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OPTIMIZATION OF LEFT TURN PHASE SEQUENCE IN SIGNALIZED NETWORKS USING MAXBAND 86

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16. Abstract

MAXBAND has been enhanced to provide optimal traffic signal timing plans for general grid networks, using bandwidth as the criterion. The program is user friendly and has several new features. Grid networks as large as 20 arterials with up to 20 signalized intersections per arterial could be solved, but present specifications limit the number of signals in the network to 50 until more operational experience with the system is obtained. Phase sequence optimization is provided together with NEMA, eight-phase numbering. MAXBAND 86 is written in FORTRAN 77.

Volume 1, Summary Report, provides the basic model theory for calculating progression bandwidths in arterials. Additional material describes how the arterial model formulation is integrated into closed network analysis using closed loop equations. An overview of MAXBAND input, operational and output features are provided.

The new MAXBAND 86 system is described in a 3-volume final report:

Volume 1 - FHWA/RD-84/082	Summary Report
Volume 2 - FHWA/RD-84/083	User's Manual
Volume 3 - FHWA/RD-84/084	Program Manual

This volume is the Summary Report.

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INTRODUCTION

BACKGROUND

The need for efficient traffic flow in complex traffic networks, such as downtown grid systems, is paramount. The economic vitality of a major city depends on the smooth flow of persons and goods into and out of the central core of the city. Traffic engineers have long recognized that the traffic signals located within the downtown network should be coordinated to provide orderly movement of vehicular traffic. The ultimate objective of network signal timing is to keep the traffic moving in platoons throughout the signal system by the timely display of green signals to the platoons traveling down the streets.

Traffic engineers have resorted to a number of techniques for developing effective network signal timing plans. Manually developed trial-and-error systems were initially implemented. Three-dimensional, stick-and-string, physical scale models have also been used to aid traffic engineers in visualizing the complex problem of coordinating two-way platoon flow on intersecting cross-streets. The progression bandwidths could be visualized, but not quantified, by these methods. Progression of the through bands, however, remained the principal control objective.

Network signal timing and progression-based optimization can now be obtained using MAXBAND 86. The four basic pretimed signal control variables of optimal cycle, green splits, progression offsets, and phase sequence are determined by MAXBAND 86 which maximizes the bandwidth progression within the network. A complete signal timing plan for each intersection is an output feature of the program.

MAXBAND is a bandwidth optimization program, unlike TRANSYT-7F [Robertson, 1969] or SIGOP III [Leiberman, 1976] which optimize delay-based disutility functions and from which green bands cannot be always obtained. In addition, the TRANSYT and SIGOP programs have no capability to perform a left turn phase sequence optimization. Studies on arterial signal timing plans (Cohen 1983, Rogness 1981) have shown that left turn phase sequence optimization can substantially improve performance of signal timing plans. MAXBAND was originally developed to optimize progression (maximize two-way bandwidths) along arterial streets and triangular loops [Little and Kelson, 1980]. MAXBAND uses a mixed-integer, linear programming formulation of signal systems originally presented by Little [1966] and later extended by Little [1977] for phase sequence optimization of multiphase arterial signal systems.

MAXBAND 86

The evolution of MAXBAND to general network applications has been attained within this research effort. The new program is called MAXBAND 86. Algorithms have been developed that convert network loop characteristics into equivalent mixed-integer, linear programming formulations. A global time reference system for signal offsets is provided for convenient reference of all offsets within the network. An improved green-split model also has been added.

The MAXBAND 86 computer code has been updated to FORTRAN 77 coding standards. Mixed-integer, linear programming formulation of the optimization of a network-wide, signal timing problem is performed. The current program still uses Land and Powell's [1973] MPCODE branch and bound algorithm for optimization. A single arterial street can be analyzed as well as a downtown grid system.

The prior version of MAXBAND [Little and Kelson, 1980] provided the optimal solution of arterial problems or a single triangular loop consisting of three arterials. It permitted a maximum of 20 intersections on one arterial and a maximum of 16 intersections per arterial in a triangular network. The extended MAXBAND program produced by this research (MAXBAND 86) is capable of addressing up to 20 arterials, with a maximum of 20 intersections on a single arterial and a total of 50 intersections in the network. Further, the level of user-friendliness of the code has been increased such that no substantial burden is placed on the user to code network problems. In particular, the extended program is capable of identifying the intersections involved in loop constraints and subsequently generating the loop equations without the user specifying the loops or providing a substantial increase in input information. Similarly, other input parameters (such as arterial priority weights) may be generated by the program without substantially degrading program flexibility.

The user may find that large and/or complex network problems may tax the optimization technique beyond its current capability to produce optimal solutions within reasonable computational time. The scope of this research did not permit the research team to address this issue. Thus the Land and Powell optimization scheme was retained. However, considerable effort was expanded in developing an efficient input routine, generating loop equations, transferring to and from the optimization procedure, and producing user-friendly output. The resulting product of this research is a MAXBAND code capable of generating formulations for general grid networks. Whether an optimal solution can be obtained by the optimization methodology for large and complex grid problems is open to question. However, some reasonably sized examples have been solved within this developmental work.

Design Assumptions

The research goal was to develop a program "to optimize general grid networks of up to 50 intersections." The term general grid networks is not well defined, and thus some additional specifications were added to bound the scope of networks which may be analyzed by the program. The following specifications identify cases considered outside the new program scope of MAXBAND 86:

1. The network must be completely connected; that is, there can be no disjoint arterials or subnetworks. (Note, these latter cases may be treated by solving each of the independent subsystems and then combining the results.)
2. No more than two arterials may compose an intersection; that is, there are no five-way or six-way intersections. (The green-split calculations do not currently permit this more complex analysis.)
3. Prior MAXBAND code allowed the user to input data which might not be used for arterial calculations. This feature was retained for arterials; however, the user can not input unused data for networks. In the network case, all intersections and links entered must impact the solution.

Overview

Figure 1 provides an overview of the architecture of the revised MAXBAND 86 program. The revisions did not change the prior architecture to any significant extent. However, the MPCODE module is the only module that was not substantially revised. Changes in each of the modules range in degree and character. The next section deals with each of the four modules which communicate with the main program (MAXBAND). The revisions to the main program itself consisted of changes in dimensions of existing variables, redefinition of some variables, and the addition of new variables. Volumes II and III provide complete details.

Figure 2 is a block diagram of the revised input module. The input cards were modified to accomodate the generalized network structure. The prior format of input was retained insofar as practical. The major change occurred in the input of network parameters and a variable number of artery descriptions.

It is important to note that a compact means for input of the cross artery bandwidth information was provided which enhances the user-friendliness of the code. Details are provided later.

The major routines added or substantially modified in the INPUT module were as follows:

1. The major addition was subroutine LGEN and its supporting routines. This set of routines identifies the network loops and reduces them to their simplest form. They also develop the array INTER which identifies the entry and exit points of the arteries with respect to the loops. This specifies the topology of the network and provides the information required to write the loop equations.
2. Another addition was a set of subroutines controlled by CKDATA that checks input data for errors. Data are examined to determine if the total data needs of the intersection as a whole are satisfied and if allowable ranges of parameters are not exceeded. While checks are made for consistency of duplicate data entries, flexibility of data entry is permitted.
3. A number of routines were substantially modified to read, convert and calculate the objective function coefficients and the cross artery bandwidth ratios.

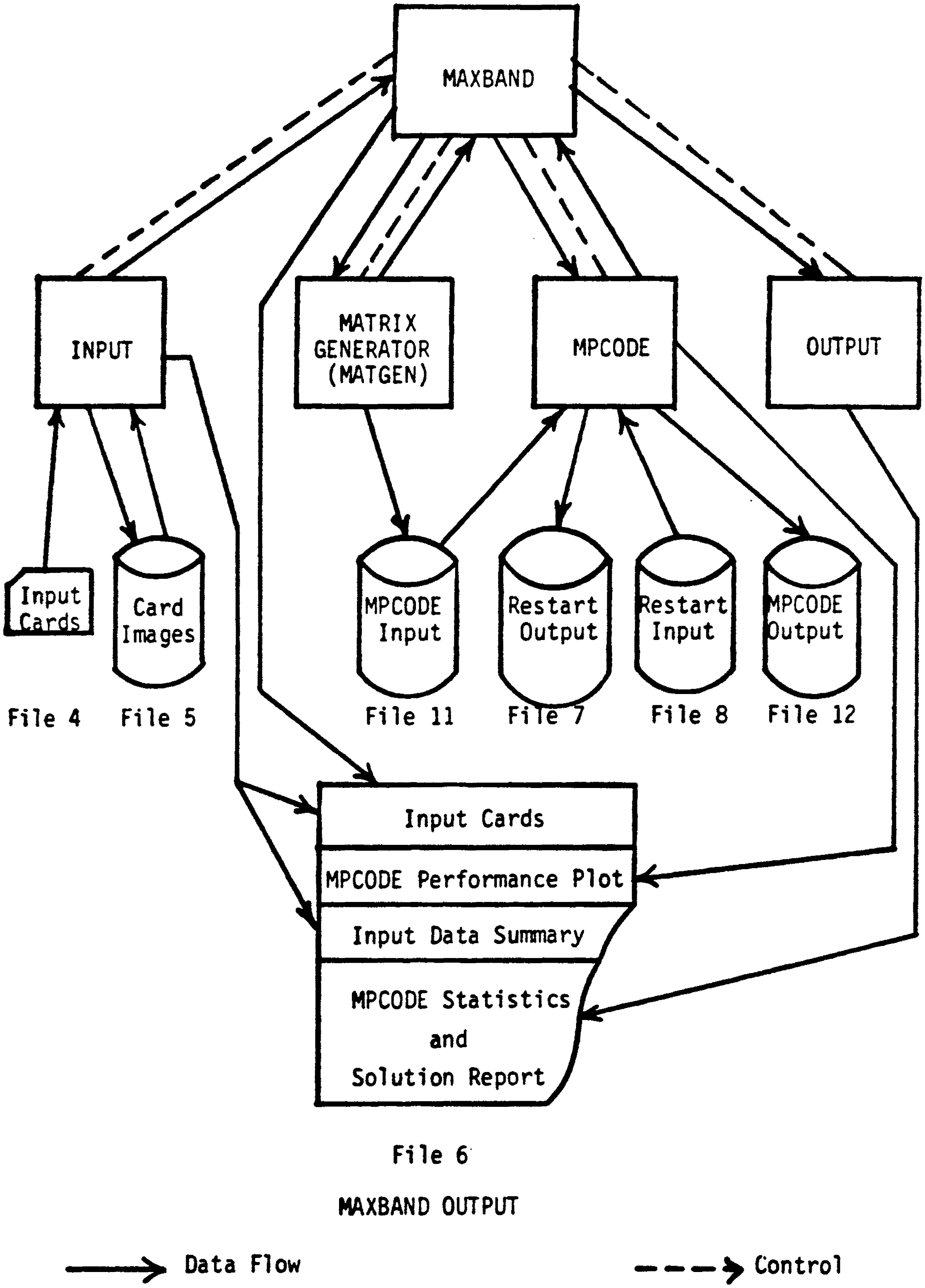


Figure 1. The MAXBAND system.

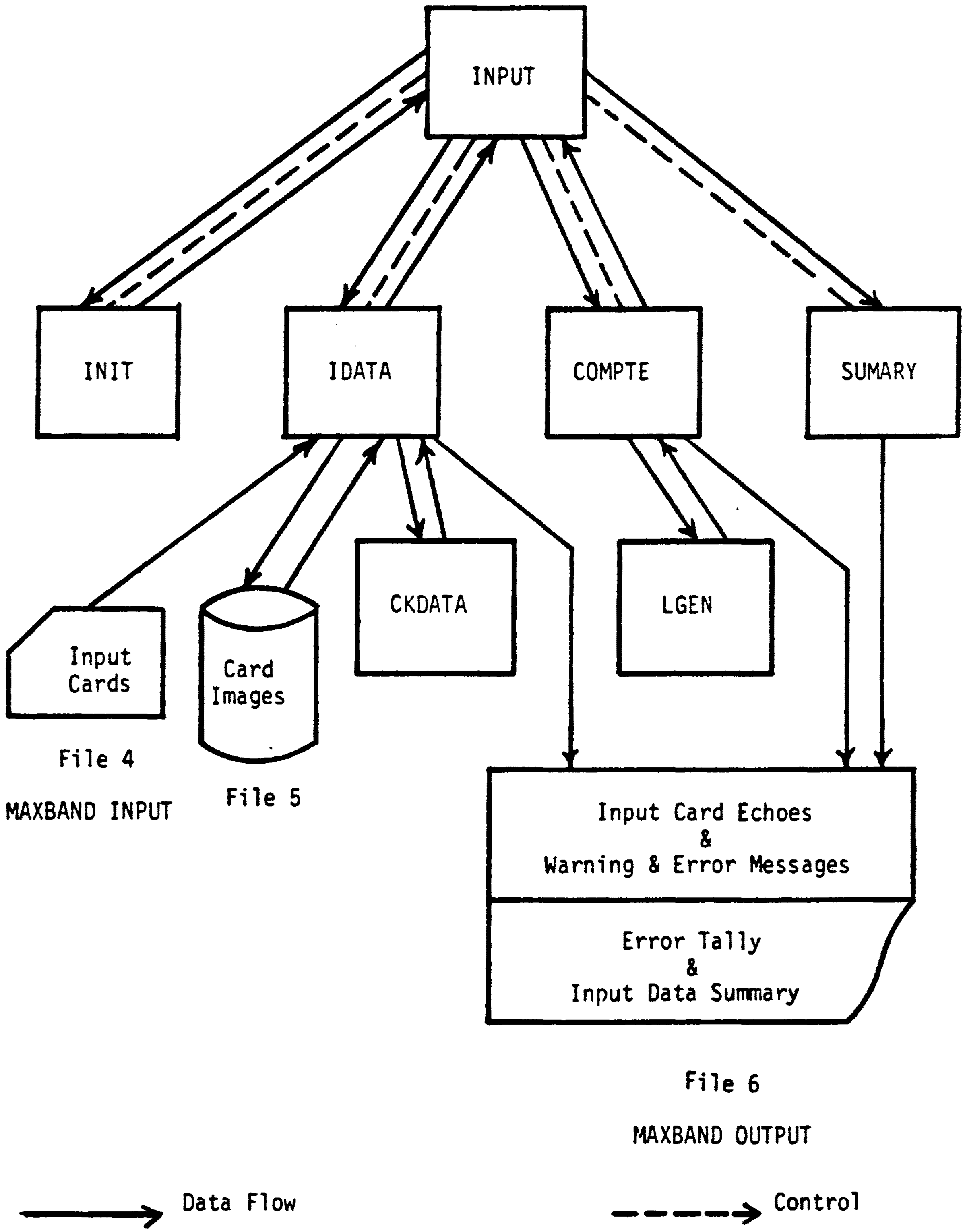


Figure 2. The INPUT module.

4. A number of routines were modified to account for the fact that the number of arteries in a network is a variable. Similarly, expansion of the code to encompass a variable number of loops was also required.

Figure 3 is a block diagram of the revised MATGEN module. Significant changes to this module were in the MATGNN submodule (formerly called MATGNL). Revisions to this submodule may be classified into two categories:

1. Changes due to considerable increase in size (number of arteries and intersections) and the more general nature of the problem.
2. Changes due to the increased and variable number of loops in the network problem.

The first set of revisions required increasing array dimensions, inserting "DO LOOPS" to replace simple statements, and generalizing portions of calculations for the multi-artery case. The second set of revisions required considerable more creativity. The crucial issue was to take the loops identified in the prior module along with indicator variables which describe the network topology and generate the left-hand side of the multiple loop constraints for the mixed-integer linear program. This was accomplished by using an array INTRA which relates the arteries to the loops. Details are provided later.

Changes in MPCODE were minor. These module changes consisted of expanding the dimensions of variables and inclusion of statements to print a performance plot of the optimization process. The required expansion of dimensions are fully explained in Chapter 7 of "Fortran Codes for Mathematical Programming", by A. Land and S. Powell. Details will follow.

The OUTPUT Module was substantially revised in order to encompass the expanded requirements of a network and to embrace the NEMA convention. A design objective of the OUTPUT Module was to provide compatibility with TRANSYT/7F to the extent possible; however, the nature of the optimization in MAXBAND differs such that the output is not a duplicate. The revised output of MAXBAND includes three major additions:

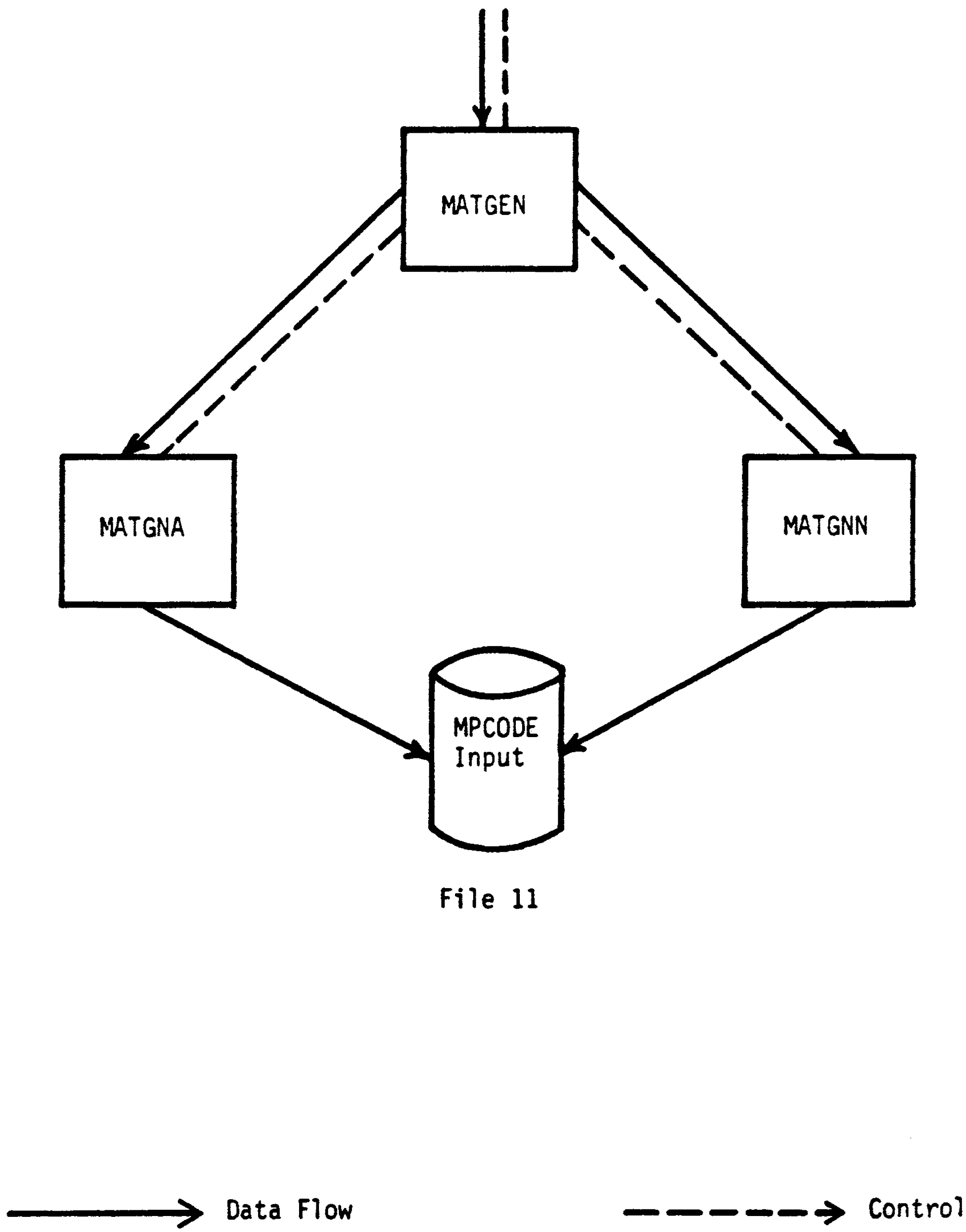


Figure 3. The MATGEN module.

1. A new network signal timing summary;
2. A new intersection phase movement reference table; and
3. An enhanced intersection controller setting table.

An example of the revised output features of MAXBAND is presented in Appendix A. This revision was accomplished by adding a new subroutine NETOUT and extensively expanding subroutines PHSFRC and PHSSEC.

RESEARCH

The research performed under this contract did not involve a significant expansion of the prior optimization model from a theoretical standpoint. Little's formulation suggested the expansion to generalized networks which is presented in the methodology section to follow. The prior version of MAXBAND implemented this optimization approach for the single artery and the three-artery, single loop cases.

The crux of this new research effort was to extend the previous implementation to a general grid network containing many loops. Further, this extended version had to retain the same user-friendly decision support environment as before. These requirements posed a significant research challenge since the variety of possible network topology, as compared to fixed topology in the prior arterial and triangular loop version, dictated a more complex program code. In order to accomplish this expanded implementation, the following tasks had to be executed:

1. Develop a procedure for locating the set of loops in the network which will be used to develop the loop equations;
2. Develop a method for defining the topology of the network in terms of the loops and their composition (arteries, signals, etc.);
3. Develop a means for translating user input into appropriate bandwidth weights (objective function coefficients) and relationships among bandwidths (target bandwidth ratios); and
4. Provide generalization of prior code elements to deal with increased size and/or generality.

Each of these methodology questions will be addressed in the following sections along with the expanded formulation.

METHODOLOGY

OPTIMIZATION

The optimization formulation draws on Little (1966,1977). The basic geometry is shown in figure 4.

Let

$b(\bar{b})$ = outbound (inbound) bandwidth (cycles).

S_i = ith signal, $i = 1,\ldots,n$.

$r_i(\bar{r}_i)$ = outbound (inbound) red time at S_i (cycles).

$w_i(\bar{w}_i)$ = time from right (left) side of red at S_i to left (right) edge of outbound (inbound) green band (cycles).

$t(h,i)[\bar{t}(h,i)]$ = travel time from S_i to S_h outbound [S_h to S_i inbound] (cycles).

$\phi(h,i)[\bar{\phi}(h,i)]$ = time from center of an outbound [inbound] red at S_h to the center of a particular outbound [inbound] red at S_i. The two reds are chosen so that each is immediately to the left [right] of the same outbound [inbound] green band. $\phi(h,i)[\bar{\phi}(h,i)]$ is positive if S_i's center of red lies to the right [left] of S_h's (cycles).

Δ_i = time from center of $\bar{r}_i$ to nearest center of r_i. Positive if center of r_i is to right of center of $\bar{r}_i$ (cycles).

$\tau_i(\bar{\tau}_i)$ = queue clearance time, an advance of the outbound (inbound) bandwidth upon leaving S_i (cycles).

The fundamental equation for formulating the arterial problem arises from a physical constraint. We derive it with the help of fig. 4 by expressing the difference in time from (A) to (B) in two

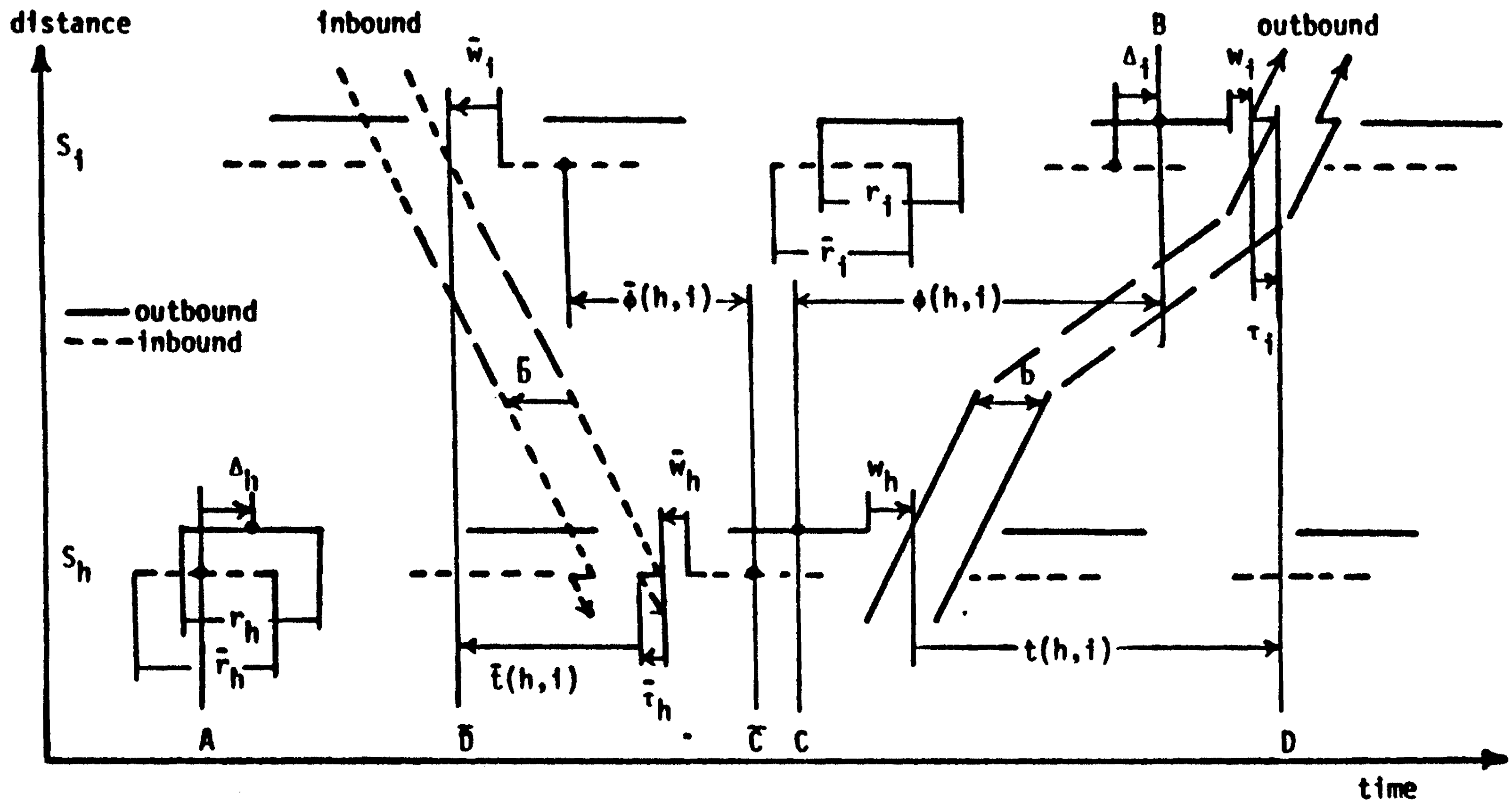


Figure 4. Space-time diagram showing greenbands. Inbound and outbound greenbands pass through signals S_h and S_i. Quantities with bars refer to inbound direction; those without, outbound. Outbound reds are drawn solid and above inbound reds which are dashed. Non-overlapping periods accomodate left turns.

different ways:

Using outbound-defined quantities,

$$\text{time (A) to (B)} = \Delta_h + \text{integer no. of cycles} + \phi(h,i).$$

Using inbound-defined quantities,

$$\text{time (A) to (B)} = \text{integer no. of cycles} - \bar{\phi}(h,i)$$
$$+ \text{another integer no. of cycles} + \Delta_i.$$

Setting these times equal, rearranging and coalescing the integers into a single variable, $m(h,i)$:

$$\phi(h,i) + \bar{\phi}(h,i) + \Delta_h - \Delta_i = m(h,i). \qquad (1)$$

We call $m(h,i)$ the <u>loop integer</u> in recognition of the more general case of networks. The terminology applies in the present case because the links S_h to S_i and S_i to S_h form a loop and (1) states that the sum of times around the loop is an integer number of cycles.

From figure 4 we also read from (C) to (D).

$$\phi(h,i) + (1/2)r_i + w_i + \tau_i = (1/2)r_h + w_h + t(h,i), \qquad (2a)$$

and from $(\bar{C})$ to $(\bar{D})$

$$\bar{\phi}(h,i) + (1/2)\bar{r}_i + \bar{w}_i = (1/2)\bar{r}_h + \bar{w}_h - \bar{\tau}_h + \bar{t}(h,i). \qquad (2b)$$

Substituting (2) into (1) to eliminate ϕ and $\bar{\phi}$ gives:

$$t(h,i) + \bar{t}(h,i) + (1/2)(r_h + \bar{r}_h) + (w_h + \bar{w}_h)$$
$$- (1/2)(r_i + \bar{r}_i) - (w_i + \bar{w}_i) - (\tau_i + \bar{\tau}_h) + \Delta_h - \Delta_i$$
$$= m(h,i). \qquad (3)$$

So far we have required that S_i follow S_h in the outbound direction but this restriction is not necessary. For physical reasons we wish $t(.)$ to satisfy

$$t(h,j) = t(h,i) + t(i,j);$$

whence, setting $h = j$, we shall require

$$t(i,h) = -t(h,i)$$

and by a similar argument $\bar{t}(i,h) = -\bar{t}(h,i)$. With these relations (2) and (3) hold for arbitrary S_h and S_i and

$$\phi(h,j) = \phi(h,i) + \phi(i,j)\ , \qquad \phi(h,i) = -\phi(i,h)$$

$$m(h,j) = m(h,i) + m(i,j)\ , \qquad m(h,i) = -m(i,h)$$

along with corresponding expressions for $\bar{\phi}$.

Notation becomes simpler if the signals are numbered sequentially from 1 to n in the outbound direction. Then define

$$x_i = x(i,i+1) \quad \text{for} \quad x = t,\bar{t},m,\phi,\bar{\phi}.$$

Now (3) gives

$$\begin{aligned} t_i + \bar{t}_i + (w_i + \bar{w}_i) - (w_{i+1} + \bar{w}_{i+1}) + \Delta_i - \Delta_{i+1} \\ = -(1/2)(r_i + \bar{r}_i) + (1/2)(r_{i+1} + \bar{r}_{i+1}) + (\bar{\tau}_i + \tau_{i+1}) + m_i\ . \end{aligned} \tag{4}$$

From fig. 4 we also see that

$$w_i + b \leq 1 - r_i \tag{5a}$$

$$\bar{w}_i + \bar{b} \leq 1 - \bar{r}_i\ . \tag{5b}$$

If for the moment we also require $b = \bar{b}$, we can collect (4) on (5) into a basic mixed integer linear program for setting arterial signals.

<u>LP1</u>: Find b, $\bar{b}$, w_i, $\bar{w}_i$, m_i to

$$\max b$$

Subject to $\qquad \bar{b} = b$

$$\left.\begin{aligned} w_i + b \leq 1 - r_i \\ \bar{w}_i + \bar{b} \leq 1 - \bar{r}_i \end{aligned}\right\} \qquad i = 1,\ldots,n$$

$$(w_i + \bar{w}_i) - (w_{i+1} + \bar{w}_{i+1}) + (t_i + \bar{t}_i) + \Delta_i - \Delta_{i+1}$$

$$= -(1/2)(r_i + \bar{r}_i) + (1/2)(r_{i+1} + \bar{r}_{i+1})$$

$$+ (\bar{\tau}_i + \tau_{i+1}) + m_i \,, \qquad i = 1,\ldots,n-1$$

$$m_i = \text{integer}$$

$$b,\bar{b},w_i,\bar{w}_i \geq 0 \,, \qquad i = 1,\ldots,n$$

LP1 has 3n constraints, 2n + 2 continuous variables and n - 1 unrestricted integer variables.

We next turn our attention to a generalization that permits the optimization program to pick when the left turn phase (if one is present) will occur with respect to the through green at any signal. The left turn green can be picked to lead or lag, whichever gives the most total bandwidth. At the same time, however, it is necessary to give the traffic engineer the ability to specify which combination of leads or lags in each direction will be permitted.

Figure 5 shows the four possible patterns of left turn green phases. Let

$g_i(\bar{g}_i)$ = outbound (inbound) green time for through traffic at S_i (cycles).

$\ell_i(\bar{\ell}_i)$ = time allocated for outbound (inbound) left turn green at S_i (cycles).

R = common red time in both directions to provide for cross street movements (cycles) .

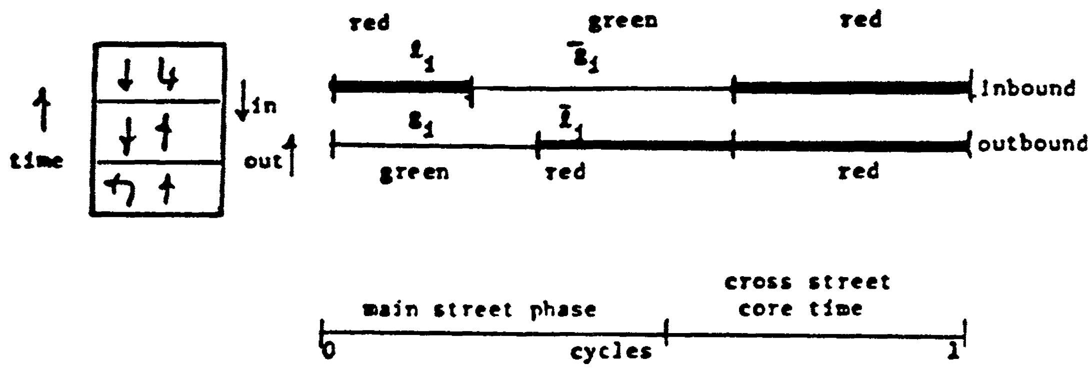
Since time allocated to outbound left turn green is inbound red time we have (see Figure 7):

$$r_i = R + \bar{\ell}_i \qquad \text{and} \qquad r_i + g_i = 1$$

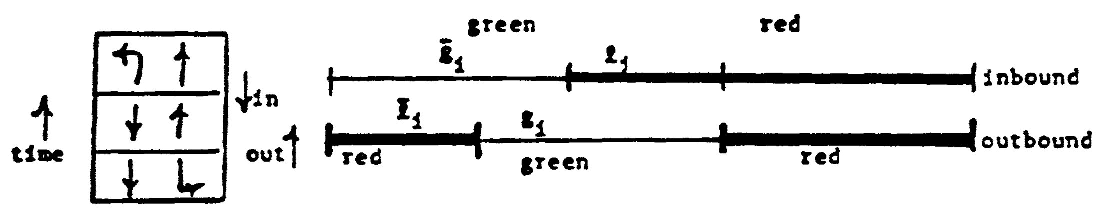
$$\bar{r}_i = R + \ell_i \qquad\qquad\quad \bar{r}_i + \bar{g}_i = 1$$

Moreover we can express Δ_i, the time from the center of $\bar{r}_i$ to the next

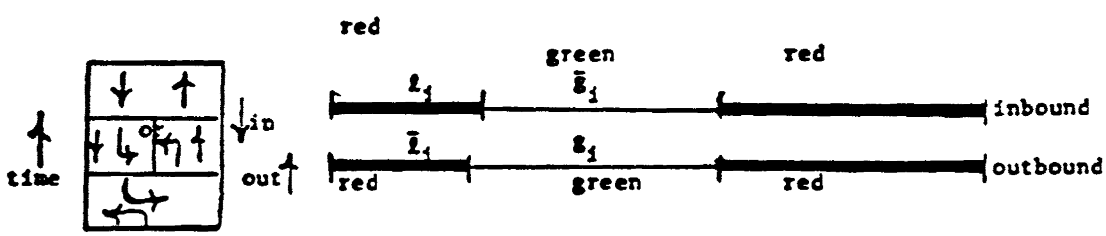
1. Outbound left leads; inbound lags (lead-lag)



2. Outbound left lags; inbound leads (lag-lead)



3. Outbound left leads; inbound leads (lead-lead)



4. Outbound left lags; inbound lags (lag-lag)

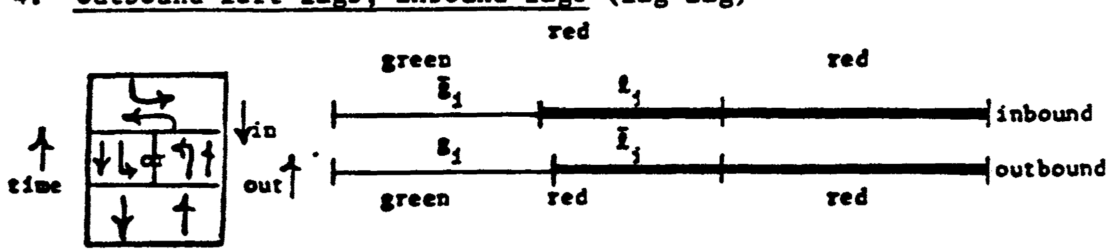


Figure 5. The 4 possible patterns of left turn phases.

center of r_i, in terms of ℓ_i and $\bar{\ell}_i$ for each case as follows:

Pattern	Δ_i
1	$-(1/2)(\ell_i + \bar{\ell}_i)$
2	$(1/2)(\ell_i + \bar{\ell}_i)$
3	$-(1/2)(\ell_i - \bar{\ell}_i)$
4	$(1/2)(\ell_i - \bar{\ell}_i)$

All of these can be expressed in the form:

$$\Delta_i = (1/2)[(2\delta_i - 1)\ell_i - (2\bar{\delta}_i - 1)\bar{\ell}_i] \qquad (6)$$

where δ_i and $\bar{\delta}_i$ are 0-1 variables and the previous cases are now picked out by

Pattern	δ_i	$\bar{\delta}_i$
1	0	1
2	1	0
3	0	0
4	1	1

Therefore we can use the mixed integer program to select the pattern that will maximize bandwidth. If only certain patterns are to be permitted, restrictions can be placed on the δ_i and $\bar{\delta}_i$ to enforce the requirements. For example, if only patterns 1 and 2 are permitted the constraint $\delta_i + \bar{\delta}_i = 1$ is added.

Notice that under some circumstances, for instance, vehicle activated left turn arrows, the time allocated to left turn green may not all be used. That is all right; the program makes no requirement that the green arrow be on. The essential point that affects bandwidth is that the through traffic faces a red light.

We often wish to let the user favor one direction, say, by manipulating the ratio of inbound to outbound bandwidth. For example, this ratio might be set to that of the two flows. Such a requirement is easily built into the LP as a constraint. However, in making one green band larger than the other, we can never make it larger than the smallest green in that direction. Once this is achieved, it is foolish to restrict the opposite direction further just to satisfy the ratio. Therefore we speak of a <u>target</u> ratio. Let

k = target ratio of inbound to outbound bandwidth .

For the case of $k < 1$ (outbound favored) we can set up the objective function and ratio constraint as

$$\max\ b + k\bar{b}$$

subject to

$$b \geq kb \ .$$

The $k > 1$ case is also accommodated if we change the formulation to

$$\max\ b + k\bar{b}$$

$$(1 - k)\bar{b} \geq (1 - k)kb \ . \qquad (7)$$

For $k = 1$, the inequalities (7) must be replaced by $b = \bar{b}$.

A further set of generalizations is possible. One of the most important is to let signal period (cycle length) and speed be variables. Each will be constrained by upper and lower limits. In addition, changes in speed from one street segment to the next can be limited.

Let

T = cycle length (signal period)(seconds).

$z = 1/T$ = signal frequency (cycles/second).

T_1, T_2 = lower and upper limits on cycle length, i.e. $T_1 \leq T \leq T_2$ (seconds).

$d(h,i)$ $[\bar{d}(h,i)]$ = distance between S_h and S_i outbound (inbound) (meters).

$$d_i = d(i,i+1), \quad \bar{d}_i = \bar{d}(i,\ i+1)$$

$e_i, f_i (\bar{e}_i, \bar{f}_i)$ = lower and upper limits on outbound (inbound) speed (meters/second).

$1/h_i, 1/g_i (1/\bar{h}_i, 1/\bar{g}_i)$ = lower and upper limits on change in outbound (inbound) reciprocal speed, i.e., $1/h_i \leq (1/v_{i+1}) - (1/v_i) \leq 1/g_i$ (meters/sec)$^{-1}$.

We are constraining change in speed by putting upper and lower limits on change in reciprocal speed. Although the two are not quite the same, either serves to prevent large abrupt speed changes. Reciprocal speed is used because it enters linearly in the constraints and can be transformed into t_i. Thus

$$t_i = (d_i/v_i)z \quad \text{and} \quad \bar{t}_i = (\bar{d}_i/\bar{v}_i)z \ . \tag{8}$$

In the expanded formulation, t_i, $\bar{t}_i$, and z are decision variables which, once known, determine progression speeds.

We add to LP1 all these generalizations to yield a more versatile mixed-integer linear program:

<u>LP2</u>. Find $b, \bar{b}, z, \bar{w}_i, t_i, \bar{t}_i, \delta_i, \bar{\delta}_i, m_i$

subject to to max $b + k\bar{b}$

$$(1-k)\bar{b} \geq (1-k)kb \tag{9}$$

$$1/T_2 \leq z \leq 1/T_1 \tag{10}$$

$$\left.\begin{array}{ll} w_i + b \leq 1 - r_i & \text{(11a)} \\ \bar{w}_i + \bar{b} \leq 1 - \bar{r}_i & \text{(11b)} \end{array}\right\} \quad i = 1,\ldots,n$$

$$\begin{aligned} &(w_i + \bar{w}_i) - (w_{i+1} + \bar{w}_{i+1}) + (t_i + \bar{t}_i) + \delta_i \ell_i - \bar{\delta}_i \bar{\ell}_i \\ &\quad - \delta_{i+1}\ell_{i+1} + \bar{\delta}_{i+1}\bar{\ell}_{i+1} - m_i \\ &\quad = (r_{i+1} - r_i) + (\bar{\tau}_i + \tau_{i+1}) \ , \qquad i = 1,\ldots,n-1 \end{aligned} \tag{12}$$

$$\left.\begin{array}{ll} (d_i/f_i)z \leq t_i \leq (d_i/e_i)z & \text{(13a)} \\ (\bar{d}_i/\bar{f}_i)z \leq \bar{t}_i \leq (\bar{d}_i/\bar{e}_i)z & \text{(13b)} \end{array}\right\} \quad i = 1,\ldots,n-1$$

$$\left.\begin{aligned}(d_i/h_i)z \le (d_i/d_{i+1})t_{i+1} - t_i \le (d_i/g_i)z \\ (\bar{d}_i/\bar{h}_i)z \le (\bar{d}_i/\bar{d}_{i+1})\bar{t}_{i+1} - \bar{t}_i \le (\bar{d}_i/\bar{g}_i)z\end{aligned}\right\} i = 1,\dots,n-2 \qquad \begin{matrix}(14a)\\(14b)\end{matrix}$$

$$b,\ \bar{b},\ z,\ w_i,\ \bar{w}_i,\ t_i,\ \bar{t}_i \ge 0$$

$$m_i \text{ integer}$$

$$\delta_i, \bar{\delta}_i 0,1$$

where if k = 1 (9) is replaced by $\bar{b} = b$.

LP2 involves (11n-10) constraints and (4n + 1) continuous variables, up to 2n 0-1 variables and n-1 unrestricted integer variables, not counting slack variables. In addition, if the user decides to require or prohibit certain left turn patterns, constraints on δ_i and $\bar{\delta}_i$ are added up to a maximum of 2n.

LP2 describes how the arterial case is solved. The mathematical program for a network consists of (1) an objective function which is a weighted conbination of the objective functions of individual LP2's (the weights being set by the user to express the relative importance of bandwidth on the arteries in a network), (2) cross artery bandwidth constraints, (3) all the constraints of individual LP2's, and (4) a loop constraint for each independent loop in the network.

The cross artery bandwidth constraints are added in a network problem formulation in order to let the user favor one artery over another. The logic in deriving these constraints is the same as that for the within artery bandwidth constraint (equation 9) of LP2.

In general, the loop constraint is given by

$$\sum_{(i,j)\epsilon L} \psi_{ij} = n_L$$

where ψ_{ij} is the offset for link (i,j) in loop L and n_L is the loop integer. The derivation of the loop constraints will be explained using an example loop given in figure 6. The loop constraint will be developed assuming that the loop is traversed in the clockwise direction. It is further assumed for convenience that the outbound directions of all arteries match with the clockwise orientation.

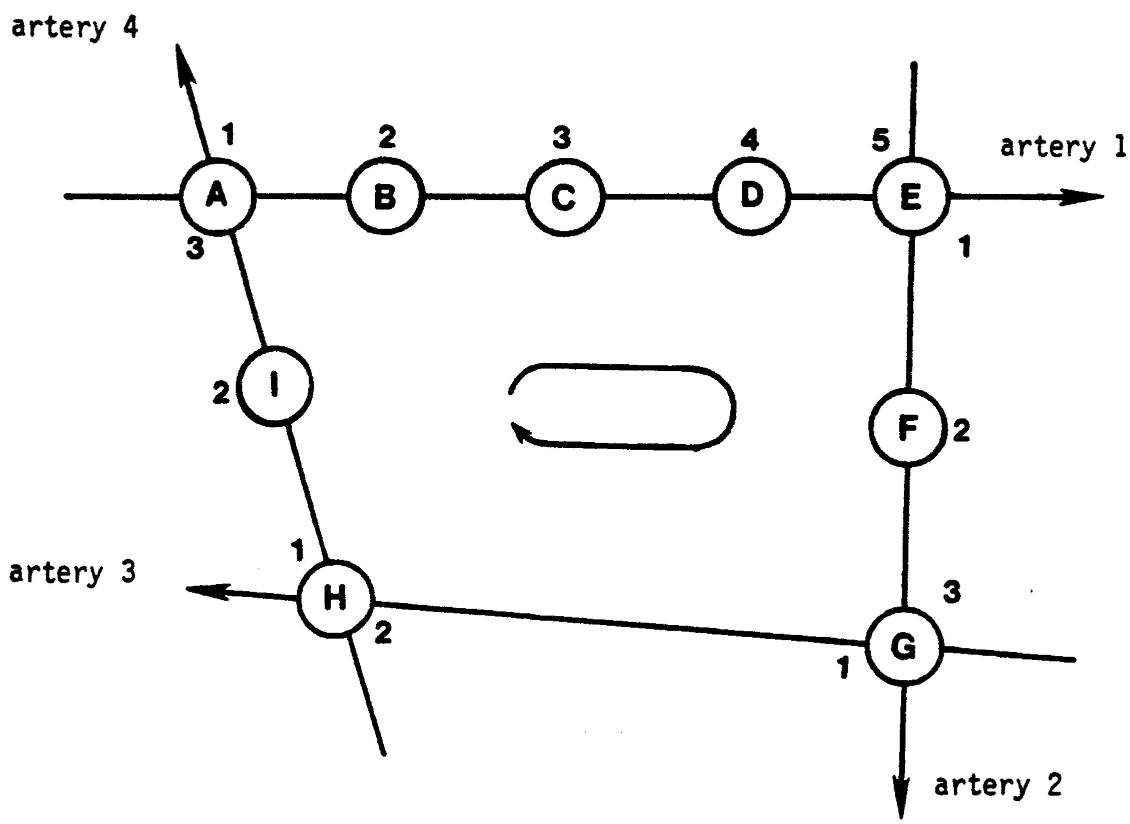


Figure 6: Example loop formed by 4 arteries.

Let

$\Delta_{i,j}$ = time between reds at an intersection for arteries i and j; and

$\phi_{i,j}$ = time from the center of an outbound red at s_i to the center of a particular outbound red at s_{i+1} for artery j.

Then, the equation for the example loop is given by:

$$\begin{aligned} &\phi_{1,1} + \phi_{2,1} + \phi_{3,1} + \phi_{4,1} + \Delta_{1,2} \\ &+ \phi_{1,2} + \phi_{2,2} + \Delta_{2,3} \\ &+ \phi_{1,3} + \Delta_{3,4} \\ &+ \phi_{1,4} + \phi_{2,4} + \Delta_{4,1} \\ &= n_L \end{aligned} \tag{15}$$

For ith the signal of artery art, $\phi_{i,art}$ is given by:

$$\begin{aligned} \phi_{i,art} = &(r_{i,art})/2 - (r_{i+1,art})/2 + W_{i,art} - W_{i+1,art} \\ &+ t_{i,art} - \tau_{i+1,art} \end{aligned} \tag{16}$$

Substituting equation 16 into equation 15 and simplifying yields:

$$\begin{aligned} &[(r_{1,1})/2 - (r_{5,1})/2 + W_{1,1} - W_{5,1} + t_{1,1} + t_{2,1} + t_{3,1} + t_{4,1} \\ &- \tau_{2,1} - \tau_{3,1} - \tau_{4,1} - \tau_{5,1}] \\ &+ [(r_{1,2})/2 - (r_{3,2})/2 + W_{1,2} - W_{3,2} + t_{1,2} + t_{2,2} - \tau_{2,2} - \tau_{3,2}] \\ &+ [(r_{1,3})/2 - (r_{2,3})/2 + W_{1,3} - W_{2,3} + t_{1,3} - \tau_{23}] \\ &+ [(r_{1,4})/2 - (r_{3,4})/2 + W_{1,4} - W_{3,4} + t_{1,4} + t_{2,4} - \tau_{2,4} - \tau_{3,4}] \\ &+ [\Delta_{1,2} + \Delta_{2,3} + \Delta_{3,4} + \Delta_{4,1}] \\ &= n_L \end{aligned} \tag{17}$$

Consider the intersection where an artery is exited and another artery is entered while traversing a loop. In the example given in figure 6, there are four such intersections. Figure 7 illustrates the four possible left turn patterns where:

g_1 = green split in outbound direction on artery 1;

$\bar{\ell}_1$ = left split in inbound direction on artery 1;

g_2 = green split in outbound direction on artery 2;

$\bar{\ell}_2$ = left split in inbound direction on artery 2;

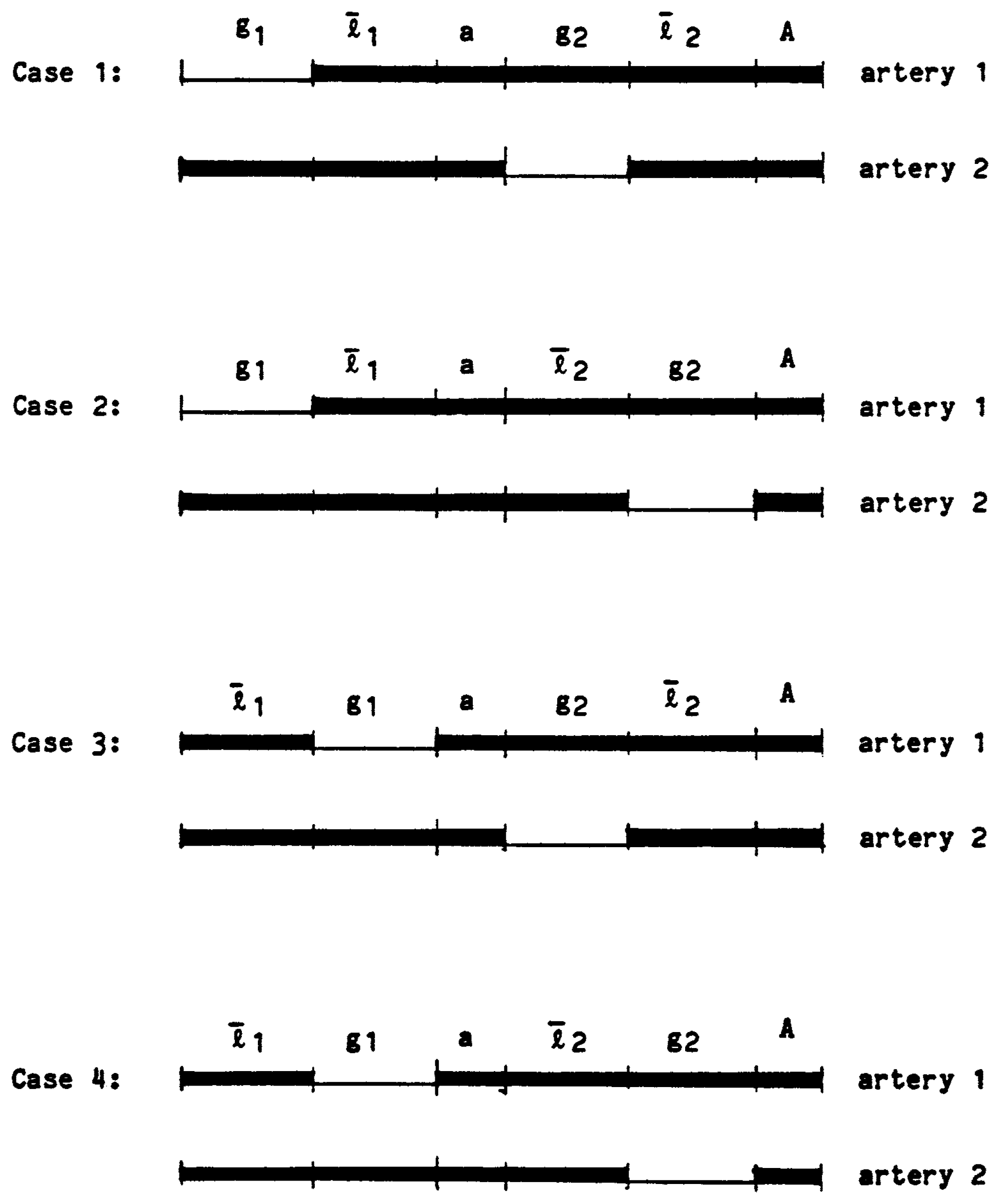


Figure 7: The four left-turn phase patterns for a loop corner.

a = portion of all-red time allocated to the end of the phase on artery 1; and

A = portion of all-red time allocated to the end of the phase on artery 2.

Note that there may or may not be any all-red time at an intersection.

Then we have, for the intersection of arteries 1 and 2:

Case 1: $\Delta_{1,2} = (\bar{\ell}_{5,1} - \bar{\ell}_{1,2})/2 + (1-A+a)/2$

Case 2: $\Delta_{1,2} = (\bar{\ell}_{5,1} + \bar{\ell}_{1,2})/2 + (1-A+a)/2$

Case 3: $\Delta_{1,2} = -(\bar{\ell}_{5,1} + \bar{\ell}_{1,2})/2 + (1-A+a)/2$

Case 4: $\Delta_{1,2} = -(\bar{\ell}_{5,1} - \bar{\ell}_{1,2})/2 + (1-A+a)/2$

This can be written in a comprehensive form as:

$$\Delta_{1,2} = -[(2 * \bar{\delta}_{1,2}-1) * \bar{\ell}_{1,2} - (2 * \bar{\delta}_{5,1} - 1) * \bar{\ell}_{5,1}]/2 + (1-A+a)/2$$

Similarly, we can get Δ_{23}, Δ_{34} and Δ_{41} which are given below.

$$\Delta_{2,3} = -[(2 * \bar{\delta}_{1,3}-1) * \bar{\ell}_{1,3} - (2 * \bar{\delta}_{3,2} - 1) * \bar{\ell}_{3,2}]/2 + (1-A+a)/2$$
$$\Delta_{3,4} = -[(2 * \bar{\delta}_{1,4}-1) * \bar{\ell}_{1,4} - (2 * \bar{\delta}_{2,3} - 1) * \bar{\ell}_{2,3}]/2 + (1-A+a)/2$$

and

$$\Delta_{4,1} = -[(2 * \bar{\delta}_{1,1}-1) * \bar{\ell}_{1,4} - (2 * \bar{\delta}_{3,4} - 1) * \bar{\ell}_{3,4}]/2 + (1-A+a)/2$$

Define

inter(1,art) = intersection where artery art is entered while traversing on the loop; and

inter(2,art) = intersection where artery art is exited while traversing on the loop.

then

$\Delta_{1,2} + \Delta_{2,3} + \Delta_{3,4} + \Delta_{4,1}$ can be rewritten by combining all the terms for artery art together as

$$\Delta_{1,2} + \Delta_{2,3} + \Delta_{3,4} + \Delta_{4,1} = \sum_{art=1}^{4} -[(2*\bar{\delta}_{inter(1,art)} - 1)*\bar{\ell}_{inter(1,art)} - (2*\bar{\delta}_{inter(2,art)} - 1)*\bar{\ell}_{inter(2,art)}]/2 + \sum_{art=1}^{4} (1-A+a)/2 \qquad (18)$$

Now using the variable inter defined above, simplifying and substituting equation (18) into (17) yields:

$$\text{repeat for } art = 1, \ldots, 4 \left\{ \begin{array}{l} \overset{n_L}{-} W_{inter(1,art)} + W_{inter(2,art)} \\ - t_{inter(1,art)} - \cdot \cdot \cdot \cdot - t_{inter(2,art)} - 1 \end{array} \right.$$

$$=$$

$$\text{repeat for } art = 1, \ldots, 4 \left\{ \begin{array}{l} (r_{inter(1,art)})/2 + (r_{inter(2,art)})/2 \\ - \tau_{inter(1,art)+1} - \cdot \cdot \cdot \cdot - \tau_{inter(2,art)} \\ - \bar{\delta}_{inter(1,art)} * \bar{\ell}_{inter(1,art)} + (\bar{\ell}_{inter(1,art)})/2 \\ + \bar{\delta}_{inter(2,art)} * \bar{\ell}_{inter(2,art)} - (\bar{\ell}_{inter(2,art)})/2 \\ + (1-A+a)/2 \end{array} \right. \qquad (19)$$

let

AR = all-red time

γ = all-red time allocation variable defined on the interval [0,1]

where

$AR = a+A = 1-g_1-\bar{\ell}_1 -g_2 -\bar{\ell}_2$

If

$a = (1-\gamma)*AR$, then $A = \gamma*(AR)$

also

$\bar{\ell} = r-R$

Further simplifying (19) using the above defined quantities gives the final loop equation for our example.

$$
\begin{array}{ll}
 & \quad n_L \\
\text{repeat for } art = 1, \ldots, 4 & \left\{ \begin{array}{l}
- \; W_{inter(1,art)} + W_{inter(2,art)} \\
- \; t_{inter(1,art)} - \cdots - t_{inter(2,art)} - 1 \\
+ \; \bar{\delta}_{inter(1,art)} * \bar{\ell}_{inter(1,art)} \\
- \; \bar{\delta}_{inter(2,art)} * \bar{\ell}_{inter(2,art)}
\end{array} \right. \\
\text{repeat for } intersection = 1, \ldots, 4 & \left\{ \; + \; \gamma_{intersection} * (AR_{intersection}) \right. \\
 & = \\
\text{repeat for } art = 1, \ldots, 4 & \left\{ \begin{array}{l}
\quad r_{inter(1,art)} - \bar{\ell}_{inter(2,art)} \\
- \; \tau_{inter(1,art)} + 1 - \cdots - \tau_{inter(2,art)}
\end{array} \right.
\end{array}
\qquad (20)
$$

The initial assumption that the outbound direction on each artery belonging to the loop is the same as the direction of traversal around the loop can now be relaxed and a more general loop equation derived:

$$
\begin{array}{ll}
 & \quad n_L \\
\text{repeat for } art = 1, \ldots, 4 & \left\{ \begin{array}{l}
- \; W_{inter(1,art)} + W_{inter(2,art)} \\
\left\{ \begin{array}{l}
- \; t_{inter(1,art)} - \cdots - t_{inter(2,art)} - 1 \\
\qquad \text{if } inter(1,art) \leq inter(2,art) \\
+ \; t_{inter(1,art)} + \cdots + t_{inter(2,art)} - 1 \\
\qquad \text{if } inter(1,art) > inter(2,art)
\end{array} \right. \\
+ \; \bar{\delta}_{inter(1,art)} * \bar{\ell}_{inter(1,art)} \\
- \; \bar{\delta}_{inter(2,art)} * \bar{\ell}_{inter(2,art)}
\end{array} \right. \\
\text{repeat for } intersection = 1, \ldots, 4 & \left\{ \; + \; \gamma_{intersection} * (AR_{intersection}) \right. \\
 & =
\end{array}
$$

$$
\begin{array}{ll}
\text{repeat for} & \\
\text{art} = 1, \ldots, 4 &
\left\{
\begin{array}{l}
r_{\text{inter}(1,\text{art})} - \quad \text{inter}(2,\text{art}) \\
\left\{
\begin{array}{l}
- \ \tau_{\text{inter}(1,\text{art})+1} - \cdot \cdot \cdot \cdot - \quad \text{inter}(2,\text{art}) \\
\qquad\qquad \text{if inter}(1,\text{art}) \leq \text{inter}(2,\text{art}) \\
+ \ \tau_{\text{inter}(1,\text{art})+1} + \cdot \cdot \cdot \cdot + \quad \text{inter}(2,\text{art}) \\
\qquad\qquad \text{if inter}(1,\text{art}) > \text{inter}(2,\text{art})
\end{array}
\right.
\end{array}
\right.
\end{array}
\qquad (21)
$$

The incorporation of all-red time variable (γ), in the loop constraint derived above, implicitly assumes that the labels "first" and "second" assigned to arterials at an intersection, match with the orientation of the loop. In a general network with multiple loops, however, it may not be possible to define labels that match with the orientation of all loops having that intersection as a common corner point. This problem can be resolved by arbitrairily assigning the labels "first" and "second" to the arterials on an intersection and modifying the loop equation as follows:

$$
\begin{array}{ll}
 & n_L \\
\text{repeat for} & \\
\text{art} = 1, \ldots, 4 &
\left\{
\begin{array}{l}
- \ W_{\text{inter}(1,\text{art})} + W_{\text{inter}(2,\text{art})} \\
\left\{
\begin{array}{l}
- \ t_{\text{inter}(1,\text{art})} - \cdot \cdot \cdot \cdot - t_{\text{inter}(2,\text{art})-1} \\
\qquad\qquad \text{if inter}(1,\text{art}) \leq \text{inter}(2,\text{art}) \\
+ \ t_{\text{inter}(1,\text{art})} + \cdot \cdot \cdot + t_{\text{inter}(2,\text{art})-1} \\
\qquad\qquad \text{if inter}(1,\text{art}) > \text{inter}(2,\text{art})
\end{array}
\right. \\
+ \ \delta_{\text{inter}(1,\text{art})} * \text{inter}(1,\text{art}) \\
- \ \delta_{\text{inter}(2,\text{art})} * \text{inter}(2,\text{art})
\end{array}
\right.
\end{array}
$$

$$
\begin{array}{ll}
\text{report for} & \\
\text{intersection} & \\
= 1, \ldots, 4 &
\left\{
\begin{array}{l}
+ \ \gamma_{\text{intersection}} * (AR_{\text{intersection}}) \\
\qquad \text{if definition of arterials at an intersection} \\
\qquad \text{matches with loop orientation} \\
+ \ (1-\gamma)_{\text{intersection}} * (AR_{\text{intersection}}) \\
\qquad \text{otherwise}
\end{array}
\right.
\end{array}
$$

$$=$$

$$
\begin{array}{ll}
\text{repeat for} & \\
\text{art} = 1, \ldots, 4 &
\left\{
\begin{array}{l}
r_{\text{inter}(1,\text{art})} - \quad \text{inter}(2,\text{art}) \\
\left\{
\begin{array}{l}
- \ \tau_{\text{inter}(1,\text{art})+1} - \cdot \cdot \cdot \cdot - . \ \text{inter}(2,\text{art}) \\
\qquad\qquad \text{if inter}(1,\text{art}) \leq \text{inter}(2,\text{art}) \\
+ \ \tau_{\text{inter}(1,\text{art})+1} + \cdot \cdot \cdot \cdot + \quad \text{inter}(2,\text{art}) \\
\qquad\qquad \text{if inter}(1,\text{art}) > \text{inter}(2,\text{art})
\end{array}
\right.
\end{array}
\right.
\end{array}
\qquad (22)
$$

The loop equation derived above strictly applies only for the case when a network consists of 4 arteries and all of them are part of the loop. If there is more than one loop in the network, each loop will be formed by a different set of arteries whose numbers may not be in an ordered sequence. Also, the number of arteries in a loop may vary from 3 to a maximum allowable 6. To be able to describe any loop, the variable 'inter' defined and used previously must be expanded and two more variables defined. These actions are explained in detail below.

inter(i, art, iloop) describes loop geometry.

- subscript 1: Signal numbers at entering (1) and leaving (2) points in artery 'art' of loop iloop.
- subscript 2: Artery number in the range 1 to 6.
- subscript 3: Loop number in the range 1 to 36.

intra(7, iloop) contains the number of arteries in loop iloop.

intra(art, iloop) contains actual artery number.

- subscript 1: Actual artery number corresponding to artery art of loop iloop. Range of subscript is 1 to intra(7,iloop).
- subscript 2: Loop number.

intgam(7, iloop) contains the number of all-red time variables in loop iloop.

intgam(intersection, iloop) contains pointers to indices of the actual gamma variables in loop iloop. iloop is in the range of 1 to intgam(7, iloop). If intgam(intersection,iloop) has a positive value, the term $(\gamma)_{intersection}*(AR_{intersection})$ is used in loop equation. A negative value implies that the term to be used in loop equation is $(1-\gamma)_{intersection}*(AR_{intersection})$.

Thus all variables in the loop except the all-red time variables are described using subscripts, namely inter and intra, and the all-red time variable is described using one subscript, namely intgam. For further explanation of the use of these variables and the description of the loop equation using them, refer to chapter 2 and appendix A of volume 3.

MAXBAND'S LOOP GENERATION ALGORITHM

MAXBAND uses a modified version of Paton's algorithm [1969]. The differences between the original and modified algorithm are described below.

(i) As opposed to Paton's original algorithm, the modified algorithm uses the node with most links incident to it as the root of the spanning tree. Such a node is called the highest degree node. This results in a simpler loop set for traffic networks in most cases.

(ii) The construction of the tree and cotree is completed before tracing of loops is begun.

(iii) The links in the cotree are examined and, if possible, the loops are further reduced to simpler ones.

The reason for placing more emphasis on finding simpler loops is that their coefficients in the technological coefficient matrix (A matrix) will occupy less space.

The Algorithm

Let

L = set of links of the network;

N = set of nodes of the network;

T = set of nodes already in the spanning tree;

X = set of nodes not yet examined; and

r = root of tree.

Initially T = ϕ (null set) and X = N

Steps:

1. Let r = node having the maximum number of links incident to it; break ties by selecting the node having bigger node number.
2. Let T = {r};
3. Find $T \cap X$;
4. IF $T \cap X =$ then go to step 7;
5. Let n = first element in $T \cap X$; break ties by selecting smallest node number;
6. Consider each link (n,w) in L and act as follows:

(i) If $W \in T$ add link (n,w) to the cotree, if it is not already in the tree or cotree.

(ii) If $W \notin T$ add link (n,w) to tree and W to set T.

When all links (n,w) have been considered, remove current n from X and go to step 3 above.

7. For each link in the cotree, trace a fundamental loop; and
8. For each link in the cotree starting from the second, attempt to reduce the fundamental loop to a smaller fundamental loop.

Note that in step 8 above, no attempt is made to reduce the first loop since it is always the simplest developed. For further descriptions, refer to appendix B.

Obtaining Loop Information In Terms Of Variables Used In Matrix Generator (MATGEN) Module

The loop identified using the steps of the algorithm given in previous sections is stored in terms of node identification numbers. For example, the loop for the network drawn in figure 7 will be A-B-C-D-E-F-G-H-I-A. The loop stored in this manner cannot be used to write the problem formulation. This information must be stored in variables used by the matrix generator (MATGEN) module.

The loop is reduced to only corner points before attempting to store data in appropriate variables. The reduced loop for our example will be A-E-G-H-A. The information can now be stored in the variables inter and intra described previously. These variables will have the following values:

intra(7,1) = 4, i.e., loop 1 is composed of 4 arteries.

inter(1,1,1) = 1	intra(1,1) = 1
inter(2,1,1) = 5	
inter(1,2,1) = 1	intra(2,1) = 2
inter(2,2,1) = 3	
inter(1,3,1) = 1	intra(3,1) = 3
inter(2,3,1) = 2	
inter(1,4,1) = 1	intra(4,1) = 4
inter(2,4,1) = 2	

For further description, refer to chapter 2 of volume 3.

CALCULATION OF OBJECTIVE FUNCTION WEIGHTS AND BANDWIDTH RATIOS

The objective function weights and inter- and intra-artery bandwidth ratios are related to each other in a special way. For the problem formulation to be correct, this relationship must hold. MAXBAND 86 relieves the user of this responsibility. The program has three user controlled quantities (arterial weights) that can be used to control the emphasis placed on each of the two bandwidths of an artery. The program uses these quantities to calculate the objective function coefficients and bandwidth ratios while retaining the proper relationships among them. Detailed description is provided in chapter 3 of volume 2.

DETERMINING GREEN SPLITS

One option in MAXBAND is for the user to supply the green splits. Alternatively, the user can provide traffic volume and capacity information from which the program will calculate the green splits. This is done essentially by using the theory of Webster (1958). Webster has shown that under certain circumstances, total delay at an intersection is minimized by dividing the available cycle time among competing streams of traffic proportional to their volumes divided by their saturation capacities.

In MAXBAND, the user who wishes to use this option provides volume and capacity information for the traffic, classified into 4 through movements and 4 left turn movements of each intersection. Let

TRAT(i) = through-traffic ratio of volume to saturation capacity in direction i;

LRAT(i) = left turn traffic ratio of volume to saturation capacity in direction i; and

i = OUT, IN, OUTC, INC = outbound main, inbound main, outbound cross street, inbound cross street.

The procedure calculates

MAIN = max{TRAT(OUT) + LRAT(IN), TRAT(IN) + LRAT(OUT)}

= the larger of through volume/capacity plus opposite left turn volume/capacity for the two directions on the main street.

CROSS = max{TRAT(OUTC) + LRAT(OUTC), TRAT(INC) + LRAT(OUTC)} =

the same quantity for the cross street.

The basic split between main street and cross street is

$$MM = \frac{MAIN}{MAIN + CROSS} = \text{total time allocated to main street (fraction of cycle)}$$

$$CC = \frac{CROSS}{MAIN + CROSS} = \text{total time allocated to cross street (fraction of cycle)}$$

Let

L(OUT) [L(IN)] = outbound [inbound] left split; and

G(OUT) [G(IN)] = outbound [inbound] through split.

Then

$$L(OUT) = \frac{LRAT(OUT)}{TRAT(OUT) + LRAT(IN)} \times MM$$

$$L(IN) = \frac{LRAT(IN)}{TRAT(OUT) + LRAT(IN)} \times MM$$

$$G(OUT) = MM - L(IN)$$

$$G(IN) = MM - L(OUT)$$

If necessary, these splits are then modified slightly to meet minimum green requirements provided by the user or as a default by MAXBAND.

COMPUTER PROGRAM

The computer program consists of (1) a control section, (2) an input section to accept basic traffic data from the user, (3) a matrix generator that transforms the input into a form usable by the mixed integer linear program, (4) a mathematical programming package, and (5) an output routine that interprets the mathematical programming results and prints them out in a form usable by a traffic engineer.

The program contains 16,200 lines of FORTRAN 77 code, broken out as follows:

Control program (MAXBAND)	100
Input program (INPUT)	6,050
Matrix generator (MATGEN)	3,375
Optimization code (MPCODE)	2,675
Output program (OUTPUT)	4,000
	16,200

CONTROL PROGRAM

The control program (MAXBAND) manages the overall computation, calling each of the other programs as needed.

INPUT

Input to the program is on IBM cards or card images on a CRT unit. The basic inputs are:

1. Overall problem information. This includes a name for the run, an indicator for whether it is a network problem or an artery problem, an indicator for whether metric or English units are used, the acceptable range of cycle lengths, and the three weights for each artery, unless these are to be computed from volumes. Usually default values are used in the mathematical programming package for certain parameters, such as the maximum number of iterations and reinversions, but, if the user wishes, these can be supplied as part of the overall problem information.

2. Network geometry. The order and unique identification number of the signals on each artery is given, along with the distances between them (which may be different in each direction), and the names of their intersections.

3. Green splits or traffic flow and capacities. The user may specify the green splits at each signal as a fraction of the overall cycle time. Alternatively, traffic flows and capacities can be given on each link, including cross streets and turning movements, and the program will calculate green splits using Webster's formula.

4. Left turning patterns. Left turn phases can occur at the beginning or end of green in either direction along the artery, creating four possible patterns for the through direction at each intersection. The user can specify which of the patterns are acceptable and the program will choose among them to maximize bandwidth.

5. Queue clearance time. Queues may build up during red time as a result of turning movements onto the artery at previous intersections. Such queues may impede the flow of vehicles in the through band. The user may, therefore, specify at any intersection in either direction a queue clearance time as a fraction of the cycle length. The program will adjust the through band to arrive at the intersection after the queue has cleared and leave the intersection with the queue included as part of the band. In effect, this puts a jog into the through band, advancing it upon leaving the intersection by an amount equal to the queue clearance time.

6. Range of speed. For each link, or if preferred to the artery as a whole, the user specifies a design mean value and a tolerance for speed. The program then chooses speeds for each link from this range so as to maximize bandwidth. In addition, the user can constrain the change in speed from one link to the next. If the user does not set limits on speeds and speed changes, default values are used.

Further, more detailed specification of inputs are found in the volume 2 - User's Manual.

MATRIX GENERATOR

The mathematical program solves the general mixed integer, linear programming problem:

$$\begin{aligned} \text{max:} \quad & cx \\ \text{subject to:} \quad & Ax \lesseqgtr b \\ & x \geq 0 \\ & x_j \text{ integer; } j \in J \end{aligned}$$

where x is an n-vector of variables whose values are sought. c is an n-vector of objective function coefficients, A is an m x n matrix of coefficients, b is an n-vector of right-hand side constants and J is a set of subscripts identifying the variables required to be integer.

The traffic problem described earlier as LP2 requires specific values for A, b, c, and J. These will change as the traffic problem changes. It is necessary to have a generalized program, called the matrix generator, which will take the traffic input data and convert it into the appropriate vectors and matrices for input to the mathematical programming package.

MATHEMATICAL PROGRAMMING PACKAGE

A key part of the computer program is the routine for solving the mixed integer linear program. For the most part, mixed integer problems are solved by branch and bound methods. The basic idea is to break up the set of all solutions into smaller and smaller subsets and to calculate for each an upper bound on the value of the best solution therein. The bounds guide the partitioning of the subsets and eventually identify the maximal solution - when a subset is found whose maximal solution is greater than or equal to the upper bounds for all the other subsets, that solution is optimal. The subsets of solutions are conveniently represented as the nodes of a tree and the process of partitioning as the branching of the tree. Hence, the name 'branch and bound'.

In mixed integer problems, the upper bound is usually set by solving a continuous LP ignoring the integer constraints. This is an upper bound on the true problem since further constraining the integer variables to integer values can only worsen the objective function. Partitioning is done by identifying integer variables that do not take on integer values in the continuous solution. Suppose, for example, that in the continuous solution $x_5 = 3.7$ but x_5 is really supposed to be an integer variable. We can partition the set of all solutions to the true mixed integer problem into those for which $x_5 \leq 3$ and those for which $x_5 \geq 4$. These two subsets form two nodes branching from the previous node. Each can be given an upper bound by solving a continuous LP with the new constraint added. The new constraint is likely to produce an answer which sets $x_5 = 3$ (or 4 as the case may be). Proceeding onward we eventually get a solution with all the required variables integer. The objective function can be compared with the bounds on the other subsets to determine whether we can declare the solution to be optimal. With enough searching we will always find an optimal solution but sometimes the searching can be very extensive. Usually computation time rises exponentially with the number of integer variables.

The writing of a mixed integer code is a specialized job beyond the scope of this project. Therefore, MPCODE (which was previously being used) has been retained.

OUTPUT

MAXBAND produces up to six (6) major output sections for signal timing optimization for both signalized artery and network problems. The functional output structure of MAXBAND is illustrated in figure 8 and described as follows, and discussed in detail in "Volume II: MAXBAND User's Manual". The six major output sections are:

1. MAXBAND INPUT CARDS;
2. MAXBAND INPUT DATA SUMMARY;
3. MPCODE PERFORMANCE PLOT AND MPCODE STATISTICS;
4. MAXBAND SOLUTION REPORT;
5. REITERATION OF SETTINGS AT ARTERY MEETINGS; and
6. SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION.

The first MAXBAND INPUT CARDS section provide the echo printouts of the input cards. The second, MAXBAND INPUT DATA SUMMARY section, indicates how the input data has been interpreted and what problem values are being passed to the branch and bound routine (MPCODE). These two sections are produced by the INPUT module of MAXBAND.

The third section consists of the MPCODE PERFORMANCE PLOT and MPCODE STATISTICS portions of the output. The first of these gives statistics on the performance of the maximization routine; the second prints the signal setting solution which yields the most optimal bandwidths found so far. This section is produced by the output module of MAXBAND.

MAXBAND--MAXIMAL BANDWIDTH TRAFFIC SIGNAL TIMING OPTIMIZATION PROGRAM

I. [MAXBAND INPUT CARDS]

II. [MAXBAND INPUT DATA SUMMARY]
- MPCODE VALUES
- [NETWORK WIDE VALUES]*

  Repeat for each entry--Artery 1 through Artery N
- ARTERY WIDE VALUES
  - Cycle Length Allowable Range
  - Artery Directional Weights
  - Design Speed
- INTERSECTION VALUES
  - Arterial Direction Green Split
  - Phase Patterns
  - Minimum Green Time
- LINK VALUES
  - Speed, Volume, Capacity

III. [MPCODE PERFORMANCE PLOT] and MPCODE STATISTICS

IV. MAXBAND SOLUTION REPORT

  [Repeat for each artery--Artery 1 through Artery N]*
- ARTERY WIDE INFORMATION
  - Cycle Length, Bandwidth, Efficiency and Attainability
- INTERSECTION VALUES
  - LEFT TURN PATTERN SELECTED
  - PHASE SETTINGS (FRACTIONS OF CYCLE)
  - PHASE SETTINGS (SECONDS)
  - PROGRESSION TIMES AND SPEEDS
- MAXBAND TIME-SPACE DIAGRAM

V. REITERATION OF SETTINGS AT ARTERY MEETINGS *

  Repeat for each node -- Node 1 though Node N
  PHASE SETTINGS (FRACTIONS OF CYCLE) and (SECONDS)

VI. SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION

  Master intersection, background cycle length

  Repeat for each signalized intersection--Intersection 1
  PHASE INTERVAL, NEMA MOVEMENTS, PHASE LENGTH, PIN SETTINGS

MAXBAND BEST SOLUTION
- NEMA movement numbers

MAXBAND END

* Unique for NETWORK problems, which includes triangle and grid-type signal networks.

[ ] Means optional outputs.

Figure 8. Functional structure of the MAXBAND output.

The fourth section, MAXBAND SOLUTION REPORT, gives the optimal MAXBAND signal timing solution reports for both the artery-wide information and intersection specific settings as selected by the MAXBAND optimization process. The artery-wide summary reports include the optimum cycle length, progression bandwidths, progression efficiency, and attainability. The intersection specific information included are the optimal left turn phase sequence selected, phase settings (expressed both in seconds and fractions of a cycle), progression speeds and travel time between signalized intersections.

The fifth section, the REITERATION OF SETTINGS AT ARTERY MEETINGS, is the representation of signal phase settings at intersections where arteries meet (or the "corner" intersections) in the signalized network. In this way, the progression bands on both the main and cross arteries could be referenced at the the same time.

The sixth section of MAXBAND output, the SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION, represents the detailed signal controller pin-settings for every intersection in the study network. The revised NEMA numbers, similar to that used in the Traffic Control Systems Handbook are used to identify the MAXBAND best signal timing solutions for each signalized intersection in the network. A detailed NEMA movement number diagram, as used to produce the MAXBAND controller pin setting report, is also provided graphically for easy reference of the traffic movements used in this MAXBAND summary report. The "MAXBAND END" statement at the end of the output indicates the termination of successful execution of the MAXBAND optimization run.

MAXBAND TEST NETWORKS

A variety of real-world arteries and networks have been collected and used to test the MAXBAND 86 program as it has evolved. A representative set of four test networks is described below. The numerical data of the fourth example is presented in "appendix: Test Network Data and Run" of this volume. The arterial street examples 1 and 2, and the signalized network examples 3 and 4 are further described in detail in volume 2. The example problems are illustrated in "chapter 4: MAXBAND Examples" of volume 2. The outputs produced by these input data decks are shown in both sections in "chapter 5: MAXBAND Output" and "appendix E: Sample Outputs" of "Volume 2: MAXBAND User's Manual".

These four examples are described as follows:

1. Arterial street - Broadway, Cambridge, Massachusetts -

   The first example is a five-intersection artery from Broadway Boulevard, Cambridge, Massachusetts which uses only the basic MAXBAND features. This basic arterial street layout is shown in figure 9.

2. Arterial street - Main Street, Waltham, Massachusetts -

   The second example is an eleven-intersection artery from Main Street Waltham, Massachusetts. This example contains left turns, and illustrates the computation of splits, objective function weights and target bandwidth ratio. A schematic layout of this test arterial appears in figure 10.

3. Triangle network - Attleboro, Massachusetts -

   The third example is a three-artery triangle network from Attleboro, Massachusetts. This example uses only the most basic features of MAXBAND for solving the special case of triangle network in the signalized network. This triangle network used to be referred as the "loop problem" in the previous MAXBAND documentations. Figure 11 shows the triangle signalized network.

4. Grid Network - Hawthorne Boulevard, Los Angeles, California -

The fourth example is a grid signal network from Los Angeles, California. It uses the major features of MAXBAND for optimizing left turn sequence in a typical signalized arterial network. The Hawthorne mini-grid network is illustrated in figure 12 for the acceptance test of the MAXBAND 86 by the Contract Officer's Technical Representative (COTR) of the Federal Highway Administration (FHWA), U. S. Department of Transportation (U.S. DOT).

Test runs were then made to evaluate the optimization performance of the MAXBAND 86 program with several test example problems. The computer used was the Texas A&M University's Amdahl 470 V6 and V8 mainframe computer system. Four test runs were made from the four signal problems presented earlier. The test results are also documented in details in "Volume II: MAXBAND's User's Manual."

The results of these four tests are summarized in Table 1. As indicated, the number of signals, the size of the matrix used in the linear porgramming optimization, and the number of integer variables are provided along with the run time statistics for the four test networks. As illustrated, the computer run time statistics using MAXBAND are closely related to the total number of iterations actually performed in the linear programming optimization. Since there are many random components which may influence how a particular test problem could be formulated for the mixed integer optimization, the run time efficiency for solving a particular problem may also be different on various computer systems. The different ways of problem formulation in MAXBAND 86 may significantly affect the branching operation and efficiency of the MPCODE process during traffic signal timing optimization. The runs shown were summarized from from the test network runs made on the Texas A&M University's Amdahl computer system. It is intended to show that problems can be solved on a typical computer system. However, it should be noted that the run time statistics of the MAXBAND optimization runs may be different depending on the speed of the particular types of computer systems, their operating systems, and the local system load conditions during actual program execution.

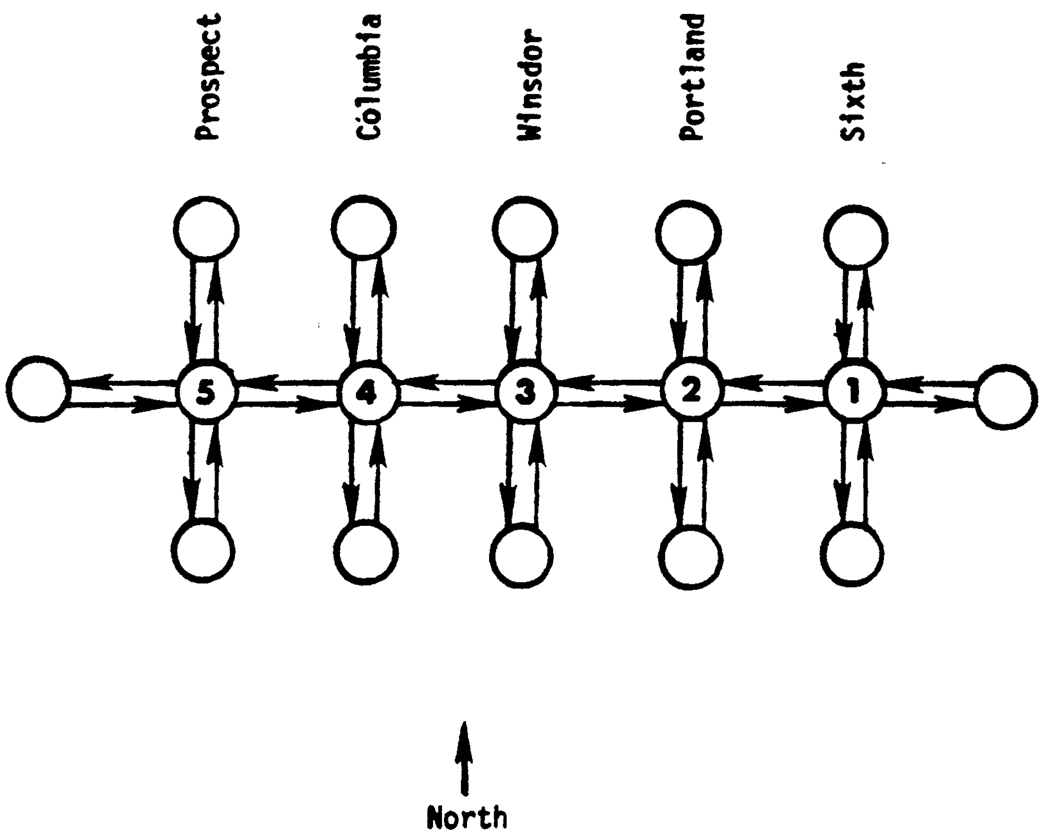


Figure 9: Broadway, Cambridge, Massachusetts.

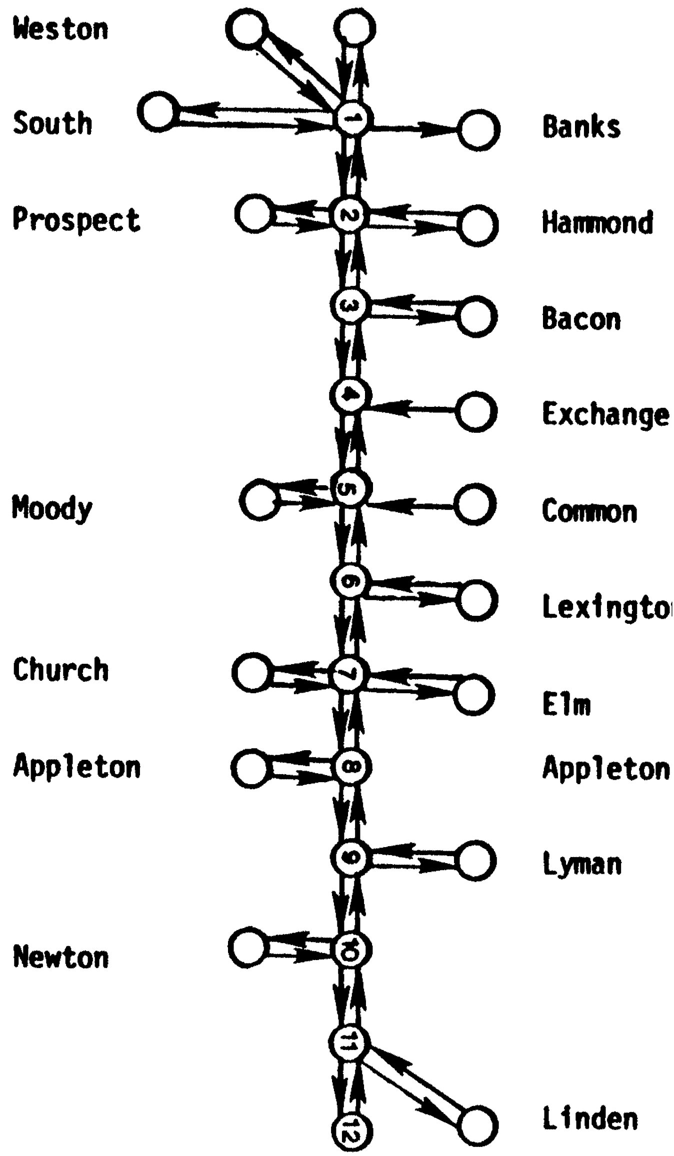


Figure 10: Main Street, Waltham, Massachusetts.

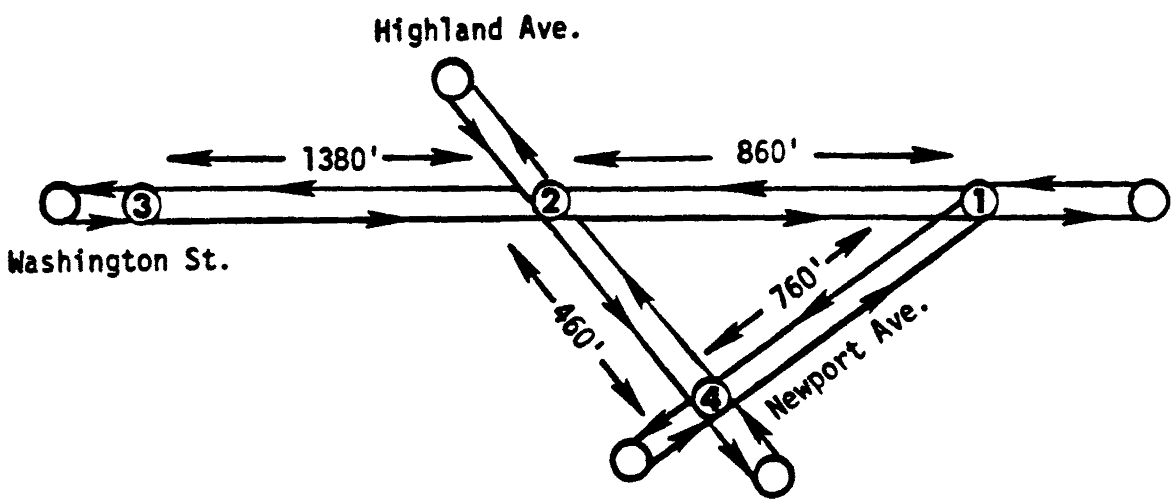


Figure 11: The Attleboro triangle network.

Hawthorne Blvd.

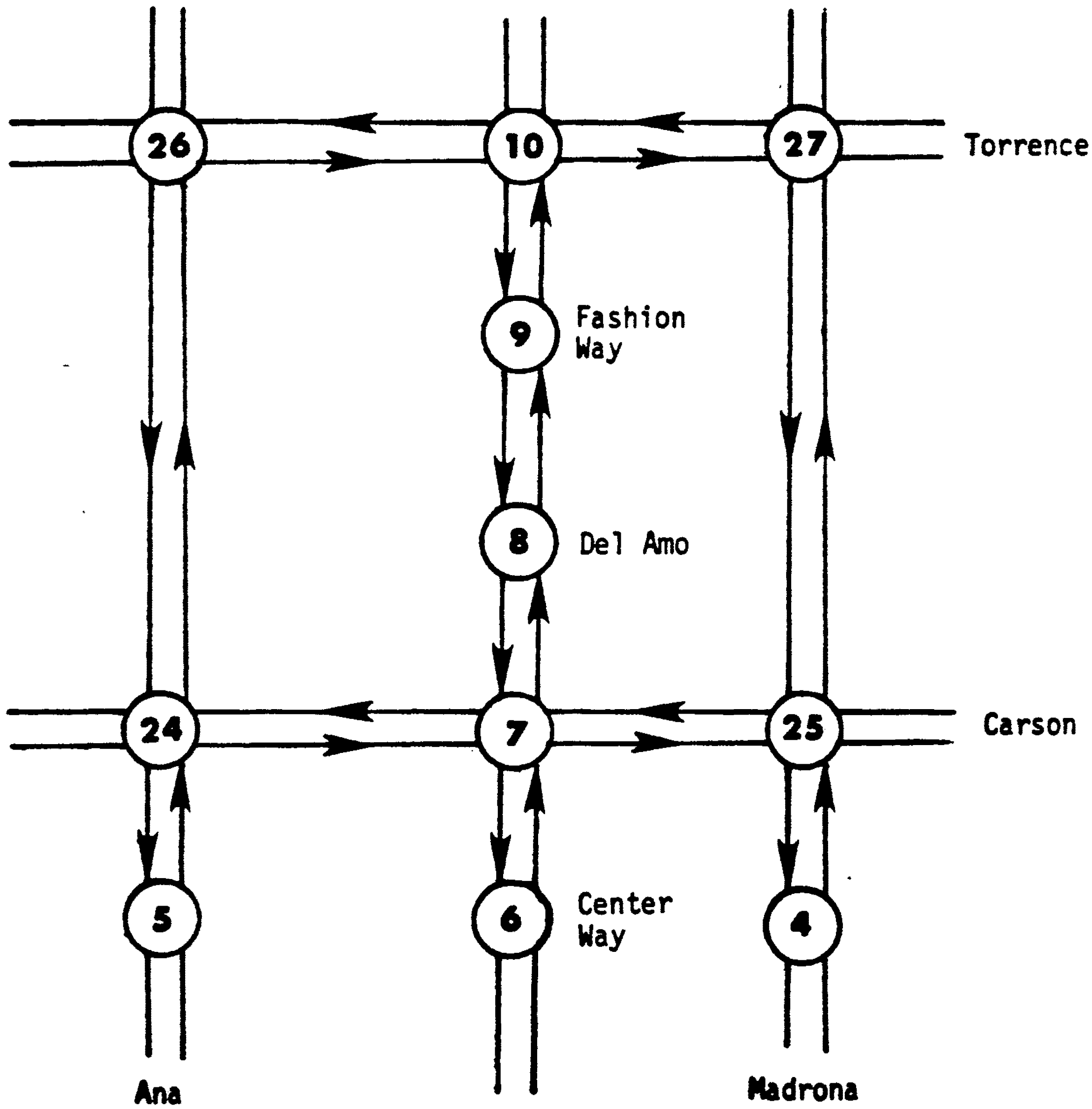


Figure 12: Hawthorne mini-grid network.

Table 1. Comparison of mixed integer optimization runs.

Problem	Number of Signals	Size Rows x Columns	Number Integer Variables	Run Time Statistics Number of Solutions	Branch and Bound	Optimal Itera-tions	CPU Sec.*
1	5	45 x 25	4	1	36	36	2.73
2	11	111 x 60	15	5	3796	2819	184.81
3	4	44 x 37	5	4	386	215	7.24
4	11	110 x 94	28	6	2306	1921	122.75

* Note -

Calculated CPU time is the normal IBM OS/MVS batch processing charges calculated by the Amdahl computer system at Texas A&M University. The total CPU charge includes the CPU time charged for actual program execution and the peripheral service charges required. This charge comprises the total amount of computer time needed to load the executable load module, internal reading, disk mounting, and the time required by the operating system in allocating memory for program execution. This measurement may vary depending on the total computer system loading conditions.

APPENDIX A

TEST NETWORK DATA AND RUN

1. Hawthorne Mini-Grid Test Network.

This is a typical grid signal network from the Hawthorne Boulevard in Los Angeles, California. It was used by FHWA COTR to evaluate all the major optimization features of MAXBAND 86 for optimizing left turn phase sequence in a signalized arterial network for acceptance test.

***** MAXBAND -- MAXIMAL BANDWIDTH TRAFFIC SIGNAL TIMING OPTIMIZATION PROGRAM *****

**** MAXBAND INPUT CARDS ****

```
COMM     HAWTHORNE BLVD MINI-NETWORK, LOS ANGELES, CA.
START         0
MPCODE        100000  100  200  100         1
SETUPN             9    5                                       HAWTHORNE MINI
NETWRK       90   90
COMM     ********************** HAWTHORNE BL **********************************
SETUP              5         3  150                   W         HAWTHORNE BL
ART2          0    1    1   45    3    3   45    3    3
MAP                6    1                                       CENTER WAY
VOLUME           282    0  166    0 1400  132  786  154
CAPACITY        1200    0 1000    0 6000 2400 6000 1500
MINGREEN         .25    0  .25    0  .25  .10  .25  .10
LENGTH                              1050      1120
LEFTPAT       1    1    1    1
MAP                7    2                                       CARSON
VOLUME           284   38  472  120 1622   34  836  112
CAPACITY        3000 1500 3000 1500 6000 1500 6000 2400
MINGREEN         .25  .10  .25  .10  .30  .10  .30  .10
LENGTH                              1120       780
LEFTPAT       1    1    1    1
MAP                8    3                                       DEL AMO CIRCLE
VOLUME            30    0  194    0 1864    0  808   90
CAPACITY        3000    0 3000    0 6000 2400 6000 2400
MINGREEN         .25    0  .25    0  .25  .10  .25  .10
LENGTH                               830       560
LEFTPAT       1    1    1    1
MAP                9    4                                       FASHION WAY
VOLUME            16    0    0    0 2032    0  898    0
CAPACITY        3000    0    0    0 6000    0 6000    0
MINGREEN         .25    0    0    0  .25    0  .25    0
LENGTH                               560       840
MAP               10    5                                       TORRENCE
VOLUME           348  104  622  200 1936  120  892  132
CAPACITY        3000 1500 3000 1500 6000 2400 6000 2400
MINGREEN         .25    0  .25    0  .25  .10  .25  .10
LENGTH                               840      1370
LEFTPAT       1    1    1    1
COMM     ********************** TORRENCE BLVD *********************************
SETUP              3         3  150                   N         TORRENCE
ART2          0    1    1   35    3    3   35    3    3
MAP               26    1                                       ANZA
VOLUME           426   93  712  128 1524    0  668    0
CAPACITY        4500 1500 3000 1500 3000    0 3000    0
MINGREEN         .30  .10  .30  .10  .30    0  .30    0
LENGTH          2600
LEFTPAT       1    1    1    1
MAP               10    2                                       HAWTHORNE BL
VOLUME           348  104  622  200 1936  120  892  132
CAPACITY        3000 1500 3000 1500 6000 2400 6000 2400
MINGREEN         .25    0  .25    0  .25  .10  .25  .10
LENGTH          2700      2600
LEFTPAT       1    1    1    1
MAP               27    3                                       MADRONA ST
VOLUME           402   44  168   24  936    0  356    0
CAPACITY        3000 1500 3000 1500 3000    0 3000    0
```

```
MINGREEN         .30  .10  .30  .10  .30    0  .30    0
LENGTH                    2700
LEFTPAT        1    1    1    1
COMM     ********************** CARSON BLVD ***********************************
SETUP              3         3  150                   N        CARSON
ART2           0    1    1   35    3    3   35    3    3
MAP               24    1                                      ANZA BLVD
LENGTH          2700
VOLUME           242    0  274    0 1504    0  322    0
CAPACITY        4000    0 3000    0 3000    0 3000    0
MINGREEN         .30    0  .30    0  .30    0  .30    0
MAP                7    2                                      HAWTHORNE BLVD
LENGTH          2400      2700
VOLUME           284   38  472  120 1622   34  836  112
CAPACITY        3000 1500 3000 1500 6000 1500 6000 2400
MINGREEN         .25  .10  .25  .10  .30  .10  .30  .10
LEFTPAT            1    1    1
MAP               25    3                                      MADRONA BLVD
LENGTH                    2400
VOLUME           326    0  608    0  912    0  312    0
CAPACITY        3000    0 4500    0 3000    0 3000    0
MINGREEN         .30    0  .30    0  .30    0  .30    0
COMM     ********************** MADRONA BLVD **********************************
SETUP              2         3  150                   W        MADRONA
ART2           0    1    1   35    3    3   35    3    3
MAP               25    1                                      CARSON
LENGTH                                        2230
VOLUME           326    0  608    0  912    0  312    0
CAPACITY        3000    0 4500    0 3000    0 3000    0
MINGREEN         .30    0  .30    0  .30    0  .30    0
MAP               27    2                                      TORRENCE
LENGTH                              2230
VOLUME           402   44  168   24  936    0  356    0
CAPACITY        3000 1500 3000 1500 3000    0 3000    0
MINGREEN         .30  .10  .30  .10  .30    0  .30    0
COMM     ********************** ANZA BLVD *************************************
SETUP              2         3  150                   W        ANZA BLVD
ART2           0    1    1   35    3    3   35    3    3
MAP               24    1                                      CARSON
LENGTH                                        2230
VOLUME           242    0  274    0 1504    0  322    0
CAPACITY        4000    0 3000    0 3000    0 3000    0
MINGREEN         .30    0  .30    0  .30    0  .30    0
MAP               26    2                                      TORRENCE
LENGTH                              2230
VOLUME           426   93  712  128 1524    0  668    0
CAPACITY        4500 1500 3000 1500 3000    0 3000    0
MINGREEN         .30  .10  .30  .10  .30    0  .30    0
END

  **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES  1 AND  3
                      (INTERSECTION  2 IN ARTERY  1 AND INTERSECTION  2 IN ARTERY  3)
                      IS LESS THAN ONE CYCLE
                      (THERE IS ALL RED TIME OF 0.0000 CYCLES).

  **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES  1 AND  2
                      (INTERSECTION  5 IN ARTERY  1 AND INTERSECTION  2 IN ARTERY  2)
                      IS LESS THAN ONE CYCLE
                      (THERE IS ALL RED TIME OF 0.0000 CYCLES).

  **** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES  2 AND  5
```

```
                  (INTERSECTION  1 IN ARTERY  2 AND INTERSECTION  2 IN ARTERY  5)
                  IS LESS THAN ONE CYCLE
                  (THERE IS ALL RED TIME OF 0.0000 CYCLES).

**** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES  2 AND  4
                  (INTERSECTION  3 IN ARTERY  2 AND INTERSECTION  2 IN ARTERY  4)
                  IS LESS THAN ONE CYCLE
                  (THERE IS ALL RED TIME OF 0.0000 CYCLES).

**** WARNING ****  THE TOTAL OF SPLITS GIVEN FOR THE MEETING OF ARTERIES  3 AND  5
                  (INTERSECTION  1 IN ARTERY  3 AND INTERSECTION  1 IN ARTERY  5)
                  IS LESS THAN ONE CYCLE
                  (THERE IS ALL RED TIME OF 0.0000 CYCLES).
```

DATA HAS BEEN SUCCESSFULLY ENTERED.

```
**** MAXBAND INPUT DATA SUMMARY ****

*** MPCODE VALUES ***

MAXIMUM BRANCH AND BOUND ITERATIONS   (MAXRBB):     100000
MAXIMUM BRANCH AND BOUND REINVERSIONS (MAXIBB):        100
MAXIMUM LINEAR PROGRAM ITERATIONS     (MAXITR):        200
MAXIMUM LINEAR PROGRAM REINVERSIONS   (MAXINV):        100

RESTART: 0     (0 -- JOB IS NOT A RESTART;          1 -- JOB IS A RESTART)
SWITCH : 1     (0 -- DO NOT PRINT PERFORMANCE PLOT; 1 -- PRINT PERFORMANCE PLOT)


IMBEDDED VALUES OF TOLERANCES ARE:

TOL 1 = 0.100E-05
TOL 2 = 0.100E-04
TOL 3 = 0.300E-05
TOL 4 = 0.300E-04
TOL 5 = 0.100E-04
TOL 6 = 0.100E-04
TOL 7 = 0.100E-04


NO TOLRN CARD.  IMBEDDED VALUES OF TOLERANCES WILL BE USED.



THIS IS A NETWORK PROBLEM.
```

*** NETWORK WIDE VALUES ***

```
NAME OF NETWORK: HAWTHORNE MINI       NUMBER OF INTERSECTIONS :     9        NUMBER OF ARTERIES        :     5
                                      NUMBER OF LINKS         :    10        NUMBER OF LOOPS           :     2
                                      LOWER CYCLE LIMIT (SECS):     90.00    UPPER CYCLE LIMIT (SECS):       90.00

WEIGHT OF ARTERIES:                SOURCE *

     ARTERY  1 :  .0 (NOT USED)     0
     ARTERY  2 :  .0 (NOT USED)     0
     ARTERY  3 :  .0 (NOT USED)     0
     ARTERY  4 :  .0 (NOT USED)     0
     ARTERY  5 :  .0 (NOT USED)     0

    * (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)


LOOP(S) IN THE NETWORK
    (SYNTHETIC LOOP(S) CONSIDERED IN THE LOOP-CLOSURE CONSTRAINT
     FOR THE SIGNAL NETWORK, AS EXPRESSED IN SERIES OF NODE NUMBERS)

     LOOP  1 :       8    7   24   26   10    9    8

     LOOP  2 :       8    7   25   27   10    9    8
```

*** ARTERY 1 ***

*** ARTERY WIDE VALUES ***

NAME OF ARTERY: HAWTHORNE BL   NUMBER OF INTERSECTIONS: 5
LOWER CYCLE LIMIT: 90.00 SECS   UPPER CYCLE LIMIT: 90.00 SECS

ARTERY IS ENTERED FROM: WEST   UNITS: ENGLISH

		SOURCE *
WEIGHT OF EASTBOUND DIRECTION OF ARTERY (W(1)):	1.0000	0
WEIGHT OF WESTBOUND DIRECTION OF ARTERY (W(2)):	1.0000	0

* (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

NOTE : REGARDLESS OF THEIR SOURCES, THESE WEIGHTS WERE SCALED USING THE WITHIN ARTERY WEIGHTS FOR SINGLE ARTERY PROBLEM.
THESE WEIGHTS WERE SCALED USING BOTH WITHIN AND CROSS ARTERY WEIGHTS FOR NETWORK PROBLEM.

	EASTBOUND	WESTBOUND
DESIGN SPEED (MILES/HOUR):	45.00	45.00
TOLERANCES (MILES/HOUR):	3.00	3.00
CHANGES BETWEEN LINKS (MILES/HOUR):	3.00	3.00

*** INTERSECTION VALUES ***

						EASTBOUND				WESTBOUND			
			LEFT		SPLITS	- - - - SPLITS - - - -			QUEUE	- - - - SPLITS - - - -			QUEUE
SIGNAL	NODE	SEQ.	CHOICES	CROSS STREET	SOURCE	GREEN	LEFT	RED	CLEARANCE	GREEN	LEFT	RED	CLEARANCE
NO.	NO.	NO.	1234 +	NAME	*	- - - (FRACTIONS OF CYCLE) - - -				- - - (FRACTIONS OF CYCLE) - - -			
1	6	1	1111	CENTER WAY	1	0.4028	0.1715	0.5972	0.0000	0.4085	0.1772	0.5915	0.0000
2	7	2	1111	CARSON	1	0.4974	0.1000	0.5026	0.0000	0.4974	0.1000	0.5026	0.0000
3	8	3	1111	DEL AMO CIRCLE	1	0.6500	0.1000	0.3500	0.0000	0.6500	0.1000	0.3500	0.0000
4	9	4	0000	FASHION WAY	1	0.7500	0.0000	0.2500	0.0000	0.7500	0.0000	0.2500	0.0000
5	10	5	1111	TORRENCE	1	0.4457	0.1313	0.5543	0.0000	0.4144	0.1000	0.5856	0.0000

* (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

NOTE: THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

+ (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

PATTERN 1 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LAGS GREEN
PATTERN 2 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 3 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 4 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LAGS GREEN

MINIMUM GREEN TIMES FOR APPROACHES -- FRACTIONS OF CYCLE

SIGNAL NO.	NORTHBOUND THROUGH	NORTHBOUND LEFT	SOUTHBOUND THROUGH	SOUTHBOUND LEFT	EASTBOUND THROUGH	EASTBOUND LEFT	WESTBOUND THROUGH	WESTBOUND LEFT
1	0.2500	0.0000	0.2500	0.0000	0.2500	0.1000	0.2500	0.1000
2	0.2500	0.1000	0.2500	0.1000	0.3000	0.1000	0.3000	0.1000
3	0.2500	0.0000	0.2500	0.0000	0.2500	0.1000	0.2500	0.1000
4	0.2500	0.0000	0.0000	0.0000	0.2500	0.0000	0.2500	0.0000
5	0.2500	0.0000	0.2500	0.0000	0.2500	0.1000	0.2500	0.1000

*** LINK VALUES ***

SIGNAL NO.		EASTBOUND LENGTH (FEET)	EASTBOUND SPEED (MILES/HOUR)	EASTBOUND TOLERANCE (MILES/HOUR)	WESTBOUND LENGTH (FEET)	WESTBOUND SPEED (MILES/HOUR)	WESTBOUND TOLERANCE (MILES/HOUR)
1							
	--------	1120.00	45.00	3.00	1120.00	45.00	3.00
2							
	--------	830.00	45.00	3.00	780.00	45.00	3.00
3							
	--------	560.00	45.00	3.00	560.00	45.00	3.00
4							
	--------	840.00	45.00	3.00	840.00	45.00	3.00
5							

VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL NO.	NORTHBOUND THROUGH	NORTHBOUND LEFT	SOUTHBOUND THROUGH	SOUTHBOUND LEFT	EASTBOUND THROUGH	EASTBOUND LEFT	WESTBOUND THROUGH	WESTBOUND LEFT
1	292.00	0.00	166.00	0.00	1400.00	132.00	786.00	154.00
2	284.00	38.00	472.00	120.00	1622.00	34.00	836.00	112.00
3	30.00	0.00	194.00	0.00	1864.00	0.00	808.00	90.00
4	16.00	0.00	0.00	0.00	2032.00	0.00	898.00	0.00
5	348.00	104.00	622.00	200.00	1936.00	120.00	892.00	132.00

CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	1200.00	0.00	1000.00	0.00	6000.00	2400.00	6000.00	1500.00
2	3000.00	1500.00	3000.00	1500.00	6000.00	1500.00	6000.00	2400.00
3	3000.00	0.00	3000.00	0.00	6000.00	2400.00	6000.00	2400.00
4	3000.00	0.00	0.00	0.00	6000.00	0.00	6000.00	0.00
5	3000.00	1500.00	3000.00	1500.00	6000.00	2400.00	6000.00	2400.00

*** ARTERY 2 ***

*** ARTERY WIDE VALUES ***

NAME OF ARTERY: TORRENCE   NUMBER OF INTERSECTIONS: 3
LOWER CYCLE LIMIT: 90.00 SECS   UPPER CYCLE LIMIT: 90.00 SECS

ARTERY IS ENTERED FROM: NORTH   UNITS: ENGLISH

		SOURCE *
WEIGHT OF SOUTHBOUND DIRECTION OF ARTERY (W(1)):	1.0000	0
WEIGHT OF NORTHBOUND DIRECTION OF ARTERY (W(2)):	1.0000	0

* (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

NOTE : REGARDLESS OF THEIR SOURCES, THESE WEIGHTS WERE SCALED USING THE WITHIN ARTERY WEIGHTS FOR SINGLE ARTERY PROBLEM.
THESE WEIGHTS WERE SCALED USING BOTH WITHIN AND CROSS ARTERY WEIGHTS FOR NETWORK PROBLEM.

		SOUTHBOUND	NORTHBOUND
DESIGN SPEED	(MILES/HOUR):	35.00	35.00
TOLERANCES	(MILES/HOUR):	3.00	3.00
CHANGES BETWEEN LINKS	(MILES/HOUR):	3.00	3.00

*** INTERSECTION VALUES ***

						SOUTHBOUND				NORTHBOUND			
			LEFT		SPLITS	- - - - SPLITS - - - -			QUEUE	- - - - SPLITS - - - -			QUEUE
SIGNAL	NODE	SEQ.	CHOICES	CROSS STREET	SOURCE	GREEN	LEFT	RED	CLEARANCE	GREEN	LEFT	RED	CLEARANCE
NO.	NO.	NO.	1234 +	NAME	*	- - - (FRACTIONS OF CYCLE) - - -				- - - (FRACTIONS OF CYCLE) - - -			
1	26	1	1111	ANZA	1	0.3528	0.1528	0.6472	0.0000	0.3000	0.1000	0.7000	0.0000
2	10	2	1111	HAWTHORNE BL	1	0.3586	0.2043	0.6414	0.0000	0.2500	0.0958	0.7500	0.0000
3	27	3	1111	MADRONA ST	1	0.3000	0.1000	0.7000	0.0000	0.3000	0.1000	0.7000	0.0000

* (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

NOTE: THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

+ (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

PATTERN 1 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT LAGS GREEN
PATTERN 2 -- SOUTHBOUND LEFT LAGS GREEN; NORTHBOUND LEFT LEADS GREEN
PATTERN 3 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT LEADS GREEN
PATTERN 4 -- SOUTHBOUND LEFT LAGS GREEN; NORTHBOUND LEFT LAGS GREEN

MINIMUM GREEN TIMES FOR APPROACHES -- FRACTIONS OF CYCLE

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	0.3000	0.1000	0.3000	0.1000	0.3000	0.0000	0.3000	0.0000
2	0.2500	0.0000	0.2500	0.0000	0.2500	0.1000	0.2500	0.1000
3	0.3000	0.1000	0.3000	0.1000	0.3000	0.0000	0.3000	0.0000

*** LINK VALUES ***

SIGNAL		SOUTHBOUND			NORTHBOUND		
NO.		LENGTH (FEET)	SPEED (MILES/HOUR)	TOLERANCE (MILES/HOUR)	LENGTH (FEET)	SPEED (MILES/HOUR)	TOLERANCE (MILES/HOUR)
1							
	--------	2600.00	35.00	3.00	2600.00	35.00	3.00
2							
	--------	2700.00	35.00	3.00	2700.00	35.00	3.00
3							

VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	426.00	93.00	712.00	128.00	1524.00	0.00	668.00	0.00
2	348.00	104.00	622.00	200.00	1936.00	120.00	892.00	132.00
3	402.00	44.00	168.00	24.00	936.00	0.00	356.00	0.00

CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	4500.00	1500.00	3000.00	1500.00	3000.00	0.00	3000.00	0.00
2	3000.00	1500.00	3000.00	1500.00	6000.00	2400.00	6000.00	2400.00
3	3000.00	1500.00	3000.00	1500.00	3000.00	0.00	3000.00	0.00

*** ARTERY 3 ***

*** ARTERY WIDE VALUES ***

NAME OF ARTERY: CARSON   NUMBER OF INTERSECTIONS: 3
LOWER CYCLE LIMIT: 90.00 SECS   UPPER CYCLE LIMIT: 90.00 SECS

ARTERY IS ENTERED FROM: NORTH   UNITS: ENGLISH

		SOURCE *
WEIGHT OF SOUTHBOUND DIRECTION OF ARTERY (W(1)):	1.0000	0
WEIGHT OF NORTHBOUND DIRECTION OF ARTERY (W(2)):	1.0000	0

* (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

NOTE : REGARDLESS OF THEIR SOURCES, THESE WEIGHTS WERE SCALED USING THE WITHIN ARTERY WEIGHTS FOR SINGLE ARTERY PROBLEM.
THESE WEIGHTS WERE SCALED USING BOTH WITHIN AND CROSS ARTERY WEIGHTS FOR NETWORK PROBLEM.

	SOUTHBOUND	NORTHBOUND
DESIGN SPEED (MILES/HOUR):	35.00	35.00
TOLERANCES (MILES/HOUR):	3.00	3.00
CHANGES BETWEEN LINKS (MILES/HOUR):	3.00	3.00

*** INTERSECTION VALUES ***

						SOUTHBOUND				NORTHBOUND			
			LEFT		SPLITS	- - - - SPLITS - - - -			QUEUE	- - - - SPLITS - - - -			QUEUE
SIGNAL	NODE	SEQ.	CHOICES	CROSS STREET	SOURCE	GREEN	LEFT	RED	CLEARANCE	GREEN	LEFT	RED	CLEARANCE
NO.	NO.	NO.	1234 +	NAME	*	- - - (FRACTIONS OF CYCLE) - - -				- - - (FRACTIONS OF CYCLE) - - -			
1	24	1	0000	ANZA BLVD	1	0.3000	0.0000	0.7000	0.0000	0.3000	0.0000	0.7000	0.0000
2	7	2	0111	HAWTHORNE BLVD	1	0.3026	0.1526	0.6974	0.0000	0.2500	0.1000	0.7500	0.0000
3	25	3	0000	MADRONA BLVD	1	0.3077	0.0000	0.6923	0.0000	0.3077	0.0000	0.6923	0.0000

* (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

NOTE: THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

+ (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

PATTERN 1 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT LAGS GREEN
PATTERN 2 -- SOUTHBOUND LEFT LAGS GREEN; NORTHBOUND LEFT LEADS GREEN
PATTERN 3 -- SOUTHBOUND LEFT LEADS GREEN; NORTHBOUND LEFT LEADS GREEN
PATTERN 4 -- SOUTHBOUND LEFT LAGS GREEN; NORTHBOUND LEFT LAGS GREEN

MINIMUM GREEN TIMES FOR APPROACHES -- FRACTIONS OF CYCLE

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000
2	0.2500	0.1000	0.2500	0.1000	0.3000	0.1000	0.3000	0.1000
3	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000

*** LINK VALUES ***

SIGNAL		SOUTHBOUND			NORTHBOUND		
NO.		LENGTH (FEET)	SPEED (MILES/HOUR)	TOLERANCE (MILES/HOUR)	LENGTH (FEET)	SPEED (MILES/HOUR)	TOLERANCE (MILES/HOUR)
1							
	--------	2700.00	35.00	3.00	2700.00	35.00	3.00
2							
	--------	2400.00	35.00	3.00	2400.00	35.00	3.00
3							

VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	242.00	0.00	274.00	0.00	1504.00	0.00	322.00	0.00
2	284.00	38.00	472.00	120.00	1622.00	34.00	836.00	112.00
3	326.00	0.00	608.00	0.00	912.00	0.00	312.00	0.00

CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	4000.00	0.00	3000.00	0.00	3000.00	0.00	3000.00	0.00
2	3000.00	1500.00	3000.00	1500.00	6000.00	1500.00	6000.00	2400.00
3	3000.00	0.00	4500.00	0.00	3000.00	0.00	3000.00	0.00

*** ARTERY 4 ***

*** ARTERY WIDE VALUES ***

NAME OF ARTERY: MADRONA NUMBER OF INTERSECTIONS: 2
LOWER CYCLE LIMIT: 90.00 SECS UPPER CYCLE LIMIT: 90.00 SECS

ARTERY IS ENTERED FROM: WEST UNITS: ENGLISH

		SOURCE *
WEIGHT OF EASTBOUND DIRECTION OF ARTERY (W(1)):	1.0000	0
WEIGHT OF WESTBOUND DIRECTION OF ARTERY (W(2)):	1.0000	0

* (0 -- GIVEN; 1 -- COMPUTED FROM VOLUME INFORMATION)

NOTE : REGARDLESS OF THEIR SOURCES, THESE WEIGHTS WERE SCALED USING THE WITHIN ARTERY WEIGHTS FOR SINGLE ARTERY PROBLEM.
THESE WEIGHTS WERE SCALED USING BOTH WITHIN AND CROSS ARTERY WEIGHTS FOR NETWORK PROBLEM.

	EASTBOUND	WESTBOUND
DESIGN SPEED (MILES/HOUR):	35.00	35.00
TOLERANCES (MILES/HOUR):	3.00	3.00
CHANGES BETWEEN LINKS (MILES/HOUR):	3.00	3.00

*** INTERSECTION VALUES ***

						EASTBOUND				WESTBOUND			
			LEFT		SPLITS	- - - - SPLITS - - - -			QUEUE	- - - - SPLITS - - - -			QUEUE
SIGNAL	NODE	SEQ.	CHOICES	CROSS STREET	SOURCE	GREEN	LEFT	RED	CLEARANCE	GREEN	LEFT	RED	CLEARANCE
NO.	NO.	NO.	1234 +	NAME	*	- - - (FRACTIONS OF CYCLE) - - -				- - - (FRACTIONS OF CYCLE) - - -			
1	25	1	0000	CARSON	1	0.6923	0.0000	0.3077	0.0000	0.6923	0.0000	0.3077	0.0000
2	27	2	0000	TORRENCE	1	0.6000	0.0000	0.4000	0.0000	0.6000	0.0000	0.4000	0.0000

* (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

NOTE: THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

+ (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

PATTERN 1 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LAGS GREEN
PATTERN 2 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 3 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 4 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LAGS GREEN

MINIMUM GREEN TIMES FOR APPROACHES -- FRACTIONS OF CYCLE

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000
2	0.3000	0.1000	0.3000	0.1000	0.3000	0.0000	0.3000	0.0000

*** LINK VALUES ***

SIGNAL NO.		EASTBOUND LENGTH (FEET)	EASTBOUND SPEED (MILES/HOUR)	EASTBOUND TOLERANCE (MILES/HOUR)	WESTBOUND LENGTH (FEET)	WESTBOUND SPEED (MILES/HOUR)	WESTBOUND TOLERANCE (MILES/HOUR)
1	--------	2230.00	35.00	3.00	2230.00	35.00	3.00
2							

VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	326.00	0.00	608.00	0.00	912.00	0.00	312.00	0.00
2	402.00	44.00	168.00	24.00	936.00	0.00	356.00	0.00

CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	3000.00	0.00	4500.00	0.00	3000.00	0.00	3000.00	0.00
2	3000.00	1500.00	3000.00	1500.00	3000.00	0.00	3000.00	0.00

*** ARTERY 5 ***

*** ARTERY WIDE VALUES ***

NAME OF ARTERY: ANZA BLVD — NUMBER OF INTERSECTIONS: 2
LOWER CYCLE LIMIT: 90.00 SECS — UPPER CYCLE LIMIT: 90.00 SECS

ARTERY IS ENTERED FROM: WEST — UNITS: ENGLISH

		SOURCE *
WEIGHT OF EASTBOUND DIRECTION OF ARTERY (W(1)):	1.0000	0
WEIGHT OF WESTBOUND DIRECTION OF ARTERY (W(2)):	1.0000	0

* (0 -- GIVEN: 1 -- COMPUTED FROM VOLUME INFORMATION)

NOTE : REGARDLESS OF THEIR SOURCES, THESE WEIGHTS WERE SCALED USING THE WITHIN ARTERY WEIGHTS FOR SINGLE ARTERY PROBLEM.
THESE WEIGHTS WERE SCALED USING BOTH WITHIN AND CROSS ARTERY WEIGHTS FOR NETWORK PROBLEM.

	EASTBOUND	WESTBOUND
DESIGN SPEED (MILES/HOUR):	35.00	35.00
TOLERANCES (MILES/HOUR):	3.00	3.00
CHANGES BETWEEN LINKS (MILES/HOUR):	3.00	3.00

*** INTERSECTION VALUES ***

						EASTBOUND				WESTBOUND			
			LEFT		SPLITS	- - - - SPLITS - - - -			QUEUE	- - - - SPLITS - - - -			QUEUE
SIGNAL	NODE	SEQ.	CHOICES	CROSS STREET	SOURCE	GREEN	LEFT	RED	CLEARANCE	GREEN	LEFT	RED	CLEARANCE
NO.	NO.	NO.	1234 +	NAME	*	- - - (FRACTIONS OF CYCLE) - - -				- - - (FRACTIONS OF CYCLE) - - -			
1	24	1	0000	CARSON	1	0.7000	0.0000	0.3000	0.0000	0.7000	0.0000	0.3000	0.0000
2	26	2	0000	TORRENCE	1	0.5472	0.0000	0.4528	0.0000	0.5472	0.0000	0.4528	0.0000

* (0 -- SPLITS GIVEN; 1 -- SPLITS COMPUTED FROM VOLUME AND CAPACITY INFORMATION)

NOTE: THE ABOVE SPLITS, REGARDLESS OF THEIR SOURCE, HAVE BEEN MODIFIED ACCORDING TO ANY MINIMUM GREEN TIMES GIVEN.

+ (0 -- PATTERN NOT ALLOWED; 1 -- PATTERN ALLOWED)

PATTERN 1 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LAGS GREEN
PATTERN 2 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 3 -- EASTBOUND LEFT LEADS GREEN; WESTBOUND LEFT LEADS GREEN
PATTERN 4 -- EASTBOUND LEFT LAGS GREEN; WESTBOUND LEFT LAGS GREEN

MINIMUM GREEN TIMES FOR APPROACHES -- FRACTIONS OF CYCLE

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000	0.3000	0.0000
2	0.3000	0.1000	0.3000	0.1000	0.3000	0.0000	0.3000	0.0000

*** LINK VALUES ***

SIGNAL NO.		EASTBOUND LENGTH (FEET)	EASTBOUND SPEED (MILES/HOUR)	EASTBOUND TOLERANCE (MILES/HOUR)	WESTBOUND LENGTH (FEET)	WESTBOUND SPEED (MILES/HOUR)	WESTBOUND TOLERANCE (MILES/HOUR)
1 2	--------	2230.00	35.00	3.00	2230.00	35.00	3.00

VOLUMES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	242.00	0.00	274.00	0.00	1504.00	0.00	322.00	0.00
2	426.00	93.00	712.00	128.00	1524.00	0.00	668.00	0.00

CAPACITIES ON APPROACHES -- VEHICLES PER HOUR

SIGNAL	NORTHBOUND		SOUTHBOUND		EASTBOUND		WESTBOUND	
NO.	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT	THROUGH	LEFT
1	4000.00	0.00	3000.00	0.00	3000.00	0.00	3000.00	0.00
2	4500.00	1500.00	3000.00	1500.00	3000.00	0.00	3000.00	0.00

**** MPCODE PERFORMANCE PLOT ****

BEST OBJECTIVE FUNCTION VALUE =	3.228553	NUMBER OF BRANCH AND BOUND ITERATIONS =	214
BEST OBJECTIVE FUNCTION VALUE =	3.370391	NUMBER OF BRANCH AND BOUND ITERATIONS =	519
BEST OBJECTIVE FUNCTION VALUE =	3.428554	NUMBER OF BRANCH AND BOUND ITERATIONS =	584
BEST OBJECTIVE FUNCTION VALUE =	3.932085	NUMBER OF BRANCH AND BOUND ITERATIONS =	832
BEST OBJECTIVE FUNCTION VALUE =	3.932085	NUMBER OF BRANCH AND BOUND ITERATIONS =	936
BEST OBJECTIVE FUNCTION VALUE =	3.995796	NUMBER OF BRANCH AND BOUND ITERATIONS =	1921

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MPCODE HAS BEEN SUCCESSFULLY COMPLETED.

A REPORT BASED ON THE OPTIMAL SOLUTION WILL BE WRITTEN.

                                        **** MPCODE STATISTICS ****

  NUMBER OF BRANCH AND BOUND ITERATIONS PERFORMED:       2306     NUMBER OF BRANCH AND BOUND REINVERSIONS PERFORMED:     0

  MAXIMUM NUMBER OF   ITERATIONS PERFORMED BY A LINEAR PROGRAM:     91
  MAXIMUM NUMBER OF REINVERSIONS PERFORMED BY A LINEAR PROGRAM:      0

  NUMBER OF SOLUTIONS FOUND:   6     VALUE OF OBJECTIVE FUNCTION AT LAST SOLUTION:     3.995796
```

**** MAXBAND SOLUTION REPORT ****

THIS IS A NETWORK PROBLEM.

NAME OF NETWORK: HAWTHORNE MINI   NUMBER OF INTERSECTIONS: 2

INTERSECTION NUMBERS AT ARTERY MEETINGS:

ARTERY 1 AND ARTERY 3 MEET AT INTERSECTION 2 IN ARTERY 1 AND AT INTERSECTION 2 IN ARTERY 3.
ARTERY 1 AND ARTERY 2 MEET AT INTERSECTION 5 IN ARTERY 1 AND AT INTERSECTION 2 IN ARTERY 2.
ARTERY 2 AND ARTERY 5 MEET AT INTERSECTION 1 IN ARTERY 2 AND AT INTERSECTION 2 IN ARTERY 5.
ARTERY 2 AND ARTERY 4 MEET AT INTERSECTION 3 IN ARTERY 2 AND AT INTERSECTION 2 IN ARTERY 4.
ARTERY 3 AND ARTERY 5 MEET AT INTERSECTION 1 IN ARTERY 3 AND AT INTERSECTION 1 IN ARTERY 5.
ARTERY 3 AND ARTERY 4 MEET AT INTERSECTION 3 IN ARTERY 3 AND AT INTERSECTION 1 IN ARTERY 4.

**** BEST NETWORK SOLUTION ****

NETWORK WIDE CYCLE TIME: 90.00 SECS

BANDWIDTHS (FRACTIONS OF CYCLE):

ARTERY 1:	EASTBOUND: 0.3507	WESTBOUND: 0.3507
ARTERY 2:	SOUTHBOUND: 0.2500	NORTHBOUND: 0.2500
ARTERY 3:	SOUTHBOUND: 0.2500	NORTHBOUND: 0.2500
ARTERY 4:	EASTBOUND: 0.6000	WESTBOUND: 0.6000
ARTERY 5:	EASTBOUND: 0.5472	WESTBOUND: 0.5472

OBJECTIVE FUNCTION: 3.995796

*** ARTERY 1 ***

NAME OF ARTERY: HAWTHORNE BL NUMBER OF INTERSECTIONS: 5
ARTERY IS ENTERED FROM: WEST UNITS: ENGLISH

*** ARTERY WIDE INFORMATION ***

CYCLE TIME: 90.00 SECS EASTBOUND BANDWIDTH (B(1)): 0.3507 (FRACTION OF CYCLE) WESTBOUND BANDWIDTH (B(2)): 0.3507 (FRACTION OF CYCLE)

EFFICIENCY(%): 35.07 ATTAINABILITY(%): 86.47

(EFFICIENCY - AVERAGE FRACTION OF CYCLE LENGTH FOR PROGRESSION)
(ATTAINABILITY - AVERAGE FRACTION OF ARTERIAL MINIMUM THROUGH GREENS FOR PROGRESSION)

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

*** INTERSECTION INFORMATION ***

SIGNAL NO.	NODE NO.	SEQUENCE NO.	CROSS STREET NAME	LEFT TURN PATTERN SELECTED	SIGNAL NO.
1	6	1	CENTER WAY	1	1
2	7	2	CARSON	2	2
3	8	3	DEL AMO CIRCLE	2	3
4	9	4	FASHION WAY		
5	10	5	TORRENCE	1	5

**** PHASE SETTINGS -- FRACTIONS OF CYCLE ****

SIGNAL NO.	DIRECTION	---- GREEN ----			---- LEFT ----			---- RED ----			------- BAND -------			
		BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	.0000	.4028	0.4028	.0000	.1715	0.1715	.4028	.0000	0.5972	.0000	.3507	0.3507	0.0000
	WESTBOUND	.1715	.5800	0.4085	.4028	.5800	0.1772	.5800	.1715	0.5915	.2292	.5800	0.3507	0.0000
2	EASTBOUND	.0908	.5881	0.4974	.4881	.5881	0.1000	.5881	.0908	0.5026	.1774	.5281	0.3507	0.0000
	WESTBOUND	.9908	.4881	0.4974	.9908	.0908	0.1000	.4881	.9908	0.5026	.0508	.4015	0.3507	0.0000
3	EASTBOUND	.0183	.6683	0.6500	.5683	.6683	0.1000	.6683	.0183	0.3500	.3176	.6683	0.3507	0.0000
	WESTBOUND	.9183	.5683	0.6500	.9183	.0183	0.1000	.5683	.9183	0.3500	.9183	.2690	0.3507	0.0000
4	EASTBOUND	.4180	.1680	0.7500			0.0000	.1680	.4180	0.2500	.4180	.7688	0.3507	0.0000
	WESTBOUND	.4180	.1680	0.7500			0.0000	.1680	.4180	0.2500	.8173	.1680	0.3507	0.0000
5	EASTBOUND	.5027	.9483	0.4457	.5027	.6340	0.1313	.9483	.5027	0.5543	.5658	.9165	0.3507	0.0000
	WESTBOUND	.6340	.0483	0.4144	.9483	.0483	0.1000	.0483	.6340	0.5856	.6658	.0165	0.3507	0.0000

** PHASE SETTINGS -- SECONDS **

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	BAND ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	0.0	36.2	36.2	0.0	15.4	15.4	36.2	0.0	53.8	0.0	31.6	31.6	0.0
	WESTBOUND	15.4	52.2	36.8	36.2	52.2	15.9	52.2	15.4	53.2	20.6	52.2	31.6	0.0
2	EASTBOUND	8.2	52.9	44.8	43.9	52.9	9.0	52.9	8.2	45.2	16.0	47.5	31.6	0.0
	WESTBOUND	89.2	43.9	44.8	89.2	8.2	9.0	43.9	89.2	45.2	4.6	36.1	31.6	0.0
3	EASTBOUND	1.6	60.1	58.5	51.1	60.1	9.0	60.1	1.6	31.5	28.6	60.1	31.6	0.0
	WESTBOUND	82.6	51.1	58.5	82.6	1.6	9.0	51.1	82.6	31.5	82.6	24.2	31.6	0.0
4	EASTBOUND	37.6	15.1	67.5			0.0	15.1	37.6	22.5	37.6	69.2	31.6	0.0
	WESTBOUND	37.6	15.1	67.5			0.0	15.1	37.6	22.5	73.6	15.1	31.6	0.0
5	EASTBOUND	45.2	85.4	40.1	45.2	57.1	11.8	85.4	45.2	49.9	50.9	82.5	31.6	0.0
	WESTBOUND	57.1	4.3	37.3	85.4	4.3	9.0	4.3	57.1	52.7	59.9	1.5	31.6	0.0

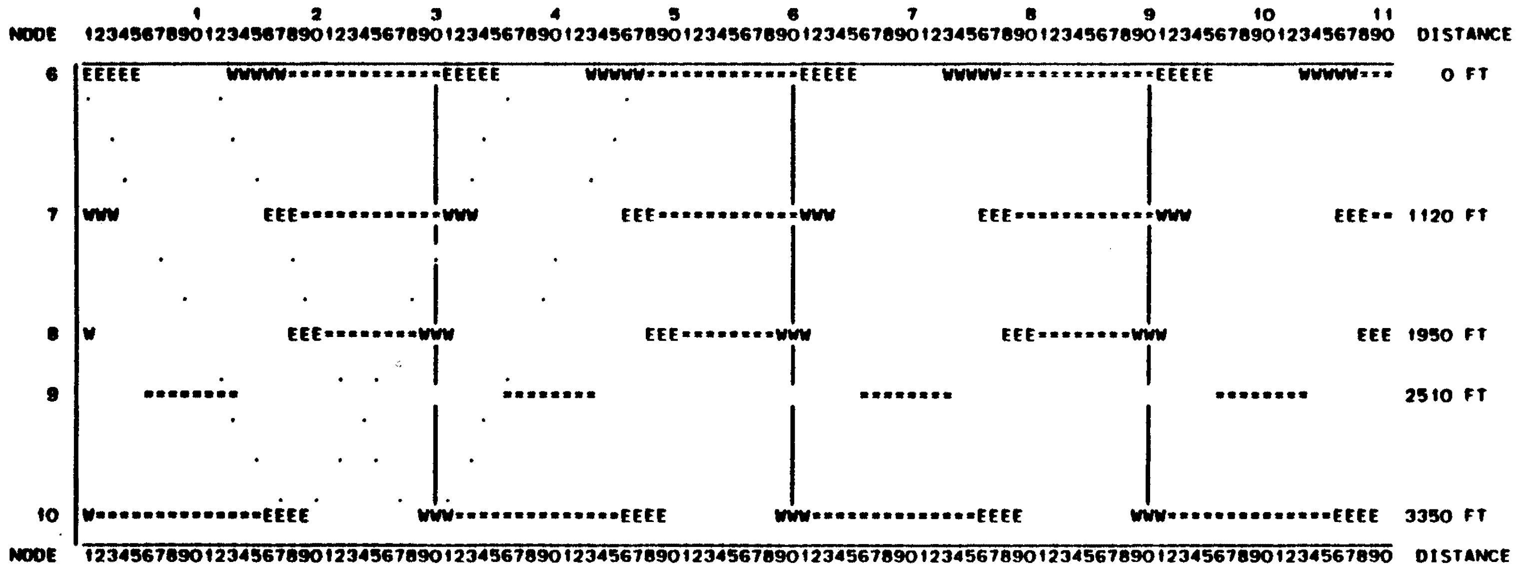
** PROGRESSION TIMES AND SPEEDS **

SIGNAL NO.		EASTBOUND LENGTH (FEET)	EASTBOUND PROGRESSION TRAVERSAL TIME (SECS)	EASTBOUND PROGRESSION SPEED (MILES/HOUR)	WESTBOUND LENGTH (FEET)	WESTBOUND PROGRESSION TRAVERSAL TIME (SECS)	WESTBOUND PROGRESSION SPEED (MILES/HOUR)
1							
	--------	1120.00	15.96	47.83	1120.00	16.06	47.55
2							
	--------	830.00	12.62	44.85	780.00	11.92	44.60
3							
	--------	560.00	9.04	42.22	560.00	9.09	42.00
4							
	--------	840.00	13.30	43.07	840.00	13.64	42.00
5							
ENTIRE ARTERY		3350.00	50.92	44.86	3300.00	50.71	44.37

****** MAXBAND TIME-SPACE DIAGRAM ******

NAME OF ARTERY: HAWTHORNE BL — TIME SCALE = 3 SEC/CHAR

CYCLE LENGTH : 90.00 SECONDS — DIST. SCALE = 150 FT/LINE



NODE 6 ---> NODE 10: EASTBOUND DIRECTION (DOWN)
NODE 10 ---> NODE 6: WESTBOUND DIRECTION (UP)
EASTBOUND BAND = 31.6 SECONDS AT 44.9 MILES/HOUR
WESTBOUND BAND = 31.6 SECONDS AT 44.4 MILES/HOUR

EEE EASTBOUND GREEN (DOWN)
WWW WESTBOUND GREEN (UP)
GREEN IN BOTH DIRECTIONS
*** RED IN BOTH DIRECTIONS

*** ARTERY 2 ***

NAME OF ARTERY: TORRENCE NUMBER OF INTERSECTIONS: 3
ARTERY IS ENTERED FROM: NORTH UNITS: ENGLISH

*** ARTERY WIDE INFORMATION ***

CYCLE TIME: 90.00 SECS SOUTHBOUND BANDWIDTH (B(1)): 0.2500 (FRACTION OF CYCLE) NORTHBOUND BANDWIDTH (B(2)): 0.2500 (FRACTION OF CYCLE)

EFFICIENCY(%): 25.00 ATTAINABILITY(%): 90.91

(EFFICIENCY - AVERAGE FRACTION OF CYCLE LENGTH FOR PROGRESSION)
(ATTAINABILITY - AVERAGE FRACTION OF ARTERIAL MINIMUM THROUGH GREENS FOR PROGRESSION)

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

*** INTERSECTION INFORMATION ***

SIGNAL NO.	NODE NO.	SEQUENCE NO.	CROSS STREET NAME	LEFT TURN PATTERN SELECTED	SIGNAL NO.
1	26	1	ANZA	1	1
2	10	2	HAWTHORNE BL	3	2
3	27	3	MADRONA ST	2	3

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	BAND ADVANCED BY QUEUE CLEAR TIME
1	SOUTHBOUND	.9990	.3528	0.3528	.9990	.1528	0.1528	.3528	.9990	0.6472	.1028	.3528	0.2500	0.0000
	NORTHBOUND	.1528	.4528	0.3000	.3528	.4528	0.1000	.4528	.1528	0.7000	.1528	.4028	0.2500	0.0000
2	SOUTHBOUND	.5222	.8807	0.3586	.4264	.6307	0.2043	.8807	.5222	0.6414	.6307	.8807	0.2500	0.0000
	NORTHBOUND	.6307	.8807	0.2500	.4264	.5222	0.0958	.8807	.6307	0.7500	.6307	.8807	0.2500	0.0000
3	SOUTHBOUND	.1307	.4307	0.3000	.3307	.4307	0.1000	.4307	.1307	0.7000	.1690	.4190	0.2500	0.0000
	NORTHBOUND	.0307	.3307	0.3000	.0307	.1307	0.1000	.3307	.0307	0.7000	.0424	.2924	0.2500	0.0000

** PHASE SETTINGS -- SECONDS **

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	ADVANCED BY QUEUE CLEAR TIME
1	SOUTHBOUND	89.9	31.8	31.8	89.9	13.8	13.8	31.8	89.9	58.2	9.3	31.8	22.5	0.0
	NORTHBOUND	13.8	40.8	27.0	31.8	40.8	9.0	40.8	13.8	63.0	13.8	36.3	22.5	0.0
2	SOUTHBOUND	47.0	79.3	32.3	38.4	56.8	18.4	79.3	47.0	57.7	56.8	79.3	22.5	0.0
	NORTHBOUND	56.8	79.3	22.5	38.4	47.0	8.6	79.3	56.8	67.5	56.8	79.3	22.5	0.0
3	SOUTHBOUND	11.8	38.8	27.0	29.8	38.8	9.0	38.8	11.8	63.0	15.2	37.7	22.5	0.0
	NORTHBOUND	2.8	29.8	27.0	2.8	11.8	9.0	29.8	2.8	63.0	3.8	26.3	22.5	0.0

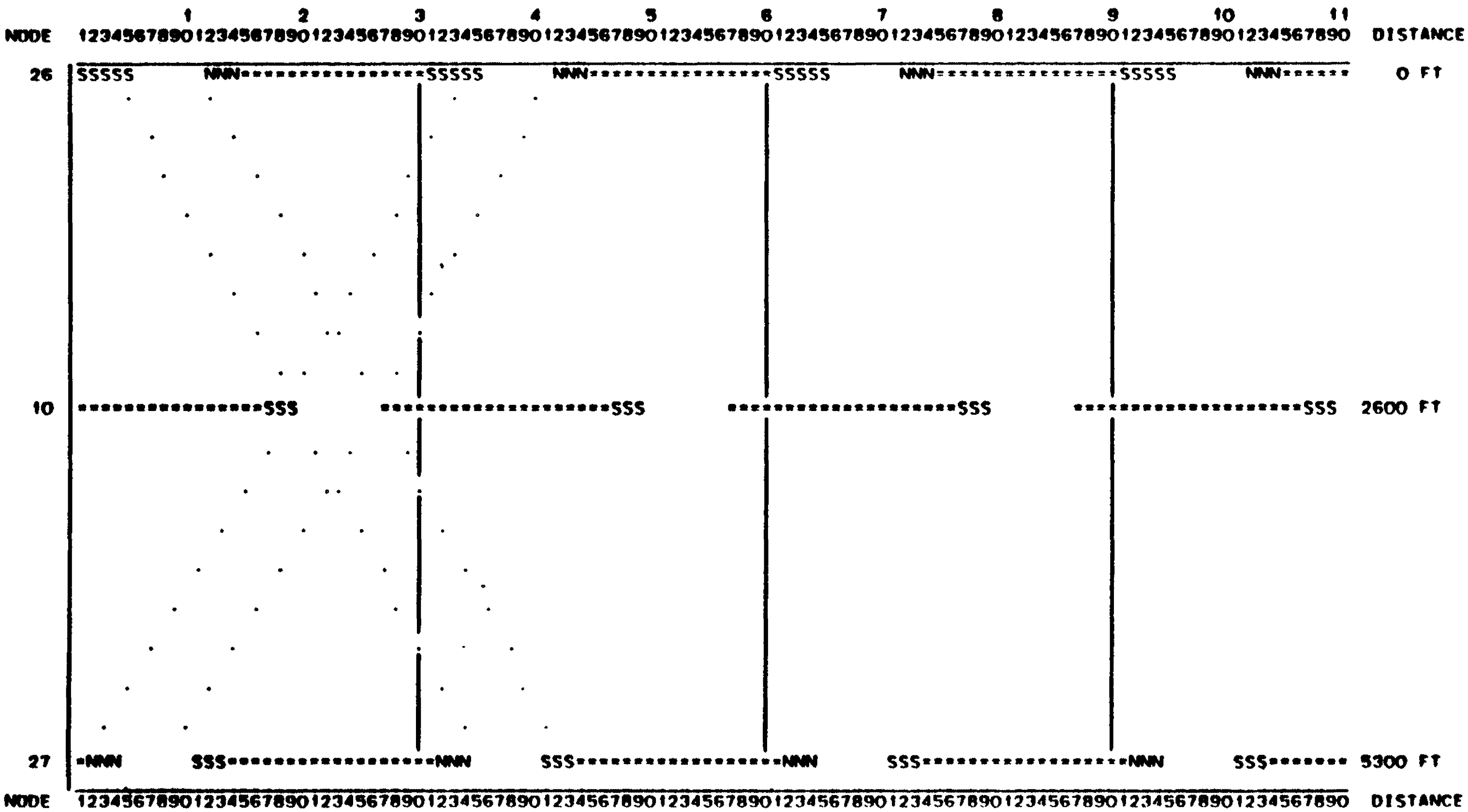
** PROGRESSION TIMES AND SPEEDS **

SIGNAL NO.		SOUTHBOUND LENGTH (FEET)	SOUTHBOUND PROGRESSION TRAVERSAL TIME (SECS)	SOUTHBOUND PROGRESSION SPEED (MILES/HOUR)	NORTHBOUND LENGTH (FEET)	NORTHBOUND PROGRESSION TRAVERSAL TIME (SECS)	NORTHBOUND PROGRESSION SPEED (MILES/HOUR)
1							
	--------	2600.00	47.51	37.31	2600.00	46.99	37.73
2							
	--------	2700.00	48.45	38.00	2700.00	52.95	34.77
3							
ENTIRE ARTERY		5300.00	95.96	37.66	5300.00	99.94	36.16

**** MAXBAND TIME-SPACE DIAGRAM ****

NAME OF ARTERY: TORRENCE　　　　TIME SCALE = 3 SEC/CHAR

CYCLE LENGTH : 90.00 SECONDS　　　　DIST. SCALE = 150 FT/LINE



NODE 26 ---> NODE 27: SOUTHBOUND DIRECTION (DOWN)
NODE 27 ---> NODE 26: NORTHBOUND DIRECTION (UP)
SOUTHBOUND BAND = 22.5 SECONDS AT 37.7 MILES/HOUR
NORTHBOUND BAND = 22.5 SECONDS AT 36.2 MILES/HOUR

SSS SOUTHBOUND GREEN (DOWN)
NNN NORTHBOUND GREEN (UP)
GREEN IN BOTH DIRECTIONS
*** RED IN BOTH DIRECTIONS

*** ARTERY 3 ***

NAME OF ARTERY: CARSON — NUMBER OF INTERSECTIONS: 3
ARTERY IS ENTERED FROM: NORTH — UNITS: ENGLISH

*** ARTERY WIDE INFORMATION ***

CYCLE TIME: 90.00 SECS — SOUTHBOUND BANDWIDTH (B(1)): 0.2500 (FRACTION OF CYCLE) — NORTHBOUND BANDWIDTH (B(2)): 0.2500 (FRACTION OF CYCLE)

EFFICIENCY(%): 25.00 — ATTAINABILITY(%): 90.91

(EFFICIENCY - AVERAGE FRACTION OF CYCLE LENGTH FOR PROGRESSION)
(ATTAINABILITY - AVERAGE FRACTION OF ARTERIAL MINIMUM THROUGH GREENS FOR PROGRESSION)

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

*** INTERSECTION INFORMATION ***

SIGNAL NO.	NODE NO.	SEQUENCE NO.	CROSS STREET NAME	LEFT TURN PATTERN SELECTED	SIGNAL NO.
1	24	1	ANZA BLVD		
2	7	2	HAWTHORNE BLVD	2	2
3	25	3	MADRONA BLVD		

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

		- - - - GREEN - - - -			- - - - LEFT - - - -			- - - - RED - - - -			- - - - - - - - BAND - - - - - - - -			
SIGNAL NO.	DIRECTION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	SOUTHBOUND	.9868	.2868	0.3000			0.0000	.2868	.9868	0.7000	.0000	.2500	0.2500	0.0000
	NORTHBOUND	.9868	.2868	0.3000			0.0000	.2868	.9868	0.7000	.0235	.2735	0.2500	0.0000
2	SOUTHBOUND	.5383	.8409	0.3026	.6883	.8409	0.1526	.8409	.5383	0.6974	.5383	.7883	0.2500	0.0000
	NORTHBOUND	.4383	.6883	0.2500	.4383	.5383	0.1000	.6883	.4383	0.7500	.4383	.6883	0.2500	0.0000
3	SOUTHBOUND	.9591	.2667	0.3077			0.0000	.2667	.9591	0.6923	.0167	.2667	0.2500	0.0000
	NORTHBOUND	.9591	.2667	0.3077			0.0000	.2667	.9591	0.6923	.9591	.2091	0.2500	0.0000

** PHASE SETTINGS -- SECONDS **

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	BAND ADVANCED BY QUEUE CLEAR TIME
1	SOUTHBOUND	88.8	25.8	27.0			0.0	25.8	88.8	63.0	0.0	22.5	22.5	0.0
	NORTHBOUND	88.8	25.8	27.0			0.0	25.8	88.8	63.0	2.1	24.6	22.5	0.0
2	SOUTHBOUND	48.4	75.7	27.2	61.9	75.7	13.7	75.7	48.4	62.8	48.4	70.9	22.5	0.0
	NORTHBOUND	39.4	61.9	22.5	39.4	48.4	9.0	61.9	39.4	67.5	39.4	61.9	22.5	0.0
3	SOUTHBOUND	86.3	24.0	27.7			0.0	24.0	86.3	62.3	1.5	24.0	22.5	0.0
	NORTHBOUND	86.3	24.0	27.7			0.0	24.0	86.3	62.3	86.3	18.8	22.5	0.0

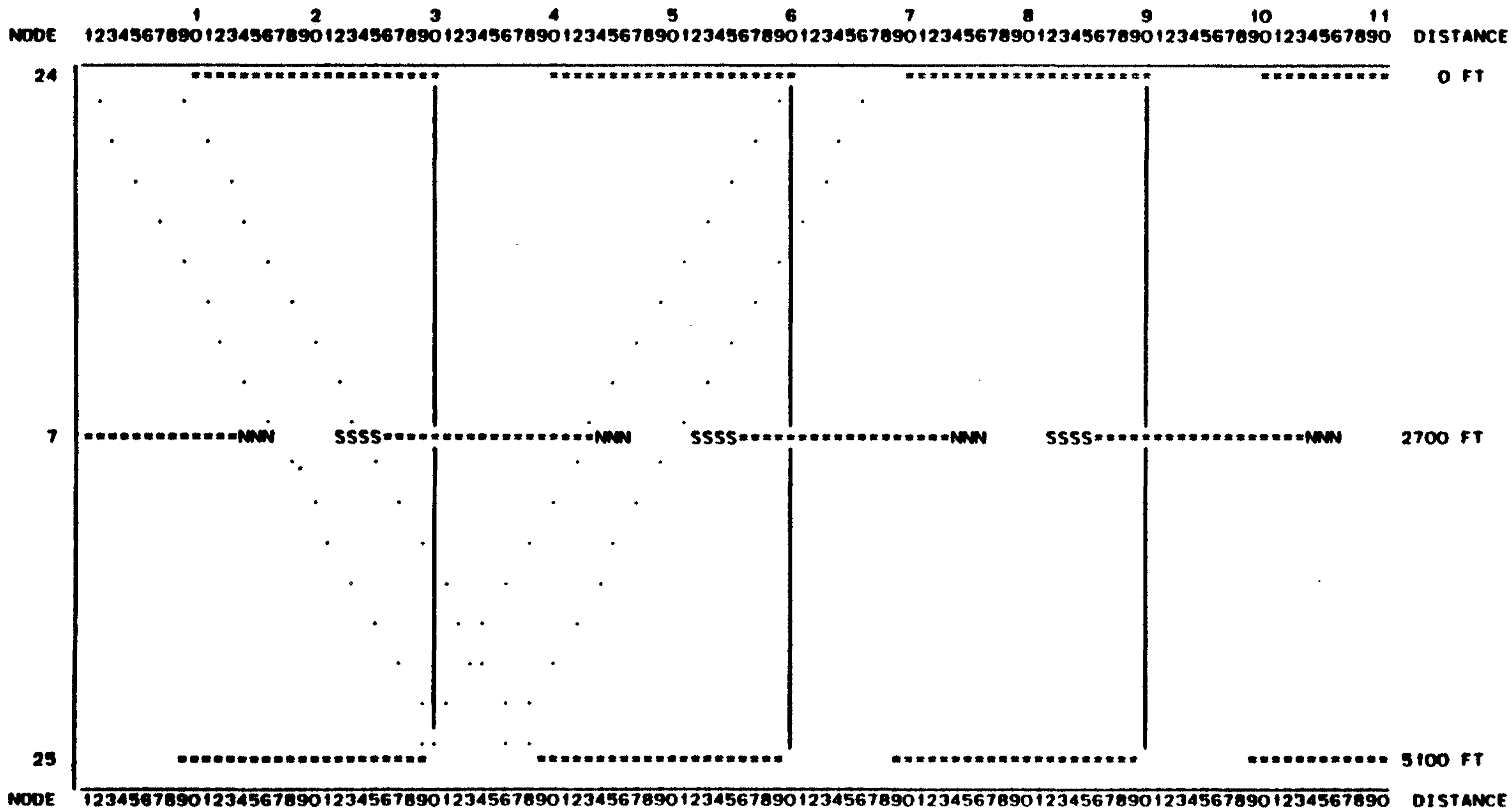
** PROGRESSION TIMES AND SPEEDS **

SIGNAL NO.		SOUTHBOUND LENGTH (FEET)	SOUTHBOUND PROGRESSION TRAVERSAL TIME (SECS)	SOUTHBOUND PROGRESSION SPEED (MILES/HOUR)	NORTHBOUND LENGTH (FEET)	NORTHBOUND PROGRESSION TRAVERSAL TIME (SECS)	NORTHBOUND PROGRESSION SPEED (MILES/HOUR)
1							
	---------	2700.00	48.45	38.00	2700.00	52.67	34.95
2							
	---------	2400.00	43.06	38.00	2400.00	43.13	37.94
3							
ENTIRE ARTERY		5100.00	91.51	38.00	5100.00	95.80	36.30

**** MAXBAND TIME-SPACE DIAGRAM ****

NAME OF ARTERY: CARSON — TIME SCALE = 3 SEC/CHAR

CYCLE LENGTH : 90.00 SECONDS — DIST. SCALE = 150 FT/LINE



NODE 24 ---> NODE 25: SOUTHBOUND DIRECTION (DOWN)
NODE 25 ---> NODE 24: NORTHBOUND DIRECTION (UP)
SOUTHBOUND BAND = 22.5 SECONDS AT 38.0 MILES/HOUR
NORTHBOUND BAND = 22.5 SECONDS AT 36.3 MILES/HOUR

SSS SOUTHBOUND GREEN (DOWN)
NNN NORTHBOUND GREEN (UP)
GREEN IN BOTH DIRECTIONS
*** RED IN BOTH DIRECTIONS

*** ARTERY 4 ***

NAME OF ARTERY: MADRONA NUMBER OF INTERSECTIONS: 2
ARTERY IS ENTERED FROM: WEST UNITS: ENGLISH

*** ARTERY WIDE INFORMATION ***

CYCLE TIME: 90.00 SECS EASTBOUND BANDWIDTH (B(1)): 0.6000 (FRACTION OF CYCLE) WESTBOUND BANDWIDTH (B(2)): 0.6000 (FRACTION OF CYCLE)

EFFICIENCY(%): 60.00 ATTAINABILITY(%): 100.00

(EFFICIENCY - AVERAGE FRACTION OF CYCLE LENGTH FOR PROGRESSION)
(ATTAINABILITY - AVERAGE FRACTION OF ARTERIAL MINIMUM THROUGH GREENS FOR PROGRESSION)

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

*** INTERSECTION INFORMATION ***

SIGNAL NO.	NODE NO.	SEQUENCE NO.	CROSS STREET NAME	LEFT TURN PATTERN SELECTED	SIGNAL NO.
1	25	1	CARSON		
2	27	2	TORRENCE		

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

		GREEN			LEFT			RED			BAND			
SIGNAL NO.	DIRECTION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	.8546	.5469	0.6923			0.0000	.5469	.8546	0.3077	.9145	.5145	0.6000	0.0000
	WESTBOUND	.8546	.5469	0.6923			0.0000	.5469	.8546	0.3077	.8870	.4870	0.6000	0.0000
2	EASTBOUND	.4424	.0424	0.6000			0.0000	.0424	.4424	0.4000	.4424	.0424	0.6000	0.0000
	WESTBOUND	.4424	.0424	0.6000			0.0000	.0424	.4424	0.4000	.4424	.0424	0.6000	0.0000

** PHASE SETTINGS -- SECONDS **

		GREEN			LEFT			RED			BAND			
SIGNAL NO.	DIRECTION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	76.9	49.2	62.3			0.0	49.2	76.9	27.7	82.3	46.3	54.0	0.0
	WESTBOUND	76.9	49.2	62.3			0.0	49.2	76.9	27.7	79.8	43.8	54.0	0.0
2	EASTBOUND	39.8	3.8	54.0			0.0	3.8	39.8	36.0	39.8	3.8	54.0	0.0
	WESTBOUND	39.8	3.8	54.0			0.0	3.8	39.8	36.0	39.8	3.8	54.0	0.0

** PROGRESSION TIMES AND SPEEDS **

	EASTBOUND			WESTBOUND		
SIGNAL NO.	LENGTH (FEET)	PROGRESSION TRAVERSAL TIME (SECS)	PROGRESSION SPEED (MILES/HOUR)	LENGTH (FEET)	PROGRESSION TRAVERSAL TIME (SECS)	PROGRESSION SPEED (MILES/HOUR)
1 --------- 2	2230.00	47.51	32.00	2230.00	40.01	38.00
ENTIRE ARTERY	2230.00	47.51	32.00	2230.00	40.01	38.00

**** MAXBAND TIME-SPACE DIAGRAM ****

NAME OF ARTERY: MADRONA TIME SCALE = 3 SEC/CHAR

CYCLE LENGTH : 90.00 SECONDS DIST. SCALE = 150 FT/LINE

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                1           2           3           4           5           6           7           8           9          10          11
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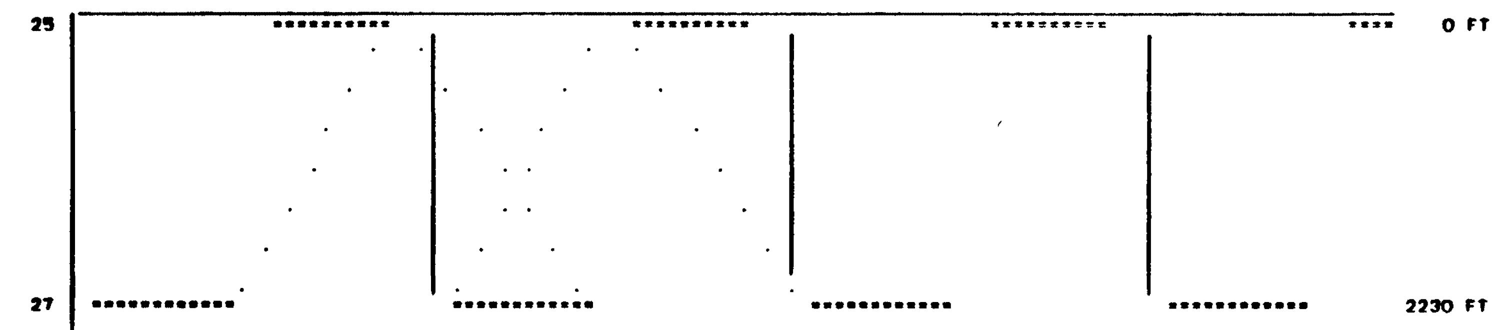


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NODE  1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890  DISTANCE
```

NODE 25 ---> NODE 27: EASTBOUND DIRECTION (DOWN)
NODE 27 ---> NODE 25: WESTBOUND DIRECTION (UP)
EASTBOUND BAND = 54.0 SECONDS AT 32.0 MILES/HOUR
WESTBOUND BAND = 54.0 SECONDS AT 38.0 MILES/HOUR

EEE EASTBOUND GREEN (DOWN)
WWW WESTBOUND GREEN (UP)
GREEN IN BOTH DIRECTIONS
*** RED IN BOTH DIRECTIONS

*** ARTERY 5 ***

NAME OF ARTERY: ANZA BLVD — NUMBER OF INTERSECTIONS: 2
ARTERY IS ENTERED FROM: WEST — UNITS: ENGLISH

*** ARTERY WIDE INFORMATION ***

CYCLE TIME: 90.00 SECS — EASTBOUND BANDWIDTH (B(1)): 0.5472 (FRACTION OF CYCLE) — WESTBOUND BANDWIDTH (B(2)): 0.5472 (FRACTION OF CYCLE)

EFFICIENCY(%): 54.72 — ATTAINABILITY(%): 100.00

(EFFICIENCY - AVERAGE FRACTION OF CYCLE LENGTH FOR PROGRESSION)
(ATTAINABILITY - AVERAGE FRACTION OF ARTERIAL MINIMUM THROUGH GREENS FOR PROGRESSION)

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

*** INTERSECTION INFORMATION ***

SIGNAL NO.	NODE NO.	SEQUENCE NO.	CROSS STREET NAME	LEFT TURN PATTERN SELECTED	SIGNAL NO.
1	24	1	CARSON		
2	26	2	TORRENCE		

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

		- - - - GREEN - - - -			- - - - LEFT - - - -			- - - - RED - - - -			- - - - - - - BAND - - - - - - -			
SIGNAL NO.	DIRECTION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	.3210	.0210	0.7000			0.0000	.0210	.3210	0.3000	.4528	.0000	0.5472	0.0000
	WESTBOUND	.3210	.0210	0.7000			0.0000	.0210	.3210	0.3000	.3420	.8892	0.5472	0.0000
2	EASTBOUND	.8974	.4446	0.5472			0.0000	.4446	.8974	0.4528	.8974	.4446	0.5472	0.0000
	WESTBOUND	.8974	.4446	0.5472			0.0000	.4446	.8974	0.4528	.8974	.4446	0.5472	0.0000

** PHASE SETTINGS -- SECONDS **

SIGNAL NO.	DIRECTION	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	ADVANCED BY QUEUE CLEAR TIME
1	EASTBOUND	28.9	1.9	63.0			0.0	1.9	28.9	27.0	40.8	0.0	49.2	0.0
	WESTBOUND	28.9	1.9	63.0			0.0	1.9	28.9	27.0	30.8	80.0	49.2	0.0
2	EASTBOUND	80.8	40.0	49.2			0.0	40.0	80.8	40.8	80.8	40.0	49.2	0.0
	WESTBOUND	80.8	40.0	49.2			0.0	40.0	80.8	40.8	80.8	40.0	49.2	0.0

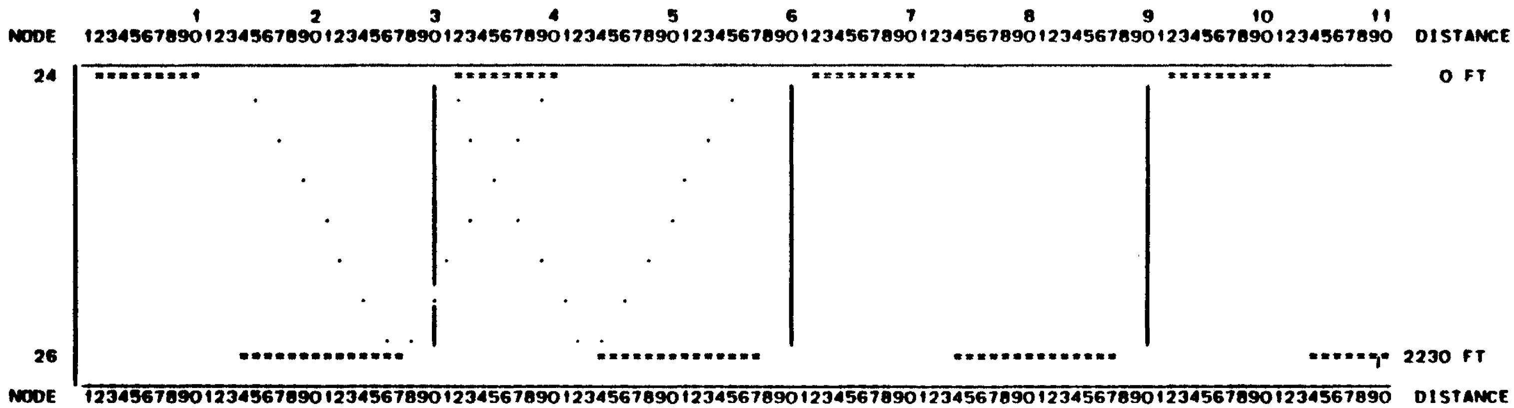
** PROGRESSION TIMES AND SPEEDS **

SIGNAL NO.		EASTBOUND LENGTH (FEET)	EASTBOUND PROGRESSION TRAVERSAL TIME (SECS)	EASTBOUND PROGRESSION SPEED (MILES/HOUR)	WESTBOUND LENGTH (FEET)	WESTBOUND PROGRESSION TRAVERSAL TIME (SECS)	WESTBOUND PROGRESSION SPEED (MILES/HOUR)
1 - 2	--------	2230.00	40.01	38.00	2230.00	40.01	38.00
ENTIRE ARTERY		2230.00	40.01	38.00	2230.00	40.01	38.00

**** MAXBAND TIME-SPACE DIAGRAM ****

NAME OF ARTERY: ANZA BLVD   TIME SCALE = 3 SEC/CHAR

CYCLE LENGTH : 90.00 SECONDS   DIST. SCALE = 150 FT/LINE



NODE 24 ---> NODE 26: EASTBOUND DIRECTION (DOWN)
NODE 26 ---> NODE 24: WESTBOUND DIRECTION (UP)
EASTBOUND BAND = 49.2 SECONDS AT 38.0 MILES/HOUR
WESTBOUND BAND = 49.2 SECONDS AT 38.0 MILES/HOUR

EEE EASTBOUND GREEN (DOWN)
WWW WESTBOUND GREEN (UP)
GREEN IN BOTH DIRECTIONS
*** RED IN BOTH DIRECTIONS

**** REITERATION OF SETTINGS AT ARTERY MEETINGS ****

ALL PHASE STARTING TIMES ARE RELATIVE TO THE START OF GREEN IN THE EASTBOUND DIRECTION AT SIGNAL 1 IN ARTERY 1.

NODE # 7 ARTERY 1 AND ARTERY 3 MEET AT INTERSECTION 2 IN ARTERY 1 AND AT INTERSECTION 2 IN ARTERY 3.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION	GREEN			LEFT			RED			BAND			
SIGNAL 2 IN ARTERY 1:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
EASTBOUND	.0908	.5881	0.4974	.4881	.5881	0.1000	.5881	.0908	0.5026	.1774	.5281	0.3507	0.0000
WESTBOUND	.9908	.4881	0.4974	.9908	.0908	0.1000	.4881	.9908	0.5026	.0508	.4015	0.3507	0.0000
SIGNAL 2 IN ARTERY 3:													
SOUTHBOUND	.5383	.8409	0.3026	.6883	.8409	0.1526	.8409	.5383	0.6974	.5383	.7883	0.2500	0.0000
NORTHBOUND	.4383	.6883	0.2500	.4383	.5383	0.1000	.6883	.4383	0.7500	.4383	.6883	0.2500	0.0000

ALL RED TIMES -- BEFORE ARTERY 3 PHASE: .5838 .4383 0.8545 AFTER ARTERY 3 PHASE: .8409 .9865 0.1456

** PHASE SETTINGS -- SECONDS **

DIRECTION	GREEN			LEFT			RED			BAND			
SIGNAL 2 IN ARTERY 1:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
EASTBOUND	8.2	52.9	44.8	43.9	52.9	9.0	52.9	8.2	45.2	16.0	47.5	31.6	0.0
WESTBOUND	89.2	43.9	44.8	89.2	8.2	9.0	43.9	89.2	45.2	4.6	36.1	31.6	0.0
SIGNAL 2 IN ARTERY 3:													
SOUTHBOUND	48.4	75.7	27.2	61.9	75.7	13.7	75.7	48.4	62.8	48.4	70.9	22.5	0.0
NORTHBOUND	39.4	61.9	22.5	39.4	48.4	9.0	61.9	39.4	67.5	39.4	61.9	22.5	0.0

ALL RED TIMES -- BEFORE ARTERY 3 PHASE: 52.5 39.4 76.9 AFTER ARTERY 3 PHASE: 75.7 88.8 13.1

NODE # 10 ARTERY 1 AND ARTERY 2 MEET AT INTERSECTION 5 IN ARTERY 1 AND AT INTERSECTION 2 IN ARTERY 2.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION	GREEN			LEFT			RED			BAND			
SIGNAL 5 IN ARTERY 1:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
EASTBOUND	.5027	.9483	0.4457	.5027	.6340	0.1313	.9483	.5027	0.5543	.5658	.9165	0.3507	0.0000
WESTBOUND	.6340	.0483	0.4144	.9483	.0483	0.1000	.0483	.6340	0.5856	.6658	.0165	0.3507	0.0000
SIGNAL 2 IN ARTERY 2:													
SOUTHBOUND	.5222	.8807	0.3586	.4264	.6307	0.2043	.8807	.5222	0.6414	.6307	.8807	0.2500	0.0000
NORTHBOUND	.6307	.8807	0.2500	.4264	.5222	0.0958	.8807	.6307	0.7500	.6307	.8807	0.2500	0.0000

ALL RED TIMES -- BEFORE ARTERY 2 PHASE: .0165 .4264 0.4099 AFTER ARTERY 2 PHASE: .8807 .4709 0.5901

** PHASE SETTINGS -- SECONDS **

DIRECTION	GREEN			LEFT			RED			BAND			
SIGNAL 5 IN ARTERY 1:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
EASTBOUND	45.2	85.4	40.1	45.2	57.1	11.8	85.4	45.2	49.9	50.9	82.5	31.6	0.0
WESTBOUND	57.1	4.3	37.3	85.4	4.3	9.0	4.3	57.1	52.7	59.9	1.5	31.6	0.0
SIGNAL 2 IN ARTERY 2:													
SOUTHBOUND	47.0	79.3	32.3	38.4	56.8	18.4	79.3	47.0	57.7	56.8	79.3	22.5	0.0
NORTHBOUND	56.8	79.3	22.5	38.4	47.0	8.6	79.3	56.8	67.5	56.8	79.3	22.5	0.0

ALL RED TIMES -- BEFORE ARTERY 2 PHASE: 1.5 38.4 36.9 AFTER ARTERY 2 PHASE: 79.3 42.4 53.1

NODE # 26 ARTERY 2 AND ARTERY 5 MEET AT INTERSECTION 1 IN ARTERY 2 AND AT INTERSECTION 2 IN ARTERY 5.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION	---- GREEN ----			---- LEFT ----			---- RED ----			------- BAND -------			
SIGNAL 1 IN ARTERY 2:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	.9990	.3528	0.3528	.9990	.1528	0.1528	.3528	.9990	0.6472	.1028	.3528	0.2500	0.0000
NORTHBOUND	.1528	.4528	0.3000	.3528	.4528	0.1000	.4528	.1528	0.7000	.1528	.4028	0.2500	0.0000
SIGNAL 2 IN ARTERY 5:													
EASTBOUND	.8974	.4446	0.5472			0.0000	.4446	.8974	0.4528	.8974	.4446	0.5472	0.0000
WESTBOUND	.8974	.4446	0.5472			0.0000	.4446	.8974	0.4528	.8974	.4446	0.5472	0.0000

ALL RED TIMES -- BEFORE ARTERY 5 PHASE: .4528 .8974 0.4446 AFTER ARTERY 5 PHASE: .4446 .0000 0.5554

** PHASE SETTINGS -- SECONDS **

DIRECTION	---- GREEN ----			---- LEFT ----			---- RED ----			------- BAND -------			
SIGNAL 1 IN ARTERY 2:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	89.9	31.8	31.8	89.9	13.8	13.8	31.8	89.9	58.2	9.3	31.8	22.5	0.0
NORTHBOUND	13.8	40.8	27.0	31.8	40.8	9.0	40.8	13.8	63.0	13.8	36.3	22.5	0.0
SIGNAL 2 IN ARTERY 5:													
EASTBOUND	80.8	40.0	49.2			0.0	40.0	80.8	40.8	80.8	40.0	49.2	0.0
WESTBOUND	80.8	40.0	49.2			0.0	40.0	80.8	40.8	80.8	40.0	49.2	0.0

ALL RED TIMES -- BEFORE ARTERY 5 PHASE: 40.8 80.8 40.0 AFTER ARTERY 5 PHASE: 40.0 0.0 50.0

NODE # 27 ARTERY 2 AND ARTERY 4 MEET AT INTERSECTION 3 IN ARTERY 2 AND AT INTERSECTION 2 IN ARTERY 4.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION	---- GREEN ----			---- LEFT ----			---- RED ----			------- BAND -------			
SIGNAL 3 IN ARTERY 2:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	.1307	.4307	0.3000	.3307	.4307	0.1000	.4307	.1307	0.7000	.1690	.4190	0.2500	0.0000
NORTHBOUND	.0307	.3307	0.3000	.0307	.1307	0.1000	.3307	.0307	0.7000	.0424	.2924	0.2500	0.0000
SIGNAL 2 IN ARTERY 4:													
EASTBOUND	.4424	.0424	0.6000			0.0000	.0424	.4424	0.4000	.4424	.0424	0.6000	0.0000
WESTBOUND	.4424	.0424	0.6000			0.0000	.0424	.4424	0.4000	.4424	.0424	0.6000	0.0000

ALL RED TIMES -- BEFORE ARTERY 4 PHASE: .4424 .4424 0.0000 AFTER ARTERY 4 PHASE: .0424 .0424 0.0000

** PHASE SETTINGS -- SECONDS **

DIRECTION	---- GREEN ----			---- LEFT ----			---- RED ----			------- BAND -------			
SIGNAL 3 IN ARTERY 2:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	11.8	38.8	27.0	29.8	38.8	9.0	38.8	11.8	63.0	15.2	37.7	22.5	0.0
NORTHBOUND	2.8	29.8	27.0	2.8	11.8	9.0	29.8	2.8	63.0	3.8	26.3	22.5	0.0
SIGNAL 2 IN ARTERY 4:													
EASTBOUND	39.8	3.8	54.0			0.0	3.8	39.8	36.0	39.8	3.8	54.0	0.0
WESTBOUND	39.8	3.8	54.0			0.0	3.8	39.8	36.0	39.8	3.8	54.0	0.0

ALL RED TIMES -- BEFORE ARTERY 4 PHASE: 39.8 39.8 0.0 AFTER ARTERY 4 PHASE: 3.8 3.8 0.0

NODE # 24 ARTERY 3 AND ARTERY 5 MEET AT INTERSECTION 1 IN ARTERY 3 AND AT INTERSECTION 1 IN ARTERY 5.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION SIGNAL 1 IN ARTERY 3:	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	.9868	.2868	0.3000			0.0000	.2868	.9868	0.7000	.0000	.2500	0.2500	0.0000
NORTHBOUND	.9868	.2868	0.3000			0.0000	.2868	.9868	0.7000	.0235	.2735	0.2500	0.0000
SIGNAL 1 IN ARTERY 5:													
EASTBOUND	.3210	.0210	0.7000			0.0000	.0210	.3210	0.3000	.4528	.0000	0.5472	0.0000
WESTBOUND	.3210	.0210	0.7000			0.0000	.0210	.3210	0.3000	.3420	.8892	0.5472	0.0000

ALL RED TIMES -- BEFORE ARTERY 5 PHASE: .3000 .3000 0.0000 AFTER ARTERY 5 PHASE: .0000 .0000 0.0000

** PHASE SETTINGS -- SECONDS **

DIRECTION SIGNAL 1 IN ARTERY 3:	GREEN BEGIN	GREEN END	GREEN DURATION	LEFT BEGIN	LEFT END	LEFT DURATION	RED BEGIN	RED END	RED DURATION	BAND BEGIN	BAND END	BAND DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	88.8	25.8	27.0			0.0	25.8	88.8	63.0	0.0	22.5	22.5	0.0
NORTHBOUND	88.8	25.8	27.0			0.0	25.8	88.8	63.0	2.1	24.6	22.5	0.0
SIGNAL 1 IN ARTERY 5:													
EASTBOUND	28.9	1.9	63.0			0.0	1.9	28.9	27.0	40.8	0.0	49.2	0.0
WESTBOUND	28.9	1.9	63.0			0.0	1.9	28.9	27.0	30.8	80.0	49.2	0.0

ALL RED TIMES -- BEFORE ARTERY 5 PHASE: 27.0 27.0 0.0 AFTER ARTERY 5 PHASE: 0.0 0.0 0.0

NODE # 25 ARTERY 3 AND ARTERY 4 MEET AT INTERSECTION 3 IN ARTERY 3 AND AT INTERSECTION 1 IN ARTERY 4.

** PHASE SETTINGS -- FRACTIONS OF CYCLE **

DIRECTION	- - - - GREEN - - - -			- - - - LEFT - - - -			- - - - RED - - - -			- - - - - - - BAND - - - - - - -			
SIGNAL 3 IN ARTERY 3:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	.9591	.2667	0.3077			0.0000	.2667	.9591	0.6923	.0167	.2667	0.2500	0.0000
NORTHBOUND	.9591	.2667	0.3077			0.0000	.2667	.9591	0.6923	.9591	.2091	0.2500	0.0000
SIGNAL 1 IN ARTERY 4:													
EASTBOUND	.8546	.5469	0.6923			0.0000	.5469	.8546	0.3077	.9145	.5145	0.6000	0.0000
WESTBOUND	.8546	.5469	0.6923			0.0000	.5469	.8546	0.3077	.8870	.4870	0.6000	0.0000

** PHASE SETTINGS -- SECONDS **

DIRECTION	- - - - GREEN - - - -			- - - - LEFT - - - -			- - - - RED - - - -			- - - - - - - BAND - - - - - - -			
SIGNAL 3 IN ARTERY 3:	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	BEGIN	END	DURATION	ADVANCED BY QUEUE CLEAR TIME
SOUTHBOUND	86.3	24.0	27.7			0.0	24.0	86.3	62.3	1.5	24.0	22.5	0.0
NORTHBOUND	86.3	24.0	27.7			0.0	24.0	86.3	62.3	86.3	18.8	22.5	0.0
SIGNAL 1 IN ARTERY 4:													
EASTBOUND	76.9	49.2	62.3			0.0	49.2	76.9	27.7	82.3	46.3	54.0	0.0
WESTBOUND	76.9	49.2	62.3			0.0	49.2	76.9	27.7	79.8	43.8	54.0	0.0

**** SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION ****

*-[MASTER INTERSECTION] = INTERSECTION NO. 6 CYCLE LENGTH = 90.00 SEC

INTERSECTION NO. 6

CENTER WAY (N-S) AT HAWTHORNE BL (W-E)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER	1	2	3			4	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	2+5	2+6	1+6	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	15.4	20.8	15.9	-	-	37.8	0.0	31.6	20.6	52.2	0.0	0.0
PHASE (%)	17.1	23.1	17.7	-	-	42.0	0.0	35.1	22.9	58.0	0.0	0.0
PIN SET (%) 100 /	0.0	17.1	40.3	-	-	58.0	0.0	35.1	22.9	58.0		

OFFSET POINT = 0.0 SEC (0.0%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 7

CARSON (N-S) AT HAWTHORNE BL (W-E)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER	1	2	3	4	5	6	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	1+6	2+6	2+5	4+7	4+8	3+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	9.0	35.8	9.0	9.0	13.5	13.7	16.0	47.5	4.6	36.1	0.0	0.0
PHASE (%)	10.0	39.7	10.0	10.0	15.0	15.3	17.7	52.8	5.1	40.2	0.0	0.0
PIN SET (%) 100 /	0.0	10.0	49.7	59.7	69.7	84.7	17.7	52.8	5.1	40.2		

OFFSET POINT = 8.2 SEC (9.1%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 8

DEL AMO CIRCLE (N-S) AT HAWTHORNE BL (W-E)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER	1	2	3			4	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	1+6	2+6	2+5	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	9.0	49.5	9.0	-	-	22.5	28.6	60.1	82.6	24.2	0.0	0.0
PHASE (%)	10.0	55.0	10.0	-	-	25.0	31.8	66.8	91.8	26.9	0.0	0.0
PIN SET (%) 100 /	0.0	10.0	65.0	-	-	75.0	31.8	66.8	91.8	26.9		

OFFSET POINT = 1.6 SEC (1.8%). REFERENCED TO START OF PHASE NUMBER 1.

**** SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION (CONTINUED) ****

INTERSECTION NO. 9

FASHION WAY (N-S) AT HAWTHORNE BL (W-E)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER		1				2	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	-	2+6	-	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	-	67.5	-	-	-	22.5	37.6	69.2	73.6	15.1	0.0	0.0
PHASE (%)	-	75.0	-	-	-	25.0	41.8	76.9	81.7	16.8	0.0	0.0
PIN SET (%) 100 /	0.0	0.0	-	-	-	75.0	41.8	76.9	81.7	16.8		

OFFSET POINT = 37.6 SEC (41.8%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 10

TORRENCE (N-S) AT HAWTHORNE BL (W-E)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER	1	2	3	4	5	6	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	2+5	2+6	1+6	3+7	3+8	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	11.8	28.3	9.0	8.6	9.8	22.5	50.9	82.5	59.9	1.5	0.0	0.0
PHASE (%)	13.1	31.4	10.0	9.6	10.9	25.0	56.6	91.7	66.6	1.7	0.0	0.0
PIN SET (%) 100 /	0.0	13.1	44.6	54.6	64.1	75.0	56.6	91.7	66.6	1.7		

OFFSET POINT = 45.2 SEC (50.3%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 26

ANZA (W-E) AT TORRENCE (N-S)

	- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER	1	2	3			4	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS	2+5	2+6	1+6	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)	13.8	18.0	9.0	-	-	49.2	9.3	31.8	13.8	36.3	0.0	0.0
PHASE (%)	15.3	20.0	10.0	-	-	54.7	10.3	35.3	15.3	40.3	0.0	0.0
PIN SET (%) 100 /	0.0	15.3	35.3	-	-	45.3	10.3	35.3	15.3	40.3		

OFFSET POINT = 89.9 SEC (99.9%). REFERENCED TO START OF PHASE NUMBER 1.

**** SUMMARY OF MAXBAND BEST SIGNAL TIMING SOLUTION (CONTINUED) ****

INTERSECTION NO. 27

MADRONA ST (W-E) AT TORRENCE (N-S)

		- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER		1	2	3			4	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS		1+6	2+6	2+5	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)		9.0	18.0	9.0	-	-	54.0	15.2	37.7	3.8	26.3	0.0	0.0
PHASE (%)		10.0	20.0	10.0	-	-	60.0	16.9	41.9	4.2	29.2	0.0	0.0
PIN SET (%)	100 /	0.0	10.0	30.0	-	-	40.0	16.9	41.9	4.2	29.2		

OFFSET POINT = 11.8 SEC (13.1%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 24

ANZA BLVD (W-E) AT CARSON (N-S)

		- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER			1				2	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS		-	2+6	-	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)		-	27.0	-	-	-	63.0	0.0	22.5	2.1	24.6	0.0	0.0
PHASE (%)		-	30.0	-	-	-	70.0	0.0	25.0	2.4	27.4	0.0	0.0
PIN SET (%)	100 /	0.0	0.0	-	-	-	30.0	0.0	25.0	2.4	27.4		

OFFSET POINT = 88.8 SEC (98.7%). REFERENCED TO START OF PHASE NUMBER 1.

INTERSECTION NO. 25

MADRONA BLVD (W-E) AT CARSON (N-S)

		- MAIN STREET -			- CROSS STREET -			-- BAND COORDINATES --				-- QUEUE CLEARANCE --	
PHASE NUMBER			1				2	OUTBOUND		INBOUND		OUTBOUND	INBOUND
NEMA MOVEMENTS		-	2+6	-	-	-	4+8	BEGIN	END	BEGIN	END		
PHASE (SEC)		-	27.7	-	-	-	62.3	1.5	24.0	86.3	18.8	0.0	0.0
PHASE (%)		-	30.8	-	-	-	69.2	1.7	26.7	95.9	20.9	0.0	0.0
PIN SET (%)	100 /	0.0	0.0	-	-	-	30.8	1.7	26.7	95.9	20.9		

OFFSET POINT = 86.3 SEC (95.9%). REFERENCED TO START OF PHASE NUMBER 1.

```
                         *** MAXBAND BEST SOLUTION ***

                            NEMA MOVEMENT NUMBERS
                         ****************************

                                CROSS STREET

                          4 | | 7      |
          INBOUND           | |        |  T------ 6          INBOUND
          <-------          | L        |    L--- 1           <-------
                            T  L       |   L
MAIN STREET               ------- INTERSECTION -------
                               L       |   L   T
          OUTBOUND        5 ---L       |    L  |             OUTBOUND
          ------->        2 ------T    |     | |             ------->
                                       |   3 | | 8
```

**** MAXBAND END ****

MESSAGE SUMMARY: MESSAGE NUMBER - COUNT

208 32

Appendix B

MAXBAND'S LOOP GENERATION ALGORITHM AND THE LOOP GENERATION PROCESS.

This appendix presents the details of MAXBAND'S loop generation algorithm. Section 2.2.1.4 of MAXBAND Program Manual describes how this information is stored in variables used in the formulation.

E.1 MAXBAND'S LOOP GENERATION ALGORITHM.

MAXBAND uses a modified version of PATON'S algorithm [1969]. The differences between the original and modified algorithm are described below.

(i) As opposed to Paton's original algorithm, the modified algorithm uses the node with most links incident to it as the root of the spanning tree. Such a node is called the highest degree node. This results in a simpler loop set in most cases.

(ii) The construction of the tree and cotree is completed before tracing of loops is begun.

(iii) The links in the cotree are examined and if possible the loops are further reduced to simpler ones.

The reason for placing more emphasis on finding simpler loops is that their coefficients in formulation matrix will occupy less space.

E.1.1 The Algorithm.

Let

L = set of links of the network

N = set of nodes of the network

T = set of nodes already in the spanning tree

X = set of nodes not yet examined

r = root of tree

Initially $T = \phi$ and $X = N$

Steps:

1. let r = node having the maximum number of links incident to it; break ties by selecting the node having bigger node number.

2. let $T = \{r\}$

3. Find $T \cap X$

4. IF $T \cap X = \phi$ then go to step 7

5. let n = highest degree node in $T \cap X$; break ties by selecting smallest node number

6. Consider each link (n,w) in L and act as follows:

(i) If $W \in T$ add link (n,w) to the cotree, if it is not already in the tree or cotree.

(ii) If $W \notin T$ add link (n,w) to tree and W to set T.

When all links (n,w) have been considered, remove current n from X and go to step 3 above.

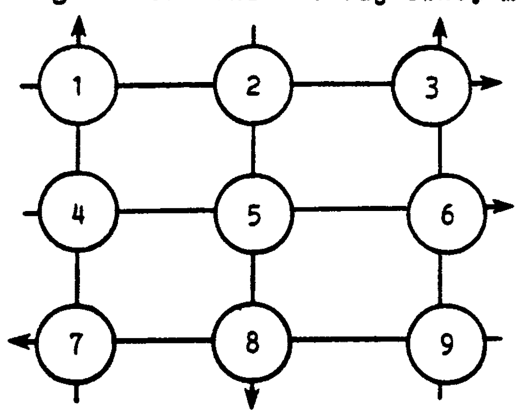
7. For each link in the cotree, trace a fundamental loop.

8. For each link in the cotree starting from the second, attempt to reduce the fundamental loop to smaller fundamental loop.

Note that in step 8 above, no attempt is made to reduce the first loop since it is always the simplest.

E.2 How MAXBAND Finds Fundamental Set of Loops.

Consider the following network and its adjacency matrix.



$$A = \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \left[\begin{array}{ccccccccc} & 1 & & 1 & & & & & \\ 1 & & 1 & & 1 & & & & \\ & 1 & & & & 1 & & & \\ 1 & & & & 1 & & 1 & & \\ & 1 & & 1 & & 1 & & 1 & \\ & & 1 & & 1 & & & & 1 \\ & & & 1 & & & & 1 & \\ & & & & 1 & & 1 & & 1 \\ & & & & & 1 & & 1 & \end{array} \right] \end{array}$$

Note: orientation of arteries has no affect on the adjacency matrix.

E.2.1 Creating the spanning tree and cotree. (steps 1-6)

T = { ϕ }
X = {1, 2, 3, 4, 5, 6, 7, 8, 9}

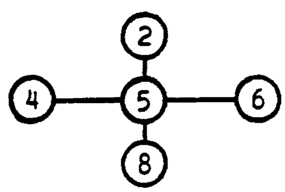
The highest degree node is 5 which has 4 links incident to it, therefore, let node 5 be the root of the tree.

T = {5}
X = {1, 2, 3, 4, 5, 6, 7, 8, 9}

Stage 1:

T $\cap$ X = 5 $\Longrightarrow$ n = 5

After considering links (5,2), (5,4), (5,6) and (5,8), the status of the tree, cotree, T set and X set is as follows:

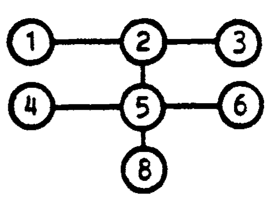
tree	links in tree	links in cotree
	5-2 5-4 5-6 5-8	none

T = {2, 4, 5, 6, 8}
X = {1, 2, 3, 4, 6, 7, 8, 9}

Stage 2:

T $\cap$ X = {2, 4, 6, 8} $\Longrightarrow$ n = 2

After considering links (2,1), (2,3) and (2,5), the status of the tree, cotree, T set and X set is as follows:

tree	links in tree	links in cotree
	5-2 5-4 5-6 5-8 2-1 2-3	none

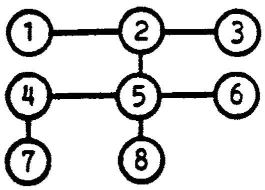
T = {1, 2, 3, 4, 5, 6, 8}
X = {1, 3, 4, 6, 7, 8, 9}

Stage 3:

T $\cap$ X = {1, 3, 4, 6, 8} $\Longrightarrow$ n = 4

After considering links (4,1), (4,5), and (4,7) the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in cotree
5-2	4-1
5-4	
5-6	
5-8	
2-1	
2-3	
4-7	

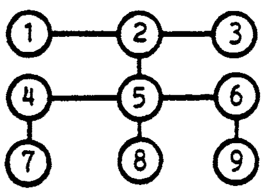
T = {1, 2, 3, 4, 5, 6, 7, 8}
X = {1, 3, 6, 7, 8, 9}

Stage 4:

$T \cap X = \{1, 3, 6, 7, 8\} \implies n = 6$

After considering links (6,3), (6,5), and (6,9), the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in cotree
5-2	4-1
5-4	6-3
5-6	
5-8	
2-1	
2-3	
4-7	
6-9	

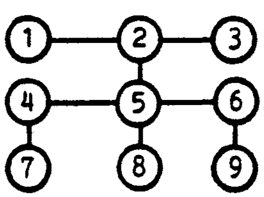
T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = {1, 3, 7, 8, 9}

Stage 5:

$T \cap X = \{1, 3, 7, 6, 8\} \implies n = 8$

After considering links (8,5), (8,7) and (8,9), the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in cotree
5-2	4-1
5-4	6-3
5-6	8-7
5-8	8-9
2-1	
2-3	
4-7	
6-9	

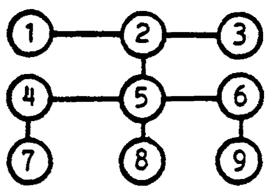
T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = {1, 3, 7, 9}

Stage 6:

T ∩ X = {1, 3, 7, 9} $\Longrightarrow$ n = 1

After considering links (1,2) and (1,4), the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in cotree
5-2	4-1
5-4	6-3
5-6	8-7
5-8	8-9
2-1	
2-3	
4-7	
6-9	

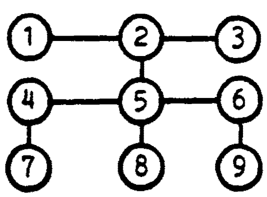
T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = {3, 7, 9}

Stage 7:

T ∩ X = {3, 7, 9} $\Longrightarrow$ n = 3

After considering links (7,4) and (7,8), the status of the tree, cotree, T set and X set is as follows.

tree



links in tree	links in cotree
5-2	4-1
5-4	6-3
5-6	8-7
5-8	8-9
2-1	
2-3	
4-7	
6-9	

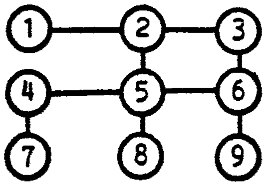
T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = {7, 9}

Stage 8:

T ∩ X = {7,9} $\Longrightarrow$ n = 7

After considering links (7,4) and (7,8), the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in cotree
5-2	4-1
5-4	6-3
5-6	8-7
5-8	8-9
2-1	
2-3	
4-7	
6-9	

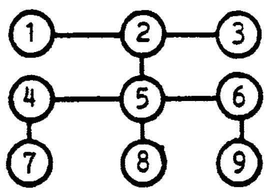
T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = {9}

Stage 9:

$T \cap X = \{9\} \Longrightarrow n = 9$

After considering links (9,6) and (9-8), the status of the tree, cotree, T set and X set is as follows:

tree



links in tree	links in-cotree
5-2	4-1
5-4	6-3
5-6	8-7
5-8	8-9
2-1	
2-3	
4-7	
6-9	

T = {1, 2, 3, 4, 5, 6, 7, 8, 9}
X = { ϕ }

Stage 10:

$T \cap X = \{ \phi \}$

Since the x set is now null, the process of constructing the tree and cotree is complete.

E.2.2 Tracing the fundamental set of loops. (Step 8)

Loop 1:

Loop 1 is generated by the first link (i.e., 4-1) in the cotree. The process consists of appending links from the tree to the loop generating link 4-1 until the loop is complete. If a loop is not found in one pass, the outmost links are deleted and the tracing procedure is repeated. Since the tree is destroyed in this process, the process uses a dummy tree identical to the tree.

Pass 1: Start from loop generating link 1-4

loop	dummy tree	
Step 1: 4-1	5-2	
	5-4	
	5-6	
	5-8	
	2-1	
	2-3	
	4-7	*
	6-9	
Step 2: 7-4-1	5-2	
	5-4	
	5-6	
	5-8	
	2-1	*
	2-3	
	6-9	
Step 3: 7-4-1-2	5-2	
	5-4	
	5-6	
	5-8	
	2-3	*
	6-9	
Step: 7-4-1-2-3	5-2	
	5-4	
	5-6	
	5-8	
	6-9	

At this step, a loop is not formed and no more links can be added.

Pass 2: Delete links (2,3) and (7-4) and repeat procedure.

loop	dummy tree	
Step 1: 4-1-2	5-2	
	5-4	*
	5-6	
	5-8	
	6-9	
Step 2: 5-4-1-2	5-2	
	5-6	
	5-8	*
	6-9	
Step 3: 8-5-4-1-2	5-2	*
	5-6	
	6-9	

Step 4: 8-5-4-1-2-5 5-6
6-9

Since 5 appears twice above, a loop is found and is obtained by deleting link 5-8.

Hence:

Loop 1 = 5-4-1-2-5

All other loops are traced in a similar fashion and are given below.

Loop 2 generated by link 6-3 is 5-6-3-2-5
Loop 3 generated by link 8-7 is 5-8-7-4-5
Loop 4 generated by link 8-9 is 6-5-8-9-6

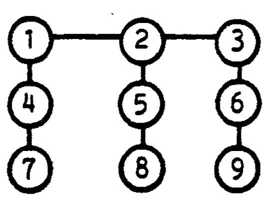
Note that all the loops found are the simplest ones and, therefore, step 8 of algorithm will give the same set of loops.

E.2.3 Reducing the loops to a smaller size. (Step 8)

The loops obtained in previous sections for the example network were the simplest. This may not be the case in general and the loops may be reduced by the procedure given. This section illustrates two points. One is mentioned above, namely the reduction of loops and the other is the importance of selecting the lightest degree node as the root of the spanning tree.

Consider the same example as given in section E.2. Let node 1 be the root of the spanning tree instead of node 5. It can be verified by the application of the algorithm illustrated in sections E.2.1 and E.2.2 that the tree, cotree and fundamental loops obtained are as follows:

tree



links in tree	links in cotree
1-2	4-5
1-4	5-6
2-3	7-8
2-5	8-9
3-6	
4-7	
5-8	
6-9	

Loop generated by link 4-5 is 2-1-4-5-2
Loop generated by link 5-6 is 3-2-5-6-3
Loop generated by link 7-8 is 2-1-4-7-8-5-2
Loop generated by link 8-9 is 2-5-8-9-6-3-2

Note that loops generated by links (7-8) and (8-9), respectively, are not the simplest. Now an attempt will be made to reduce their size.

First consider the loop generated by link (7-8). It is 2-1-4-7-8-5-2.

Consider all links in the cotree stored before link (7-8), starting from the second.

Step 1:

Consider the second link in the cotree i.e., 5-6 and check whether nodes 5 and 6 are both in the loop being considered. Since they are both not in the loop, go to step 2.

Step 2:

Consider the first link in cotree, i.e., 4-5. Since both nodes 4 and 5 are in the loop being considered, link 4-5 can reduce the loop. Therefore, delete all nodes on the left of node 4 and all nodes on the right of node 5 and copy node 4 as the last node to get the following reduced loop 4-7-8-5-4.
Now consider the loop generated by link (8-9). It is 2-5-8-9-6-3-2.

Consider all links before (8-9). It is 2-5-8-9-6-3-2. Consider all links before (8-9), starting from third.

Step 1:

Consider the third link in the cotree, i.e., 7-8. Since both nodes 7 and 8 are not in the loop being considered, go to step 2.

Step 2:

Consider the second link in the cotree, i.e., 5-6. Since both nodes 5 and 6 are in the loop, the loop can be further reduced. The reduced loop will be: 5-8-9-6-5.

REFERENCES

S. L. Cohen, "Concurrent Use of the MAXBAND and TRANSYT Signal Timing Programs for Arterial Signal Optimization." Transportation Research Record 906. 1983. pp. 81-84.

A. Land and S. Powell, FORTRAN Codes for Mathematical Programming, John Wiley & Sons, Ltd., London, 1973.

E. B. Lieberman and J. L. Woo, "SIGOP III - User's Manual," Federal Highway Administration Report No. FHWA-IP-82-A (July 1982).

J. D. C. Little, "The Synchronization of Traffic Signals by Mixed-Integer Linear Programming," Operations Research 14, 568-594 (1966).

J. D. C. Little, "Maximal Bandwidth for Arterial Traffic Signals: Theory and Interactive Computation," Sloan School Working Paper 970-78, M.I.T. (September 1977).

J. D. C. Little and M. D. Kelson, "Optimal Signal Timing for Arterial Signal Systems, Volume 1: Summary Report, "Federal Highway Administration Report No. FHWA-RD-80/082 (December 1980).

J. D. C. Little, B. V. Martin, and J. T. Morgan, "Synchronizing Traffic Signals for Maximum Bandwidth," Highway Research Record 118, 21-47 (1966).

C. J. Messer, R. H. Whitson, C. L. Dudek, and E. J. Romano, "A Variable-Sequence Multiphase Progression Optimization Program," Highway Research Record 445, 24-33 (1973).

K. Paton, "An Algorithm for Finding a Fundamental Set of Cycles of a Graph," Communications of the ACM, Vol. 12, No. 9, 514-518 (September 1969).

D. I. Robertson, "TRANSYT: A Traffic Network Study Tool," Road Research Laboratory Report LR 253, Crowthorne, Berkshire (1969).

R. O. Rogness. "Evaluation of a Heuristic Programming Approach to Arterial Street Signal Timing Operation." PhD. Dissertation. Texas A&M University. August 1981.

F. V. Webster, "Traffic Signal Settings," Road Research Technical Paper Number 39, Her Majesty's Stationary Office, London (1958).