A COMPARATIVE STUDY OF THREE URBAN NETWORK MODELS: SATURN, TRANSYT/8 AND NETSIM

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ABSTRACT: *The experience of using three urban network models for predicting the performance of signal co-ordination in an arterial road is reported. The three models, or packages, selected are SATURN, TRANSYT/8 and NETSIM. They represent different levels of modelling details. SATURN has traffic assignment capability but this aspect is not investigated in this paper. The three models were tested using a real-world network in Parramatta, N.S.W. The task of preparing three sets of consistent input data was found to be non-trivial. Several problems were encountered and could be attributed to incompatible structures in these models. For example, the simulation module of SATURN does not directly accept link traffic flows as input data. SATURN was found to underestimate total delay by 29 per cent and fuel consumption by seven per cent when compared with TRANSYT/8. There was, however, no difference between the two models in the prediction of the number of stops. NETSIM was found to have a bias in the lane distribution of traffic flows. This problem frequently created spill-back and the model was difficult to use in near-saturated conditions. TRANSYT/8 was found to be the simplest of the three models in preparing the input data and the most consistent in performance predicition.*

INTRODUCTION

The importance of computer models for traffic planning and management has been emphasised by researchers including Pretty (1982), Richardson (1983), Taylor and Anderson (1983) and Luk et al. (1983a). Eight urban network models were selected for appraisal in Luk et al. (1983a) based on published literature related to the level of model details, applications, validations with field data, traffic assignment technique, computational requirement and documentation. The eight models are CONTRAM, LATM, MICRO-ASSIGNMENT, SATURN, TRANSIGN, NETSIM, TRAFFICQ and TRANSYT/8. It was concluded that, apart from the TRANSYT model (Robertson 1969; Vincent, Mitchell and Robertson 1980), the experience of using the other seven network models is largely limited to the authors themselves. A similar observation was made by Gossip and Tudge (1983) in their evaluation of the SATURN model (Bolland, Hall and Van Vliet 1979; Van Vliet 1982)

This paper describes a comparative study of three of the eight network models, namely, TRANSYT/8, SATURN and NETSIM (Lieberman et al. 1977; Lieberman 1981). TRANSYT/8 and SATURN belong to the category of macroscopic simulation models, in which vehicle movements are modelled as progressions of vehicle platoons. NETSIM is a microscopic model in which the movement of each vehicle is traced through the study network. Neither TRANSYT/8 nor NETSIM has traffic assignment capability. Hence, this paper is limited to the simulation aspect of these models and to their capability of predicting delay and the number of stops in a test network. Readers should refer to Luk et al. (1983a) and the references quoted therein for more details of these models. They can also refer to Gossip and Tudge (1983) for the Australian experience in using the traffic assignment and other facilities of SATURN.

All computer runs for the comparative study were processed on the ARRB CYBER 171 computer. The three models were well-documented and were easily implemented. The latest available versions of each model were used, and were the eighth version of TRANSYT released in 1981, the 1982 version of SATURN (a later version was recently released), and the 1977 version of NETSIM. The NETSIM package is now part of the TRAF package which has yet to be officially released (Lieberman 1981).

DATA PREPARATION

The area chosen for the study is a small portion of the Parramatta network in New South Wales (Figs. 1 and 2) previously used in a survey for the evaluation of area traffic control networks (Luk, Sims and Lowrie 1983b). The test site offers a variety of geometrical situations that may be encountered in an urban area, and could be particularly useful for testing a microscopic model such as NETSIM. These include: double right-turn movements, T-intersections, one-way streets and diagonal turns (a diagonal turn has an obtuse turning angle, e.g. traffic movements 843 and 842 around intersection 84). The test site is modelled as a network of six entry nodes and three internal nodes as shown in Fig. 2. The three internal nodes

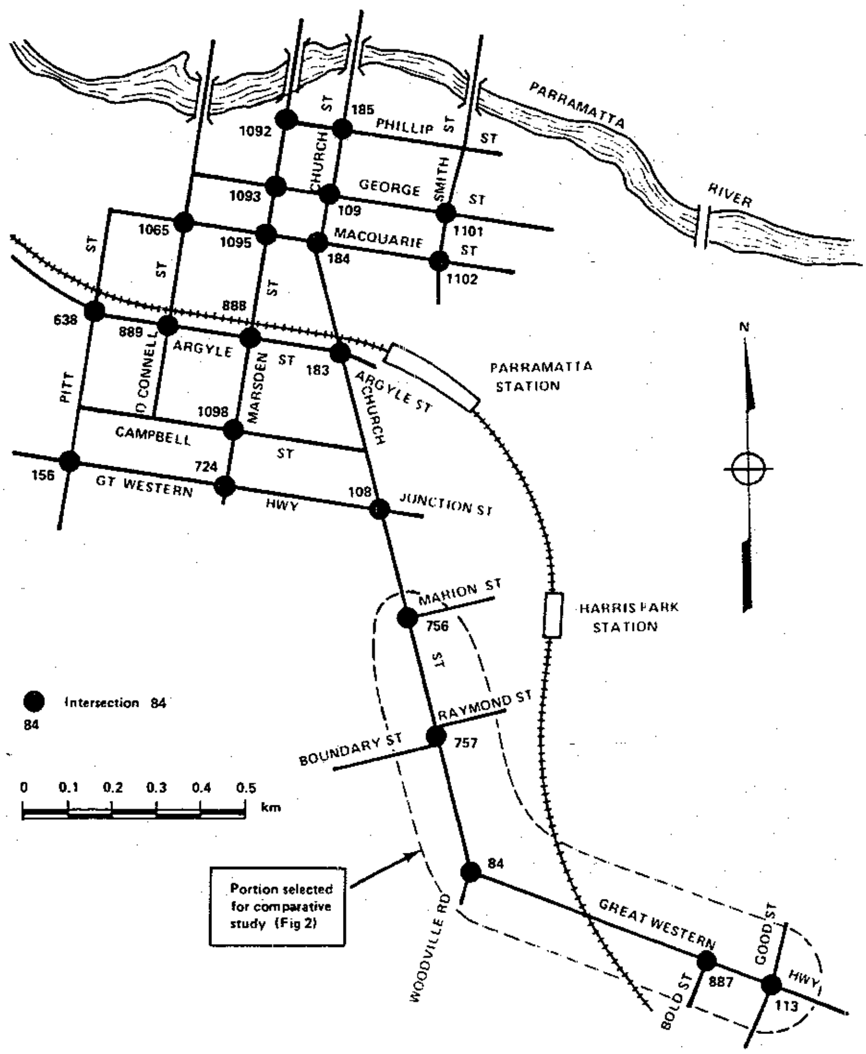

Fig 1 - The Parramatta network in N.S.W.

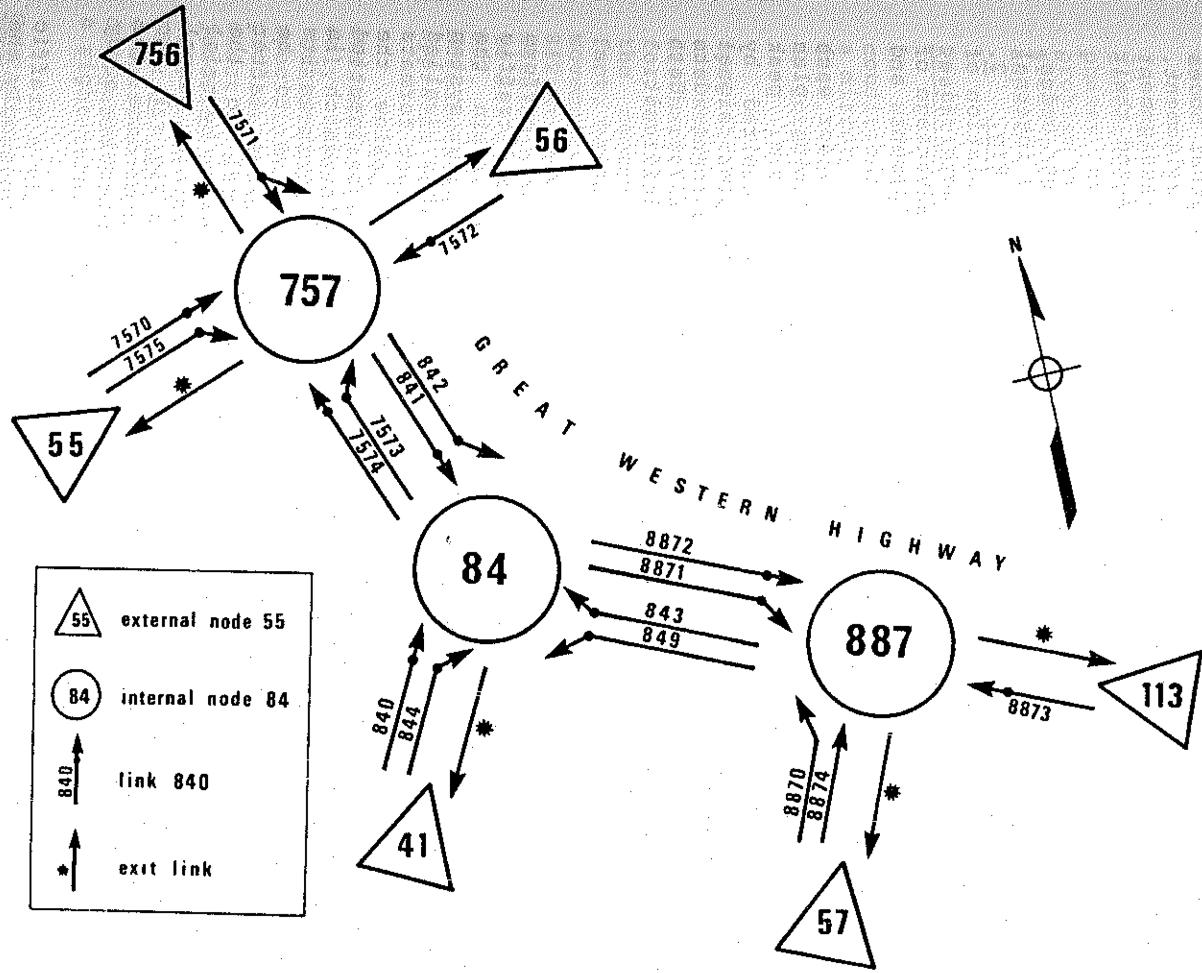

Fig 2 - Representation of the study area in links and nodes (no. 757, 84 and 887) require detailed specification of the signal timings, whereas external nodes are merely for facilitating the entry and exit traffic flows. The TRANSYT/8 model has the advantage in that it does not require external nodes to be specified. Centroids connected to the external nodes are required by SATURN for the purpose of traffic assignment. They must be specified irrespective of whether traffic assignment is performed or not. For clarity, these centroids and their connectors are not shown in Fig. 2.

Seventeen links, or traffic movements between two nodes, were used in TRANSYT/8 to simulate the entry and internal movements. The TRANSYT link numbers are also shown in Fig. 2. Both SATURN and NETSIM provide a more complete representation of the network in that traffic movements exiting the network (i.e. exit links) are also modelled. This is not a disadvantage of TRANSYT because the model is not used for traffic assignment and hence delay on exit links need not be known.

The traffic flows and network geometry data for each model were those previously used for the signal timing plan preparation in the Parramatta survey during the p.m. peak period, from 3:30 to 6:30 p.m. The input data required by TRANSYT/8 was easily generated. This is because the p.m. signal plan was originally prepared using TRANSYT/7, and the input data specification for versions 7 and 8 of TRANSYT are similar. Data preparation for SATURN and NETSIM was, however, more difficult.

Preparing Data For SATURN

The SATURN package is composed of several modules that perform tasks such as network building, traffic assignment and traffic simulation. These modules are stand-alone units within the package and are related to each other through input/output system files. TRANSYT/8 and the simulation module of SATURN (called SATSIM) have a similar structure, although their input formats are vastly different. In particular, SATSIM does not allow the direct input of link flows. Link flows have to be inputted through a system file created by the assignment module, which in turn requires an origin-destination (O-D) trip matrix as its input. Hence, for the present study, an O-D matrix had to be prepared and balanced so that the assigned flows (after processing by the assignment module) were identical to the required link flows. The balancing was done manually by trial and error for the test network but would be an impossible manual task for the whole 22 intersection network in Fig. 1. An attempt to change the SATURN program codes to accommodate the direct input of flows was unsuccessful. The comparative study therefore had to be restricted to a small network.

It should be mentioned that SATURN is basically a traffic assignment package. As such, users are expected to supply the O-D trip matrix, and not the traffic flow pattern. However, in most assignment applications, a good base situation should initially be established using existing traffic flow information. Such a base situation will provide an appropriate starting point in the assignment-simulation iterative loop within SATURN or any other similar package. The initial flow pattern in SATURN is currently determined from a fixed percentage of the user-supplied link capacities. Such a pattern naturally does not resemble any real-world traffic siutation.

A slight misinterpretation of the user's manual occurred in the specification of a traffic movement that runs into two consecutive green phases. This led to the problem of two green phases separated by a four to five second intergreen. The problem was resolved by specifying the intergreen as a separate green phase. The user's manual should be amended to clarify this aspect.

Preparing Data For NETSIM

The NETSIM package simulates North American right-hand drive conditions. The network in Fig. 2 had to be inverted to create a mirror image suitable for NETSIM. This was not a difficult task, but great care was required to prepare the input data and to interpret the results.

A more serious problem was encountered in the specification of saturation flows. The links between nodes are not separated into movements as they are in TRANSYT/8. Only one discharge headway (the reciprocal of saturation flow) is given for vehicles travelling on an approach. This headway is used as the common headway of every lane in that approach. In actual fact, headways for different lanes and/or different turning movements could vary considerably. For example, links 841 and 842 at intersection 84 represented different movements and their saturation flows were different because two lanes were allocated to 841 and only one lane was allocated to the left-turn movement 842. This inability to specify discharge headways by lanes or movements restricts the performance predictions in NETSIM to the approach level.

Another problem occurred in the specification of the channelisation of each lane according to vehicle movement. The only classification available for a through movement is 'UNRESTRICTED', and this is not clearly defined. The specification was essentially a subjective process and the problem is complicated by the fact that intersection 84 is not exactly a T-junction. The intersection is also a congested junction with heavy flows in all three approaches. Many computer runs were performed in order to classify the turning movements. Link 843 was initially designated as a right-turn movement, but excessive delay was found to occur. It was finally decided to designate 840 and 849 as left-turns, 841 as unrestricted, 844 as a right-turn, and 842 and 843 as a pair of diagonal turns.

COMPARING MODEL OUTPUTS

It was previously mentioned that 17 links were used in TRANSYT/8 to model traffic movements within the network. This level of detail appears adequate for comparison purposes. However, in NETSIM, traffic movements that belong to the same physical approach are aggregated by the model to produce a single value of delay or the number of stops for that approach. Consequently, TRANSYT/8 and SATURN are compared at the link level in Table I and all three models are compared at the approach level in Table II. The models are also compared at the network level by weighting link distance, delay and the number of stops with traffic flows as follows:

$$\text{Total delay} = \sum_i q_i . t_i \quad \text{(veh-h/h)}$$

$$\text{Total stops} = \sum_i q_i . h_i \quad \text{(veh-stops/h)}$$

$$\text{Total demand} = \sum_i q_i . l_i \quad \text{(veh-km/h)}$$

(or distance travelled)

where q_i, t_i , h_i and l_i are the flow (veh/h), delay (h), no. of stops (per h), and distance (km) of link respectively.

SATURN does not output stops prediction on a link basis, although a value for the total network stops is produced at the end of a run. Referring to Table I, the TRANSYT/SATURN comparison results are summarised as follows:

(a) The link delay (in veh-h/h) predicted by SATURN is always less than that by TRANSYT/8. The difference also increases with the degree of saturation. At the network level, SATURN was found to underestimate total delay by 29 per cent. The reason is that SATURN, as noted in the user's manual, does not consider the random delay due to the average number of vehicles that fail to discharge during the green phase and hence form an initial queue at the start of the red phase. The left-over or overflow queue fluctuates with the random arrival of vehicles at a signalised intersection and increases with the level of congestion. The uniform and random delays predicted by TRANSYT/8 are 88.4 veh-h/h and 40.1 veh-h/h respectively. The absence of the random delay would result in vehicles being assigned to links that are already quite congested.

(b) The total number of vehicle stops per hour predicted by SATURN closely matches the TRANSYT/8 prediction to within 0.1 per cent.

(c) Predictions on fuel consumption were obtained by weighting the total demand, delay and stops with three default fuel parameters in SATURN as follows (Ferreira 1983):

Fuel (L/h) = 0.07 x demand + 1.2 x delay + 0.016 x stops

The two predictions are within seven per cent.

In general, the simulation models have similar structure and, as expected, similar predictions on delay and the number of

TABLE I

LINK DELAY COMPARISON BETWEEN SATURN AND TRANSYT/8

Link No.	Flow (veh/h)	Degree of sat. (%)	Delay (veh-h/h)		
			SATURN	TRANSYT/8	% Diff.*
840	942	87	9.16	12.3	-26
841	973	93	9.73	14.9	- 3.5
842	928	55	0.31	1.01	-69
843	1425	88	4.75	7.52	-37
844	446	95	7.19	13.0	- 4.5
849	827	46	0	0.60	100†
7570	137	53	1.94	2.55	-24
7571	1585	73	14.1	15.4	- 8.6
7572	265	53	2.87	3.31	-13
7573	234	42	2.34	1.69	38
7574	2133	72	4.80	5.33	- 9.9
7575	75	16	1.06	1.13	- 6.2
8870	198	20	1.16	1.21	- 4.1
8871	433	96	6.13	12.5	-51
8872	941	33	0.97	0.78	24
8873	2211	92	20.3	27.0	-25
8874	326	90	4.89	8.60	-43
Total delay (veh-h/h)			91.7	129	-29
Total stops (per h)			9250	9262	0
Total demand (veh-km/h)			4881	4881	0
Fuel consumption (L/h)			643	600	7

* Calculated as: (SATURN-TRANSYT)/TRANSYT

† Link 849 is a permanent left-turn movement with priority in N.S.W. and was modelled in SATURN with no delay.

stops. A random delay term should be incorporated in the simulation module of SATURN so that traffic assignments can be made more realistic.

A comparison of delay prediction by the three models is shown in Table II. NETSIM delay predictions are found to be higher in most approaches except those of the minor side-streets (55, 757) and (56, 757). At the network level, the NETSIM delay is 202 veh-h/h compared to the TRANSYT/8 delay of 129 veh-h/h, and yet the network demand in NETSIM is less than that of either TRANSYT/8 or SATURN. It is apparent that NETSIM was over-loaded and could not cope with the demand. Links such as 841, 843, 8871 and 8873, with the degrees of saturation near or greater than 90 per cent, are difficult to simulate. Spill-back (i.e. blocking of the upstream intersection) occurred frequently in approaches (757, 84) and (887, 84). Hence, the results for NETSIM were based on 14 minutes of simulation, before the network was saturated.

Another problem related to the spill-back is the lane distribution of vehicles in the double right turn movement of 844 and the diagonal movement of 843. Two turning lanes were allocated to each of these movements in the model. It was found that the queue distribution was too biased towards the inside lane. As a result, vehicles in the inside lane experienced long delay and created a spill-back situation for the upstream intersection. Attempts were made to correct the problem by changing the embedded parameters of gap acceptance for lane-changing, and by re-classifying the traffic lanes around intersection 84. The effect was, however, minimal. It was decided that the loading on the network had to be reduced before any meaningful comparison could be made. The link flows were therefore reduced by 50 per cent and the predictions in the delay and the number of stops by TRANSYT/8 and NETSIM are shown in Table III.

At the 50 per cent loading level, the network demands in NETSIM and TRANSYT/8 are almost identical. The traffic demands at each approach were also similar, implying that NETSIM was able to reproduce traffic flows stipulated in the input data. In comparison with TRANSYT/8, NETSIM still overestimated delay by 11 per cent and the number of stops by 16 per cent. Although delay on the major movements was overestimated, delay on side-streets with low traffic flow was still underestimated. Overestimation in major movements could again be due to the bias towards the centre lane previously mentioned. There is, however, no obvious reason why the side-street delay should be underestimated. NETSIM could perhaps be more suitable for grid type networks where traffic demands are more evenly distributed.

DISCUSSION AND CONCLUSIONS

The use of NETSIM has not previously been reported in the literature in Australia. However, the package has been actively promoted in the U.S. in the past ten years by the Federal Highway Administration. NETSIM was used in several comparative studies with various U.S. versions of TRANSYT (e.g. Berg *et al.*

TABLE II

APPROACH DELAY COMPARISON BETWEEN THE THREE MODELS AT 100% LOADING

Approach	SATURN Delay ($\frac{veh-h}{h}$)	TRANSYT/8 Delay ($\frac{veh-h}{h}$)	NETSIM Delay ($\frac{veh-h}{h}$)
(756,757)	14.1	15.4	20.1
(55,757)	3.00	3.68	1.49
(84,757)	7.14	7.02	9.40
(56,757)	2.87	3.31	0.42
(757,84)	10.0	15.9	40.4
(41,84)	16.4	25.3	50.6
(887,84)	4.75	8.12	12.1
(84,887)	7.10	13.3	8.54
(57,887)	6.05	9.81	4.56
(113,887)	20.3	27.0	54.4
Total delay (veh-h/h)	91.7	129	202
Total demand (veh-km/h)	4881	4881	4305

TABLE III

DELAY AND STOP COMPARISON BETWEEN TRANSYT/8 AND NETSIM AT 50% LOADING

Approach No.	Demand (veh-km/h)			Delay (veh-h/h)			Stops (1/h)		
	TRANSYT/8	NETSIM	% Diff. †	TRANSYT/8	NETSIM	% Diff. †	TRANSYT/8	NETSIM	% Diff. †
(756,757)	206	208	1	5.95	6.60	11	434	520	20
(55,757)	27	26	-3.7	1.71	0.58	-66	79	86	9
(84,757)	373	370	-0.8	1.48	4.04	173	146	470	222
(56,757)	17	17	0	1.44	0.17	-88	64	84	31
(757,84)	290	286	-1.4	5.12	5.08	- 0.8	329	518	57
(41,84)	236	237	0.4	7.31	7.25	- 2.9	512	459	-10
(887,84)	642	630	-1.9	1.90	4.85	155	237	199	16
(84,887)	413	420	1.7	2.67	3.25	22	269	238	-12
(57,887)	50	50	0	3.12	1.89	-39	214	183	-14
(113,887)	188	186	-1.1	7.99	9.28	16	716	716	0
TOTAL	2442	2430	-0.5	38.7	43.0	11	3000	3470	16

† Calculated as (NETSIM-TRANSYT)/TRANSYT

1982; Dudeck, Goode and Poole 1983) where it was also found to overestimate delay. Referring to Table IV, Luk and Akcelik (1983) compared TRANSYT/8 predictions with measured data for the total survey area of Fig. 1 when under fixed-time signal co-ordination. They found that TRANSYT/8 overestimated the network slowness (i.e. the reciprocal of network speed) by 9 to 25 per cent, and the number of stops by 12 to 30 per cent. A similar observation was made by Robertson, Lucas and Baker (1980), who reported that TRANSYT/6 underestimated speed by 10 per cent. Hence, NETSIM predictions would appear to deviate further from real-world situations than TRANSYT/8 does. In a detailed validation test on NETSIM, Hillson (1979) also concluded that the conditions for which the model can reproduce field occurrences, and the loading level at which it can be used for predictive capabilities, have yet to be identified.

TABLE IV

COMPARING TRANSYT/8 PREDICTIONS WITH MEASUREMENT FOR TOTAL NETWORK

Time Period	Slowness (s/km)			Stops (per km)		
	Predicted by TRANSYT/8	Measured	Pred.-Meas. / Meas. (%)	Predicted by TRANSYT/8	Measured	Pred.-Meas. / Meas. (%)
Lunch	148	135	9.6	1.99	1.64	21
P.M.	189	160	18	2.19	1.95	12
Late P.M.	140	105	25	1.65	1.27	30

Traffic assignment is not investigated in this paper. However, the techniques of traffic assignment are well understood, and assignment accuracies largely rely on the link-delay or speed-capacity functions supplied by the user. These functions are unfortunately labour intensive to obtain. Their functional forms can be quite different, depending on whether they are used for strategic planning or for small area traffic management. Every link of a network should ideally have its own functional form to reflect reality. It appears that TRANSYT/8, while not having the capability of assignment, does provide a reliable base situation in small area studies. For these studies, the model could possibly be coupled to a manual assignment process utilising sound traffic engineering judgement and good understanding of the local traffic characteristics.

The major conclusions of this study can be summarised as follows:

(a) TRANSYT/8 is comparatively simple in both data preparation and interpretation of results. The model is capable of producing predictions in delay and the number of stops on a link by link basis. Its accuracy of prediction cannot be assessed in the present study, but it is conceptually more accurate than SATURN which does not have random delay in its formulation. TRANSYT/8 is also more consistent than NETSIM which underestimates side-street delay but overestimates delay on major movements.

(b) If SATURN allows the direct input of link flows, then the iterative assignment-simulation process within the model can begin from a good starting point representing a real-world base situation. The convergence of this iterative process should also improve. The model can further benefit from the incorporation of random delay in the simulation module as suggested in (a).

(c) NETSIM was found to be disappointing in a number of areas including, in particular, the inability to specify saturation flows by lane (or by movement), and the bias towards the centre lane in the lane distribution of traffic flows. Unlike TRANSYT, it requires the specification of external nodes and centroids even though it is also a purely simulation model. NETSIM appears least suitable for the arterial road type at a high level of congestion. It could be suitable for grid type networks where traffic flows are more evenly distributed. More validation tests are necessary before NETSIM can be used as a design tool such as TRANSYT/8.

In summary, the task of preparing three consistent sets of input data for the small study area has been found to be non-trivial. The intrinsic structure of each model was found to dictate the input data requirement. The limitations of a model should, therefore, be recognised before any meaningful interpretation of model predictions can be made.

REFERENCES

BERG, W.D., LAU, Y.K., DETTMANN, D.C. and RYLANDER, G.F. (1982). Case study evaluation of alternative signal timing plans for an oversaturated street network. ITE Journal 52(4), pp. 23-27.

BOLLAND, J.D., HALL, M.D. and VAN VLIET, D. (1979). SATURN - a model for evaluation of traffic management schemes. Inst. for Transp. Studies, Univ. Leeds, Working Paper 106.

DUDECK, G.R., GOODE, L.R. and POOLE, M.R. (1983). TRANSYT-7F and NETSIM comparison of estimated and simulated performance data. ITE Journal 53(8), pp. 32-34.

FERREIRA, L.J.A. (1983). Assessing the energy impacts of urban transport management measures. Proc. 8th Aust. Transp. Res. Forum, Canberra, Vol. 2, pp. 206-227.

GOSSIP, I. and TUDGE, R. (1983). An Australian evaluation of SATURN. Proc. 8th Aust. Transp. Res. Forum, Canberra, Vol. 2, pp. 150-170.

HILLSON, B.A. (1979). Validation and practical application of the UTCS-1 network simulation model on an urban arterial street. Purdue University, Joint Highway Research Project IN/JHRP-79-12. Interim Report.

LIEBERMAN, E., WORRALL, R.D., WICKS, D. and WOO, J. (1977). NETSIM model. U.S. Fed. Highw. Admin. Reports FHWA-RD-77-41, 42, 43, 44, 45.

LIEBERMAN, E. (1981). Enhanced NETSIM program. Transp. Res. Board, Special Rep. 194, pp. 32-35.

LUK, J.Y.K., AKCELIK, R., BOWYER, D.P. and BRINDLE, R.E. (1983a). Appraisal of eight small area traffic management models. Aust. Rd. Res. 13(1), pp. 25-33.

LUK, J.Y.K., SIMS, A.G. and LOWRIE, P.R. (1983b). The Parramatta Experiment - evaluating four methods of area traffic control. Australian Road Research Board. Research Report ARR No. 132.

LUK, J.Y.K. and AKCELIK, R. (1983). Predicting area traffic control performance with TRANSYT/8 and an elemental model of fuel consumption. Australian Road Research Board. Internal Report AIR 388-1 (also submitted to the 12th ARRB Conference).

PRETTY, R.L. (1982). A review of traffic modelling techniques. Papers, Joint SAE-A/ARRB 2nd Conference on Traffic Energy and Emissions. Melbourne, Paper 27.

RICHARDSON, A.J. (1983). Traffic simulation - its potential contribution to road planning and research. Australian Road Research Board Workshop on Rural Traffic Simulation. Program and Papers. pp. 1-12.

ROBERTSON, D.I. (1969). TRANSYT: a traffic network study tool. Road Res. Lab. (U.K.) RRL Rep. LR 253.

ROBERTSON, D.I., LUCAS, C.F. and BAKER, R.T. (1980). Coordinating traffic signals to reduce fuel consumption. Transp. Road Res. Lab. (U.K.) TRRL Lab. Rep. LR 934.

TAYLOR, M.A.P. and ANDERSON, M. (1983). A hierarchical approach to modelling network flows. Proc. 8th Aust. Transp. Res. Forum, Canberra. Vol. 2, pp. 136-149.

VAN VLIET, D. (1982). SATURN - a modern assignment model. Traff. Eng. Control 23(12), pp. 578-581.

VINCENT, R.A., MITCHELL, A.I. and ROBERTSON, D.I. (1980). User's guide to TRANSYT/8. Transp. Road Res. Lab. (U.K.) TRRL Lab. Rep. LR 888.

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