NO-STOP-1 VERSUS SIGPROG

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This paper discusses the theory and fundamentals of progressively timed signal systems, whose objective is the achievement of maximum possible bandwidth. The relationship of bandwidth to speed, cycle length, splits, and distances is defined. Two conditions concerning the centers of green and their respective eccentricities are discussed, and their relationship to the bandwidth is demonstrated. Based on these relationships, a model is developed that satisfies the conditions of the Tschebysheff theorem. This theorem serves as the optimization model for maximizing bandwidth; in it speed and cycle length are varied within reasonable and defined limits. NO-STOP-1 is an outgrowth of this model. It includes a table printout that identifies all data necessary to describe a time-space diagram as well as a computer-plotted, time-space diagram that takes into consideration various options. NO-STOP-1 then is compared to SIGPROG. NO-STOP-1 yields larger bandwidths than those produced by SIGPROG. NO-STOP-1 also has a greater variety of options. NO-STOP-1 is also briefly compared to other programs.

•MORE sophisticated traffic engineering tools are needed to lessen the burden of the increasing numbers of automobiles on already overcrowded city streets. Coordination of signals along arteries is an important means of reducing delays and unwanted stops. SIGPROG is a computer program capable of providing the traffic engineer with the data required to achieve progressive movement. This program, however, has some shortcomings. NO-STOP-1 was developed as a more sophisticated computer program to solve complex problems related to progressively timed signal systems.

FUNDAMENTALS

Relationship at an Arbitrary Signal

Figure 1 shows the constant through band for 1 direction at arbitrary signal i. It is assumed that signal i is part of a larger system that has maximized bandwidths and that this signal is critical, which means that either the upper or lower limit of the through band touches red. From Figure 1, it can be shown that

$$b_i = t_{gi} - 2E_i \qquad (1)$$

where

b = bandwidth,
t_g = green time, and
E = eccentricity.

Publication of this paper sponsored by Committee on Traffic Control Devices.

*Mr. Leuthardt was with Tippetts-Abbett-McCarthy-Stratton, New York, when this research was performed.

Normally, the split at an intersection is known and relates to the traffic volumes at that intersection. When the split is known and the cycle length is given, t_g is also known, which leaves the bandwidth a function of E.

$$b = f(E) \tag{2}$$

which is to say that the location of the band axis determines the bandwidth. E may be interpreted as the offset difference of the band axis from the center of green (CG). In ideal cases, E is zero, which means that the band axis passes exactly through CG.

Relationship in a System

The primary objective in designing a progressively timed signal system is to determine the maximum constant bandwidth for both directions. Within a system, cycle length, speed, distances, and splits are the independent variables that influence the location of the band axis, and from that, the bandwidth. Distances and splits are set values for a given system because of the volumes and the physical layout of the system. Bandwidth is a function of cycle length and speed.

$$b = f(c) * f(v) \tag{3}$$

where

c = cycle length and
v = speed.

Figure 2 shows the time trajectories of 2 vehicles departing and arriving at the first intersection at the same time. Speed and cycle length are arbitrary and may be within reasonable limits. The trajectories represent the band axes of their respective through bands. Two conditions have to be met for a symmetric system to achieve the maximum possible constant bandwidth for both directions.

1. Two successive CGs must either occur simultaneously or be offset a half cycle length from each other. The band axis in 1 direction is the mirror image of the band axis in the opposite direction (Fig. 2). Therefore it is necessary to calculate the band axis for 1 direction only.
2. Under ideal conditions, the band axis passes at each intersection exactly through the CG, thereby providing the maximum possible bandwidth. Because conditions are seldom ideal, one must try to place the CGs as close as possible to the band axis so that the maximum E becomes as small as possible (Fig. 2). This condition may be expressed as

$$\max |E| = \min \tag{4}$$

Cycle length and speed as variables that influence the bandwidth are, of course, subject to reasonable limits. The range within which they may vary has to be defined. For cycle length, a range of 40 to 120 sec is commonly used. For desired progression speed, the range or progression of speed tolerance acceptable to the driver is approximately 15 percent from the desired progression speed, as studies by Leutzbach (1) and Desrosiers and Leighty (2) have shown.

By varying the cycle length and the desired progression speed, Es and locations of CGs are affected as shown in Figure 3. Figure 3 shows a band axis with a desired

Figure 1. Relationship at arbitrary signal i.

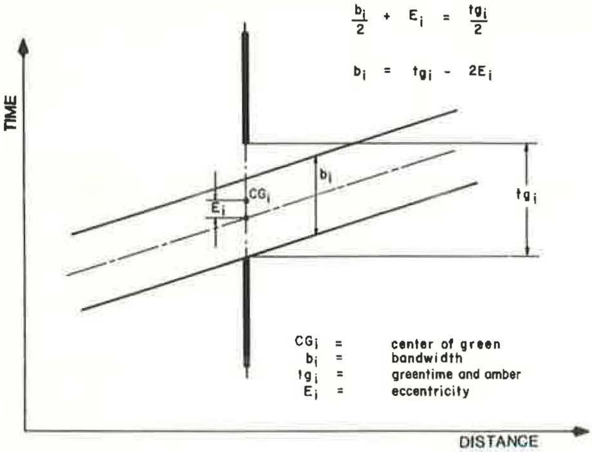
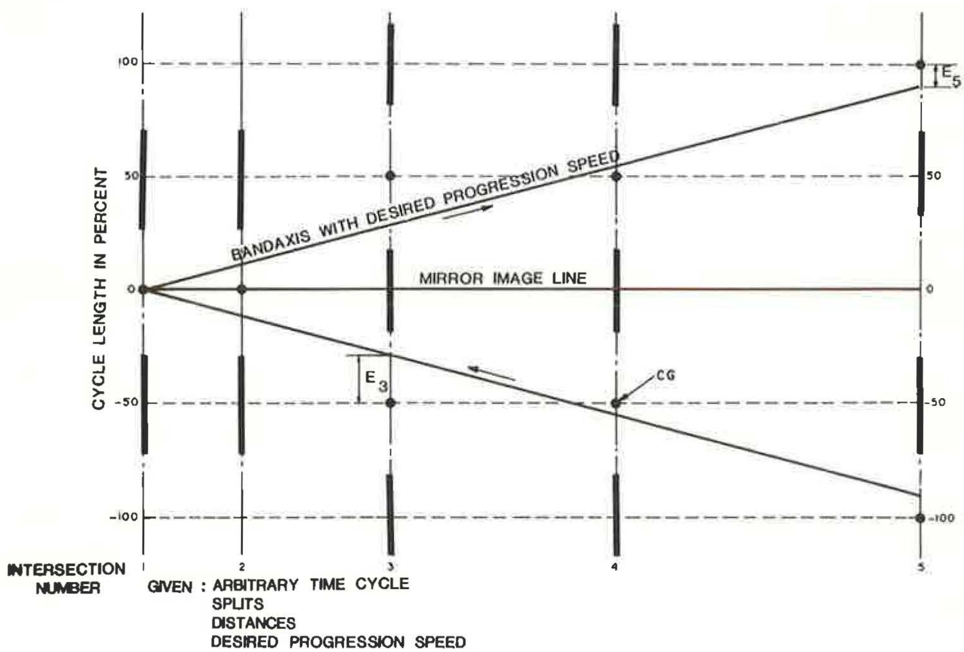


Figure 2. Relationship in a system.



progression speed and allowed tolerances (defined here as plus or minus) for an arbitrary cycle length. At intersection 5, for example, the CG for the progression speed plus the allowed tolerance would be offset 50 percent to the zero base line; the CG for the progression speed minus the allowed tolerance would be offset 100 percent (or zero) to the zero base line. To affect CGs at both ends of the signal system to the same degree when varying the speed, the progression speed in the reverse direction must also be considered (Fig. 4). Figures 3 and 4 are combined in Figure 5 to show the limits within which the band axis can be shifted and rotated to produce maximum bandwidths. For each change in cycle length, this shifting and rotating of the band axis must be repeated.

Optimization

For the largest possible bandwidth to be found, the axis of the band has to fulfill the 2 previously stated conditions. The first is rather easy to accomplish—after choosing cycle length and speed, simply place the CGs according to condition 1, as close as possible to the axis whose slope represents the speed. This in turn yields a set of eccentricities, a set of offsets, and a bandwidth. Whether this bandwidth is the largest possible remains to be seen. Of critical importance, therefore, is the second condition, which states that the largest of all eccentricities has to become as small as possible. The locations of the band axis and CGs have to be optimized with respect to each other. To find the best location of the band axis, we used the Tschebysheff theorem as the optimization model. A detailed outline of the Tschebysheff theorem is given elsewhere (5). This theorem states that the approximation of a cluster of points (in this case, the CGs) by a straight line (the band axis) yields 3 points (α, β, γ) out of the cluster of points located alternately above and below the line whose deviations, Es, from the straight line are equal. The largest of all deviations are as follows:

$$E_\alpha + E_\beta = 0$$

$$E_\beta + E_\gamma = 0 \qquad (5)$$

$$|E_\alpha| = |E_\beta| = |E_\gamma| = \max |E| \qquad (6)$$

Any other straight line will result in a larger maximum deviation and a failure to meet conditions of Eqs. 5 and 6. Thus the Tschebysheff theorem meets the requirement noted earlier that max $|E|$ = min. Figure 6 shows an example of a case in which the cluster of points represents the set of CGs and the straight line represents the band axis. E_2, E_4, and E_7 meet conditions of Eqs. 5 and 6.

In order to be able to compare bandwidths of different cycle lengths, Bleyl (3) defined efficiency as follows:

$$\text{Efficiency} = \frac{\text{bandwidth}}{\text{cycle length}} * 100$$

This efficiency will vary as cycle length is varied, and the objective is to find the cycle length that yields the highest efficiency together with the largest bandwidth.

The significance of the offset should be understood. The Traffic Engineering Handbook (4) defines offset as "the number of seconds or percent of the cycle length that the green indication appears at a given traffic control signal after a certain instant used as a time reference base." Offset, like bandwidth, centers of green, and eccentricities,

Figure 3. Band axis with desired progression speed and allowed tolerances from left to right.

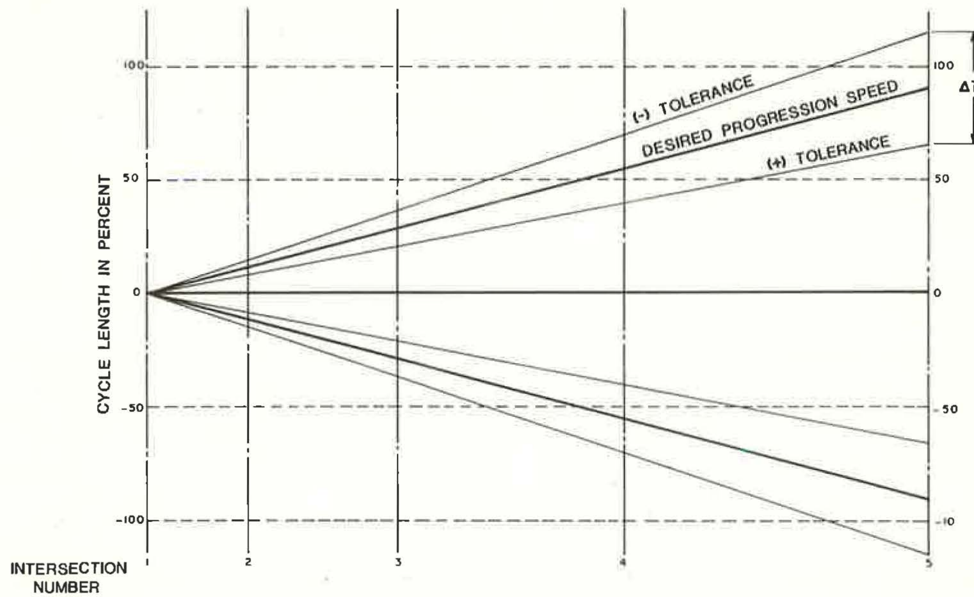


Figure 4. Band axis with desired progression speed and allowed tolerances from right to left.

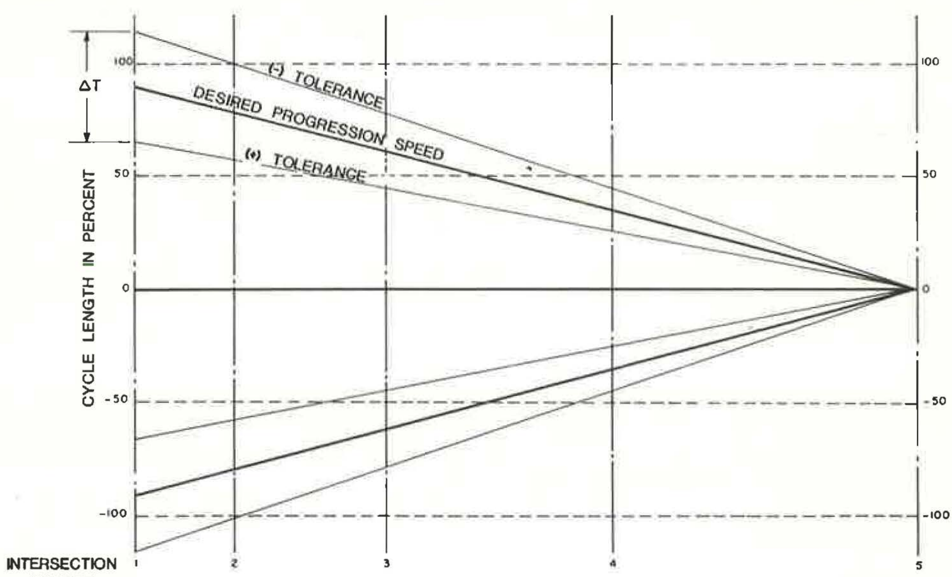


Figure 5. Array in which the band axis can be shifted and rotated within the allowed tolerances.

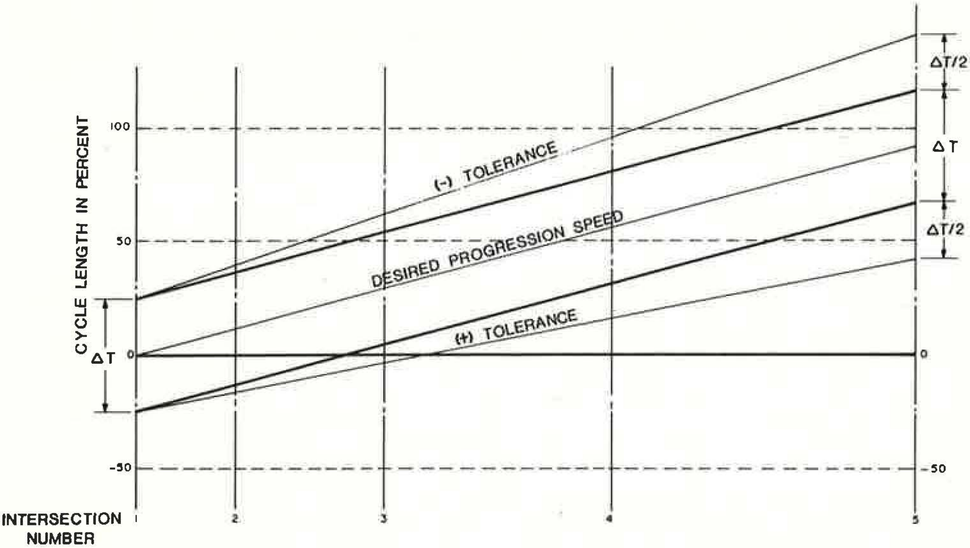


Figure 6. Approximation of a cluster of points by the Tschebysheff approximation.

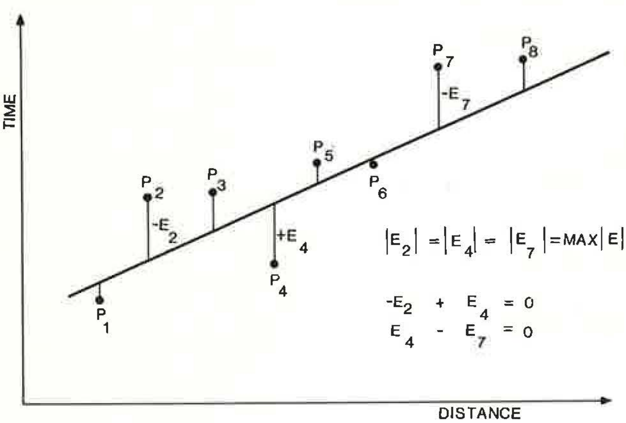


Figure 7. NO-STOP-1 computer printout of time-space diagram data.

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COMMONWEALTH  AVE  BOSTON  MASS.

AM PEAK

********************************
*CYCLE = 78.0 SEC              *
*BAND LEFT-RIGHT = 26.4 SEC    *
*BAND RIGHT-LEFT = 31.8 SEC    *
*EFF  LEFT-RIGHT = 33.9 PERCENT*
*EFF  RIGHT-LEFT = 40.8 PERCENT*
********************************
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INTERSECTION NAME	NO	DISTANCE IN FEET	SPLIT PERC.	ALL-RED SEC	RED-LR SEC	RED-RL SEC	SPEED-LR MPH	SPEED-RL MPH	OFFSET PERC.	BEG-AMBER PERCENT	BEG-RED PERC.	BEG-AMB PERC.
BABCOCK ST	1	0.0	73.0	1.0	34.0	22.0	33.0	33.0	41	69	73	96
PLEASANT ST	2	780.0	73.0	1.0	22.0	42.2	33.0	33.0	92	69	73	96
ST.PAUL ST	3	1510.0	73.0	1.0	39.0	22.0	33.0	33.0	92	69	73	96
AMORY ST.	4	2060.0	99.9	0.0	16.0	15.0	33.0	33.0	78	95	99	96
B.U.BRIDGE	5	2835.0	53.0	0.0	36.6	36.6	33.0	33.0	53	49	53	96
CARLTON ST	6	3235.0	43.0	0.0	44.4	44.4	27.5	27.5	56	39	43	96
MIDBLOCK	7	3515.0	99.9	0.0	17.0	0.0	27.5	27.5	29	95	99	96
ST.MARY'S ST	8	4045.0	99.9	0.0	17.0	17.0	27.5	27.5	78	95	99	96
CUMMINGTON	9	4485.0	70.0	1.0	24.4	24.4	27.5	27.5	94	66	70	96
GRANBY ST	10	5865.0	68.0	1.0	25.9	25.9	27.5	27.5	46	64	68	96
BLANFORD ST	11	6715.0	73.0	1.0	39.0	22.0	27.5	27.5	43	69	73	96

is a dependent variable subject to change of cycle length and progression speed. Splits and distances are assumed here to be known values. As speed or cycle length or both are varied, a set of centers of green subject to condition 1 is selected that yields a set of eccentricities, a bandwidth, and a set of offsets. If the eccentricities fulfill condition 2, the largest possible bandwidth and the best set of offsets have been found.

DESCRIPTION OF NO-STOP-1

NO-STOP-1 was developed on the fundamentals I have just discussed. A system such as that shown in Figure 5 was developed, and the band axis was shifted and rotated within the allowed tolerances. The best solution for the specific cycle length was found when the band axis (eccentricities) fulfilled condition 2 after condition 1 was observed. The cycle length was varied within specified limits, and the cycle length that yielded the highest efficiency is printed out as shown in Figure 7. Input to the program consists of 15 data cards, which are described in detail elsewhere (6). The data consist of titles, street names, cycle range with increments, speed, distances, splits, all-red clearances, and other data related to speed tolerances, amber time, metric or customary units, multiphase operations, 1-way or 2-way street systems, and bandwidth proportionment. Output consists of a table (Fig. 7) that lists all data related to a time-space diagram. Of special importance for the worker in the field are the last 4 columns, which list offsets, dial settings for begin-amber on the main street, begin-red on the main street, and begin-amber on the side street. (The begin-green setting for the main street always starts at zero percent.) If a plotter is available, the time-space diagram can be plotted directly from the computer.

The following options are available in NO-STOP-1:

1. Balanced system,
2. Unbalanced system,
3. Different speeds from segment to segment,
4. Different directional speeds per segment,
5. Multiphase operations,
6. T-intersection,
7. Midblock operation for pedestrian signals,
8. One-way street system, and
9. Completely nonconcurrent mainline green.

DESCRIPTION OF SIGPROG

The SIGPROG program has been well-defined by Bleyl (3), whose description I will use.

> The approach used by SIGPROG in determining traffic signal system timing plans converts all speed and distance units to travel time units. The diagram is then constructed in terms of time along both axes; the distance axis being replaced by an average-travel-time axis. From a base signal which is the signal having the shortest green interval, the two progressive bands for this interval width are created. The interferences to these bands resulting from both the 0 percent and 50 percent offset of centers of green conditions are determined for each signal. The total interferences to the bands is then selected in such a way that it is a minimum; hence, the bandwidth is a maximum.
>
> The input cards (to the computer program) consist of 12 general control cards and a series of sets of 2, 3 or 4 signal cards. These various cards contain the basic information needed to define the system and its variability.
>
> The printed output consists of three tables. The first table is a listing of the parameters and controls transmitted to the program from the input card deck. The second table contains the results of an incremental cycle scan between the minimum and maximum cycle lengths to find the maximum efficiency obtainable at each increment. The third tabulation indicates the timing elements that yield the greatest efficiency under the specified conditions. If desired, the program

will punch a deck of data processing cards containing all the parameters necessary for a supplemental computer program to plot, draw or print a timespace diagram.

COMPARISON OF NO-STOP-1 AND SIGPROG

Differences

The main difference between SIGPROG and NO-STOP-1 is the fact that NO-STOP-1 varies speed and SIGPROG does not. SIGPROG uses the speed tolerance given as input only as a parameter for further interaction of cycle length. From this follows another major difference in the approach of selecting the centers of green. SIGPROG determines the best combination of centers of green out of a definite number of combinations derived from 1 desired progression speed. NO-STOP-1 determines from each variation in speed (change in location of band axis) a set of centers of green according to condition 1 and a set of eccentricities. If the eccentricities of the band axis fulfill condition 2, the best combination of centers of green yielding the largest possible bandwidth has been found. If they do not, the speed is varied (the band axis is shifted or rotated or both), and new sets of centers of green and eccentricities are determined until condition 2 is fulfilled.

Examples

Two examples are given to illustrate the differences between NO-STOP-1 and SIGPROG. SIGPROG time-space diagrams for Mohawk Street and Genesee Street were prepared during the TOPICS study for Utica, New York. Subsequently, the NO-STOP-1 program was run for each street.

Figures 8 and 9 show the time-space diagrams produced by SIGPROG and NO-STOP-1 respectively for Mohawk Street. Similarly, Figures 10 and 11 show the time-space diagrams for Genesee Street. Dashed vertical lines indicate intersecting streets. Percentage of cycle is on the vertical axis, and distance is on the horizontal axis. Table 1 gives the results of the comparison. NO-STOP-1 showed an increase in efficiency over SIGPROG of 5.3 percent for Mohawk Street and 14.3 percent for Genesee Street. Each method produced a different best cycle length for the same range of cycle lengths. Even when SIGPROG and NO-STOP-1 had the same cycle lengths the efficiencies of NO-STOP-1 were 5.2 and 6.7 percent higher for Mohawk and Genesee streets respectively.

For Mohawk Street, the speed yielded by the NO-STOP-1 program was 1.4 mph (2.3 km/h) or 5.6 percent lower than the originally desired progression speed. For Genesee Street, NO-STOP-1 produced the originally desired speed as the optimum speed. Both methods produced the same speed for Genesee Street; this illustrates the importance of proper selection of the centers of green. The centers of green differed at 6 locations, which explains the large difference in efficiencies in both methods. The centers of green for Mohawk Street were the same for both methods, but the speeds were different. This is why NO-STOP-1 has higher efficiency than SIGPROG has.

Other Differences

There are other differences between the SIGPROG and NO-STOP-1 programs. NO-STOP-1 can handle multiphase operations, completely nonconcurrent mainline green, T-intersections at divided and undivided highways, and midblock pedestrian crossings. SIGPROG cannot handle these things. In the time-space diagram, NO-STOP-1 can plot directional speeds for each section, and SIGPROG can plot only 1 speed.

Figure 8. Time-space diagram for Mohawk Street produced by SIGPROG.

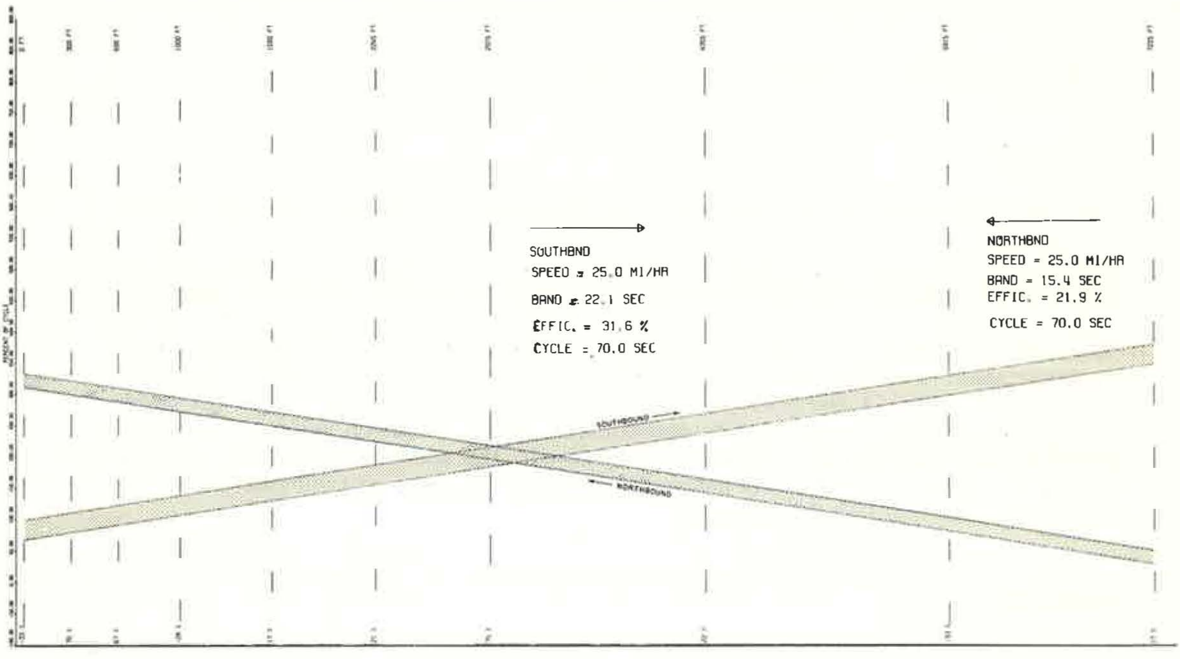


Figure 9. Time-space diagram for Mohawk Street produced by NO-STOP-1.

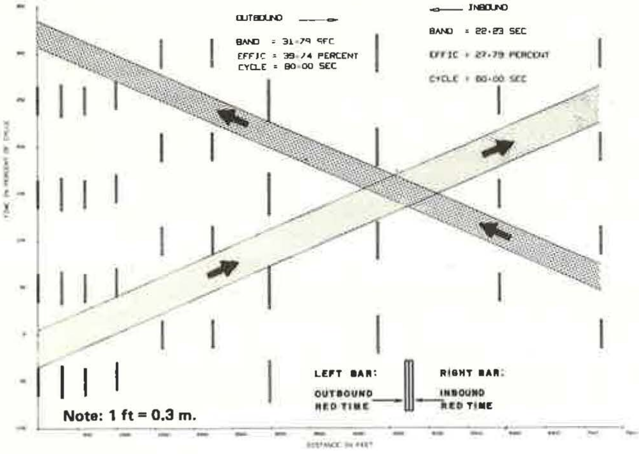


Figure 10. Time-space diagram for Genesee Street produced by SIGPROG.

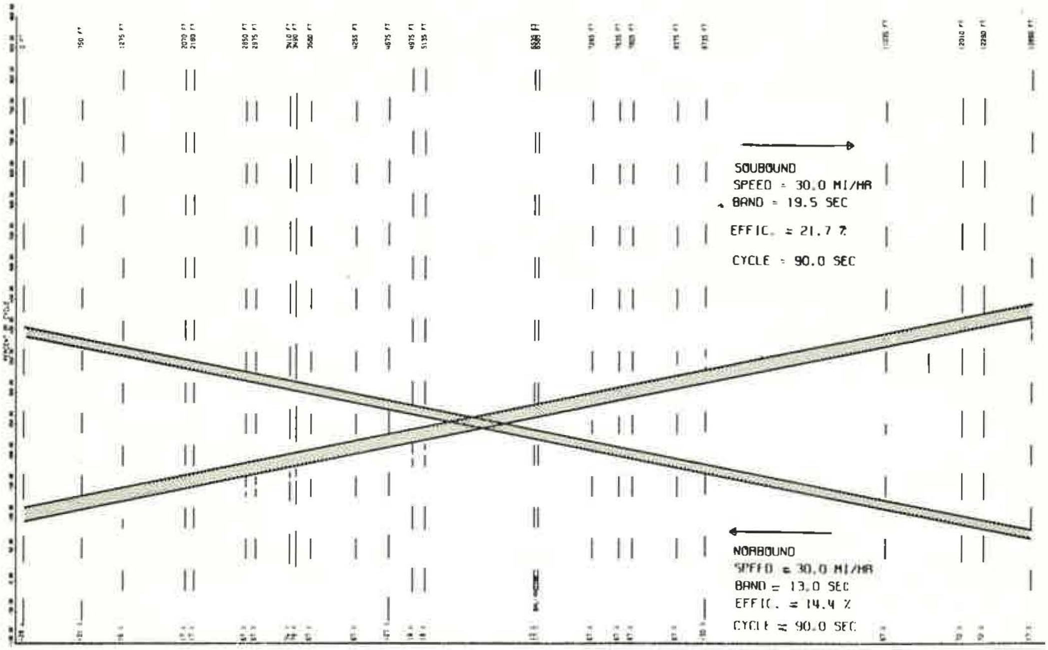
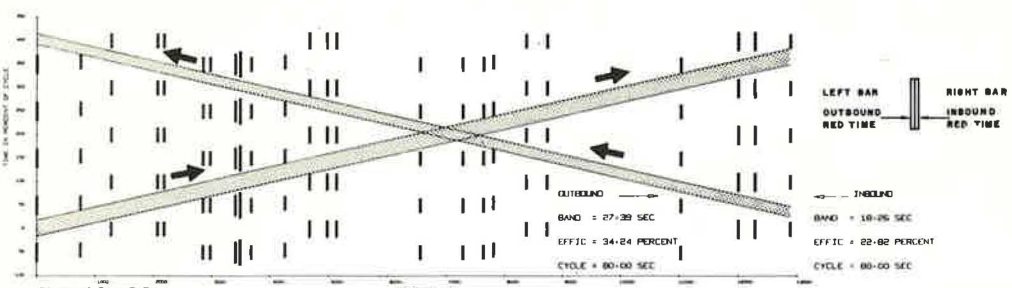


Figure 11. Time-space diagram for Genesee Street produced by NO-STOP-1.



Note: 1 ft = 0.3 m.

Table 1. Comparison of 2 SIGPROG and NO-STOP-1 examples.

		NO STOP-1	
Category	SIGPROG	Cycle Length Different From SIGPROG	Cycle Length Same As SIGPROG
Mohawk Street			
Cycle range, sec	50 to 80	50 to 80	
Chosen cycle length, sec	70	80	70
Speed, mph	25	23.6	26.9
Bandwidths[a], sec	43.5	53.9	47.1
Efficiency (total)[a], percent	62.1	67.4	67.3
Genesee Street			
Cycle range, sec	60 to 100	60 to 100	
Chosen cycle length, sec	90	80	90
Speed, mph	30	30	28.0
Bandwidths[a], sec	38.5	45.7	44.5
Efficiency (total)[a], percent	42.8	57.1	49.5

Note: 1 mile = 1.6 km.

[a]Sum for both directions.

COMPARISON OF NO-STOP-1 TO OTHER METHODS

No practical comparison has been made between NO-STOP-1 and SIGOP (7), the maximal bandwidth program developed by Little, Martin, and Morgan (8), and TRANSYT (9). SIGOP uses the least squares method as the optimization model to determine the best set of offsets. Because the least squares method minimizes the sum of the squares of the differences of the set of offsets to their respective ideal offsets, it cannot at the same time minimize the maximal amount of those differences or meet the requirement that max $|E|$ = min, which can only be accomplished by the Tschebysheff approximation. The program by Little, Martin, and Morgan cannot vary the speed within allowed tolerances whereas SIGPROG can. Furthermore it cannot handle multiphase operations, T-intersections, and completely nonconcurrent mainline green. TRANSYT uses a "hill-climbing" process to optimize the offsets. However, a characteristic of hill-climbing methods is that the optimum they find is not necessarily the best because the offset, which is a dependent variable and a function of the cycle length and progression speed, is used in the optimization process as an independent variable.

CONCLUSIONS

The objectives of this paper were to develop the fundamentals of progressively timed street signal systems, to demonstrate the capabilities of 2 programs—NO-STOP-1 and SIGPROG—to find the best timing plan for progressively timed signal systems, and to compare the results of both programs.

It was shown that the cycle length and the desired progression speed are the parameters that have to be varied within defined limits to achieve the maximum constant bandwidth, and that the Tschebysheff theorem is an appropriate optimization model to achieve that objective. Based on these fundamentals, the NO-STOP-1 program was developed, which included a wide variety of options from multiphase operations to midblock pedestrian crossings. By contrast, the SIGPROG program does not vary the desired progression speed, and has a rather limited variety of options.

The results of both programs were compared, and the NO-STOP-1 program yielded results that were better by up to 15 percent. NO-STOP-1, when compared to SIGOP, the program by Little, Martin, and Morgan, and TRANSYT, also proved superior. Based on these findings, the NO-STOP-1 program is an improved tool for the traffic engineer. Its general versatility recommends itself for widespread use.

ACKNOWLEDGMENT

The author wishes to extend his gratitude to Thomas F. Sergi of Tippetts-Abbett-McCarthy-Stratton whose help in developing the NO-STOP-1 program was essential.

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