# Demonstration of the Characteristics of the TRANSYT-7F Model as Modified To Represent Near-Side Transit Stops

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The TRANSYT-7F model has been altered to represent the common case of near-side transit stops in shared lanes. This paper demonstrates the operation and principal characteristics of the new simulation model by describing its application to a sample network. It is seen that delays and stops can be reduced considerably when signal timings reflect the transit loading operation appropriately. Some rules of thumb for timing of traffic signals in response to the arrival of transit vehicles are developed through the new model and discussed in the paper. It is seen that some accepted intuitive responses to transit arrivals are wrong.

The intrinsic characteristics of the TRANSYT model (*1*) and the TRANSYT/5 extension, commonly known as BUS-TRANSYT (*2,3*), do not represent the situation in which the transit vehicle holds up other traffic during its passenger loading or unloading operations, referred herein as loading. Therefore, the on-line near-side transit stop, which is common at signalized intersections in North America, cannot be represented properly.

## TRANSIT-RELATED ENHANCEMENTS

To remedy this situation, a simulation supplement, compatible with fixed-time control models such as TRANSYT-7F, was developed to capture the real-time effect of the near-side transit stops on the other traffic (Jacques and Yagar, unpublished data).

This supplement was incorporated into TRANSYT-7F to produce a deterministic simulation model that simulates the traffic at each time increment (step) until the whole simulation period (usually two cycles) is covered. The supplement makes the following changes or approximations, none of which should seriously compromise its realism and some of which improve its representation:

- Instead of relying on a single signal cycle for all cycles, with or without transit, as previous versions of TRANSYT did, this supplemented model considers an appropriate mix and sequence of nontransit cycles (NTCs) and transit cycles (TCs).
- The number of TCs and NTCs is assumed constant for the considered time period.
- Any sequence of (TC) and (NTC) can be approximated in terms of the following three sets of two-cycle sequences: (TC-NTC), (TC-TC), and (NTC-NTC), which do not spill over to one another.
- The different two-cycle sequences are modeled by means of independent parallel network structures.
- The hourly traffic volumes are allocated among the links of the parallel network structures on the basis of the percentage of the total cycles they represent, with appropriate saturation flow rates.
- The transit vehicles arrive at external links once per TC and at the same point in time in each TC.
- The transit vehicles are not dispersed (as per platoon dispersion).
- The transit link, and the links sharing the lane with it, move only in protected phases; there is no gap seeking.
- The transit vehicle may start loading during either the green or red phase if it reaches the designated stop location (green phase) or a position sufficiently close to the stop location while in queue (red phase).
- The approach saturation flow can be set to zero (for the case of total blockage of the approach) or to any other appropriate value during the load and unload operation.

The model's assumptions and characteristics, as well its implementation into the TRANSYT-7F program, are described elsewhere (Jacques and Yagar, unpublished data).

## CHARACTERISTICS OF THE ENHANCED TRANSYT MODEL

Although transit operations do not allow for an equilibrium cycle operation as is assumed by the TRANSYT model, it is feasible to reasonably represent the operation by an equivalent mixture of equilibrium two-cycle "supercycles," of the type shown in Figure 1.

Figure 1 shows the TRANSYT flow profiles leaving an intersection for a two-cycle sequence, represented by 120 TRANSYT steps (e.g., of 1-sec duration) during which a transit vehicle arrives during the first red phase and loads during most of the next green phase. Although the new model may allow a queued transit vehicle to start loading at any specified position that is sufficiently close to the designated loading position, in this case it is assumed that it may load only after it has reached the front of the queue. In the upper diagram of Figure 1(*a*), there are only small slivers of time

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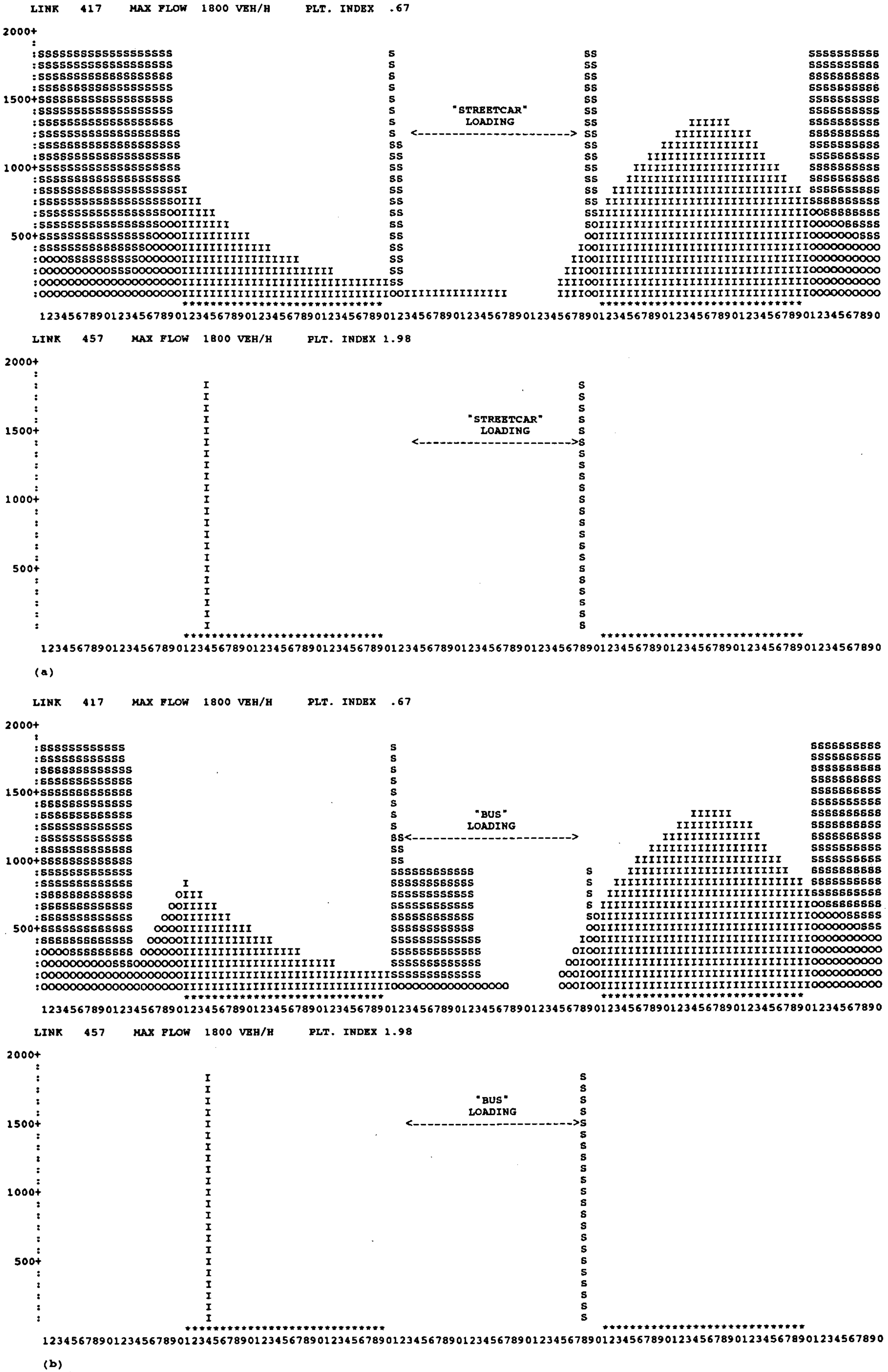


FIGURE 1 Adjustment of service capacities for *(a)* full or *(b)* partial blockage caused by transit loading.

at the beginning and end of this first green phase that can serve vehicles. Otherwise the saturation flow is zero in the 26-step period denoted as "streetcar loading," during which the transit vehicle effectively blocks the whole approach, as would be the case with a streetcar loading in the median lane from the sidewalk. In Figure 1(*b*) the saturation flow is merely reduced during the loading time because the transit loading operation blocks only part of the approach (such as a bus loading in one lane while traffic passes in other lanes).

The symbols used in Figure 1 and other figures in this paper have the following standard TRANSYT meaning (*4*):

- For the flow profile, I = arrivals that queue; S = departures from queue, either at the saturation flow rate or maximum flow rate; and O = arrivals and departures during green phase; when below S's or I's, these arrivals join the back of the queue.
- For the horizontal axis, (blank) = protected green intervals; * = red intervals; and (numbers) = the time scale in units of steps.

In Figure 1 (and Figures 4–9, which appear later in the paper), the actual loading times for the transit vehicles are specified to orient the reader.

The lower portion of Figure 1(*a*) represents a streetcar (denoted by the spike of I's) (a) arriving early in the red phase; (b) reaching the front of the queue and starting to load early in the green phase; and (c) finishing the passenger loading late in that green phase and departing (spike of S's).

There is no streetcar arrival during the second phase, which wraps around to the left side of the diagram in TRANSYT's representation.

The upper portion of Figure 1(*a*) (starting at the left side) shows the following:

- A queue being served at the saturation flow of about 1,800 vph of green (S's and O's) for virtually the whole green phase,
- Arrivals queuing during the red phase (I's),
- A short period of queue service at saturation flow (S's) until the streetcar reaches the loading spot and halts the flow of traffic for a period of time ("streetcar loading") equal to the loading time,
- Another short period of queue service before the signal turns red,
- A red phase (I's),
- A green phase serving at saturation flow (S's) and wrapping back around to the left side.

This example shows a case in which the green phase with the streetcar is mostly wasted because of the streetcar loading, causing the green without the streetcar to be virtually fully saturated. The only difference between the bus example in Figure 1(*b*) and the previous streetcar example is the saturation flow during the loading time. In the bus case a saturation flow of 900 vph of green can be maintained during the loading procedure (to represent blockage of only one of two traveled lanes, for example). Because this is enough capacity to serve the queue, there is no leftover queue at the end of that green phase. Therefore, the next green phase (which wraps around to the left side) is far less saturated and can finish serving its queue with about one-fourth of the green time left.

Figure 1 shows that the transit-enhanced version of TRANSYT-7F can reasonably represent the noncyclical transit effects in terms of cyclical multicycle "supercycles" and shows this in terms of typical streetcar–no streetcar and bus–no bus sequences. This was done to orient the reader to the new form of transit-enhanced flow profiles that can be produced by the TRANSYT model.

A corridor operation will be modeled in the next section to demonstrate (a) TRANSYT's flow profiles in a network context, (b) the characteristics of transit-responsive signal timings, and (c) benefits in terms of performance index that might be achieved with the use of an appropriate transit modeling procedure within TRANSYT.

## EXAMPLE APPLICATION OF THE NEW TRANSYT MODEL

The operation of the new model is illustrated using the four-signal one-way arterial shown in Figure 2. This sample arterial has been given the following characteristics for the following reasons:

- Only one-way traffic was used to allow the optimization to easily achieve the characteristics that a TRANSYT solution would tend toward in cases in which it can account for the interference of transit loading with flow. Although two-way flow could have been simulated and optimized by the model, it would have needlessly complicated the demonstration objectives of this paper.
- Low transit speeds (20 km/hr) and no platoon dispersion were used for the transit vehicles, in contrast to higher travel speeds (40 km/hr) and platoon dispersion for private vehicles. This was combined with large intersection spacings to simulate breaking of the platoons behind transit vehicles and observe TRANSYT's reactions in terms of signal timings.

### Data

- Streetcar volume = 45 vph,
- Car volume = 1,000 vph,

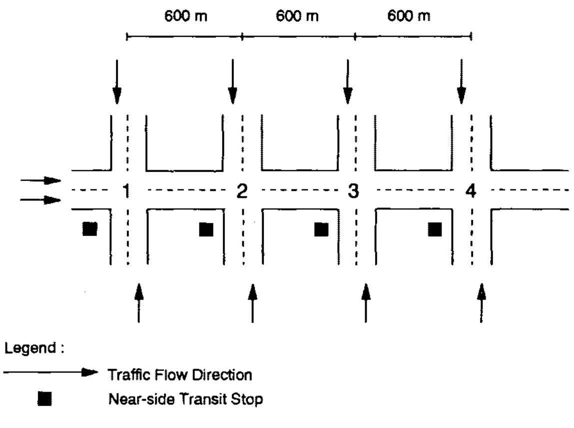


**FIGURE 2 One-way street with near-side streetcar stops and no refuge island for passengers.**

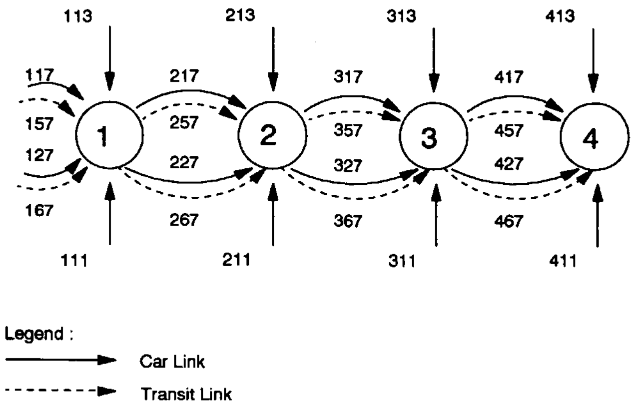
- Saturation flow (two lanes) = 3,600 vphg,
- Cycle length = 60 sec,
- Average car speed = 40 km/hr (25 mph),
- Average streetcar speed = 20 km/hr (12.5 mph), and
- Average dwell time for all stops = 25 sec.

Consistent with the procedure of the new transit-enhanced model described elsewhere (*4*) and the data just presented, the standard 1-hr TRANSYT study period is considered to consist of 45 TCs and 15 NTCs. The type of cycle occurring with the smaller frequency (15 NTCs in this case) is combined with an equal number, 15, of TCs to form 15 double cycles of the (TC-NTC) type. This leaves 15 (TC-TC) cycles in the parallel network. An example of a (TC-NTC) type double-cycle has already been shown by the case shown in Figure 1.

The link-node representation for the parallel networks required to simulate the above (TC-NTC) and (TC-TC) cycles using the modified TRANSYT model is shown in Figure 3. The input data for the modified TRANSYT-7F simulation run are presented in Table 1.

These data are similar to those required by the conventional TRANSYT-7F (*4*), except for the inclusion of some "optional" cards (Card Type 3, Card Type 30, and Card Type 32), which indicate that the new simulation model is being selected, and provide the parameters for the use of this new model. Details on the new model input data cards are provided elsewhere (Jacques and Yagar, unpublished data).

In Table 1, the first column of data indicates the card number. Card Type 30 shows the identifying numbers for the links that form the parallel network structure. Consider, for example, the first Type 30 card. According to this card, the links 117, 127, 157, and 167 form a parallel network structure. Links 117 and 157 operate in the sequence (TC-NTC), whereas links 127 and 167 operate in the sequence (TC-TC). This is specified by Card Type 32, where the second field indicates how the transit links have to be simulated: a 3 means that the transit link is to be simulated in the sequence (TC-NTC), and a 4 means that transit link is to be simulated according to the sequence (TC-TC). Because each type of sequence represents exactly half of the 1-hr study period (15 of 30 double cycles), the total nontransit flow in the approach (1,000 vph) is split equally between links 117 and 127; the total saturation flow is split in the same way, as can be observed from the two first Type 28 cards used for Node 1. Because links 117 and 157, and 127 and 167 are, respectively, shared stopline links (see Card Type 7), no saturation flow rate is specified for transit links 157 and 167.



| Shared Stopline Links | | Sequence Type |
|---|---|---|
| 117 | 157 | [TC-NTC] |
| 127 | 167 | [TC-TC] |
| 217 | 257 | [TC-NTC] |
| 227 | 267 | [TC-TC] |
| 317 | 357 | [TC-NTC] |
| 327 | 367 | [TC-TC] |
| 417 | 457 | [TC-NTC] |
| 427 | 467 | [TC-TC] |

**FIGURE 3 Node-link representation.**

## Results of Simulation and Optimization Runs

The total system results for both simulation and optimization runs are presented in Table 2, which indicates a significant improvement in performance index for both transit and cars when the transit-enhanced TRANSYT optimizes the signal timings (splits and offsets). Although this is encouraging, it might be expected, especially for a one-way street.

The results are examined next by intersection and discussed in detail for Intersection 2.

### *Intersection 1*

Intersection 1 may be considered an upstream dummy intersection used for the input of flows at a fixed rate, as specified by TRANSYT. In contrast, transit vehicles are represented as discrete vehicles in the transit-enhanced TRANSYT, and are inserted onto the transit line at consistent times in TRANSYT cycles. Although it will be seen that transit vehicles will quickly tend to converge to a pattern of fixed arrival times at downstream signals, it is nevertheless best to insert them into the network at optimal times and not risk messing up one or more intersections on the network boundary.

Operating agencies may select the times within the signal cycle at which to release streetcars at the beginning of the line. This may be simulated using a dummy intersection. Various transit entry times may be tried within the cycle and TRANSYT run for each to determine the best insertion times for the particular network and transit line. In this case the streetcars are released from Intersection 1 at the beginning of the green phase, causing them to arrive at Intersection 2 (on links 257 and 267) 16 sec before the end of the green phase.

### *Intersection 2*

Figures 4(*a*) and 5(*a*) show how the streetcars hold up the traffic while loading and then leave precisely at the beginning of the next green phase. In optimizing, TRANSYT shifted the phases by 10 sec, as shown in Figures 4(*b*) and 5(*b*), so that the lost green time due to loading was reduced to 6 sec. The authors note the following, however:

- The streetcar still leaves the intersection at precisely the beginning of the next green phase; and

**TABLE 1 Input Data for TRANSYT-7F**

```
     1   60   60         1    1    0    0    1   10    0   60    0    0    1
     3    2                  25
     7  117  157
     7  127  167
     7  217  257
     7  227  267
     7  317  357
     7  327  367
     7  417  457
     7  427  467
    10    1
 *
 *  NODE  1
 *
    12    1    0    1   30    0    1   28    0    1
    21    1    1    1    2    3   31  117  157  127  167
    22    1    4    4    5    6   29  111  113
    28  117    0 1800  500
    28  127    0 1800  500
    28  157    0         15                  2025
    28  167    0         30                  2025
    28  111    0 1800  200
    28  113    0 1800  200
 *
 *  NODE  2
 *
    12    2   40    1   30    0    1   28    0    1
    21    2    1    1    2    3   31  217  227  257  267
    22    2    4    4    5    6   29  211  213
    28  217  600 1800  500       117  500   40
    28  227  600 1800  500       127  500   40
    28  257  600         15       157   15 2025
    28  267  600         30       167   30 2025
    28  211    0 1800  200
    28  213    0 1800  200
 *
 *  NODE 3
 *
    12    3   30    1   30    0    1   28    0    1
    21    3    1    1    2    3   31  317  327  357  367
    22    3    4    4    5    6   29  311  313
    28  317  600 1800  500       217  500   40
    28  327  600 1800  500       227  500   40
    28  357  600         15       257   15 2025
    28  367  600         30       267   30 2025
    28  311    0 1800  200
    28  313    0 1800  200

 *  NODE 4
 *
    12    4   50    1   30    0    1   28    0    1
    21    4    1    1    2    3   31  417  427  457  467
    22    4    4    4    5    6   29  411  413
    28  417  600 1800  500       317  500   40
    28  427  600 1800  500       327  500   40
    28  457  600         15       357   15 2025
    28  467  600         30       367   30 2025
    28  411    0 1800  200
    28  413    0 1800  200
 *
    30  117  127  157  167
    30  217  227  257  267
    30  317  327  357  367
    30  417  427  457  467
 *
    32    3  157  257  357  457
    32    4  167  267  367  467
 *
    40  117  157  127  167
    40  217  257  227  267
    40  317  357  327  367
    40  417  457  427  467
 *
    50
    90
```

**TABLE 2 Global Results of the Simulation and Optimization Runs**

```
                                        SIMULATION RUN

                              <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
   TOTAL      TOTAL   TOTAL     TOTAL     TOTAL   AVERAGE       TOTAL       TOTAL
DISTANCE     TRAVEL  UNIFORM   RANDOM     DELAY   DELAY        UNIFORM       FUEL   OPERATING  PERFORMANCE  SPEED
TRAVELED      TIME    DELAY     DELAY                           STOPS       CONSUM     COST       INDEX
(VEH-KM/H)(VEH-H/H)(VEH-H/H)(VEH-H/H)(VEH-H/H)(SEC/VEH) (VEH/H-%)      (LI/H)                               (KM/H)

1881.00    114.66    40.38     25.04     65.42     40.74  4404.8( 76%)  494.65     357.87     66.64     17.81 <TOTALS>

  81.00      8.02     2.70      1.07      3.77     75.44   180.0(100%)   62.06      28.84      3.82     10.72 <BUSES>

1800.00    106.64    37.68     23.97     61.64     39.63  4224.8( 75%)  432.59     329.03     62.82     18.35 <OTHER>

                                        OPTIMIZATION   RUN

                              <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
   TOTAL      TOTAL   TOTAL      TOTAL      TOTAL  AVERAGE     TOTAL        TOTAL
DISTANCE     TRAVEL  UNIFORM     RANDOM     DELAY  DELAY       UNIFORM       FUEL    OPERATING PERFORMANCE SPEED
TRAVELED      TIME    DELAY      DELAY                         STOPS        CONSUM      COST      INDEX
(VEH-KM/H)(VEH-H/H)(VEH-H/H)(VEH-H/H)(VEH-H/H)(SEC/VEH) (VEH/H-%)      (LI/H)                               (KM/H)

1881.00     75.59    25.05      1.29     26.34     16.41  4034.8( 70%)  371.54     289.61     27.47     28.26 <TOTALS>

  81.00      6.01     1.71       .05      1.76     35.24   180.0(100%)   47.01      22.67      1.81     14.61 <BUSES>

1800.00     69.58    23.34      1.24     24.58     15.80  3854.8( 69%)  324.53     266.95     25.65     29.50 <OTHER>

 NOTE: PERFORMANCE INDEX IS DEFINED AS:

       PI = DELAY + STOPS
```

- The lost time is reduced by 10 sec, effectively increasing the approach capacity and reducing delays to the streetcars.

It has been shown that TRANSYT tends to have the streetcars leave the intersection at the beginning of the green phase, thereby reducing delays and increasing capacities. This solution will tend to maximize capacity and is quite robust to variations in loading time.

Figures 6 and 7 show the flows into and out of Intersection 3, and Figures 8 and 9 show the flows into and out of Intersection 4.

The (*a*) parts of Figures 4 through 9 are those created from the input data of Table 1 (simulation run), whereas the (*b*) parts show the flow profiles corresponding to signal timings for the optimization run.

The optimization run alters the offsets in such a way that they tend to cause the transit load and unload operations to occur mainly during the red signal indication, resulting in savings in capacity. The amount of improvement varies from link to link. Figure 4(*a*) indicates that existing settings cause a loss of 16 sec of green, respectively, whereas the optimal settings reduce this loss to 6 sec, as shown in Figure 4(*b*) for the (TC-NTC) sequence at Intersection 2. For the (TC-TC) sequence, the lost green time for the existing timings [Figure 5(*a*)] is only 12 sec because the streetcar arrives to find a residual queue caused by a streetcar in the other half of the double cycle and must wait 4 sec to preempt that approach's capacity. It still has plenty of time to load before the next green phase and therefore leaves at the beginning of that next green phase.

### *Intersections 3 and 4*

The optimization procedure produces even greater reductions in loss of green time at Intersection 3 (Figures 6 and 7) and Intersection 4 (Figures 8 and 9).

The following features of the new transit simulation model are observed from these figures. First, the transit vehicle arriving during the green starts its load and unload operations only when it reaches the stopline, after all vehicles queued ahead it have been dispatched [see the simulation runs of Figures 5(*a*), 6(*a*), and 7(*a*)]. Second, when the transit vehicle arrives during the red, if the number of cars queued ahead it is greater than the upper limit on the number which will still allow it to start its loading time (zero in this case), it cannot begin the load and unload operations until after the cars queued ahead of it have been dispatched during the next green [see Figures 8(*a*) and 9(*a*), simulation run]. This is the worst case because the transit vehicle is delayed at the intersection by both the red signal indication and the loading time. Figures 8(*b*) and 9(*b*) show how a proper coordination can eliminate this undesirable situation.

It also can be verified that when the network operates under the optimal signal settings, the combined effect of the red signal and loading time ensures that the results of the simu-

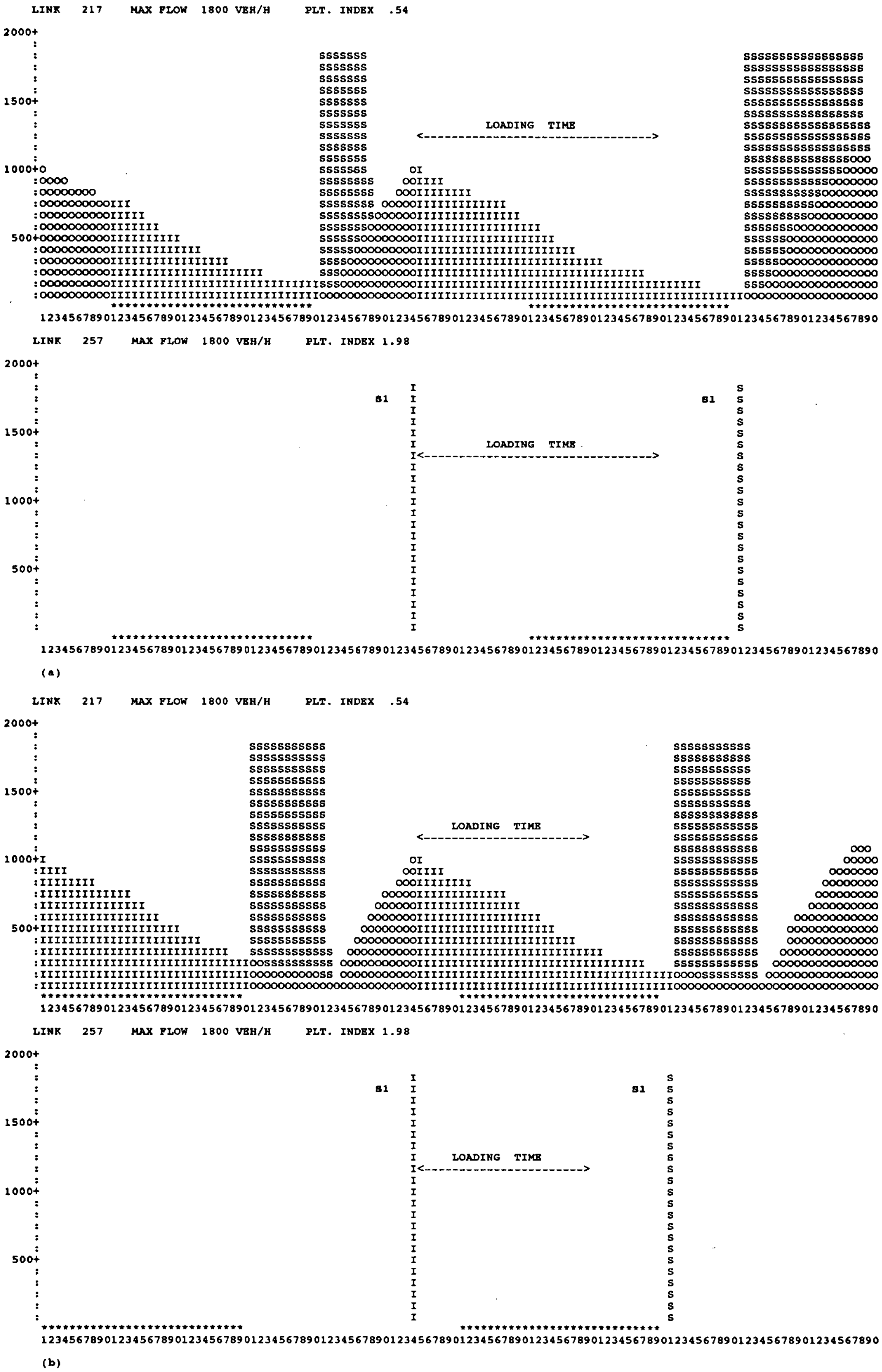


**FIGURE 4** Flow profiles for (TC-NTC) links (217, 257): (*a*) simulation and (*b*) optimization.

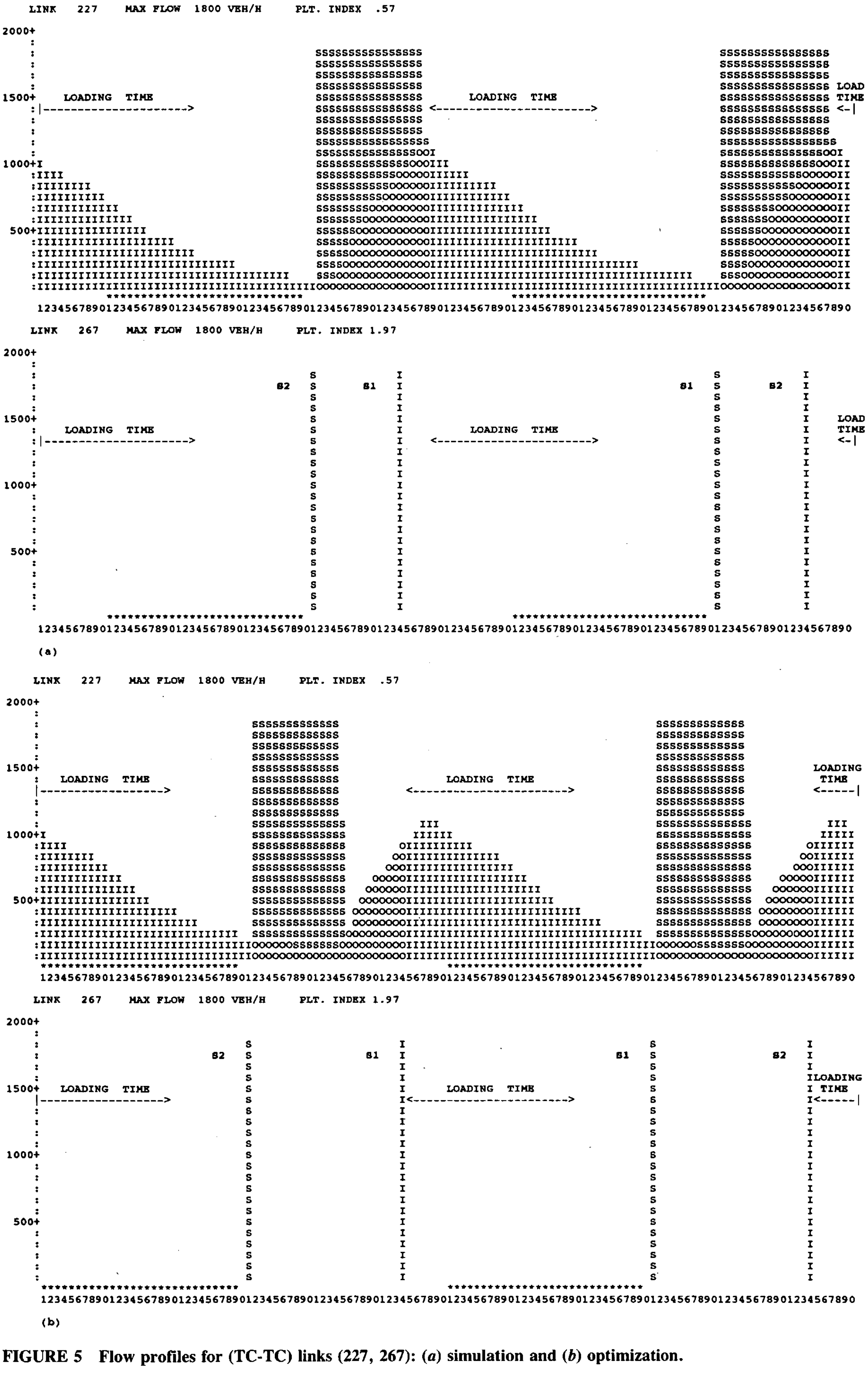


FIGURE 5 Flow profiles for (TC-TC) links (227, 267): (*a*) simulation and (*b*) optimization.

```
    LINK   317    MAX FLOW  1800 VEH/H     PLT. INDEX  .61

2000+
    :
    :                               SSSSSSSSSSSSSSSSSSSSSS                                     SSSSSSS
    :                               SSSSSSSSSSSSSSSSSSSSSS                                     SSSSSSSS
    :                               SSSSSSSSSSSSSSSSSSSSSS                                     SSSSSSSS
    :                               SSSSSSSSSSSSSSSSSSSSSS                                     SSSSSSSS
1500+                               SSSSSSSSSSSSSSSSSSSSSS                                     SSSSSSSS
    :LOADING                        SSSSSSSSSSSSSSSSSSSSSSS                                    SSSSSSSS
    :TIME                           SSSSSSSSSSSSSSSSSSSSSSS                                    SSSSSSSS     LOADING  TIME
    |-->                            SSSSSSSSSSOSSSSSSSSSSSS                                    SSSSSSSS<---------------------|
    :                               SSSSSSSOOOOOOOOOOOSSSSS                                    SSSSSSSS
    :                               SSSSSSOOOOOOOOOOOOOOOOS                                    SSSSSSSS
1000+                               SSSSOOOOOOOOOOOOOOOOOOO                                    SSSSSSSS
    :                               SSSOOOOOOOOOOOOOOOOOOOOO                                   SSSSSSSS
    :                               SOOOOOOOOOOOOOOOOOOOOOOOOO                                 SSSSSSSS
    :                               OOOOOOOOOOOOOOOOOOOOOOOOOOO                               IOOOOOOOO
    :                              IOOOOOOOOOOOOOOOOOOOOOOOOOOOOO                            IIOOOOOOOOII
    :                             IIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIII                        IIIOOOOOOOOIIII
 500+                            IIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIII                     IIIIOOOOOOOOIIIIIII
    :                           IIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIII                  IIIIIOOOOOOOOIIIIIIIIII
    :                          IIIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIII             IIIIIIOOOOOOOOIIIIIIIIIIIIII
    :                         IIIIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIII     IIIIIIIOOOOOOOOIIIIIIIIIIIIIIIIIII
    :IIIII                   IIIIIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOIIIIIIIIIIIIIIIIIIIIII
    :IIIIIIIIIIIIIIIIIIIIII  IIIIIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOIIIIIIIIIIIIIIIIIIIIII
     *****************************                               *****************************
     123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
    LINK   357    MAX FLOW  1800 VEH/H     PLT. INDEX 1.98

2000+
    :
    :                              S                                                              I
    :                         S1   S                                                         S1   I
    :                              S                                                              I
    :                              S                                                              I
1500+                              S                                                              I
    :                              S                                                              I
    :LOADING                       S                                                              I
    :TIME                          S                                                              I         LOADING  TIME
    |-->                           S                                                              I    <---------------------|
    :                              S                                                              I
1000+                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
 500+                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
    :                              S                                                              I
     *****************************                               *****************************
     123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

     (a)

    LINK   317    MAX FLOW  1800 VEH/H     PLT. INDEX  .50

2000+
    :
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
1500+SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                     LOADING  TIME              SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS               <----------------------->        SSS
    :SSSSSSSS                                                SSSSSSSSSSSSS                                                SSS
1000+SSSSSSSS                 O                              SSSSSSSSSSSSS              O                                 SSS
    :SSSSSSSS               OOOI                             SSSSSSSSSSSSS             OOII                               SSS
    :SSSSSSSS              OOOOIIII        IIIIII            SSSSSSSSSSSSSS          OOOOIIII                             SSS
    :SSSSSSSS             OOOOOIIIIIIIIIIIIIIIIIII           SSSSSSSSSSSSSS         OOOOOIIIIIIIIIIIIII                   SSS
    :SSSSSSSSS           OOOOOOIIIIIIIIIIIIIIIIIIIII         SSSSSSSSSSSSSS        OOOOOOIIIIIIIIIIIIIIII                 SSS
    :SSSSSSSSS         OOOOOOOOIIIIIIIIIIIIIIIIIIIIIIII      SSSSSSSSSSSSSS       OOOOOOOIIIIIIIIIIIIIIIIII               SSS
 500+SSSSSSSSS        OOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIII    SSSSSSSSSSSSSS      OOOOOOOOIIIIIIIIIIIIIIIIIIIII            SSS
    :SSSSSSSSS        OOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIII SSSSSSSSSSSSSS     OOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIII         SSS
    :SSSSSSSSS       OOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOSSSSSSSSSSS    OOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIII     SSS
    :SSSSSSSSS      OOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOSSSSSS   OOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIISSS
    :OOOOOSSSS     OOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOOOOOOOOO OOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
                               *****************************                               *****************************
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    LINK   357    MAX FLOW  1800 VEH/H     PLT. INDEX 1.98

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     (b)
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**FIGURE 6** **Flow profiles for (TC-NTC) links (317, 357): (*a*) simulation and (*b*) optimization.**

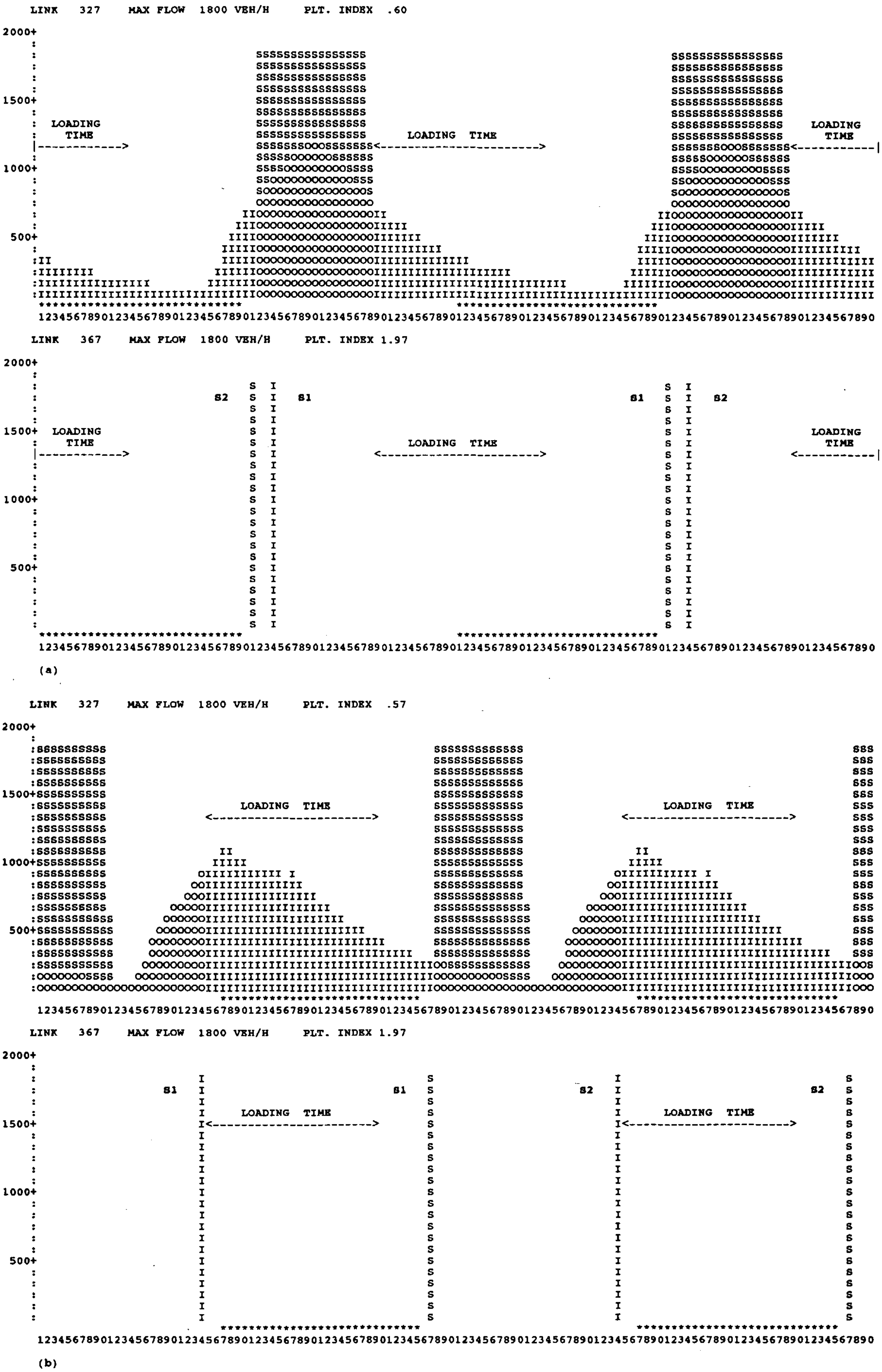

FIGURE 7 Flow profiles for (TC-TC) links (327, 367): (*a*) simulation and (*b*) optimization.

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    LINK   417    MAX FLOW  1800 VEH/H     PLT. INDEX  .67

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    LINK   457    MAX FLOW  1800 VEH/H     PLT. INDEX 1.98

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1500+                       I                                                     S
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1000+                       I                                                     S
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    (a)

    LINK   417    MAX FLOW  1800 VEH/H     PLT. INDEX  .48

2000+
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    :IIIIIIIIII           SSSSSSSSSSSSSS          OOOOOIIIIIIIIII    IIIIII          SSSSSSSSSSSS            OOOOOOIIIIIIIIII
    :IIIIIIIIIIII         SSSSSSSSSSSSSS         OOOOOOIIIIIIIIIIIIIIIIIIIII         SSSSSSSSSSSS           OOOOOOOIIIIIIIIII
 500+IIIIIIIIIIIIIII      SSSSSSSSSSSSSS        OOOOOOOIIIIIIIIIIIIIIIIIIIIIIII      SSSSSSSSSSSS          OOOOOOOOIIIIIIIIII
    :IIIIIIIIIIIIIIIIII   SSSSSSSSSSSSSS       OOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIII   SSSSSSSSSSSS         OOOOOOOOOIIIIIIIIII
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    LINK   457    MAX FLOW  1800 VEH/H     PLT. INDEX 1.98

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     123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

    (b)
```

**FIGURE 8 Flow profiles for (TC-NTC) links (417, 457): (*a*) simulation and (*b*) optimization.**

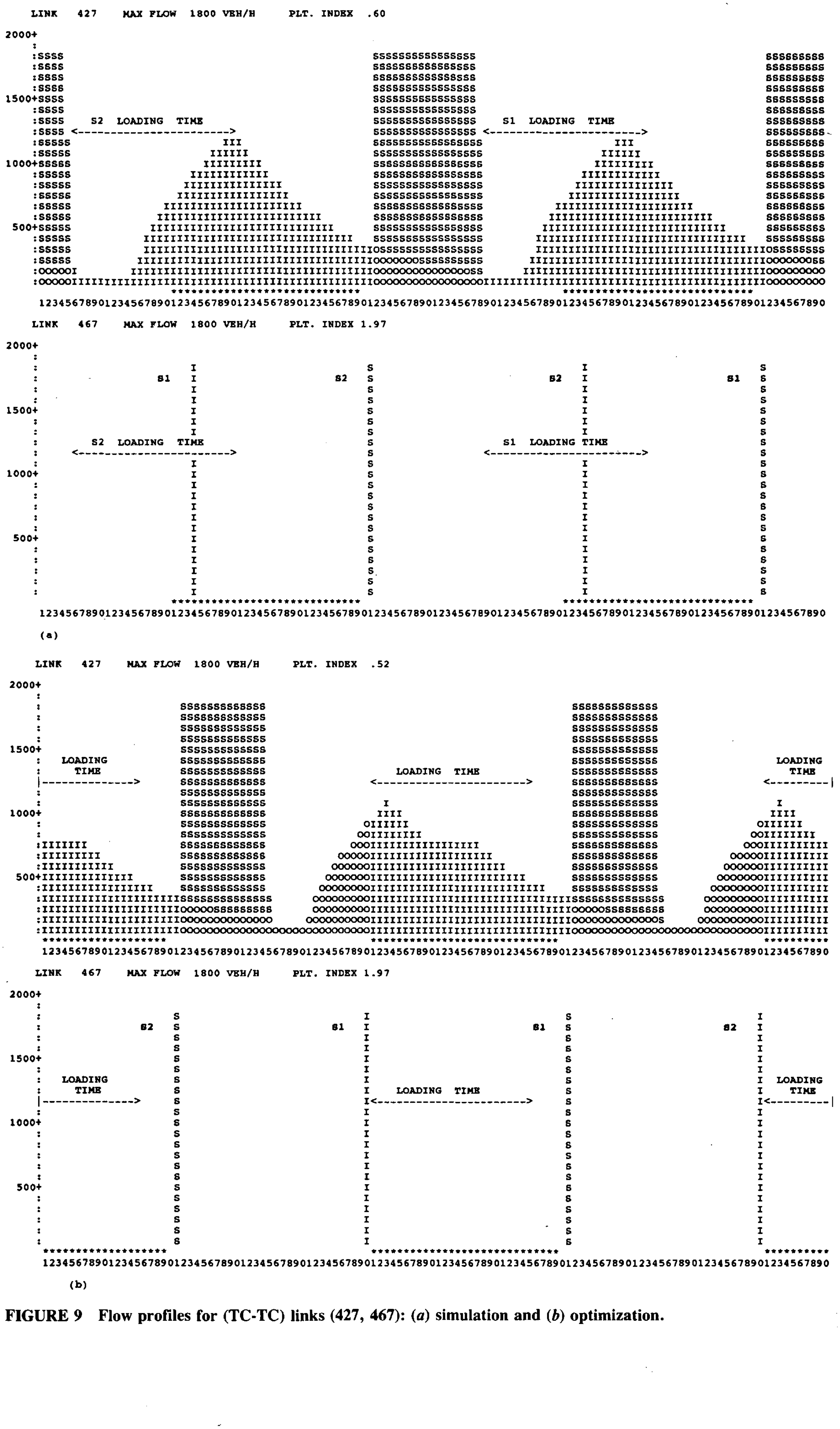

**FIGURE 9** Flow profiles for (TC-TC) links (427, 467): (*a*) simulation and (*b*) optimization.

lation will be valid even for some random variations in the loading time because the transit vehicle will leave at precisely the beginning of the green phase if it finishes loading at any time during the red phase.

On the other hand, when the network operation is simulated using the original signal settings, the results provided by the model are not as robust to variation in loading times and may not hold for certain large variations in the loading time. For example, in Figure 6, the simulation results will hold for loading times varying from 22 to 51 sec, all of which correspond to finishing the loading during the red phase and then merely waiting for the next green phase. However, if the actual loading time is less than 22 sec, the results of the simulation under the original settings are no longer valid because the streetcar would really leave at some time during the same green phase in which it arrived, resulting in flow profiles different from those shown in Figure 6(*a*).

Similarly, the results of the simulation with optimal settings will be valid for any loading time from 3 to 32 sec, which is a more realistic interval for an average loading time of 25 sec.

As an extreme case, the simulation results with the original signal settings in Figure 8(*a*) are only valid for loading times exactly equal to the mean value, whereas with the optimal settings of Figure 8(*b*) the model's results are valid for loading times from 0 to 29 sec.

## DISCUSSION OF RESULTS

When used for optimization purposes, the transit-enhanced TRANSYT model tends to coordinate the intersections such that the transit load and unload operations occur mainly during the red phase. In fact, the optimal settings tend to cause the transit vehicle to dwell for an entire red phase (while loading or waiting for a green signal). This can be seen as a disadvantage for the transit vehicle if its loading time is usually less than the length of the red signal. That is, allowing the transit vehicle to load and unload during the green might have given it the opportunity of being delayed only by the amount of time corresponding to its loading time.

However, a more careful analysis could conclude that on the basis of overall network performance it is usually better to have the transit vehicle load during the red phase, even if it could otherwise have left during the same green phase in which it arrived. The adverse effect of the lost capacity caused by loading during the green phase is probably worse than the added delay for the transit vehicle caused by waiting for the next green, except for the case of short loading times. Also, allowing the transit vehicle to load and unload during the green phase may lead to excessive delay when it cannot complete the process during that green phase.

It was found that for our transit-enhanced networks a different list of step sizes for the optimization hill-climbing process gave better results than the default TRANSYT-7F sequence. Although the reason for this is not clear, it indicates that some research in this area might be productive.

## CONCLUSIONS

The principal advantages of applying the transit-enhanced TRANSYT model to find optimal signal settings are as follows:

- More regularity and predictability in transit operations,
- Substantial reduction of the cases in which the transit vehicle is delayed by both loading time and red signal indication,
- Reduction of the adverse effect of near-side transit stops on the other traffic, and
- Maximization of the approach capacity.

## REFERENCES

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