEH TIME (MIN)
VARIABLE 1
BUS STOP SPACNG        VARIABLE 2 BUS HEADWAY (MIN)
   (FT)
                2.50      5.00      10.00     20.00     30.00

   200.00      27.44     27.52     27.67     27.96     28.26
   300.00      21.38     21.49     21.71     22.16     22.60
   400.00      18.07     18.22     18.52     19.12     19.71
   500.00      16.00     16.19     16.56     17.30     18.05
   600.00      14.60     14.83     15.27     16.16     17.06
   700.00      13.61     13.87     14.39     15.44     16.48
   800.00      12.88     13.18     13.77     14.96     16.15
   900.00      12.32     12.66     13.32     14.66     16.00
  1000.00      11.88     12.25     12.99     14.48     15.97
  1100.00      11.52     11.93     12.75     14.39     16.02
  1300.00      11.00     11.48     12.45     14.38     16.31
  1500.00      10.63     11.19     12.30     14.53     16.77
  2000.00      10.10     10.84     12.33     15.30     18.28
  2500.00       9.85     10.78     12.64     16.36     20.08
  3000.00       9.75     10.87     13.10     17.56     22.02
  3500.00       9.73     11.03     13.64     18.84     24.05
  4000.00       9.76     11.25     14.23     20.18     26.13
```

SCREEN 9:

           `*** OPTIMAL SIGNAL TIMING - RESULTS ***`

                       `CYCLE.ST1G/C (SEC.%)`

VARIABLE 1 BUS ST. 1 (B/LN-HR)	VARIABLE 2 BUS ST. 2 (B/LN-HR)				
	0.00	5.00	10.00	15.00	20.00
0.00	70.50	75.50	70.49	75.48	80.48
1.00	70.50	75.50	70.49	75.48	80.48
2.00	70.50	75.50	75.50	75.48	80.48
3.00	70.50	70.50	75.50	75.48	75.48
4.00	75.51	70.50	75.50	80.49	75.48
5.00	75.51	70.50	75.50	80.49	75.48
6.00	75.51	70.50	75.50	80.49	80.49
7.00	70.52	75.51	75.50	75.50	80.49
10.00	70.52	75.51	80.50	75.50	80.49
15.00	75.52	80.52	75.51	80.50	85.50
20.00	80.53	75.52	80.52	85.51	80.50
25.00	75.54	80.53	85.52	80.52	85.51
30.00	80.54	85.53	85.52	85.52	90.52
35.00	85.55	85.53	85.53	90.53	95.52
40.00	85.55	85.55	90.54	90.53	95.52
45.00	90.55	90.55	90.54	95.53	95.53
50.00	90.56	90.55	95.54	100.53	100.53

SCREEN 10:
         *** HIGH OCCUPANCY VEHICLE LANES ***

	Alternative			
	#1	#2	#3	#4
DIRECTION I:				
Pass. Car Flow	4000	3400	4000	3400
PC Slowness	1.25	1.11	1.17	1.11
Level of Service	D	C	D	C
Bus Flow	300	300	300	300
Carpool Flow	0	200	0	200
BS-CP Slowness	-	1.01	1.00	1.01
DIRECTION II:				
Pass. Car Flow	2400	2400	2400	2400
PC Slowness	1.02	1.10	1.02	1.02
Level of Service	B	C	B	B
BOTH DIRECTIONS:				
Vehicle Flow	6820	6420	6820	6420
Person Flow	25820	25740	25820	25740
Person Slowness	1.20	1.07	1.04	1.05

Note: Alternative 1: Six lane freeway without a HOV-lane.
      Alternative 2: With a contra-flow exclusive HOV lane
         in the off-peak direction. Two hundred carpools
         use the HOV-lane.
      Alternative 3: With a median exclusive HOV-lane, no
         carpool allowed to use the lane.
      Alternative 4: With a median exclusive HOV lane, two
         hundred carpools use the lane.

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