

A COMPARISON OF THE SIMULATION MODULES OF THE TRANSYT AND INTEGRATION MODELS

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ABSTRACT

The TRANSYT simulation/optimization model serves as an unofficial international standard against which many measure the efficiency of other methods of coordinating networks of traffic signals that operate at a constant and common cycle length. However, dynamics due to traffic re-routing, the simultaneous operation of adjacent traffic signals at different cycle lengths, the effect of queue spill backs on the capacity of upstream links, and various forms of real-time intersection control cannot be modeled using a static model such as TRANSYT. This has created a unique niche for a more dynamic signal network simulation tool. Before modeling such special dynamic scenarios, there first exists a need to validate the static signal control features of such a model, and to determine if its unique dynamic features still permit it to yield credible static results.

This paper therefore strives to achieve two objectives. In the first instance, it attempts to illustrate to what extent the estimates of vehicle travel time, vehicle delay and number of vehicle stops are related when a standard static signal network is examined using both TRANSYT and INTEGRATION. Secondly, the paper strives to illustrate the types of more complex signal timing problems, which at present cannot be examined by the TRANSYT model, can be

examined using the dynamic features of INTEGRATION. The results are intended to permit the reader to better appreciate both their differences and similarities, and to permit a more intelligent decision as to when and where each model should be used.

The paper demonstrates that INTEGRATION simulates traffic signalized networks in a manner that is consistent with TRANSYT, for conditions where TRANSYT is valid. Specifically, the total travel time and percentage of vehicle stops' difference is within 5 percent. In addition, it is also shown that INTEGRATION can simulate conditions that represent the limitations to the current TRANSYT model, such as degrees of saturation in excess of 95 percent and adjacent signals operating at different cycle length durations.

This analysis of the simulation features of TRANSYT and INTEGRATION is intended to be a pre-cursor to a comparison of their respective optimization routines.

INTRODUCTION

The simulation of most urban areas requires both freeways, traffic signals and the traffic assignment between them to be considered. Earlier efforts have compared INTEGRATION freeway routines to *FREQ* (1), and its traffic assignment to the Frank-Wolfe algorithm (2) and *CONTRAM* (3). This paper examines the details of the manner in which the simulation of phase split, cycle length and offset features compare to TRANSYT. It should be noted that INTEGRATION is similar to the *NETSIM* (4, 5, and 6) and *TRAFFICQ* (7 and 8) models, in terms of its microscopic representation of traffic signals, but the latter two models lack freeway or traffic assignment modules, or both (9 and 10).

A Description of the TRANSYT Model

The TRANSYT (TRAffic Network StudY Tool) model was developed at the Transport Research Laboratory (TRL) in Britain (11). Many versions of this basic model have emerged since its first development (12). One of these is the TRANSYT-7F model, which was developed at the University of Florida (13).

TRANSYT is an off-line macroscopic, deterministic, simulation and optimization model that simulates traffic as Cyclic Flow Profiles (CFP) and traces the flow of the CFP from link to link throughout the network. The model makes systematic changes to the offset, phase split and cycle length of the traffic signals, and also simulates the associated traffic conditions to estimate a corresponding Performance Index (PI). This PI is a linear combination of vehicle delay and number of vehicle stops. For each candidate signal timing parameter the model then uses a hillclimbing technique to systematically search for the settings that minimize the PI. The simulation module within the TRANSYT model is a critical component of the model as it evaluates the objective function that is to be minimized. This paper attempts to evaluate the simulation rather than optimization capabilities of the TRANSYT model.

A Description of the INTEGRATION Model

The INTEGRATION model is a microscopic simulation model that models vehicles as individual entities (9, 14, and 15). The model was designed specifically to evaluate integrated freeway and traffic signal network controls. The model is unique in that it combines the simulation of freeways and arterials into a single model, and that it permits for the dynamic assignment and diversion of traffic to alternate routes.

INTEGRATION (version 2.0) models the microscopic characteristics of lane and car-following in detail, as well as gap acceptance behavior at intersections. The model is capable of modeling microscopic platoon dispersion using a process similar to TRANSYT's macroscopic process. In addition, the INTEGRATION model is capable of reading in any number of signal plans that were generated externally, in addition to performing a form of real-time isolated control based on the procedures of the Canadian Capacity Guide (17) and coordination control based on dynamic cyclic flow profiles.

DESCRIPTION OF NETWORK

This Section of the paper first describes the network that was used for purposes of the comparison of INTEGRATION and TRANSYT. As the TRANSYT model is macroscopic and the INTEGRATION model is microscopic, macroscopic and microscopic analytical solutions are also presented.

The Network Description

The network, that was utilized in this study, was composed of a bi-directional arterial connecting zones 1 and 2, as illustrated in Figure 1. Traffic signal 1, which was located at node 10, was set to be the master signal relative to which the offset of traffic signal 2 (at node 11) was referenced.

All links were assigned a free-flow speed of 60 km/hr. and a constant speed/flow relationship in order to replicate TRANSYT's implicit assumption that the link travel time is relatively independent of the link flow. All the links were configured to be composed of 2 lanes in each direction, each with a 1500 vph/lane saturation flow rate. The Origin-Destination (O-D) demands used in the analysis were as follows: from 1 to 2 a demand of 1200 vph was assigned, from 2 to 1

a demand of 1200 vph was assigned, from 3 to 4 a 1200 vph demand was loaded and from 6 to 5 a demand of 800 vph was given.

No platoon dispersion was considered at first for primarily two reasons. First, no platoon dispersion permits the generation of analytical solutions to the problem. Secondly, any stochastic effects could then be removed and any remaining differences in the solutions would be a result of strictly deterministic modeling differences.

The TRANSYT signal optimizer was first used to determine the optimum signal settings. The optimum cycle length was estimated to be of 60 second duration, with a 50:50 phase split at signal 1 and a 60:40 phase split for signal 2. In the above phase coding scheme, phase 1 served the east/west traffic and phase 2 served the north/south traffic. In addition, the optimum offset of signal 2 with respect to signal 1 was estimated to be 28 seconds, while intergreen durations were set at 4 seconds.

Macroscopic Analytical Solution

The macroscopic analytical solution, that is presented first, represented the flow of vehicles as a continuous flow of fluid as opposed to representing the flow as discrete entities. This macroscopic solution corresponds most closely to the macroscopic approach of TRANSYT. The macroscopic analytical solution was derived using both the optimum cycle length and phase split signal settings that were generated by the TRANSYT model. However, offsets of signal 2 relative to signal 1 were varied ranging from 0 to 50 seconds at 10 second increments.

The total delay for each approach was then calculated by integrating the area under the queue/time relationship, and the number of vehicle stops was estimated by summing up all vehicle arrivals during both the red interval and the portion of the green interval during which a

queue existed. The total delay and number of stops calculated for a single cycle length of 60 seconds were then multiplied by the number of cycles in one hour (namely 60) in order to estimate the total hourly delay and total number of vehicle stops, respectively.

Microscopic Analytical Solution

The microscopic analytical solution tracked each vehicle from its point of entrance on the network to its final exit from the network. The intent was to execute an analytical procedure that was most similar to the INTEGRATION model. However, this microscopic solution did not incorporate any car-following or lane changing logic, and assumed the vehicle queue to be vertical. This microscopic solution which was developed on a spreadsheet is demonstrated in Table 1. It must be noted that the values presented in Table 1 are not typical, as the network was considered to be empty at the start of the analysis and thus no queues existed at the start of the green interval. Consequently, the spreadsheet was made to track vehicles for 360 seconds, which is equivalent to 6 cycle lengths, and the total travel time and number of vehicle stops were estimated for the entire hour based on the estimates of the number of stops and delay of the final 3 cycles. A single cycle length would be sufficient to develop the correct queue size if there was no over-saturation, as is the case in this sample analysis. Finally, the analysis was conducted for a period of 180 seconds, as it is the smallest common multiple of a 60 and 90 second cycle length, as is required in order to conduct further analysis later in the paper.

As an example, vehicle 7 in Table 1, was considered to enter the network after 19.5 seconds and thus arrived at signal 1 (which is located at node 10) after 31.5 seconds. As traffic signal 1 operated at a 60 second cycle length, with a 50:50 phase split and 0 second offset, it would be red at the time of arrival of vehicle 7. Consequently, vehicle 7 would experience a single stop, as

indicated by the stop flag of “1” in column 5 of Table 1. As the signal did not turn green until time 60, vehicle 7 experienced a delay of 29.7 seconds at traffic signal 1. Furthermore, as vehicle 7 was the second vehicle in the queue it would therefore depart 1.2 seconds after the traffic signal turned green, which is equivalent to the minimum saturation flow headway ($3000/3600$). In absolute terms, the vehicle would therefore depart after 61.2 seconds ($60+1.2=61.2$). Vehicle 7 would then arrive at traffic signal 2, which is located at node 11, after 91.2 seconds ($61.2+30$). As the traffic signal would be green, at the time at which the vehicle would reach the stop line of signal 2, it would not need to stop and thus would experience no further delay at this signal.

Vehicle 7 would reach its destination after 103.2 seconds and thus experience a travel time of 83.7 seconds. This procedure was repeated for all the four O-D demands and for all six cycle length durations. The analytical results for an entire hour were generated as illustrated in Figures 2(a) and 2(b).

Comparison of the Macroscopic and Microscopic Analytical Solutions

It is evident from Figure 2(a) that the macroscopic analytical solution consistently estimated the total travel time to be higher than the microscopic analytical solution. Furthermore, it is also evident that the macroscopic analytical solution again consistently estimated the number of vehicle stops to be higher than that estimated by the microscopic analytical solution. However, it can be noted that this systematic bias is relatively minor (approximately 1 percent). It is also conditional on the assumptions about the departure time of the first vehicle and/or any roundoff errors.

COMPARISON OF TRANSYT AND INTEGRATION RESULTS

In order to compare the TRANSYT and INTEGRATION simulation models, the signal timings that were utilized in estimating the analytical solutions, were also input into each of these models.

Modeling Considerations

In conducting this study a number of modifications were required to be applied to some of the default input and output data of the TRANSYT model. The first consideration was to include the travel times on the exit links of the network in the TRANSYT estimate of total travel time, which amounted to 14.7 veh-hr/hr. This extra travel time was added externally to the internal TRANSYT total travel time estimate, in order to compare the results of the different methods on an equitable basis.

In addition, the total travel time estimated by the TRANSYT simulator included a random delay component. This random delay component was also subtracted externally from TRANSYT's total travel time estimate, as it was desired to first compare the deterministic aspects of the models.

In order to not model any platoon dispersion along the links, the platoon dispersion factor in the TRANSYT model was set to 1. However, because the TRANSYT specific travel time factor (β) is fixed at a constant value of 0.8, this resulted in the vehicles traversing the link at 0.8 the average link travel time. This effect is caused by TRANSYT's basic recursive model. Thus, the link travel times input to the TRANSYT model were increased by 25 percent in order to make the analysis directly comparable.

In computing the percentage vehicle stops, the total number of hourly vehicles was considered to be 11,200 ($8 \times 1200 + 2 \times 800$), which also includes the flow on the exit links that are not modeled in TRANSYT.

Comparison of Total Travel Time Estimates

The results of executing the TRANSYT simulation model, after subtracting the random delay component, are illustrated in Figures 2(a) and (b). It is evident from Figure 2(a) that the total travel times for all of the different scenarios were very similar. Specifically, the percentage difference in total travel time estimated by the different scenarios was within 1 percent.

As the average travel time estimates were very similar between the INTEGRATION model, the TRANSYT model and the analytical solutions, and as the adjusted total travel distances were identical, the average network speeds (total travel distance/total travel time) were also very similar. They are therefore not discussed further here.

Comparison of Percent Vehicle Stops

A comparison of the percentage vehicle stops presented in Figure 2(b), indicates that the INTEGRATION model systematically under-estimated the number of vehicle stops when compared to TRANSYT. The difference in percentage vehicle stops between the INTEGRATION and TRANSYT models did not exceed 3 percent. This finding is similar to the findings from the comparison of the microscopic analytical approach relative to the macroscopic analytical approach. Furthermore, it is also evident from Figure 2(b) that the overall trend in the number of vehicle stops, as a function of the offset, is consistent.

Summary

The difference in average travel time estimates between the two models and the analytical solutions was found to be within 1 percent. The INTEGRATION and microscopic analytical solutions were found to underestimate the number of vehicle stops relative to TRANSYT and the macroscopic analytical solution by approximately 3 percent.

Various studies have been conducted to compare the delay and number of vehicle stops estimated by the TRANSYT simulator to field measurements. Specifically, a study conducted in Australia (19) showed that TRANSYT/8 over-estimated the number of vehicle stops by 12 percent to 30 percent when compared to the field measurements. The study also showed that TRANSYT was more accurate than SATURN and NETSIM in estimating vehicle delay and the number of vehicle stops. Another study (20) also demonstrated that the TRANSYT simulator overestimated the journey time by 7 percent to 27 percent and overestimated the number of vehicle stops by 12 percent to 32 percent when compared to field measurements. TRANSYT's overestimation of vehicle stops appears to be consistent with the results presented in this paper.

SENSITIVITY ANALYSIS OF SIMULATION PREDICTIONS

In order to further compare the estimates of the INTEGRATION and TRANSYT simulators for a variety of different signal and traffic conditions, a limited sensitivity analysis of cycle length, phase split and offset was conducted. The intent of this sensitivity analysis was to compare, in further detail, the traffic signal simulation module of the TRANSYT and INTEGRATION models.

In this analysis the TRANSYT default partial stop/delay relationship was utilized in both models. Further, the TRANSYT model was simulated using a time horizon of 60 minutes, while the INTEGRATION model was loaded with O-D demands for an entire hour, following which the simulation period was extended for an additional hour in order to allow any vehicles (that were still queued on the network) sufficient time to reach their final trip destinations.

Again it must be noted that no platoon dispersion was modeled in order to remove any stochastic effects that would result, such that sensitivity analysis was entirely deterministic.

Cycle Length Sensitivity Analysis

The first sensitivity analysis was conducted by ranging the cycle length from 40 seconds to 120 seconds at a 10 second increment. For each cycle length the optimum phase split for each signal was maintained (50:50 split at signal 1 and a 60:40 split at signal 2). Also, the initial offset of signal 2 with respect to signal 1, of 28 seconds, was maintained for each of the different cycle lengths.

A comparison of the total travel time estimates of INTEGRATION and TRANSYT is presented in Figure 3. Evidently both models predicted the optimum cycle length to range between 50 and 60 seconds. Furthermore, the delay and stop predictions were also very similar for the entire range of cycle lengths evaluated. The percentage vehicle stops estimated by the INTEGRATION simulation model was again systematically less than that estimated by the TRANSYT model. However, this difference in the percentage vehicle stops typically did not exceed about 2 percent.

Phase Split Sensitivity Analysis

During this analysis, the duration of phase 1, at signal 2, was varied from 15 to 45 seconds in 5 second increments, while the cycle length was held fixed at 60 seconds. Two scenarios were evaluated using the INTEGRATION model. In the first scenario the flows were loaded for an hour and the simulation was terminated at the end of the hour. In the second scenario, the simulation period was extended for an extra hour to clear the network of any queued vehicles that still needed to traverse the network at the conclusion of the hour.

For phase 1 durations of 15, 20 and 25 seconds the network was over-saturated, and thus the total travel time for the two INTEGRATION scenarios were different as illustrated in Figure 4. This difference is attributed to the fact that, by ending the simulation period after 1 hour, those vehicles that have not reached their intended destinations are not considered in estimating the total travel time, nor are they considered in estimating the total number of vehicle stops. This phenomenon is common to almost any microscopic simulation model where the simulation statistics depend on whether the simulated entity has cleared the simulated system. The total travel time estimated by the TRANSYT model fell within the range of estimates of the two INTEGRATION scenarios. It is also evident from Figure 4 that both the INTEGRATION and TRANSYT models produced similar trends in terms of relative delays for different phase splits.

It must be noted that for phase durations of 15, 20 and 25 seconds, the network was over-saturated. For these over-saturated conditions the number of vehicle stops estimated by the models were not consistent. However, during uncongested conditions, at a phase duration of 30 seconds, (degree of saturation of 92 percent), the stops estimated by both models were similar (difference of 3 percent). This demonstrates, as has been acknowledged by the developers of

TRANSYT, that TRANSYT can produce unrealistic results if the degree of saturation exceeds 90 to 95 percent.

It is also evident from column 5 of Table 2 that for a phase 1 duration of 15 seconds at signal 2, the queue on link 10 spilled back to link 5 in INTEGRATION, and thus increased the percent vehicle stops to 99 percent. This value was slightly less than a 100 percent, as some initial vehicles managed to proceed through the intersection without stopping, prior to the onset of over-saturated conditions. The TRANSYT model, however, did not model any queue spill backs on to link 5. Therefore, the link was not considered to be over-saturated, such that the number of vehicle stops remained at 87 percent. The TRANSYT model simulated links 10 and 8 to be over-saturated, as indicated by the asterisk in Table 2, although the percentage vehicle stops was low at 46 percent.

Summary

In summary, the TRANSYT model is an ideal tool for optimizing the signal settings of a network of traffic signals when the degree of saturation is below 95 percent. However, the model cannot simulate let alone optimize traffic conditions accurately when the degree of saturation exceeds approximately 95 percent. Interestingly, Luk and Stewart (19) compared SATURN, TRANSYT8 and NETSIM, and found NETSIM to be the least suitable model under high levels of congestion. Consequently, because in many congested urban areas the degree of saturation does exceed 95 percent at some intersections, there is a need for a model that can simulate realistic queue spill back effects. In this example the INTEGRATION model was shown to capture the queue spill back effects. Aultman-Hall (21), for example, compared the estimated INTEGRATION queues to standard queuing theory during over-saturated conditions (with some adjustments to the

queuing theory to account for the spatial dimensions of vehicle queues) and found the INTEGRATION model's estimates of vehicle queues to be consistent with queuing theory.

MODELING OF DIFFERENT CONCURRENT CYCLE LENGTHS

The TRANSYT model attempts to model a single cycle as being representative for a set of similar traffic conditions throughout the rest of the peak period. In order for traffic conditions to remain constant, however, all traffic signals must operate at a common cycle length or at simple multiples of this common cycle length. This requirement clearly limits the use of TRANSYT as a traffic network simulation tool. In contrast, the INTEGRATION model simulates traffic conditions for each individual cycle during an analysis period. This feature relaxes TRANSYT's constraint of either an identical cycle length at all intersections at any one point in time, or the need for a constant cycle length at one intersection for an entire analysis period.

In order to examine this feature of INTEGRATION, the traffic signals in the network of Figure 1 were simulated to operate at different cycle lengths. Specifically, signal 1 at node 10 was coded to operate at a 90 second cycle length and a 50:50 phase split, while signal 2 at node 11, was coded to operate at a 60 second cycle length and a 60:40 phase split. Again, phase 1 was coded to serve the east/west traffic, while phase 2 served the north/south traffic. The offset of signal 2 was varied at 10 second increments ranging from 0 to 50 seconds. No platoon dispersion was modeled and thus the results were forced to be purely deterministic. For each offset the macroscopic and microscopic analytical solutions were estimated based on an analysis of a 180 second time period (2 or 3 cycle lengths for signals 1 or 2) and the results were compared to the output of the INTEGRATION model for a 1 hour simulation.

Comparison of Total Travel Time & Vehicle Stops

Two analytical solutions were once again generated, namely a macroscopic and a microscopic solution. The two analytical and one simulation estimate of total travel time were very similar, and the variation in total travel time did not exceed 5 percent. As indicated earlier, a similar TRANSYT analysis of this scenario was not possible due to the theoretical limitations of the model.

The INTEGRATION model estimated the vehicle stops very similar to the microscopic analytical solution (within 5 percent). Alternatively, the macroscopic approach differed at an offset of 30 seconds by approximately 8 percent. This difference was likely caused by the macroscopic vs. microscopic difference of vehicle stop estimation, as discussed earlier.

SUMMARY AND CONCLUSIONS

Although the TRANSYT model serves as an unofficial international standard, against which many measure the accuracy of other methods of coordinating a network of static traffic signals, the simulation module within the TRANSYT model is not capable of capturing the dynamics of vehicle re-routing, different cycle lengths, the effect of queue spill backs on upstream links and various forms of critical or real-time intersection control. INTEGRATION, in contrast, is capable of capturing these dynamic effects, but represents less of a known reference for signalized networks. This paper therefore first compared both the INTEGRATION and TRANSYT models to macroscopic and microscopic analytical solutions for a simple two-signal network, for conditions that all four methods could consider. The total travel times estimated by the INTEGRATION and TRANSYT models were in this case found to differ from each other by less

than 5 percent on average, where these differences paralleled the differences between macroscopic and microscopic analytical solutions.

The number of vehicle stops estimated by the INTEGRATION and TRANSYT models were also compared to a microscopic and macroscopic analytical solution. Within this comparison, the INTEGRATION and TRANSYT models and both analytical solutions were found to produce a similar trend in the variation of the number of stops for different offsets. However, the INTEGRATION model and the microscopic analytical solutions generally under-estimated the number of vehicle stops relative to the TRANSYT model and the macroscopic analytical solution. While the preference of using a microscopic vs. a macroscopic model is more of a philosophical rather than a technical issue, it is interesting to note that previous studies have shown that the TRANSYT model over-estimates the number of vehicle stops by 10 percent to 30 percent (19).

In conclusion, this study has shown that the INTEGRATION model can simulate traffic signalized networks as accurately as the TRANSYT model, for static conditions where TRANSYT is valid. However, it has also been shown that INTEGRATION can also simulate important dynamic conditions that represent limitations to the current TRANSYT model. However, until recently TRANSYT maintained a distinct advantage over INTEGRATION, as it possessed an optimizer of signals in view of any coordination effects. Research is underway at present to explore the evaluation of the optimization features of INTEGRATION.

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Table 1: Vehicle tracking for vehicles traveling from zone 1 to zone 2 for an offset of 0 seconds at traffic signal 2

Vehicle #	Entry	Signal 1				Signal 2				exit time (sec)	Travel time (sec)
	time (sec)	arrive time (sec)	depart time (sec)	stop flag	delay (sec)	arrive time (sec)	depart time (sec)	stop flag	delay (sec)		
1	1.5	13.5	13.5	0	0	43.5	60	1	16.5	72	70.5
2	4.5	16.5	16.5	0	0	46.5	61.2	1	14.7	73.2	68.7
3	7.5	19.5	19.5	0	0	49.5	62.4	1	12.9	74.4	66.9
4	10.5	22.5	22.5	0	0	52.5	63.6	1	11.1	75.6	65.1
5	13.5	25.5	25.5	0	0	55.5	64.8	1	9.3	76.8	63.3
6	16.5	28.5	60	1	31.5	90	90	0	0	102	85.5
7	19.5	31.5	61.2	1	29.7	91.2	91.2	0	0	103.2	83.7
8	22.5	34.5	62.4	1	27.9	92.4	92.4	1	27.6	132	109.5
9	25.5	37.5	63.6	1	26.1	93.6	93.6	1	27.6	133.2	107.7
10	28.5	40.5	64.8	1	24.3	94.8	94.8	1	27.6	134	105.9

Table 2: Percent vehicle stops for each link estimated by the INTEGRATION and TRANSYT models for phase 1 durations of 15, 20, 25 and 30 seconds at signal 2

start node	end node	link #	O-D pair	INTEGRATION model phase 1 duration in seconds				TRANSYT model phase 1 duration in seconds			
				15	20	25	30	15	20	25	30
1	10	5	1-2	99	98	96	82	87	87	87	87
10	11	10	1-2	99	99	98	5	46*	29*	65*	4
11	2	2	1-2	0	0	0	0	na	na	na	na
2	11	8	2-1	99	99	99	84	46*	40*	87*	87
11	10	7	2-1	2	12	18	18	19	27	36	40
10	1	1	2-1	0	0	0	0	na	na	na	na
3	10	6	3-4	82	82	82	82	87	87	87	87
10	4	3	3-4	0	0	0	0	na	na	na	na
6	11	9	6-5	34	46	58	69	37	7	9	71
11	5	4	6-5	0	0	0	0	na	na	na	na

Where:

* = oversaturated

na= not applicable (i.e. not estimated)

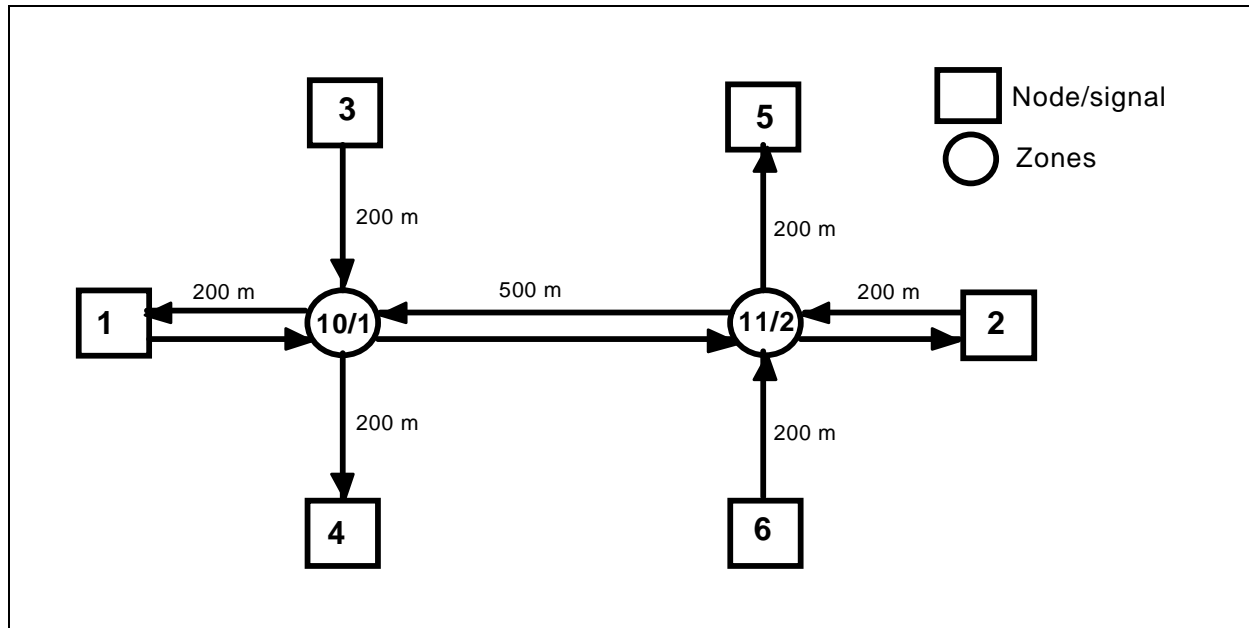


Figure 1: INTEGRATION coding scheme of the two-signal network

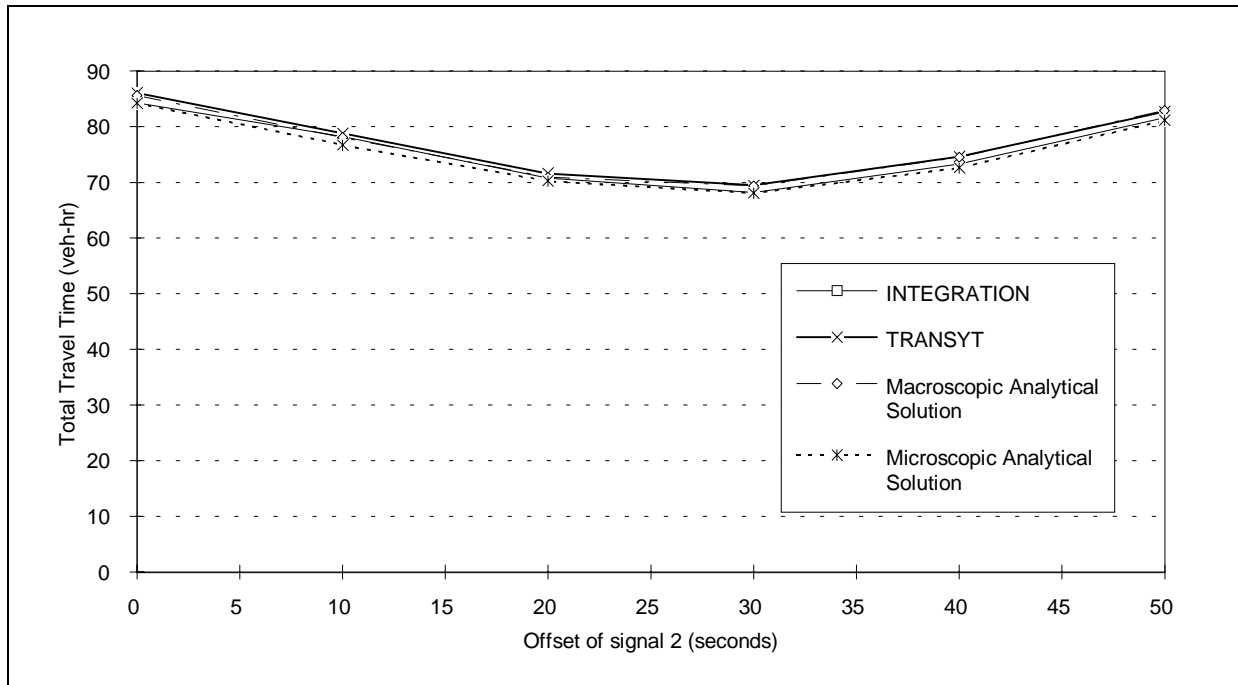


Figure 2(a): Total travel time estimate by analytical solutions, INTEGRATION and TRANSYT models

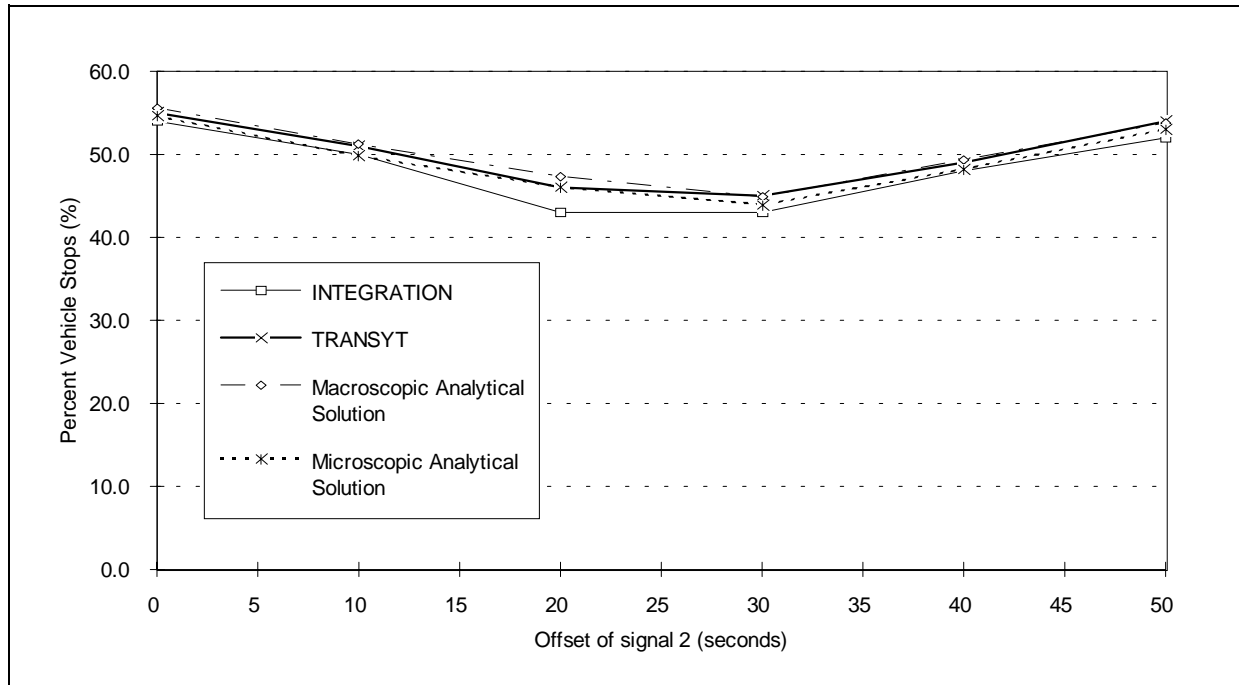


Figure 2(b): Percent stops estimated by analytical solutions, INTEGRATION and TRANSYT models

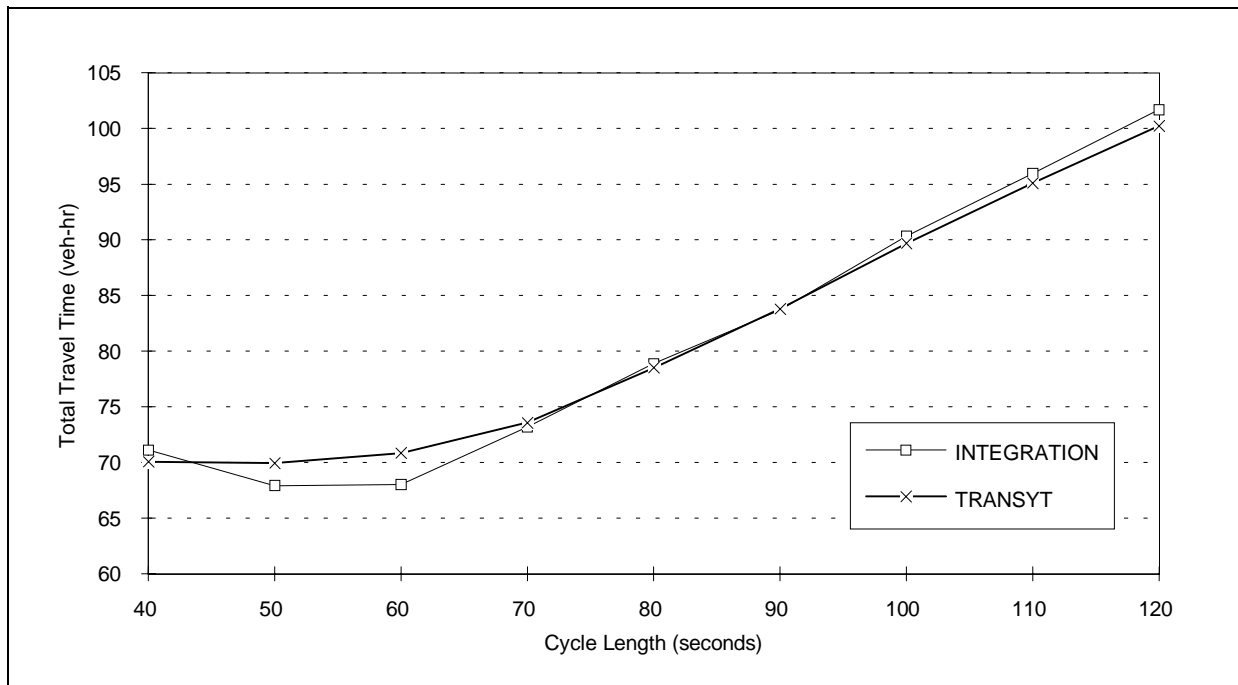


Figure 3: Total travel time variation as a function of cycle length

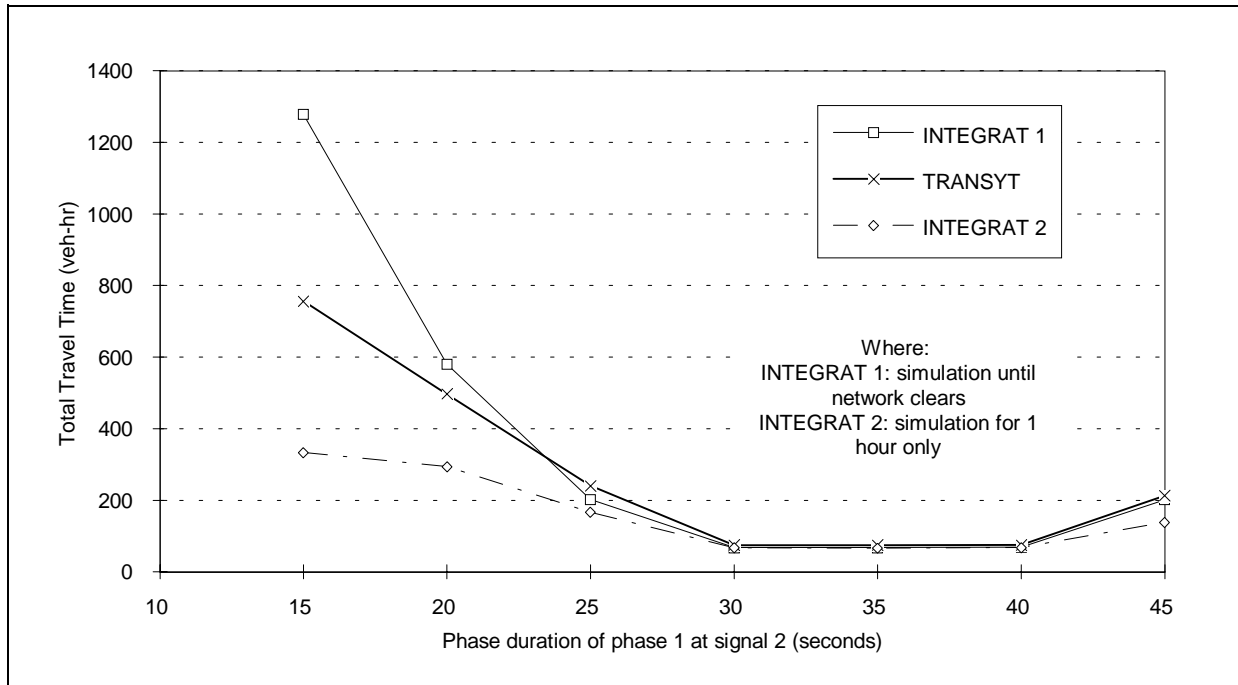


Figure 4: Total travel time variation as a function of phase split