

'AN APPLICATION OF EMME/2 AUTO-ASSIGNMENT WITH DETAILED MODELING OF ACTIVITY AT NODES'

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Abstract

The Auckland Region of New Zealand has a metropolitan population of some 1,000,000. Traffic in the order of 150,000 veh/day occurs on some roads. The sub-regional area of Waitakere, population 150,000, has been used for the development of an Auckland Sub-regional Road Traffic Assignment Model (ASRTAM). The road trip matrices used are dis-aggregated traversals of regional matrices produced by the Auckland Regional Council's 4-stage transportation model.

The regional model has large zones and a relatively coarse network with delay functions for links. In ASRTAM the emphasis is on delay functions for turns and a compatible zone structure. The delay functions stem from select analytic models for priority, roundabout and signal controlled intersections, and they are allocated to every turn in the network; provision is made for bottlenecks.

For the purpose of EMME/2 assignment a 3-parameter conic function is fitted to the analytic delay function of each turn. The more numerous parameters of the latter are either fixed (eg intersection lanes with their turn disciplines), or volume dependent variable (eg capacities for priority controlled turns, green times for signal controlled turns).

Fixed parameters are input as EMME/2 turn attributes. Variable parameters are also turn attributes but are calculated after assignment using the (damped) volumes put out by the assignment; then the assignment is run again. This feedback is automated and repeated the number of times required for steady results. Although the nature of the process can be debated it has produced accepted outcomes for Waitakere City and other parts of the Region.

The paper provides a context of statistics for the Waitakere network and traffic zone structure, an outline of the functions and procedures used in ASRTAM, and briefly summarizes the validation methodology and validation results for Waitakere City.'

1 INTRODUCTION

1.1 Background

The Auckland Region of New Zealand has a metropolitan population of some 1,000,000. Traffic in the order of 150,000 veh/day occurs on some roads. The sub-regional road network for Waitakere, population 150,000, has been used (1995-96) for the development of an Auckland Sub-regional Road Traffic Assignment Model (ASRTAM). The trip matrices are dis-aggregated traversals of regional matrices produced by the Auckland Regional Council's 4-stage transportation model.

The regional model has large zones and a relatively coarse network with delay functions for links. In ASRTAM the emphasis is on delay functions for turns and a compatible zone structure. These functions stem from select analytic models for priority, roundabout and signaled intersections and are allocated to every turn in the network; provision is made for bottlenecks.

For the purpose of EMME/2 assignment a 3-parameter conic function is fitted to the analytic delay function for each turn. The more numerous parameters of the latter are either fixed (eg intersection lanes with their turn disciplines), or volume dependent variable (eg capacities for priority controlled turns, green times for signal controlled turns).

Fixed parameters are input as EMME/2 turn attributes. Variable parameters are also turn attributes but are calculated after EMME/2 assignment using the (damped) volumes put out by the assignment;

then the assignment is run again. This feedback is automated and repeated the number of times required for steady results.

Although accepted outcomes have resulted in the Waitakere case and for other parts of the Region, the feedback process has been questioned recently by a consultant to Auckland City; it is contended that a unique optimal solution is not guaranteed. Auckland, which has widespread congestion, is to develop a less detailed assignment process that avoids feedback.

1.2 Motivation

Travel in a network is by way of roads and intersections. Intersection time is generally a significant proportion of total travel time and it is desirable that it be explicitly accounted for in traffic assignment. Neighbourhood operating characteristics are required for detailed network investigations, the economic evaluation of projects, and are of interest to the elected representatives of the community.

Given a zone structure fine enough to appropriately limit the traffic generated through centroids and a good trip matrix, it was considered possible by Foster [1], with turn delays modelled, to assign traffic with a precision where turn volumes would have an RMSE of as little as 50 veh/hr. Also, the EMME/2 network calculator could be used to derive from such assignments a range of road user costs specified for project evaluation by Transfund New Zealand [2].

A limitation might have been the run time for an assignment with turns modelled but the run time proved to be tolerable and could be expected to improve with PC development.

1.3 Orientation

In EMME/2 roads are referred to as 'links', intersections as 'nodes', and movements as 'turns'.

Nodes are referred to by their unique 'node numbers', 'j'. For nodes, 3 node specific data items referred to as 'uj1', 'uj2', 'uj3', and extra attributes referred to by chosen names '@name', can be used.

In ASRTAM uj1 is an integer code for the control type appertaining to node j. As examples, 4 implies a 4 leg intersection under priority control, 5 a roundabout with 3 legs, and 8 an intersection under signal control.

'Penalty' (that is delay) functions, fpNN, with 'index' numbers NN, can be formulated for turns. The independent variable of the penalty function for a turn is its turn volume 'pvolau'. The function can have up to 3 (turn specific) parameters, 'up1', 'up2', and 'up3'. During assignment upi have fixed values.

Any 'extra attribute' of turns can be referenced by a chosen name '@name'. In ASRTAM these are the independent variables of formulae for upi (for example, @u the green time to cycle time ratio for a signalled turn), or more fundamental quantities (for example, @ri, the number of exclusive right turn lanes of the intersection approach serving the subject turn).

An important turn extra attribute, @tt, is used to transmit the intersection type to the OPFLOW and SIGMA programs (see below). This is the same as uj1 for non-signalled turns, but for signalled turns it includes a code for the applicable signal phasing. As examples, 303 implies a 3-leg intersection with phasing type 3, and 413 means a 4-leg intersection with phasing type 1 for road 1 and phasing type 3 for road 2.

Turns are also given systematic reference numbers, @tpf, for use by OPFLOW and SIGMA. For 3-leg non-signalled intersections turns are numbered 1 through 9 anti-clockwise from the left turn of the side road. For 4-leg non-signalled intersections turns are numbered 1 through 12 from the left turn of the southern most leg. For signalled intersections the turn numbers are the same except that 20 is

added. For banned turns, @tpf is 0, and the turn penalty function index, NN, is also 0. NN = -1 implies that turn delays are not calculated for the turn.

'Turn tables' can be assembled for nodes. Each row of the turn table for a node contains the data for a particular turn. The data for a turn are its 'at', 'from' and 'to' node numbers, its delay function index, NN, its specific values for the 3 delay function parameters, upi, its specific values for extra attributes, @name, its turn volume, pvolau, and its delay as calculated by its turn penalty function.

1.4 Assignment Procedure Overview

Figure 1 provides an overview of the ASRTAM assignment procedure. Apart from the OPFLOW and SIGMA programs, all elements of Figure 1 are EMME/2 features. OPFLOW and SIGMA are FORTRAN routines that model aspects of non-signalised and signalised intersection operations.

OPFLOW calculates opposing volumes for turns. It was written to test procedures before commissioning the more complex SIGMA program; it could be replaced by an EMME/2 macro.

Signalised intersection analysis is more complicated and SIGMA is considered to be a vital element. SIGMA distributes turn volumes to lanes, finds signal cycle and phase times, also required factors for turn volumes when they are used in the signal delay function.

OPFLOW and SIGMA produce the extra attributes used by the EMME/2 network calculator to compute the turn penalty function parameters, upi.

The procedure is controlled continuously by EMME/2 macros developed by Valero and Balance [3]. The data flows labelled [1] and [2] in Figure 1 occur by way of text file batching. The procedure can be cold started by switching off all turn penalties for the initial assignment, or by using warm values for variable attributes.

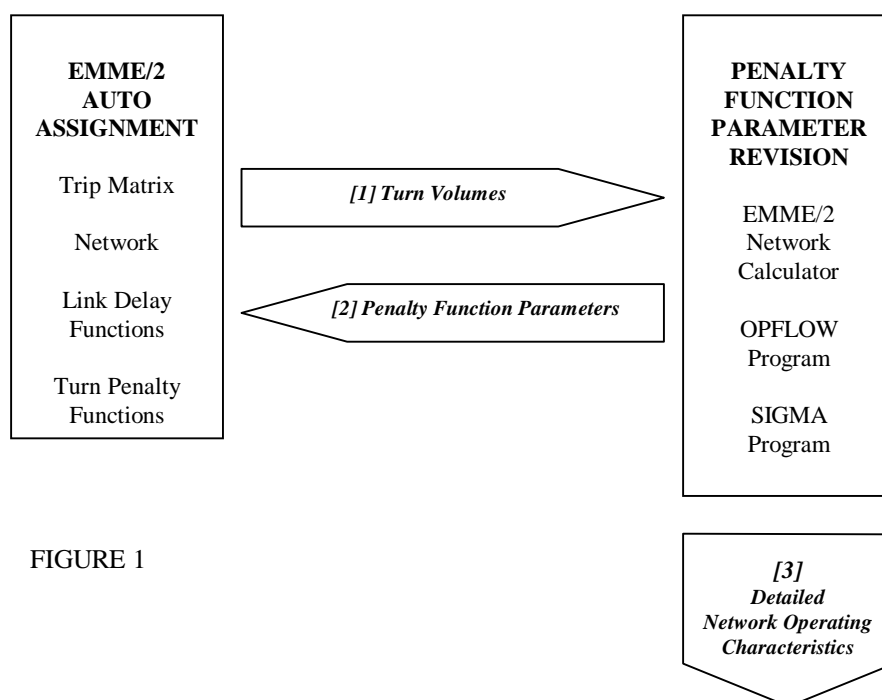


FIGURE 1

2 PRECISION

2.1 Precision and Precision Conditions

It should be apparent that a coarse zone structure would not be compatible with a detailed network. Prior to the development of ASRTAM Foster [1] defined levels of precision for assignment volume outputs and stated the conditions he believed necessary for their attainment. This information is tabled.

ITEM	GUIDELINE PRECISION LEVEL 1 (250 veh/hr RMSE)	GUIDELINE PRECISION LEVEL 2 (100 veh/hr RMSE)	GUIDELINE PRECISION LEVEL 3 (50 veh/hr RMSE)
[1] Intersection Delays Estimated At	Links/Nodes	Approaches	Lanes by Turn
[2] Household Equivalents / Zone (1)	1000-1500	400-600	200-300
[3] Peak Direction Volume / Zone	1000 per hour	500 per hour	250 per hour
[4] Centroid Connectors / Zone	4	2-3	1-2
[5] Parking Areas Represented	>150 spaces	>100 spaces	>50 spaces
[6] Links / Zone	8	5	3
[7] Analysis Period (minute)	60/120	15/60	10/15

Note (1) 1 retail job = 4.0 household units, 1 non-retail job = 1.2 household units

Foster [1] emphasised that precision could be affected by the trip matrices derived from the regional model, and that adjustments might be required when they are dis-aggregated in sub-regional areas.

2.2 Waitakere Profile (See Appendix 1 Map)

Waitakere Eco City lies to the west of Auckland and North Shore Cities and between them the Waitemata Harbour. The main road connections are a state highway, in part a harbour edge Motorway (30,000 to 80,000 veh/day), and a parallel spinal arterial (25,000 to 35,000 veh/day) the Great North Road. Waitakere has two sub-regional commercial centres, New Lynn in the south, Henderson central; a large new centre, Westgate, is being developed in the north. There are several industrial zones but a majority of residents commute by car, bus and train from Waitakere to jobs elsewhere.

For the base year am peak traffic period, subject of this paper, traffic queues of up to 2 km occurred on the Great North Road and queues of 2 km and more occurred on the Motorway.

The Waitakere model meets the Level of Precision 3 guideline conditions for items [1] through [6] of the table but is subject to the quality of the regional matrix. Condition [7] is not satisfied since the matrix is a 2-hour matrix, but this is mitigated by the application of peak flow factors in the delay calculations.

The model has 11 external zones, 225 internal zones with 260 centroid connectors; there are 4 zones with peak direction volumes greater than 250 veh/hour but these correspond to real connections from 'end' zones.

There are some 1300 links. Of the 950 nodes 36 are signal controlled, 25 are roundabouts, and 190 are priority controlled. The others are geometric nodes or remote nodes of no significance to traffic operations.

The zone structure was deliberately designed to satisfy the conditions for Level of Precision 3, and the modelling of turns in terms of Figure 1 was considered viable.

3 FEED BACK PROGRAMS AND PROCEDURES

3.1 SIGMA Program

Introduction

The SIGMA program accepts from EMME/2 lane configurations for the intersection approaches, lane saturation flows, signal phasing type, and current turn volumes, to produce for each turn and return to EMME/2, its 'turn volume factor', its cycle time, and green to cycle time ratio. These are required for the network calculator to produce up1, up2, and up3 for the conic signal delay function.

The procedure and analysis were conceived and specified by the author. Details were developed and programmed into some 5000 lines of FORTRAN code by Hoogenboom [4]. The intention was to have a fast program that would deal with signal control at a level of detail appropriate to network planning; intricate treatments for short lanes and the like are not catered for and are not considered to be required.

It is assumed that all lanes of an approach that serve a common demand will be given the same saturation flow. However, significant turn restraints are allowed for by factoring turn volumes to equivalent 'through units'.

Distribution of Traffic to Lanes

The first step in SIGMA is the distribution of approach traffic to approach lanes on the assumption that the resultant levels of saturation in related lanes will be equal. This can be involved if there are several lanes, some of which are shared by different turns. In SIGMA all possibilities are anticipated and solved by simple algebra or a 'linear program'.

Having completed the distribution of demand to lanes, 'turn volume factors', K , can be found. The turn volume factor concept is best appreciated by example. Suppose for an approach that the left, through, and right volumes are respectively 100, 700, and 200 veh/hr, and that there is 1 lane shared by left and through turns, and 1 lane shared by right and through turns. Suppose that the right turn equivalent has been computed by SIGMA as 3, and that the left turn equivalent is 1.25.

Simple algebra finds that there would be 588 through veh/hr in the shared left turn lane, and 112 through veh/hr in the shared right turn lane. Each lane carries the equivalent of 712 through veh/hr. Subsequently, when the signal cycle time and the green phase times are determined, SIGMA would allow for 713 equivalent veh/hr in these lanes. And so when the delay function is used in EMME/2, a factor of $712/100 = 7.1$ is applied to the left turn volume, and likewise factors $713/700 = 1.1$ and $713/200 = 3.6$ are applied to, respectively, the through turn volume and the right turn volume.

Critical Movements

The signal phasing identifies turns that are allowed together, and the order of occurrence of turns that are not allowed together. If the time required for each turn is known, these times and the phasing define a 'network of turns' for which there is a 'critical path'. SIGMA uses this device to find the critical turns for the signal cycle. The required times for a turn are taken to be (demand in vehicle/hour)*(saturation flow headway in seconds)/(cycle/hour), with the cycle time for this purpose being 100 seconds. 5 second of lost time is assumed between critical turns in series, and for turns in parallel the turn requiring most time is critical.

Cycle Time and Green Time Ratios

SIGMA uses critical turns data to compute an optimum signal cycle and the effective green times for the signal phases, in accordance with:

$$C = (1.5 * 5 * n + 5) / (1 - \text{SUM}(K * q/s)) \quad [3:1]$$

$$g = (C - 5 * n) * (K * q/s) / \text{SUM}(K * q/s) \text{ and } u = g/C \quad [3:2]$$

Where n is the number of phases (ratio)
 K is the turn factor for q (ratio)
 s is the saturation flow for q (veh/hour)
 q is the (damped) critical volume (veh/hour)

Features

The through equivalent for an opposed right turn is calculated as $\text{MIN}[5, (1 + \text{opposing volume}/250)]$; the through equivalent for a left turn is a fixed attribute defaulted to 1.05.

For 3-leg intersections there are 5 phasing arrangements, and for 4-leg intersections there are 27 phasing arrangements; further arrangements can be programmed as required.

SIGMA provides for parallel and exclusive pedestrian phases, one way streets, and banned turns. Sensible minimum green times are assured by a minimum volume for all turns of 75 veh/hr.

SIGMA does not deal with signal linking; the effect of co-ordination is allowed for by appropriate factors applied to the delay function results, (see extra attribute Z referred to in Section 4.1).

Signal Management Strategy

The green ratios, u , have the potential to profoundly affect travel paths, since delay is very sensitive to this ratio. The ASRTAM feed back procedures could lead to green ratios that are globally efficient but not in accordance with sensible expectations at the local level. The simple inclusion of a signalled intersection in the model does not imply the existence of an associated traffic management strategy.

Provision is made for 3 levels of freedom in signalled intersection analysis using SIGMA; C , u and k are all allowed to vary, only u and k are allowed to vary, only k varies. A turn extra attribute, @cal, is used to indicate the option required. This provision and the provision for signal linking factors, Z , enable a management strategy to be represented in the procedures.

3.2 OPFLOW Program

For each turn of a priority-controlled intersection OPFLOW adds up the volumes of turns having priority over the subject turn to produce the opposing flow volume. Allowance is made for factors to be applied to the opposing turn volume components as required. These factors are extra attributes of the turn; for example, if a turn is made into a fully protected lane where it would otherwise have encountered opposing traffic the factor value is 0 for that opposing traffic.

The opposing traffic volume for a turn is required for the calculation of its entry capacity, which is then used in the priority turn delay function (see Section 6.1).

3.3 Feedback Procedure

Introduction

There was the concern that feed back might result in oscillating results and that the assignment run times might be impractical.

Delays at traffic signals are very sensitive to green ratios. To reduce the interaction between signal timings and adjusting turn volumes priority control parameters are updated more frequently than signal control parameters. One 'ASTRAM iteration' consists of one EMME/2 assignment for which signal and priority parameters have been updated and fed back, followed by three EMME/2 assignments for which only priority control parameters have been updated and fed back.

Also to reduce sensitivity, the turn volumes used by SIGMA are the averages of the latest assigned and the previously used volumes.

Base Year Convergence

The effect of the number of ASRTAM iterations and number of EMME/2 iterations was studied to determine the minimum iterations required for a stable outcome. The delay function parameters for each ASRTAM iteration were inspected, and the EMME/2 iteration effects were assessed by scattergram comparisons of results.

It was considered on this basis that 10 ASRTAM and 15 EMME/2 iterations would do for Waitakere City base year investigations. In confirmation, convergence results for the Great North Road / Sabulite Road intersection, which are typical, are tabled first, followed by some EMME/2 assignment finishing conditions.

Great North / Sabulite Intersection
Stability Inspection for Base Year
Iteration sequence 10/15

Turn	Iteration >	1	2	3	4	5	6	7	8	9	10
		u	u	u	u	u	u	u	u	u	u
S l		0.18	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
S t		0.18	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
S r		0.18	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
E l		0.27	0.25	0.24	0.24	0.24	0.23	0.23	0.24	0.24	0.24
E t		0.27	0.25	0.24	0.24	0.24	0.23	0.23	0.24	0.24	0.24
E r		0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
N l		0.14	0.16	0.17	0.18	0.18	0.18	0.18	0.19	0.18	0.18
N t		0.14	0.16	0.17	0.18	0.18	0.18	0.18	0.19	0.18	0.18
N r		0.14	0.16	0.17	0.18	0.18	0.18	0.18	0.19	0.18	0.18
W l		0.45	0.44	0.43	0.43	0.42	0.42	0.42	0.42	0.42	0.42
W t		0.45	0.44	0.43	0.43	0.42	0.42	0.42	0.42	0.42	0.42
W r		0.23	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
		K	K	K	K	K	K	K	K	K	K
S l		1.00	1.12	1.15	1.15	1.14	1.14	1.14	1.13	1.14	1.13
S t		1.53	1.28	1.26	1.26	1.28	1.27	1.28	1.28	1.27	1.28
S r		2.90	3.07	2.97	2.96	2.95	2.94	2.96	2.96	2.96	2.96
E l		3.27	3.36	3.37	3.37	3.34	3.34	3.35	3.34	3.34	3.34
E t		0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
E r		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N l		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N t		1.90	1.75	1.75	1.77	1.77	1.75	1.77	1.78	1.76	1.79
N r		2.11	2.33	2.33	2.30	2.29	2.33	2.29	2.28	2.31	2.27
W l		8.66	8.85	8.77	8.71	8.58	8.47	8.57	8.61	8.62	8.63
W t		0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
W r		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cycle Time (seconds) >		117	94	95	96	96	93	95	96	95	96

Note (1) 10/15 implies 10 ASRTAM and 15 EMME/2 iterations used etc.

Parameter	Iterations 10/15	Iterations 10/14	Iterations 50/50	Iterations 6/10*
Run Time	1.8 hour	1.7 hour	8.0 hour	0.8 hour
Normal Gap	0.15	0.36	0.10	0.43
Relative Gap	0.87%	0.95%	0.53%	2.51%
Max Abs Diff	125 veh/2 hour	101 veh/2hour	92 veh/2hour	138 veh/2hour
Regression 'A'		-1.47	-4.01	2.87
Regression 'B'		0.9996	1.0003	0.9992
Regression STD		26 veh/2 hour	34 veh/2 hour	30 veh/2 hour
RMSE %		3.8	8.8	5.5
veh-km	526,656	525,800 (0.998)	524,901 (0.997)	527,922 (1.002)
veh-hr links	10,274	10,259 (0.999)	10,144 (0.997)	10,288 (1.001)
veh-hr nodes	2,489	2,489 (1.000)	2,452 (0.985)	2,623 (1.054)

veh-hr total	12,763	12,748 (0.999)	12,696 (0.995)	12,912 (1.012)
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Note (1) Relative characteristics are with respect to the 10/15 iteration sequence chosen for general work.

Note (*) One priority parameter only feedback per ASRTAM iteration applies for the 6/10 sequence.

Note (2) Run time for Pentium 90 with 12MB RAM.

Future Year Convergence

To determine whether the model would be suitable for future year studies the base network was loaded with the 2021-year trip matrix and the results inspected. It was found for the '10/15' iteration sequence that the parameters had settled into medium to small ranges with some oscillation remaining. For the last 10 of the '50/50' iteration sequence the results were stable with no significant oscillations. The final outcomes for the two iteration sequences are tabled for the Great North / Sabulite Intersection.

Great North / Sabulite Intersection : 2021 Year / Base Network Final Results for the 10/15 and 50/50 Iteration Sequences

Turn	u		K		Delay		Volume	
	10/15	50/50	10/15	50/50	10/15	50/50	10/15	50/50
S l	0.14	0.14	1.13	1.13	0.77	0.75	372	375
S t	0.14	0.14	1.28	1.28	0.85	0.83	345	350
S r	0.14	0.14	2.95	2.98	0.66	0.67	124	130
E l	0.24	0.26	3.34	3.31	0.47	0.45	33	33
E t	0.24	0.26	0.59	0.59	0.51	0.48	101	101
E r	0.05	0.05	1.00	1.00	0.84	0.84	902	888
N l	0.18	0.14	1.00	1.00	0.72	0.74	518	373
N t	0.18	0.14	1.79	1.86	0.55	0.65	195	176
N r	0.18	0.14	2.27	2.16	0.55	0.63	149	142
W l	0.42	0.46	8.63	9.43	0.43	0.36	148	130
W t	0.42	0.46	0.53	0.53	0.48	0.45	2541	2802
W r	0.23	0.25	1.00	1.00	0.51	0.49	507	504

4 GENERAL TURN AND LINK DELAY FUNCTIONS

4.1 Analytic Turn Penalty Function

In ASRTAM the turn penalty function has the general form:

$$\begin{array}{llll} \text{Where} & \mathbf{fpNN(x)} & = \mathbf{Z * D(x) + G} & \text{(min/veh)} & \mathbf{[4:1]} \\ \text{and} & \mathbf{x} & = \mathbf{\# * pvolau} & \text{(ratio)} & \mathbf{[4:2]} \\ & \mathbf{\#} & = \mathbf{(P * K) / (T * Q)} & & \mathbf{[4:3]} \end{array}$$

Here, D (x) is a chosen analytic queuing delay function, Z is a multiplier defaulting to 1 and used to allow for signal co-ordination in terms of guideline factors such as those in the Highway Capacity Manual [5], and G is the geometric delay and currently defaulted to 0.1 minute for all turns.

pvolau is the EMME/2 assigned turn volume in veh per analysis period of T hours, and Q is the capacity of the turn in veh/hour.

P is a 'peaking factor' applying to pvolau. This allows for flow fluctuation during the analysis period and enables the delay function to produce the correct average delay, as suggested by Akcelik and Roupail [6]. P is the average flow rate for the analysis period divided into the average flow rate for flows greater than the average flow rate. For Waitakere, T=2 hours and P varies by location ranging from about 1.1 in busy parts to 1.4 or more on the outskirts.

K is the turn volume factor. It is required for the penalty function to produce correct average delay allowing that the traffic lane chosen for delay estimation may be a shared lane and/or not take all the volume of the subject turn (pvolau). See Section 3.1, 'Distribution of Traffic to Lanes', for further details regarding K.

4.2 Conic Turn Penalty Function

For the purpose of EMME/2 assignment a 3-parameter conic function equivalent to $D(x)$ is used instead. It is a slightly generalised form of the 2-parameter conic form identified by Spiess [7] and stated by him to be ideal for the purpose. It is a monotonic increasing function as required for the EMME/2 assignment algorithms, and is computationally efficient. The conic has the formula:

$$\text{SQRT}\{ \underline{A}*(1-x)^2 + \underline{B}^2\} - \{ \underline{A}*(1-x) + \underline{B} \} + \underline{C} \quad [4:4]$$

Where \underline{A} , \underline{B} and \underline{C} are the 3 parameters to be determined for each turn.

The author found during the development of ASRTAM that the conic function could be fitted to each desired analytic function by equating the values and gradients of the two functions at $x = 1$:

$$\underline{A} = D'(1) \quad [4:5]$$

$$\underline{C} = D(1) \quad [4:6]$$

$$\text{Also } \underline{B} = \{ [\underline{C} - D(0)]/2 \} * \{ [2*\underline{A} - (\underline{C} - D(0))]/[\underline{A} - (\underline{C} - D(0))] \} \quad [4:7]$$

The parameters referred to by the assigning turn penalty function are \underline{A} , \underline{B} , \underline{C} , #, G, and Z. The number of parameters is 6, double the number provided for, and namely up1, up2, up3. This limitation is overcome through a method due to the author. Significant digits of the required parameters, are 'packed' into selected parts only of the digit fields available for upi.

Although this works, computing efficiency is lost in reassembling the parameters for each calculation. Since, the turn penalties are calculated countless times in the course of assignment, it would be desirable to increase the number of turn penalty function parameters in EMME/2 from 3 to at least 6.

4.3 Link Delay Function

Formulation

For ASRTAM the advice from Foster [1] has been accepted that link speed $V(x)$ is not strongly related to x . Traffic is delayed mainly as a result of intersection conditions and in ASRTAM this is modelled through the turn penalty functions. $V(x)$ is taken to fall linearly from free speed $V(0)$, by $v*V(0)$ when volume reaches capacity, v being a small fraction in the order of 0.1, and hence $D(x)$ for links is determined to be:

$$\begin{aligned} D(x) &= 60 * \text{length} / [V(0) - x * (V(0) - V(1))] && (\text{min}) && [4:8] \\ \text{with } V(1) &= (1-v) * V(0) && (\text{km/hr}) && [4:9] \\ \text{and so } D(x) &= 60 * \text{length} / [V(0) * (1-v*x)] && (\text{min}) && [4:10] \\ \text{also } x &= \text{volau} / (T * Q * \text{lanes}) && (\text{ratio}) && [4:11] \end{aligned}$$

Where T is the analysis period in hours
 Q is the lane capacity in veh/hour
 lanes is the number of lanes, a standard link attribute

$V(0)$, v , and Q are the extra link attributes required for each link.

Representation in EMME/2

The user parameters for links are calculated as:

$$\text{ul1} = V(0) \quad [4:12]$$

$$\text{ul2} = 1/(T*Q*\text{lanes}) \quad [4:13]$$

$$\text{ul3} = v \quad [4:14]$$

And the EMME/2 link delay function is simply:

$$\text{fd11} = 60*\text{length}/[(\text{ul1}*(1.0-\text{ul3}*v\text{olau}*\text{ul2})] \quad [4.15]$$

Comments

The default value for v is 0.1. $V(0)$ and Q should be chosen consistently throughout the network and the tabled values are recommended.

Link Type	Free Speed $V(0)$	Capacity Q
Motorway	100	2200
Arterial 70km/hr Speed Limit	70	2000
Arterial 50km/hr Speed Limit	60	2000
Collector Road	50	1800
Local Road	50	1800
Slow Road 40km/hr Design Speed	40	1800
Slow Road 20km/hr Design Speed	30	1800

It is apparent that link speeds from assignments may not indicate traffic conditions on links. Slow speed conditions must be identified, graphically or numerically, in terms of high turn delays or long turn queues. However, the extra attributes do allow exceptional links to be characterised; for example, lanes that are severely affected by parking manoeuvres can be allocated lower free speeds and capacities.

5 SIGNAL DELAY FUNCTION

5.1 Analytic Function

The signal delay function, $D(x)$ minute, selected for ASRTAM is from Akcelik and Chung [8]. This choice was made because the function copes with traffic loads in excess of capacity.

$$D(x) = D_u(x) + D_o(x) \quad [5:1]$$

$$D_u(x) = \begin{cases} [1+R*(x^{0.1})]*[C*((1-u)^2)/(120*(1-u*x))] & \text{if } x < 1 \\ C*(1-u)/120 & \text{if } x \geq 1 \end{cases} \quad [5:2]$$

$$D_o(x) = \begin{cases} 15*T*[(x-1)+SQRT\{(x-1)^2+4.4*(x-x_o)/(s*u*C)\}] & \text{if } x \geq x_o \\ 0 & \text{if } x < x_o \end{cases} \quad [5:3]$$

$$R = 0.1*fi*((s*u*C/3600)^{0.25})*(u^{0.1}) \quad [5:4]$$

$$x_o = \text{MIN}(0.95, 0.4*((s*u*C/3600)^{0.2})) \quad [5:5]$$

$$x = \text{pvolau}*K*P/Q \quad \text{with } Q = s*u*T \quad [5:6]$$

$$Z = Z \quad [5:7]$$

Where C is the signal cycle time (second)
 fi is the proportion of un-bunched traffic in pvolau (ratio)
 K is the turn volume factor (ratio)
 P is the flow peaking factor for pvolau (ratio)

s	is the saturation flow available to pvolau	(veh/hr/lane)
T	is the analysis period	(hour)
u	is the effective green time for pvolau	(ratio to cycle time)
Z	is the delay adjustment factor for signal co-ordination	(ratio)

These are required extra attributes of any signalled turn. C, u, s, and K. are batched into their extra attribute vectors from external text files created by SIGMA or other external models, a process controlled by EMME/2 macros in the feed back procedure.

Extra attribute vectors for fi, Z, and P are best filled initially with the respective default values, 0.5, 0.85, and 1.1, using the EMME/2 defaults facility, and then modified interactively in accordance with guidelines.

5.2 Conic Parameters

Calibration of the general conic to the turn penalty function for signal control using the method given in Section 4.2 gives the following conic constants for use in the EMME/2 auto-assignment:

$$\begin{aligned} \underline{A} &= C*[u+(0.1+0.9*u)*R]/120 + 15*T*[1+0.5*SQRT(4.4/(s*u*T*(1-xo)))] [5:8] \\ \underline{C} &= C*(1-u)*(1+R)/120+15*T*SQRT[4.4*(1-xo)/(s*u*T)] [5:9] \\ \underline{B} &= [(\underline{C}-D(0))/2]*\{2*\underline{A}-(\underline{C}-D(0))\}/[\underline{A}-(\underline{C}-D(0))] [5:10] \\ D(0) &= C*[(1-u)^2]/120 [5:11] \end{aligned}$$

A inspection of the analytic and conic function values, found that the fit could be improved if \underline{A} was multiplied by 0.95 and $-[50*(u^2)-50*u+4.5]*[0.00833*C-0.25]/60$ was added to \underline{C} . The differences were then a small number of seconds or a small percentage. D(x) with fpNN(x) so adjusted are tabled for the case where T = 1 hour, fi = 0.5, C = 120 second, s = 2000 veh/hour, and u = 0.4; the results are typical.

x	0.10	0.30	0.50	0.70	0.90	1.00	1.10	1.30
D(x)	0.41	0.45	0.49	0.55	0.67	1.19	3.79	9.73
fpNN(x)	0.46	0.46	0.48	0.51	0.65	1.29	3.80	9.98
Diff %	12	4	-3	-8	-4	8	0	2

5.3 Representation in EMME/2

The value ranges for \underline{A} , \underline{B} , and \underline{C} allow them to be packed in the EMME/2 penalty function parameters as:

$$\text{up1} = 10,000 * \text{int}(10*\underline{A}) + \text{int}(100*\underline{B}) \quad [5:12]$$

$$\text{up2} = P*K/(s*u*T) \quad [5:13]$$

$$\text{up3} = \text{int}(100*\underline{C}+Z/10) \quad [5:14]$$

With this formulation of upi the turn penalty function for signalled turns can be expressed as:

$$\text{fp1} = (\text{int}(\text{up3}/100) - \text{put}(((\text{int}(\text{up1}/10,000))/10)*(1-\text{pvolau}*\text{up2})) - \text{put}(100*((\text{up1}/10,000 - \text{int}(\text{up1}/10,000)) + \text{sqrt}((\text{get}(1))^2 + \text{get}(2))^2)) * (\text{up3} - \text{int}(\text{up3}))*10 + 0.1) \quad [5:15]$$

5.4 Comments

f_i , the unbunched traffic proportion, is not important for congested conditions since the overflow component of delay dominates. Even in light conditions the correct value of f_i will not effect the delay found using the default value by more than about 10%. Where f_i is considered to be important an estimate can be made using $f_i = \max(0.05, 0.95 - 0.90 * \text{distance}/1000)$ where 'distance' is distance in metre from the nearest upstream traffic signal.

Tailored values for Z can be added to the macro for signal delay. The Highway Capacity Manual [5] provides a range of factors. Also, estimates can be made using $Z = 1 + 1.44 / (C * (1 - u))$ for un-linked turns, and $Z = 1 - (18 / (C * (1 - u) * (1 + \text{time})))$ for the linked turns; 'time' is the travel time in minutes from the upstream linked node. These factors are due to Robertson [9].

Starting values for C , u , s and k can be estimated in various ways. In the Waitakere test bed SIDRA values for C , u , k and s were used to obtain assigned flows for input to SIGMA. An alternative is to obtain initial assigned flows from an assignment in which NN is set to -1 for all turns. Assignment results for perturbations of the starting values may be required if the uniqueness of the solution is in doubt.

6 PRIORITY DELAY FUNCTION

6.1 Analytic Function

The priority delay function, $D(x)$ minute, selected for ASRTAM is due to Fisk [11] but with a capacity module due to Joubert and Van As [12]. The delay function choice was made because the function can cope with traffic loads well in excess of capacity. The capacity module was chosen because it was shown to produce results that correlate very well with the results of detailed simulations.

$$D(x) = \{60 + 15 * [\text{SQRT}((2 + Q * T * (1 - x))^2 + (8 * Q * T * x)) - (2 + Q * T * (1 - x))] / Q \quad [6:1]$$

$$Q = \text{MAX}\{Q_{\min}, f_i * (q_0 + 0.1) * [\text{EXP}(-(A + d - H) * q_1)] / [1 - \text{EXP}(-F * q_1)]\} \quad [6:2]$$

$$q_1 = \begin{cases} f_i * [(q_0 + 0.1) / 3600] / [1 - H * ((q_0 + 0.1) / 3600)] & \text{if } q_0 \leq (3600 / H) - 1 \\ f_i * [(3600 / H) + 0.1] / 3600 & \text{if } q_0 > (3600 / H) - 1 \end{cases} \quad [6:3]$$

$$x = \text{pvolau} * P / (Q * T * n) \quad [6:4]$$

Where Q is the absorption capacity of the opposing flow(s) (veh/hour)

Q_{\min} is the minimum value for Q (veh/hour)

q_0 is the aggregate of factored opposing flows (veh/hour)

A is the acceptance gap (second)

d is 0.35 * standard deviation of A (second)

F is the follow up headway (second)

f_i is the un-bunched traffic in the opposing flow (ratio)

H is the headway in platoons (second)

T is the analysis period (hour)

P is the flow peaking factor for the analysis period (ratio)

n is the number of lanes for the turn (number)

These are required extra attributes of any priority turn.

The EMME/2 network calculator computes Q . Q_{\min} is the value of a further required extra attribute '@qmin' with a default value of 75 veh/hr. Q_{\min} is to allow for the priority reversal that occurs with severe congestion.

q_0 is batched into its extra attribute vector from external text files created by OPFLOW or generated by direct network calculation using a macro; the process is controlled by EMME/2 macros in the feed back procedure. In determining opposing flows a component will sometimes need to be factored. For example,

in the case of a right turn to a protected lane only a proportion of the opposing flow from the left is relevant. Such factors are extra attributes that are applied through the OPFLOW program. These factors for opposing flow components can also have large effects and need to be applied with discretion in the absence of survey data.

The other extra attribute vectors are filled initially with the default values (see Section 6.4) using the EMME/2 defaults facility, and then modified interactively as appropriate.

6.2 Conic Parameters

Calibration of the general conic to the turn penalty function for priority control using the method given in Section 4.2 gives the following conic constants for use in the EMME/2 Auto-assignment:

$$\begin{aligned} \underline{A} &= 15 * T * (1 + \sqrt{1 + 2 * Q * T}) & [6:5] \\ \underline{C} &= 30 * (1 + \sqrt{1 + 2 * Q * T}) / Q & [6:6] \\ \underline{B} &= ((\underline{C} - D(0)) / 2) * (2 * \underline{A} - (\underline{C} - D(0))) / (\underline{A} - (\underline{C} - D(0))) & [6:7] \\ D(0) &= 60 / Q & [6:8] \end{aligned}$$

A comparison of the values of the turn penalty function with the corresponding values of the conic, over the full range of the independent variables, found that the direct fit requires no modification. This is not surprising in that Fisk's formula is similar to the conic formula.

Data is tabled to demonstrate the sensitivity of capacity and hence delay to H and fi. The example gives capacities and delays for a left turn into an opposing through volume of 1000 veh/hour from the right, and T is 1 hour.

Condition	Q	x>	0.30	0.50	0.70	0.90	1.00	1.10	1.30
fi = 0.1 H=1.8	661	D(x)>	0.23	0.28	0.40	0.85	1.80	3.91	9.48
fi = 0.5 H=1.8	376	D(x)>	0.33	0.42	0.61	1.29	2.37	4.38	9.76
fi = 0.9 H=1.8	209	D(x)>	0.51	0.66	1.00	1.98	3.18	5.11	10.24
fi = 0.5 H=0.6	682	D(x)>	0.23	0.28	0.39	0.83	1.77	3.89	9.47

6.3 Representation in EMME/2

The value ranges for A, B, and C allow them to be packed in the EMME/2 penalty function parameters as:

$$\begin{aligned} \text{up1} &= 10000 * \text{int}(100 * \underline{A}) + \text{int}(100 * \underline{B}) & [6:9] \\ \text{up2} &= P / (Q * n * T) & [6:10] \\ \text{up3} &= \underline{C} & [6:11] \end{aligned}$$

With this formulation of upi the turn penalty function for priority controlled turns can be expressed as:

$$\text{fp2} = (\text{up3} - \text{put}(((\text{int}(\text{up1}/10000))/100) * (1 - \text{pvolau} * \text{up2}))) - \text{put}(((100 * (\text{up1}/10000 - \text{int}(\text{up1}/10000)))) + \text{sqrt}((\text{get}(1))^2 + (\text{get}(2))^2)) + 0.1 \quad [6:12]$$

6.4 Comments

Guidelines for critical acceptance gaps, A, based on the Highway Capacity Manual [5] are as tabled. The acceptance gap values have a strong effect on assignment.

Turn	Opposing Road	Opposing Road	Opposing Road	Opposing Road	Opposing Road	Opposing Road	Used In
------	---------------	---------------	---------------	---------------	---------------	---------------	---------

	40-60 km/hr 2-lanes	40-60 km/hr 4-lanes	60-80 km/hr 2-lanes	60-80 km/hr 4-lanes	80-100 km/hr 2-lanes	80-100 km/hr 4-lanes	Default Macro
OUT							
Left	4.50 s*	4.50 s*	4.75 s*	4.75 s*	5.00 s*	5.00 s*	4.6 s*
Right	5.50 s*	6.00 s*	6.00 s*	6.50 s*	6.50 s*	7.00 s*	6.2 s*
Across	5.00	5.50	5.50	6.00	6.00	6.50	5.7
IN							
Left	3.50 s	3.50 s	3.50 s	3.50 s	3.50 s	3.50 s	3.5 s
Right	4.50 s	5.00 s	4.75 s	5.25 s	5.00 s	5.50 s	5.1 s

- Subtract 0.5 s if the left turn is via an easy path or if the right turn is to a protected lane.

The standard deviation of A is taken to be 2 s in accordance with Joubert and van As [12]. In ASRTAM the follow up headway, F, is taken to be half of A, a rough approximation.

The proportion of unbunched traffic, f_i , in the opposing flow crucial. An estimate for an approaching stream is $f_i = \max(0.05, 0.95 - 0.90 * \text{distance}/1000)$, where 'distance' is the distance in metre from the nearest upstream traffic signal. For two or more streams a volume-weighted average of the individual f_i values is suggested.

The minimum platoon headway, H, is crucial. In accordance with Joubert and van As [11] 1.8 s is suggested for a single opposing lane; for two lanes $H = 1.8 - 0.6 * r$ is suggested on an intuitive basis, r being the ratio of the smaller to the larger flow, and giving, for example, 0.6 s for equal flows on a two way road.

The number of lanes available, n, is self evident for exclusive turn lanes. In Waitakere, where the intersection is of importance, there is usually a separate lane for each opposed turn; otherwise a fractional n is determined for a each turn by using guessed delay weighted volumes for the turns sharing the lane. It is intended to introduce a rigorous method for distributing approach traffic to lanes and estimating shared lane parameters; shared lanes are not uncommon at priority controlled intersections.

7 BOTTLENECK DELAY FUNCTION AND BLOCKING BACK

7.1 Analytic Function for a Bottleneck

A 'bottleneck' is taken to be an intersection where flow is normally continuous but the number of departure lanes is less than the number of approach lanes. Examples are beyond a motorway on ramp on the motorway where the number of motorway lanes is fixed, or beyond the bifurcation for a motorway off ramp on the off ramp.

Traffic leaving a motorway on ramp bottleneck is akin to traffic leaving a queue at a traffic signal. Indeed, the way ahead is unrestricted except for the speed limit; also, since motorway lane flows can meet or exceed those of signal lane saturation flows, a bottleneck must be capable of feeding traffic to the departure lanes at the similar rates. In the bottleneck, traffic may stop randomly but briefly as drivers adjust to pack in prior to departure.

Volume equals speed times density, and so within a bottleneck it must be possible to achieve sufficient overall speed at high density to 'match' the tidier saturation flows from traffic signals. Signal delay is a function of saturation flow, itself a product of feasible speeds and densities, and so the analytic functions for signal delay should be adaptable to the representation of a bottleneck.

On this heuristic basis the bottleneck delay function selected is the signal delay function (see Section 5.1). Bottleneck nodes should be incorporated just beyond the on ramp noses, on the off ramps, and at any location where there is a drop in the number of available traffic lanes.

Extra attribute values have been determined by trials in which queues from the EMME/2 assignments were compared with the observed queues at motorway bottlenecks.

Successful assignments were achieved with attribute values in the order $C = 200$ second, $u = 0.95$ and $s = 2000$ veh/hour, $f_i = 0.1$, $k = 1/\text{lanes}$, $Z = 0.85$, and $P = 1.1$. Also, C and u are fixed using @cal (see Section 3.1 Signal Management Strategy). Graphed results for variations on these settings are informative; the function generally has negligible effect up to capacity, over which range the link function reduces speed by about 10%, but then affects delay substantially, and the associated queue lengths are realistic.

Bottleneck performance will depend on the general skill and motivation of the drivers in the bottleneck. It can be expected that the attribute settings may vary from location to location. The settings above are guideline settings intended to serve initially as defaults prior to network tuning.

7.3 Blocking Back

Introduction

High intersection delay in association with a high demand volume will result in a long queue, whether or not the intersection is a bottleneck. Such a queue may result in delay to traffic not even routing through the blocking point.

For example, traffic destined to a certain motorway off ramp may become interspersed with the bottleneck queue traffic destined to the down stream on ramp. This situation must delay the off ramp traffic and increase the delay to the bottleneck traffic. Neither of these potential significant secondary delays is accounted for by the link delay and turn delay estimation procedures already described. It is the same for the on ramp bottleneck queue. This may extend through priority and/or signal controlled intersections in the surface road network, reducing the approach capacities at those intersections, and so increasing unaccountably the delay on various routes.

Any intersection type with over saturation may give rise to such blocking back effects.

Blocking Back Procedure

A procedure for dealing with blocking back effects, due to the author, was tested in the Waitakere model. This has not been automated, but has potential for development and implementation through macros. The secondary effects of two long isolated queues from motorway on ramp bottlenecks were treated by manual calculations in an external spreadsheet. Three feed backs were required to achieve sufficient convergence. Significant improvements to the assignment resulted and pertinent results are tabled.

ROUTE	COUNT (veh/2 hour)	ASSIGNMENT With Bottleneck Only (veh/2 hour)	ASSIGNMENT With Blocking Back (veh/2 hour)
Motorway Route			
On Ramp 1	1520	2350	1830
M'way from On Ramp 1	4010	5230	4350
On Ramp 2	2250	2290	2000
M'way from On Ramp 2	5390	6820	5480
On Ramp 3	1850	1670	1980
M'way from On Ramp 3	7700	8530	8460
Alternative Routes			
Central Park Drive	820	400	770
Great North Road	1650	1410	1820
Te Atatu Road	3230	2270	2910

Steps in the procedure, outlined in terms of a motorway on ramp bottleneck, are as follow:

- [1] Calculate the maximum queue length per lane, $\max L_q$, using [7:1]:

Clearly $N \cdot T = q \cdot d$ and $\max Lq = p \cdot N \cdot l$ and so $\max Lq = p \cdot q \cdot d \cdot l / N$ [7:1]

Where, q and d are EMME/2 assignment results for respectively the lane volume and average delay per vehicle; N is the average number in the queue over the analysis period T ; p is the factor (in the order of 2) to convert N to its maximum value, and l is the average queue length per vehicle in metre.

[2] In the bottleneck the volumes in each lane are equal. However, the queue calculated in the ramp side motorway lane divides into a motorway queue and a ramp queue, the lengths of which are taken to be proportional to the respective approach volumes for the ramp side lane and the ramp.

Accordingly, undertake division of the queue in the ramp side lane.

[3] Calculate the average 'composite' speed, V_c , links upstream from the bottleneck using [7:2]:

$$V_c = L / \{ (t_0/T) \cdot (1 - L/(2 \cdot \max Lq)) \cdot (1/V_q - 1/V_o) + 1/V_f \} \quad [7:2]$$

Where t_0 is the duration of the queue (hour)
 T is the analysis period (hour)
 L is the link length subject to V_c (metre)
 $\max Lq$ is the maximum queue length (metre)
 V_q is the speed in the queue (km/hour)
 V_f is the link free speed (km/hour)

This relation was obtained using a distance time diagram exhibiting a triangular queue profile (height $\max Lq$, base t_0), and integration over the analysis period of the algebraic time for a typical vehicle passing through the queued and not queued sections of the link. The formula gives, for example, $V_c = 50$, when $\max Lq = 1.5$, $L = 1.0$, $T = t_0 = 2$, $V_f = 100$, and $V_q = 30$.

For the motorway queue, L is the distance back to the off ramp bifurcation; for the ramp queue L is the distance back to the first intersection feeding the ramp.

[4] For the motorway queue apply analogous calculations to the next logical road section upstream of the off ramp (eg to the next on ramp). For this section:

$$t_0 \text{ becomes } t_0 \cdot (\max Lq - L) / \max Lq \quad [7:3]$$

$$\text{and } \max Lq \text{ becomes } (\max Lq - L) \cdot (q - q_{on} + q_{off}) / q_{off} \quad [7:4]$$

where q_{off} is the off ramp volume and q_{on} is the on ramp volume

Apply the same process to ensuing residual queues until a normal signal or priority intersection is reached on the surface network, or the end of the queue is reached on the motorway.

[5] For the original on ramp queue, reduce the capacities of the turns at the node feeding it, so that their sum is a little less than the take away capacity, Q_{ta} , of the on ramp queue, and retain the turn penalty functions applying at the subject intersection. Fix these capacities using @cal.

Apply like calculations to analogous residual queues stemming from the motorway queue (see step [4] above).

In this step the reduced capacity replacing Q is $Q_{ta} \cdot Q / \sum Q$. For signal control the reduction factor can be applied the phase green times for the subject turns, since $Q = s \cdot u \cdot T$. Reduced capacity at the subject intersection applies for a part of the analysis period only, and the estimation of Q_{ta} must allow for that.

Long queues generated by signal and priority controlled intersections are treated in the same way. The link free speed is replaced by an appropriate link composite speed, and feed capacity is reduced to match the takeaway capacity of the queue; this pattern is repeated along the queue trunk and branches to their ends.

8 ROUNDABOUT DELAY FUNCTION

8.1 Analytic Function

A roundabout can be considered as a ring of individual priority controlled intersections of the circulating road with the side roads. At each side road intersection the entering traffic gives way to the circulating traffic, and, owing to ambiguity, to some of the traffic exiting to the same side road.

It is apparent that the priority delay function described in Section 6 should be applicable to roundabout entries.

8.2 Comments

A difficulty in using the chosen function is the setting of sensible values for the extra attributes used to calculate the required entry capacities. It was suggested initially that the acceptance gap, A , be 4.5, 4.0, and 3.5 seconds for 'normal', 'medium' and 'high' pressure situations, respectively. This was found to give unsatisfactory results for some large roundabouts.

Subsequently, the specialised formulae used in the SIDRA program [10], for the estimation of the subject attribute values, have been partly incorporated by Valero [3] into a macro for roundabout capacity calculation. These formulae take into account the roundabout diameter, the number of circulating lanes, the number and width of the entry lanes, and the origin/destination pattern of the entering volumes. The capacity formula of Joubert [12], is practically the same as the one used in SIDRA .

9 VALIDATION

9.1 Procedure

The validation procedure for ASRTAM in Waitakere Eco City was the final round of repetitive actions used to develop the model and as follow:

- [1] checking the effect of the EMME/2 generalised cost constant and ASRTAM volume feedback weight.
- [2] checking that the iteration feedback sequence produces a stable outcome.
- [3] checking that the number of centroid connectors and centroid volumes match the set criteria.
- [4] checking traversal link volumes against ground counts.
- [5] checking screen line volumes against ground counts.
- [6] checking turn volumes against ground counts.
- [7] checking assigned travel times against surveyed times.
- [8] checking for and correcting rogue turn penalty delays.
- [9] checking the sensitivity of results to function parameter settings.
- [10] checking the stability of outcomes for future year traffic loads.
- [11] justifying all function parameters not set to default or guideline values.
- [12] recommending on the applicability of the model.

Should any check reveal significant discrepancies these would be assessed. Inferred legitimate modifications would then be made to the model and the check repeated and so on until the potential for improvement was exhausted.

Data comparisons were assisted by use of RMSE (square root of the mean of the squared differences between modelled and observed values), GEH (the positive difference divided by the square root of the mean for a modelled and observed value), and inspection of the scatter-gram of modelled and observed values with an emphasis on the interpretation of outliers.

9.1 Actions [1], [2], [10], [3]

When the cost constant was varied some outcomes improved while others degraded; the effects were not considered to be of significance and a value of 0.7 was chosen for consistency with the regional model. The volume feed back weighting was not investigated; the average of the assigned volume and previously used volume was considered to be satisfactory.

The zone and centroid configurations were set to satisfy conditions for Level of Precision 3 as outlined in Section 2.2.

The model exhibited remarkable stability under both base year and horizon year traffic loads and as outlined in Section 3.3.

9.2 Traversal Volumes

The external cordon of 22 directional links exhibits an RMSE of 22 veh/hr for outbound and 42 veh/hr for inbound volumes but including 3 links with a GEH of 12 or more. In all the modelled external trips show a surplus over the ground counts of in the order of 1500 veh/hr each way, see Appendix 1. This was considered undesirable but tolerable for the purpose of validating the assignment processes.

9.3 Screen Line Volumes

A screen line map and selected volume results are shown in Appendix 1. The total screen line volumes bear fair correlation with ground counts. However, the Henderson Centre cordon, 'H', exhibits a large deficit of modelled trips, whilst screen line 'S3' associated with the New Lynn Centre and the external cordon exhibits a good balance between modelled volumes and counts. These observations for H and S3 are reflected in the results for their individual link volumes.

The Henderson results indicate that either the trip matrix is deficient in trips associated with commercial uses and/or there is too little extraneous traffic assigned through Henderson. The latter is not supported by assigned volumes on alternative routes and is inconsistent with the volume imbalance noted for the external cordon. Further, counts taken of the traffic generated by 2 large shopper car parks in New Lynn proved that the given matrix was deficient in trips for commercial uses there. This effect is masked in the S3 cordon results owing to the excess of modelled trips in the external cordon.

These findings in regard to the trip matrix are important to the ASRTAM validation, which is to do with the traffic assignment procedures and delay functions.

The target RMSE for links at Level of Precision 3 is between 100 and 50 veh/hr. The result for the 78 directed links of the screen lines is 150 veh/hour. However, there are 8 significant outliers in scatter-gram for this data, and most of them can be attributed to the deficiencies of the trip matrix. If these are excluded the RMSE improves to 100 veh/hour. It can be concluded that if the matrix were actually corrected then the ASRTAM assignment procedure would achieve a RMSE in the target range.

9.5 Turn Volumes

To assess the quality of the assigned turn volumes, turns were counted at 17 intersections through the study area as shown in the Appendix 1 map. There are 174 turns across the 2 priority, 7 roundabout, and 8 signal controlled intersections.

The target RMSE for Level of Precision 3 is 50 veh/hour, whilst the result from the assignment is 100 veh/hr. However, the scatter-gram for this data discriminates 17 outlier turns and most of them can be attributed to the deficiencies of the trip matrix (see Section 9.4). If the 17 outliers are excluded the RMSE

improves to 65 veh/hour and it is again concluded that if the matrix were actually corrected the ASRTAM assignment procedure would achieve a RMSE close to the target of 50 veh/hr.

9.6 Corridor Travel Times

Appendix 2 provides histograms comparing assigned with surveyed total travel times for 14 directional corridors. It can be seen that there is generally very good correlation. For some corridors a large proportion of the time is accounted for by the estimated turn delays. In the case of corridor 9 (along the motorway in the peak direction) the modelled travel times are from the bottleneck function and the composite link speeds produced by the blocking back procedure, (see Section 7.3).

The diagram for corridor 1 is interesting. The Titirangi Road intersection is over-saturated and this is reflected in the assigned travel time from West Coast Road of 4.75 min (includes a turn delay of 3.5 min). The total surveyed travel time is almost 2 min less. However it can be seen that the surveyed travel time to the two upstream intersections is about 2 min more than the corresponding assigned travel times there. That is, the surveyed and assigned travel times agree over the three intersections, including the queue generating Titirangi Road intersection. Had the blocking back procedure been applied the queuing delay would have been apportioned to each of the 3 intersections and there would have been agreement at each location.

It is concluded, on the basis of the travel time surveys, that the outcomes from the delay functions and procedures are realistic.

9.7 Rogue Intersection Delays

Each turn in the network was given a value of 1 or 0 for extra attribute @val depending on whether from local knowledge the turn delay was known to be high or low. The network was then scanned using a macro which lists the intersections with an unexpected quantum of turn delay. In such cases the source problem is identified and corrections made. As a result, all turn assigned delays are known to be consistent with the Council's local knowledge of traffic conditions in the network.

This method found unexpected high delays for many priority controlled right turns onto arterial roads; this led to a realisation that 1.8 second platoon headways were inappropriate for this situation.

9.8 Assigned Volume Sensitivity to Turn Parameter Values

This matter had to be addressed since for some parameters no parameter value data was available and intuitive settings were used.

An example is the heavily over-saturated priority controlled left turn from Rimu Street into the 2 approaching lanes of Rata Street. The opposing volume is not simply the total volume in the Rata Street lanes, since a significant proportion of the left turns are made into the near lane when there is traffic passing in the far lane. Thus there is uncertainty about the value of the relevant opposing flow factor and the platoon headway to be applied. Sensitivity testing found that the assigned left turn volume had a sensible range of 600 to 900 veh/2 hour in comparison with a ground count of 600 veh/2hour; there was also an effect on the assigned motorway volume which fell in the range of 7500 to 7900 veh/2hour.

It was concluded that pending the collection of data to properly calibrate the delay functions sensitivity analysis could be used to estimate the likely range of operating conditions associated with any proposed project.

9.9 Non-Default Parameter List and Justification

The purpose of the non-default list is to facilitate the auditing of the model by Transfund New Zealand.

9.10 Recommendation and Application

The validation report concluded that:

[1] the validation had not attempted to correct results for every corner of the network but had ensured that the model was working well globally and in corridors and sectors. Specific problems could now be successfully investigated by a focused application of the model in which further focused work with the base year data, or census year data might be appropriate.

[2] the model is suitable for the evaluation of future traffic conditions in Waitakere Eco City to at least horizon year 2021.

[3] The attainment of Level of Precision 3 is subject to correction of the regional matrix, in respect to the generation and attraction characteristics of the major commercial zones of Henderson and New Lynn, and the Whenuapai air base.

It was recommended for Waitakere Eco City that the general network and zone structure, together with the delay functions and procedures, be recognised by the Auckland Models Technical Advisory Group as suitable for investigations requiring a Level of Precision of up to 3, but depending on the quality of the trip matrices available for any such investigation.

The Auckland Models Technical Advisory Group accepted this recommendation, and the model has since been used successfully to obtain project funds from Transfund New Zealand.

10 INSTABILITY CONVERGENCE AND UNIQUENESS

10.1 Introduction

Instability may be defined as a manifestation of oscillating values for function parameters, or oscillating volumes on competitive traffic routes, from assignment iteration to iteration. Without instability, convergence close enough to a solution for a reliable comparison of options may require a few or a large number of iterations. With convergence, there remains the matter of whether the solution is the optimal solution, and if not, of how far the subject solution is from the optimal one.

The resolution of the issue of instability, convergence and uniqueness is beyond the scope of this paper. The purpose of this section to raise the issue as a counterpoise to the very positive assignment results obtained in the Waitakere case.

10.2 Discussion

For Waitakere, EMME/2 facilities have been applied with detailed modelling of activity at nodes and a supplementary feedback process to achieve converged results. These have been validated by their comparison with observed network conditions. The stability of the model has also been demonstrated with the network subject to traffic demands projected for 2021.

It is considered that a major factor contributing to the stability of the procedure in the Waitakere case is the zone structure and arrangement of centroid connectors, designed for compatibility with turn delay modelling.

It has been contended that, even so, stability and uniqueness is not guaranteed by the process, but rather it is fortuitous that favourable patterns of transport demand and supply appertain in the Waitakere area.

This contention is based on the fact that the ASRTAM iterations are not analogous to the EMME/2 iterations in respect to the criterion of increasing monotonicity of turn delay. An ASRTAM iteration could result in delay to an increasing turn volume to drop; this may occur when turn capacity increases in response to the opposing volume reducing. From a practical point of view this is logical, but it appears that theory does not guarantee the results of the method.

Thus the very positive results achieved for Waitakere need to be considered with caution, in so far as possible applications of the method elsewhere are concerned.

The following points can be made:

[1] for the EMME/2 assignments of the ASRTAM procedure, conditions for convergence and uniqueness are maintained; each turn penalty function is a monotonic increasing function of the turn volume.

[2] for demand and supply patterns giving rise to local instability, there may be corresponding real world instability, and an objective of the overarching study will be to identify network improvements that overcome instability. Such instability in the model could be relevant and illuminating and could be exploited.

[3] in regard to uniqueness, the feed back process could be developed to cover the possibility of alternative solutions.

This might entail,

[a] controlled random perturbations of the starting conditions. For example, after an initial assignment sequence, subsequent sequences could begin with penalty functions altered in a controlled way in differing random patches of the network. This would generate solution ranges or confirm a single result.

[b] intelligent starting conditions designed to nudge the assignment to alternative route emphases. For example, an arrangement of turn parameter settings could be contrived to ease access to motorways and reduce access to surface arterial roads, by biasing signal phase times. If the outcomes were the same there would be confidence in the result; if not the results might well be useful to clarify the problem and suggest a solution.

[c] variation of the damping formula for volume feed back.

[d] other methods.

[4] in regard to uniqueness, a tendency for the process to trend to impractical results should certainly be tempered by the use of extra attributes reflecting a traffic management strategy.

[5] if indeed there are a number of near optimal solutions it would seem inappropriate to contrive a procedure to produce a single outcome and accept that as the only one for consideration, particularly since traffic benefits are not the only benefits assessed in project evaluations.

A disadvantage of turns modelling is the considerable work that may be required and as implied above, to arrive at an acceptable result, especially as assignment run times are long. This is the price that may be required in some cases for a high level of assignment precision.

11 CONCLUSIONS

This paper has described an application of EMME/2 auto-assignment with detailed modelling of activity at nodes. Although the target precision of an RMSE of 50 veh/hour for turn volumes was not achieved in the validation, this was not attributed to the turn delay functions or the assignment procedure, but to deficiencies in the trip matrix provided. In that light the results for Waitakere Eco City are very positive, and the model has been used successfully in support of applications for funding assistance from Transfund New Zealand.

The turn penalty parameters for each EMME/2 assignment were calculated using volumes from the previous assignment. For the subject case this feed back process produced stable converged results, which were validated by ground counts and measured network travel times for the base year. Results for a 2021 year matrix assignment were also stable.

It has been contended that the process will not be stable in all cases, and where there is convergence the results may not be optimal. These issues are raised for consideration and discussed, but it is beyond the scope of this paper to resolve them.

The assignment procedure requires 2 conic turn penalty functions, one requiring 6 turn specific parameters designed for signal controlled turns and bottlenecks, and one requiring 4 turn specific parameters designed for priority controlled turns including roundabout entries. Since EMME/2 allows for 3 turn specific parameters, computation to unpack the function parameters is necessary each time the functions are used. The assignment is a sequence of in the order of 40 EMME/2 assignments of 15 iterations. It is therefore desirable that the provision for turn penalty parameters in EMME/2 be increased from 3 to at least 6.

The upstream effects of long queues stemming from points of capacity overload can be crucial. A procedure was developed to deal with blocking back but not automated. It is desirable that robust algorithms and implementation macros are developed. In the method described the over saturation queue turn function is switched off. An equivalent effect is produced by means of a related 'link composite speed' which replaces the free speed value in the upstream link delay function. Also, the upstream intersection queue feeding capacities are replaced with capacities that are a practical match to the capacity of the take away queue.

The signal turns model includes algorithms to distribute assigned approach flows to lanes with given turn disciplines. It is desirable that a corresponding step be added to the procedure for priority controlled turns; at present heuristic approach specific decisions are required when approach lanes are shared by different turns.

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