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

S. L. COHEN

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 crisis of 1973 and 1974. 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 optimi-
sation procedure adjusts offsets and green times separately so as to minimize the value of a perform-
ance index (PI), which is equal to the weighted sum of stops and delay.

Although field tests (2) and simulation tests (5) 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 guar-
antees 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 con-
ists of a number of local optima. It is computa-
tionally infeasible, when using the hill-climbing
 technique, to search through all optimal 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 differ-
ent 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 op-
timum 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 intersec-
tions 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-di-
rectional through phase (lead-lead), (b) left-turn
phases in both directions following the two-di-
rectional through phases (lag-lag), (c) left-turn phase
in the inbounds direction preceding the two-di-
rectional through phase and left-turn phase in the out-
bound 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 com-
bined with a powerful mathematical programming al-
gorithm, mixed integer linear programming (MILP), to
obtain offsets, cycle length, and left-turn phase
sequence, which maximize the weighted sum of band-
widths in both directions on an arterial. The program
also has the capability to allow small devia-
tions 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 running solution, and
optimizes cycle length and phase sequence. However,
MAXBAND has the following deficiencies:

1. The traffic model is oversimplified. No ac-
count is taken of secondary flows turning from side
streets, platoon dispersion, turning traffic, 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 set-
tings 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 op-
timization capability of MAXBAND could be fully
tested. Two arterial, Hawthorne Boulevard in
Torrance, California, have 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 im-
position of a wider bandwidth in one direction than
in the other. Some preliminary runs on NETSIM indi-
cated that a weighting factor of 10/1 of the south-
bound 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 Univer-
sity 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 80-s cycle length was used except for experiments in which cycle length was optimized. In those experiments, a range of 70-110 s was searched. Traffic patterns consisted heavily of through traffic on the arterial and relatively minor secondary flow and turning traffic (except at intersections, 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 70-110 s was searched. Signal spacing varied from 500 to 1450 ft. A progression speed of 45 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.

<table>
<thead>
<tr>
<th>Exp. No.</th>
<th>Optimization Program</th>
<th>Source of Initial Offsets</th>
<th>Optimization</th>
<th>Cycle Length (s)</th>
<th>Phase Sequence</th>
<th>Speed Search</th>
<th>Cycle Length (s)</th>
<th>Delay (x/vehicle)</th>
<th>Stops (%)</th>
<th>Fuel Efficiency (miles/gal)</th>
<th>Bandwidth Percentage of Cycle</th>
<th>TRANSYT PI</th>
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<td>1.77</td>
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<td>0.047</td>
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<td>Southbound</td>
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<td></td>
</tr>
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*aGreen time optimized by TRANSYT.

Table 2. Results for University Boulevard.

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<th>Exp. No.</th>
<th>Optimization Program</th>
<th>Source of Initial Offsets</th>
<th>Optimization</th>
<th>Cycle Length (s)</th>
<th>Phase Sequence</th>
<th>Speed Search</th>
<th>Cycle Length (s)</th>
<th>Delay (x/vehicle)</th>
<th>Stops (%)</th>
<th>Fuel Efficiency (miles/gal)</th>
<th>Bandwidth Percentage of Cycle</th>
<th>TRANSYT PI</th>
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</table>

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

3. The assertion that TRANSY 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 TRANSY instead of the TRANSY 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 TRANSY (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 TRANSY was achieved. If one compares experiments 2 and 11, combining MAXBAND offsets and phase sequence in TRANSY resulted in a 20 percent improvement over TRANSY with default offsets and no sequence optimization.

5. Improvements in TRANSY-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 TRANSY PI; for University, 13 percent reduction in delay, 9 percent reduction in stops, 4 percent increase in fuel efficiency, and 10 percent reduction in TRANSY 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 TRANSY 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 TRANSY 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 TRANSY 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 TRANSY, 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 TRANSY to provide final offsets and green times.

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

REFERENCES


