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Concurrent Use of MAXBAND and TRANSYT Signal Timing Programs for Arterial Signal Optimization

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A number of computer programs have been developed for the purpose of optimizing signal timing. All of the current programs, however, have some deficiencies. The TRANSYT program, which is the most widely used, has a good traffic model and optimizes green phase time. However, it does not get a globally optimal solution, optimize phase sequence, or really optimize cycle length. The MAXBAND program, which optimizes arterial bandwidth, does all of the above but is deficient in that green time is not optimized and the traffic model used is oversimplified. It is shown that a feasible way to overcome these deficiencies is to use the MAXBAND program to develop an initial timing plan for TRANSYT. This initial timing plan includes both cycle length and phase sequence optimization. The timing plans produced by the TRANSYT and MAXBAND programs separately were compared with the combined timing plans by using the NETSIM model. The results indicate that a substantial improvement in measures of effectiveness is obtained with the combined timing plans.

In recent years, there has been increasing emphasis on conserving energy, mostly due to the gasoline shortage crises of 1973 and 1979. One of the most cost-effective traffic engineering techniques for improving traffic flow and, hence, fuel efficiency is improvement of signal timing (1). In support of this goal, the Federal Highway Administration (FHWA) undertook the National Signal Timing Optimization Project (2). As part of this project, the TRANSYT 7 program (3) was modified so that it could be more easily used by American traffic engineers to develop signal timing plans for coordinated signal systems. The revised program is called TRANSYT 7F (4).

In parallel with the TRANSYT 7F activity, another approach to arterial signal timing, using the principal of maximal green bandwidth, has been pursued. This has resulted in the development of the MAXBAND program (5).

The purpose of the work described in this paper was to explore the advantages and disadvantages of the TRANSYT and MAXBAND programs as they are applied to arterials and to demonstrate that using both programs to develop timing plans can partly overcome the disadvantages of each of them.

DESCRIPTION OF PROGRAMS

TRANSYT

The TRANSYT program includes an excellent traffic model that uses network geometry and traffic flows to make estimates of two measures of effectiveness (MOEs)--delay and stops. The hill-climbing optimization procedure adjusts offsets and green times separately so as to minimize the value of a performance index (PI), which is equal to the weighted sum of stops and delay.

Although field tests (2) and simulation tests (6) indicate that TRANSYT produces good signal timing plans, it also has a number of deficiencies:

1. The hill-climbing optimization algorithm does not generally guarantee that a global optimum for the PI will be achieved and therefore does not guarantee that the "best" signal timing plan will be found. This is because the signal timing problem in general has a solution space for the PI, which consists of a number of local optima. It is computationally infeasible, when using the hill-climbing technique, to search through all local optima to find the best one.
2. TRANSYT requires a signal timing plan as a starting solution. Because of item 1 above, the quality of the final signal settings often depends on the starting solution.
3. TRANSYT does not really optimize cycle length. One can run the program for several different cycle lengths and select the one with the best PI.
4. However, because of item 1 above, there is no way of knowing whether the selected cycle length is the best one or whether, for that cycle length, a solution was found that was closer to the global optimum than the solutions found for the other cycle lengths scanned.
5. The sequence of left-turn phases and through phases is not optimized. At signalized intersections where left-turn phases are used, there are four possible combinations for the left-turn phases and through phases in both directions: (a) left-turn phases in both directions preceding the two-directional through phase (lead-lead), (b) left-turn phases in both directions following the two-directional through phases (lag-lag), (c) left-turn phase in the inbound direction preceding the two-directional through phase and left-turn phase in the outbound direction following the two-directional through phase (lead-lag), and (d) left-turn phase in the inbound direction following the two-directional through phase and left-turn phase in the outbound direction preceding the two-directional through phase (lag-lead).

MAXBAND

The MAXBAND program uses as its traffic model the maximal green bandwidth principle (7). This is combined with a powerful mathematical programming algorithm, mixed integer linear programming (MILP), to obtain offsets, cycle length, and left-turn phase sequence, which maximize the weighted sum of bandwidths in both directions on an arterial. The program also has the capability to allow small deviations from the arterialwide progression speed on individual links, a process referred to as speed search.

Unlike TRANSYT, the MAXBAND program obtains a global optimum, requires no starting solution, and optimizes cycle length and phase sequence. However, MAXBAND has the following deficiencies:

1. The traffic model is oversimplified. No account is taken of secondary flows turning from side streets, platoon dispersion, turning traffic, or platoon shape. For this reason, it is not generally true that maximizing bandwidth minimizes such MOEs as stops or delay.
2. Green phase times are not optimized. This is because bandwidth provides no criteria for setting green times on the side street.

Summary

It is evident that the two programs described above are complementary; that is, the weaknesses of one are the strengths of the other and vice versa. Thus, it would appear likely that an approach to developing signal timing plans for arterials that used both programs might provide better signal settings than either program could provide separately. It is the purpose of this work to demonstrate the validity of this hypothesis.

EXPERIMENTAL DESIGN

A series of experiments was performed to test the advantages of using both MAXBAND and TRANSYT. The experiments were as follows:

1. TRANSYT optimization of offsets using only the default starting solution (i.e., offset = 0 for A-phase green on the arterial),
2. MAXBAND-optimized offsets without speed search as a starting solution for TRANSYT,
3. MAXBAND-optimized offsets with speed search as a starting solution for TRANSYT,
4. MAXBAND-optimized cycle length used in TRANSYT,
5. MAXBAND-optimized phase sequence used in TRANSYT, and
6. Combinations of experiments 2 and 4, 5 and 6, and 3, 4, and 5.

The purpose of running these sets of experiments was to determine the incremental effects of optimizing each of the traffic control parameters--cycle length and phase sequence--separately.

A set of green times was computed initially by using the algorithm in MAXBAND and was held fixed in both programs. After the above experiments had been performed, a green time optimization was performed by TRANSYT. Two test arterials for which data were available were selected. The major criterion for selection was the presence of left-turn bays at most of the intersections so that the phase sequence optimization capability of MAXBAND could be fully tested. The first arterial, Hawthorne Boulevard in Torrance, California, has eight intersections; the second arterial, University Avenue in Provo, Utah, also had eight intersections.

A total of 16 signal timing plans were developed for each arterial based on experiments 1-5 above. The plans were then compared by using the NETSIM microscopic traffic simulation model (7) as the test bed. One problem that arose concerned the weighting of the two directions in the MAXBAND runs. This arises from the MAXBAND capability of allowing imposition of a wider bandwidth in one direction than in the other. Some preliminary runs on NETSIM indicated that a weighting factor of 10/1 of the southbound direction over the northbound direction on Hawthorne (i.e., the bandwidth in the southbound direction is up to 10 times the bandwidth in the northbound direction) and 1/1 of the southbound direction over the northbound direction on University gave good results. However, as will be seen in the discussion of results later in this paper, the effect of these assumptions was minor.

DESCRIPTION OF ARTERIALS

The section of Hawthorne Boulevard used in this study has four lanes in each direction and two-lane left-turn bays on six of the intersection approaches. All other approaches on the arterial have one-lane left-turn bays. Volumes were about 2800 vehicles/h in the southbound direction and 1400 vehicles/h in the northbound direction. Signal spacing varied from 500 to 1300 ft. Signalization included left-turn phases in both directions on the arterial and single phasing on the side streets. The existing 100-s cycle length was used except for experiments in which cycle length was optimized. In those experiments, a range of 80-110 s was searched. Traffic patterns consisted heavily of through traffic on the arterial and relatively minor secondary flow and turning traffic (except at intersection 10, where turning movements on and off the arterial were heavier). A progression speed of 45 mph was used.

The section of University Boulevard used in this study has two lanes in each direction and one-lane turn bays on all arterial approaches. Volumes are about 900 vehicles/h in the northbound direction and about 850 vehicles/h in the southbound direction. Most of the traffic, however, consists of vehicles that turn on to the arterial from the side streets so that at most intersections secondary flow is high. Turning movements from the arterial are also substantial. Signalization included left-turn phases in both directions on all arterial approaches and single phasing on the side streets. The existing 80-s cycle length was used except for experiments in which cycle length was optimized. In those experiments, a range of 70-100 s was searched. Signal spacing varied from 500 to 1450 ft. A progression speed of 30 mph was used.

RESULTS

The results for each experiment are given in Table 1 for Hawthorne and in Table 2 for University. A number of observations can be made based on the results:

1. The assumption of a south/north bandwidth ratio of 10/1 on Hawthorne for MAXBAND turns out to be unimportant, as can be seen by looking at the result of experiment 12, in which all optimization capabilities of MAXBAND were used. Here, the southbound bandwidth equaled the shortest green in that direction so that the northbound bandwidth received any further improvement available. The resultant ratio, as indicated by Table 1, would be 1.5, which is easily justifiable by the south/north volume ratio of 2/1.

2. TRANSYT and NETSIM did not give the same answer in many experiments with regard to the relative quality of MAXBAND and TRANSYT results. For instance, compare experiments 1 and 2 on Hawthorne

Table 1. Results for Hawthorne Boulevard.

Exp. No.	Optimization Program	Source of Initial Offsets	Optimization: Cycle Length	Optimization: Phase Sequence	Speed Search	Cycle Length (s)	Delay (s/vehicle)	Stops (%)	Fuel Efficiency (miles/gal)	Bandwidth Percentage of Cycle: Southbound	Bandwidth Percentage of Cycle: Northbound	TRANSYT PI
1	MAXBAND	None	No	No	No	100	68.33	1.77	11.37	0.468	0.047	112.6
2	TRANSYT	Default	No	No	No	100	71.47	1.81	11.44	NA	NA	106.7
3	TRANSYT	MAXBAND	No	No	No	100	60.82	1.51	11.83	NA	NA	96.1
4	MAXBAND	None	No	No	Yes	100	63.11	1.60	11.65	0.526	0.053	110.6
5	TRANSYT	Default	No	No	Yes	100	61.21	1.54	11.82	NA	NA	95.7
6	MAXBAND	None	Yes	No	No	80	59.03	1.68	11.65	0.539	0.068	85.8
7	TRANSYT	Default	Yes	No	No	80	60.73	1.68	11.62	NA	NA	86.3
8	TRANSYT	MAXBAND	Yes	No	No	80	58.87	1.69	11.69	NA	NA	83.4
9	MAXBAND	None	No	Yes	No	100	58.70	1.50	11.77	0.539	0.176	108.4
10	TRANSYT	Default	No	Yes	No	100	67.34	1.68	11.68	NA	NA	102.1
11	TRANSYT	MAXBAND	No	Yes	No	100	57.45	1.48	11.98	NA	NA	94.1
12	MAXBAND	None	Yes	Yes	Yes	80	53.24	1.58	11.99	0.539	0.354	87.5
13	TRANSYT	Default	Yes	Yes	Yes	80	54.44	1.58	11.96	NA	NA	78.6
14	TRANSYT	MAXBAND	Yes	Yes	Yes	80	55.15	1.60	11.96	NA	NA	79.1
15[a]	TRANSYT	MAXBAND	Yes	Yes	Yes	80	50.14	1.38	12.16	NA	NA	78.0
16[a]	MAXBAND	None	Yes	Yes	Yes	80	48.24	1.33	12.28	0.506	0.353	-

[a]Green time optimized by TRANSYT.

Table 2. Results for University Boulevard.

Exp. No.	Optimization Program	Source of Initial Offsets	Optimization: Cycle Length	Optimization: Phase Sequence	Speed Search	Cycle Length (s)	Delay (s/vehicle)	Stops (%)	Fuel Efficiency (miles/gal)	Bandwidth Percentage of Cycle: Southbound	Bandwidth Percentage of Cycle: Northbound	TRANSYT PI
1	MAXBAND	None	No	No	No	80	41.67	1.44	9.45	0.192	0.192	84.8
2	TRANSYT	Default	No	No	No	80	40.89	1.42	9.54	NA	NA	77.4
3	TRANSYT	MAXBAND	No	No	No	80	40.53	1.40	9.57	NA	NA	77.1
4	MAXBAND	None	No	No	Yes	80	41.18	1.44	9.51	0.214	0.214	84.5
5	TRANSYT	Default	No	No	Yes	80	40.67	1.40	9.55	NA	NA	77.1
6	MAXBAND	None	Yes	No	No	76	39.46	1.44	9.59	0.211	0.211	83.0
7	TRANSYT	Default	Yes	No	No	76	39.51	1.40	9.65	NA	NA	74.0
8	TRANSYT	MAXBAND	Yes	No	No	76	38.45	1.38	9.73	NA	NA	73.9
9	MAXBAND	None	No	Yes	No	80	38.78	1.33	9.69	0.305	0.305	82.0
10	TRANSYT	Default	No	Yes	No	80	40.90	1.40	9.53	NA	NA	78.6
11	TRANSYT	MAXBAND	No	Yes	No	80	40.31	1.36	9.62	NA	NA	77.7
12	MAXBAND	None	Yes	Yes	Yes	70	33.06	1.23	10.09	0.357	0.357	71.0
13	TRANSYT	Default	Yes	Yes	Yes	70	35.01	1.32	9.97	NA	NA	68.3
14	TRANSYT	MAXBAND	Yes	Yes	Yes	70	35.48	1.29	9.95	NA	NA	70.0
15[a]	TRANSYT	MAXBAND	Yes	Yes	Yes	70	33.68	1.25	10.12	NA	NA	64.6
16[a]	MAXBAND	None	Yes	Yes	Yes	70	32.36	1.23	10.14	0.287	0.287	-

[a]Green time optimized by TRANSYT.

(Table 1), where NETSIM results indicated that the MAXBAND settings were slightly better in terms of stops and delay and TRANSYT results indicated that the TRANSYT settings were better in terms of PI (which is a weighted sum of stops and delay). This result has also been found by Rogness and Messer, as reported in a paper elsewhere in this Record.

3. The assertion that TRANSYT does not guarantee global optimum is amply demonstrated, especially on Hawthorne. Compare, for instance, experiments 2 and 3 (Table 1): Here, use of initial MAXBAND offsets in TRANSYT instead of the TRANSYT default starting timing plan resulted in a 15 percent improvement as indicated by NETSIM (using delay as a criterion) and a 10 percent improvement as indicated by TRANSYT (using PI as a criterion).

4. The improvements obtainable from optimizing phase sequence can be substantial, as seen for Hawthorne in Table 1. For instance, if experiments 1 and 9 are compared, MAXBAND settings with phase sequence optimization were 17 percent better in terms of delay than the MAXBAND settings without phase sequence optimization. In a comparison of experiments 2 and 10, an improvement of 7 percent in terms of delay for TRANSYT was achieved. If one compares experiments 2 and 11, combining MAXBAND offsets and phase sequence in TRANSYT resulted in a 20 percent improvement over TRANSYT with default offsets and no sequence optimization.

5. Improvements in TRANSYT-computed settings using MAXBAND starting offsets and all other optimization capabilities were quite good on Hawthorne and good on University. When experiments 2 and 14 for both arterials were compared, the following improvements were obtained: for Hawthorne, 23 percent reduction in delay, 12 percent reduction in stops, 5 percent improvement in fuel efficiency, and 27 percent reduction in TRANSYT PI; for University, 13 percent reduction in delay, 9 percent reduction in stops, 4 percent increase in fuel efficiency, and 10 percent reduction in TRANSYT PI. Thus, even though the incremental changes indicated by the earlier experiments were small (probably due to the lower demand levels on University), the additive effect of using all MAXBAND capabilities produced substantially better timing plans.

6. Improvements in MAXBAND settings achieved by using the green phase time optimization capability of TRANSYT were substantial on Hawthorne but quite small on University. In a comparison of experiments 12 and 16, the following improvements were obtained: (a) 9 percent reduction in delay, 16 percent reduction in stops, and 2 percent increase in fuel efficiency on Hawthorne and (b) 2 percent reduction in delay, no reduction in stops, and 0.5 percent increase in fuel efficiency on University.

CONCLUSIONS

From the results of this work, it can be concluded that using both the MAXBAND and TRANSYT programs in sequence to compute signal timing plans on arterials has a substantial potential for producing better signal timing than using either program alone. This is particularly true in cases where left-turn phasing on the arterial is used. There is also evidence that use of the TRANSYT traffic model as an evaluation tool is suspect in that it appears to underestimate the quality of bandwidth solutions.

RECOMMENDATIONS

For a practitioner who wishes to use both MAXBAND and TRANSYT, the following sequence of steps is recommended as being likely to provide near-optimum timing plans:

1. Using either volume and capacity information or existing green times, execute MAXBAND to provide offsets, cycle length, and phase sequence.
2. Using the results of step 1 as the input, execute TRANSYT to provide final offsets and green times.

This was the sequence of steps that was used to achieve the results in experiment 15.

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