

Potential Benefits to Transit in Setting Traffic Signals

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Although it is common to optimize signal settings for fixed-time operation, this serves neither transit nor private vehicles adequately when their interaction is not considered appropriately in defining the total system. The TRANSYT model claims to account for transit operation along with private vehicles, but there are some potentially fatal flaws in its representation of mixed transit and private operation. However, incorporating additional modeling techniques can lead to more realistic representations. The resultant modeling

formulation is applied to a 4-mi streetcar route in central Toronto to estimate an upper bound on the potential savings in streetcar delays due to setting traffic signals to accommodate streetcar operation. This is done by considering the idealized case where dwell times are kept constant at each given stop, varying only from stop to stop, so that a fixed-time traffic network can respond best to the streetcar arrivals. The potential gain may be worthwhile and practical effects, such as varying dwell times, should be incorporated into the modeling procedure.

A NUMBER OF MODELS are available for calculating red-green splits for traffic signals and offsets between the green phases at adjacent intersections. Although each attempts to find a global optimum, the modeling and optimization procedures vary from model to model. TRANSYT (1) is the most commonly used model for networks of fixed-time traffic signals. It has been applied and tested many times throughout the world during the past two decades.

Models for optimizing the performance of a fixed-time network of traffic signals, such as TRANSYT, are geared to minimizing aggregated measures

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of vehicle stops and delays, regardless of vehicle occupancy. If a certain type of vehicle, such as a streetcar, has a different speed from other vehicles, it can be given a higher weight in the optimization function using the more recent versions of TRANSYT (2). It would therefore appear on the surface that TRANSYT can give due weight to streetcar speeds in setting signal offsets by playing the benefits to streetcars against losses by private automobiles according to respective weights set by the analyst. For example, these weights might represent vehicle occupancy and operating costs.

Although this is the case when transit runs on exclusive rights-of-way and does not interact with other traffic, except by sharing a common green phase, it does not hold for mixed operation. TRANSYT ignores the fact that streetcars hold up private cars and other traffic when loading passengers. Therefore, it fools itself into thinking that private cars have moved downstream when they are in fact waiting for the streetcar to load. It thus tries to turn signals green too soon, and does not represent either streetcars or private car traffic properly in terms of desired offset between intersections. Other traffic signal models have not attempted to represent streetcars to the extent that TRANSYT has.

A modeling procedure for representing the effects of cars waiting while streetcars load and unload passengers is summarized below. This procedure advocates the use of additional dummy links, whereby the stopped transit vehicle holds up private car traffic in one or more lanes, to provide a more realistic representation of the mixed flow. This brief description is followed by a summary of the application of the procedure to a 4-mi stretch of mixed streetcar and private vehicle operation in downtown Toronto. To model the complex interaction between transit and private automobiles, an initial assumption of fixed transit dwell times at any given stop is made. This allows one to estimate an upper bound on the potential savings in total person delay that can be achieved by considering both public transit and private car traffic when calculating signal timing plans. The value of this potential saving can be compared with the costs of implementation to determine whether a global type of optimum, which considers transit speeds and loading time distributions, is worth pursuing.

MODELING WITH TRANSYT

Figure 1 illustrates how TRANSYT models the flow surrounding an intersection, node 1 in this case. The dashed lines represent the links on which streetcars flow to and from node 1, while the solid lines represent the links on which private cars travel to and from node 1. The common labeling procedure for links is to have the first digit represent the downstream node of the link, while the latter digits represent type and direction of flow. For example,

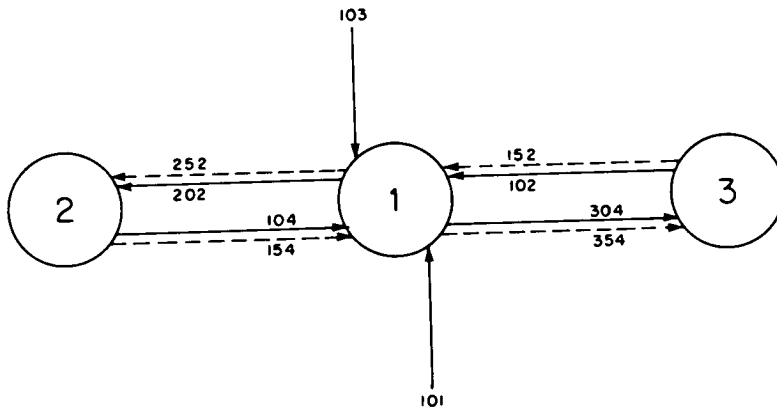


FIGURE 1 Modeling with TRANYST: intersection with shared stop lines eastbound and westbound.

in the parallel links 102 and 152, the high order 1 means into node 1, and the low order 2 means westbound. The middle 0 in 102 represents cars, while the 5 in 152 represents streetcars. Note that the cross-street traffic on links 101 and 103 has no streetcars.

Now, parallel links such as 104 and 154 can operate independently and share a common green phase at node 1. However, TRANYST allows them to also share common lanes by specifying a "shared stopline" at node 1. However, it does not allow streetcars on link 154 to delay cars on link 104 while loading. Instead it assumes that the private cars pass streetcars loading in an adjacent lane, and effectively go through or over streetcars loading in the same lane. This is unrealistic, as all lanes must stop for loading streetcars unless there is a refuge island, in which case only cars in the shared lane are held up.

MODELING STREETCAR STOPS

Figure 2 represents an expanded model for node 1 that allows for streetcars or buses to hold up all lanes in their direction while they are loading or unloading passengers. The dummy node 21 and the dummy links leading into and out of node 21 are used to represent the delaying effects in the eastbound lanes, i.e., of link 154 on link 104. Similarly, dummy node 41 and its associated dummy links are used to stop all westbound traffic while transit is loading or unloading passengers. Note that all dummy links are coded with the number of the dummy node, whether it is their upstream or downstream node, to avoid confusion with the real links. The last two digits of dummy

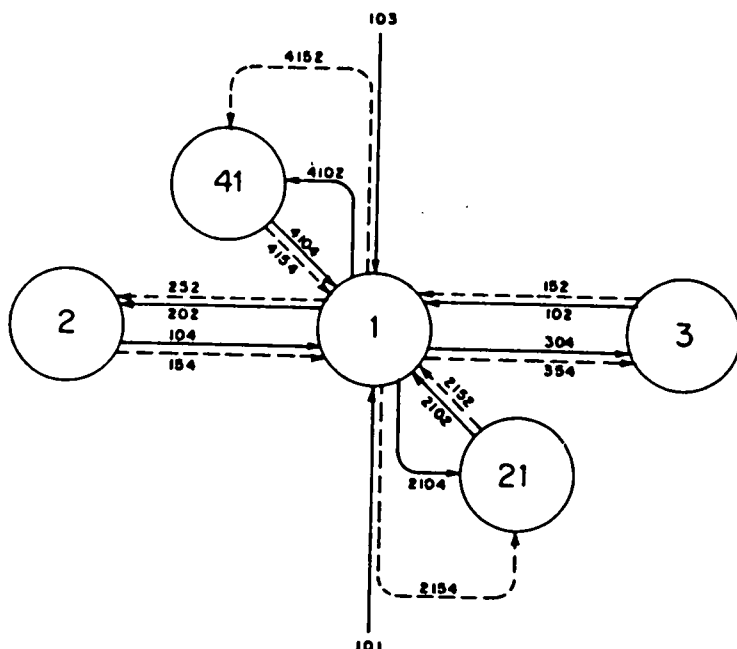


FIGURE 2 Additional dummy links allow full or partial blocking of an approach.

links entering a dummy node represent the direction of flow (e.g., 4102 is for westbound cars into dummy node 41). To draw attention to the fact that dummy links out of a dummy node have that originating dummy node's prefix, the opposite direction is used for the suffix of the dummy return links (such as 4104) for the westbound flow (i.e., as if link 4102 had taken vehicles west from node 1 and link 4104 was bringing them back east to node 1). Although somewhat confusing, this convention was adopted, after the possibilities were considered, for lack of a better one.

The key to making this formulation work is in the parameters specified for the dummy nodes. The purpose of the formulation is to require cars and trucks to wait while streetcars load and unload passengers. The procedure is described below for eastbound traffic.

Links 104 and 154 queue together at a shared stopline for the eastbound green at node 1, having traveled from node 2 at their respective cruise speeds. Cars and trucks from node 104 then take links 2104 and 2102 in sequence to link 304. Because link 2102 has the same green time as link 104, the traffic from link 104 continues through the intersection to link 304 if link 104 has a green indication, unless there is a streetcar loading. Link 2104 is red to this

car and truck traffic when, and only when, the streetcar on link 2154 is loading or unloading. This is accomplished by giving link 2154 preemptive priority at node 21 (through the highest possible weight of 9999), the minimum green time of only 1 or 2 sec, and an amber time that reflects the dwell time while the streetcar is loading or unloading.

Although it must be assumed that streetcars arrive at the same time in each cycle in order to model fixed-time transit priority, this is felt to be a reasonable requirement for fixed-time priority to work at all. It will give some upper bound on the potential benefits from fixed-time priority. For, if streetcars cannot arrive at about the same point in the cycle for uncongested operation (a requirement of TRANSYT), then there is no point in presetting signals to accommodate them. Only tests on Queen Street and other networks can provide some indication as to the extent to which fixed-time transit priority can improve overall operation.

After the streetcar has passed through node 21, its travel along link 2152 takes a time equal to its dwell time. If it gets back to node 1 while the signal is still green, it can continue on to node 3 on link 354. Otherwise, it must wait for the next cycle. The entire process at the intersection is realistic, as the streetcar can begin to load or unload into the red period as long as it reaches node 1 from link 154 before the end of green. However, it can only pass through the intersection if the signal is still green when the loading and unloading have finished.

After cars have passed through node 1 the first time (on link 104), they simply continue through node 21 and back to node 1 via links 2104 and 2102, instantaneously if there is no streetcar loading. However, if they are following a streetcar, they must wait on link 2104 until the streetcar has left. The amber time of link 2154 delays them by enough to allow the streetcar to get back to node 1 just ahead of them. If the signal turns red before the streetcar has finished loading, the vehicles are delayed on link 2102 until it turns green again.

Now, because links 104 and 2102 theoretically could both be serving queued cars in parallel, the streetcar's effect on intersection capacity could be lost on link 104. However, the capacity constraint is handled properly on link 2102. Link 2102 accepts vehicles immediately after link 104 when there are no streetcars, because link 2104 would have a red indication and zero travel time. However, when a streetcar stops, cars are queued on link 2104 and cannot reach the intersection, whose capacity goes begging for vehicles stuck behind a streetcar. This use of a series of links to model a streetcar stop breaks down the component delays at an intersection, as an event-oriented simulation would do, and actually allows TRANSYT to directly account for carry-over to the next cycle.

Pedestrian refuge islands have the effect that streetcars hold up only one lane while allowing other lanes of traffic to pass by. This is illustrated in Figure 2 by the addition of through lanes 112, 212, 114, and 314, which are not affected by the dummy transit priority considerations. Links 304 and 314 could each specify links 114 and 2102 as partial upstream links in the TRANSYT-7F input file to allow for lane changing.

APPLICATION TO TORONTO'S QUEEN STREET CORRIDOR

Figure 3 illustrates the Queen Street corridor in Toronto that was studied. Figure 4 illustrates how a portion of the Figure 3 network was modeled for optimization using the TRANSYT-7F (3) model, as per the discussion that accompanied Figure 2. Nodes 7 through 12, from Bay Street to Bathurst Street, represent the signalized intersections along Queen Street, and the four links joining each pair of these nodes represent streetcar and private vehicle flows in the eastbound and westbound directions.

For example, between nodes 7 and 8, links 802 and 852 represent private car and streetcar flows westbound, while links 104 and 154 represent their respective eastbound counterparts. Nodes 67 through 75 represent signalized intersections on the parallel one-way westbound arterial Richmond Street, which has no streetcars but requires progression in order to move greater volumes of private vehicles efficiently, as an alternative to Queen Street. The nodes 27 through 32 and 47 through 52 are dummy nodes linked to the other part of the network by dummy links. These dummy nodes and links are employed to represent the delaying effects on private traffic caused by streetcars loading at signalized intersections. The effects of streetcars loading at midblock locations can be captured without the use of these dummy links, and are therefore handled properly by TRANSYT. This is accomplished by giving both streetcars and other traffic travel times that reflect the respective delays caused by the midblock stop. The added complexity of a traffic signal with mixed loadings during green and red signal phases is not present at midblock stops, thus obviating the need for the dummy nodes described in Figure 2 for most midblock stops.

There is an underlying pattern to streetcar arrivals created by upstream signals. This is followed by a given random distribution to represent the loading and unloading of passengers at each streetcar stop. Therefore, the arrivals of streetcars are somewhat, but not totally, predictable. If they arrived at random, there would be no use trying to anticipate them in a network of fixed-time signals. On the other hand, completely deterministic streetcar

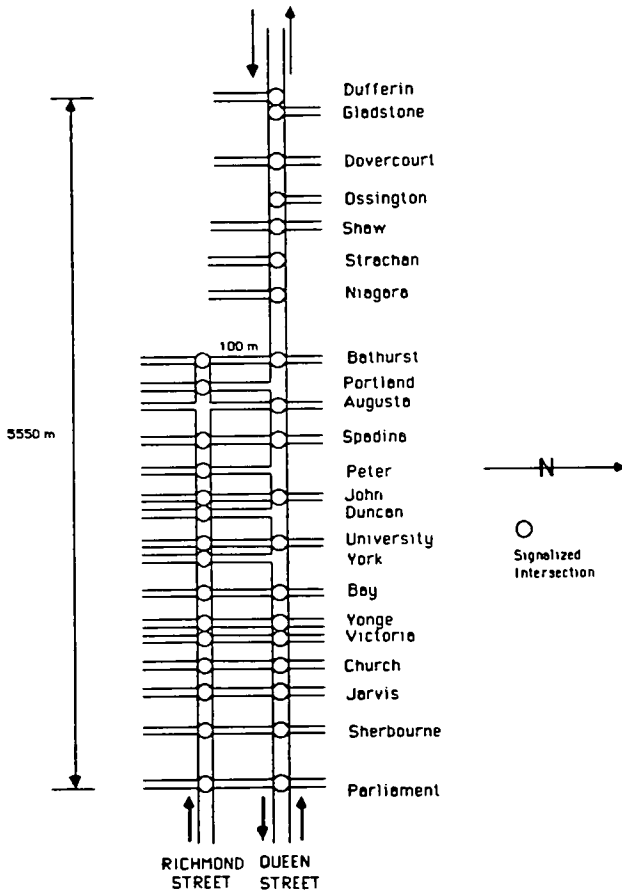


FIGURE 3 Queen Street Corridor.

arrival times present the greatest potential for fixed-time optimization. The actual case is somewhere between these extremes.

This application attempts to estimate an upper bound for the potential savings for the Queen Street network by assuming fixed stop times. If these potential benefits are not significant, then there is no point in considering the rather drastic operating measures, such as limiting the stop times for streetcar stops, that would be required to implement fixed stop times. On the other hand, a somewhat tighter operation might be made more feasible if the estimated potential benefits were too good to ignore. Riders might be willing to accept reasonable cutoff times for loading if fixed stop times could lead to faster streetcar trips and thus reduce their trip time significantly. The long

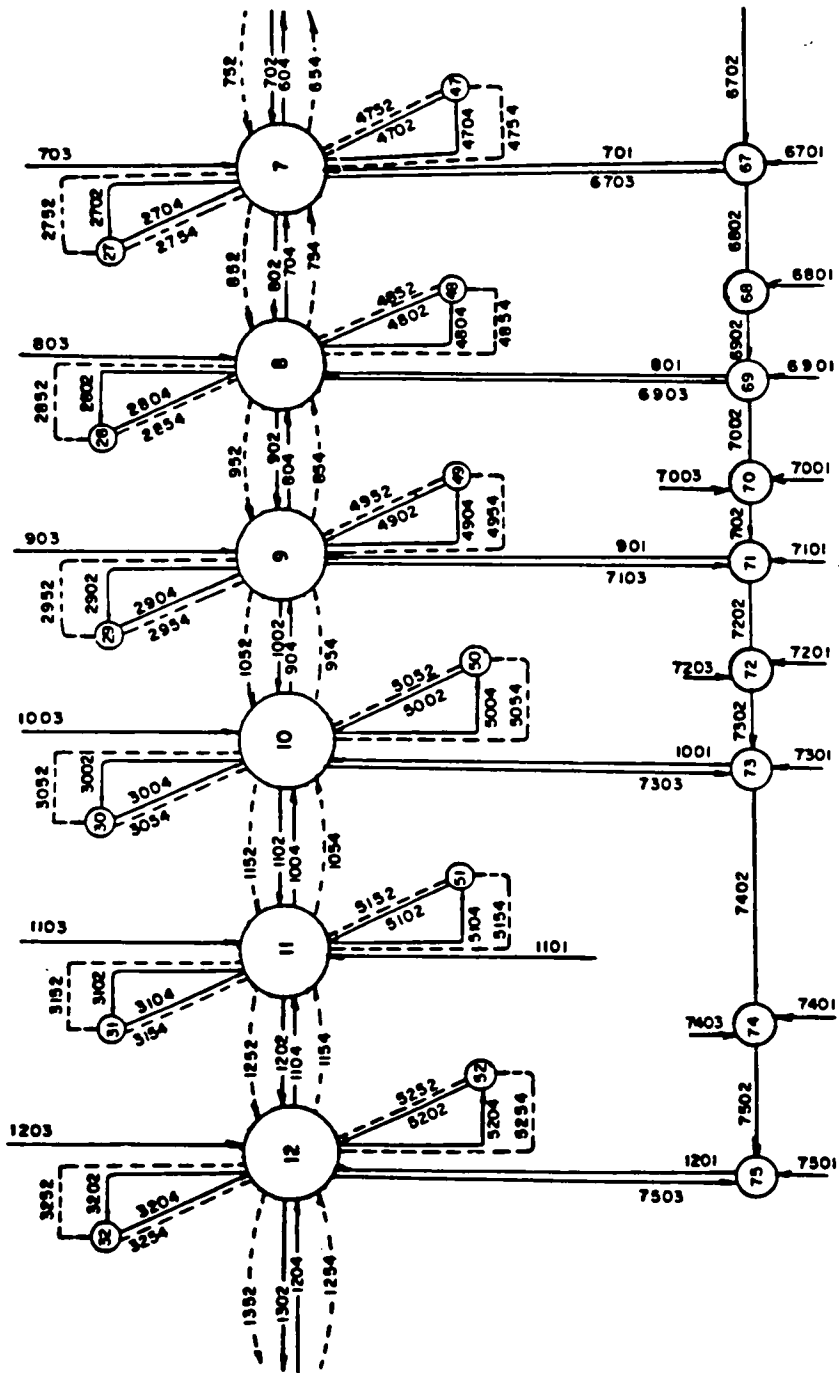


FIGURE 4 Model representation of Bay to Bathurst portion of Queen Street corridor.

loading times are often caused by crush loading, in which it takes much longer to board each incremental individual. Because loading often has to be cut off anyway, it might be advisable to cut it off when it becomes inefficient. This is similar to the gap-out procedure in which the traffic signal green phase is terminated to avoid wasting valuable green time in waiting for stragglers. Also, the operating authority might consider measures to reduce or standardize stop times if the number of streetcars to serve the route could be reduced significantly.

For this test, the representative fixed stop time used for a given stop was the average plus one-half of the standard deviation of actual stop times at that stop. Although cutting off stop times at these values would leave passengers waiting for the next vehicle, the time allowed is more than sufficient on average. The potential benefits corresponding to this type of operation would have to be weighed against added operating costs and delays to those who have to wait for the next streetcar. The potential benefits are estimated below, along with corresponding disadvantages. Implications for partial and practical implementation are then discussed.

RESULTS OF TRANSYT-7F RUNS

The corridor in Figure 3 was studied to estimate delays to streetcars and private traffic under TRANSYT-optimized traffic signal settings for each of the following scenarios:

- Streetcars having nominal weights equivalent to 5 private vehicles, and
- Streetcars having weights equivalent to 100 private vehicles.

Data used for the TRANSYT runs were derived from p.m. peak period operation in Toronto. Table 1 shows estimates of delays to streetcars and private vehicles under the following scenarios:

- Nominal streetcar weight equivalent to 5 private vehicles, and
- High streetcar weight equivalent to 100 private vehicles.

It would appear that the potential benefit from accommodating streetcars in the setting of traffic signal offsets is significant. On the surface, there is a potential saving of up to 25 percent of delays at traffic signals without unduly affecting private traffic. However, there are a number of implications in the requirement for fixed bus stop times, which are discussed below.

DISCUSSION

Although the TRANSYT results represent a specific network with specific data, it is felt that they are typical of what one might expect for other two-way

TABLE 1 PEAK HOUR DELAYS ESTIMATED BY TRANSYT-7F

| | Streetcar Weights | | | |
|-------------------------------------|-------------------|-------|------------|---------|
| | 5 | 100 | Difference | Percent |
| Streetcar delays (hrs/hr) | 14.43 | 10.76 | -3.67 | -25 |
| Delays to private vehicles (hrs/hr) | 657 | 656 | 1 | 0 |

mixed streetcar routes having on the order of 20 traffic signals. There was a considerable mix of average stop times and a network of traffic flows in all directions that had to be considered.

We feel that the default level of platoon dispersion contained in TRANSYT-7F is rather high for Toronto, where platoons tend to stay more compact than what was assumed in the calibration of the TRANSYT model. This would therefore justify additional consideration for cars in determining optimal signal offsets, and they might be hurt more when TRANSYT favors streetcars. Therefore the loss of only 1 car hour per hour in Table 1 is probably low, and a more realistic estimate would have to be weighed against gains by streetcars.

This feasibility study considered the afternoon peak period from 4 to 6 p.m. There are presumably some distinct patterns within this 2-hour period, as there would be for the whole day. Consideration of this time-based information would reduce the random variation in stop times while increasing the analytical complexity of the problem. The average stop times presumably could then be reduced at the cost of a more complex operation, which would see these stop times varying according to a predetermined pattern. This study has estimated the potential payback from such efforts to guide future development efforts either toward or away from a policy of tighter schedule adherence combined with setting of fixed-time signals to accommodate streetcar progressions.

After discussion with transit officials, the authors have determined that, although savings of the estimated magnitude are significant, they would not likely justify the drastic operating measures that are required considering present existing operating procedures and technology. However, even a fraction of this gain would be worthwhile if it could be accomplished through merely resetting traffic signal offsets. It is therefore suggested that further alterations to the modeling procedure described in Figure 2 be considered to try to accommodate random stop times within the existing statistical distributions.

CONCLUSIONS

Further work in the modeling of mixed transit and automobile flows is warranted. The potential gains from fixed-time priority to transit are too great

to ignore. It would be worthwhile to estimate the trade-offs between delays to streetcars and private vehicles if appropriate high weights could be given to streetcars in setting traffic signals without having to seriously alter existing transit operations. Although streetcar delays due to traffic signals might be reduced by upwards of 25 percent without significant increases in car delays, about half of this potential gain would have to be forfeited in the excess stop times required to make a fixed stop time practical.

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