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Queue Management Project Model

Calibration of the Traffic Model

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Contents

1 Introduction

This document constitutes a record of the steps taken to calibrate the traffic model. The first section describes the test site used to calibrate and validate the model. The second section describes the measures adopted to establish the accuracy of the model results. The third and main section describes, in chronological order, the stages which the calibration process went through. The final section gives the results of the validation stage.

2 The test site

The test site chosen was Wellington Street in Leeds. The road is a main arterial route into and out of the southern area of Leeds city centre. Working Paper 332 describes why this site was selected and Technical Note 296 describes the traffic characteristics of the site. A diagram of the site, reproduced from Technical Note 296, is given as figure 1. The link and lane numbers used in this note will be as given in figure 1.

The model was run over four adjacent time periods. The observed characteristics of the traffic over these time periods, for example input flows and turning percentages, were assembled into a model data specification file. The first two periods were in under saturated conditions whilst the last two were in over saturated conditions. The start and stop times for each data file are given in table 1.

File	Time
1	16:25 to 16:41
2	16:43 to 16:59
3	17:05 to 17:21
4	17:31 to 17:46

Table 1 - Model run time

The model was initially run with a run-in-time of 450 seconds (5 cycles), giving a total run-time of 540 seconds (6 cycles). We will assume that the stopping and starting wave profiles constructed during this last cycle are representative profiles. Later, as the model was refined, this was changed (see 4.6)

3 Calibration measures

To move towards a calibrated model the measures of maximum queue length and queue length at the end of red were used to assess how close the model was to the observed situation. The use of there maximum measures is

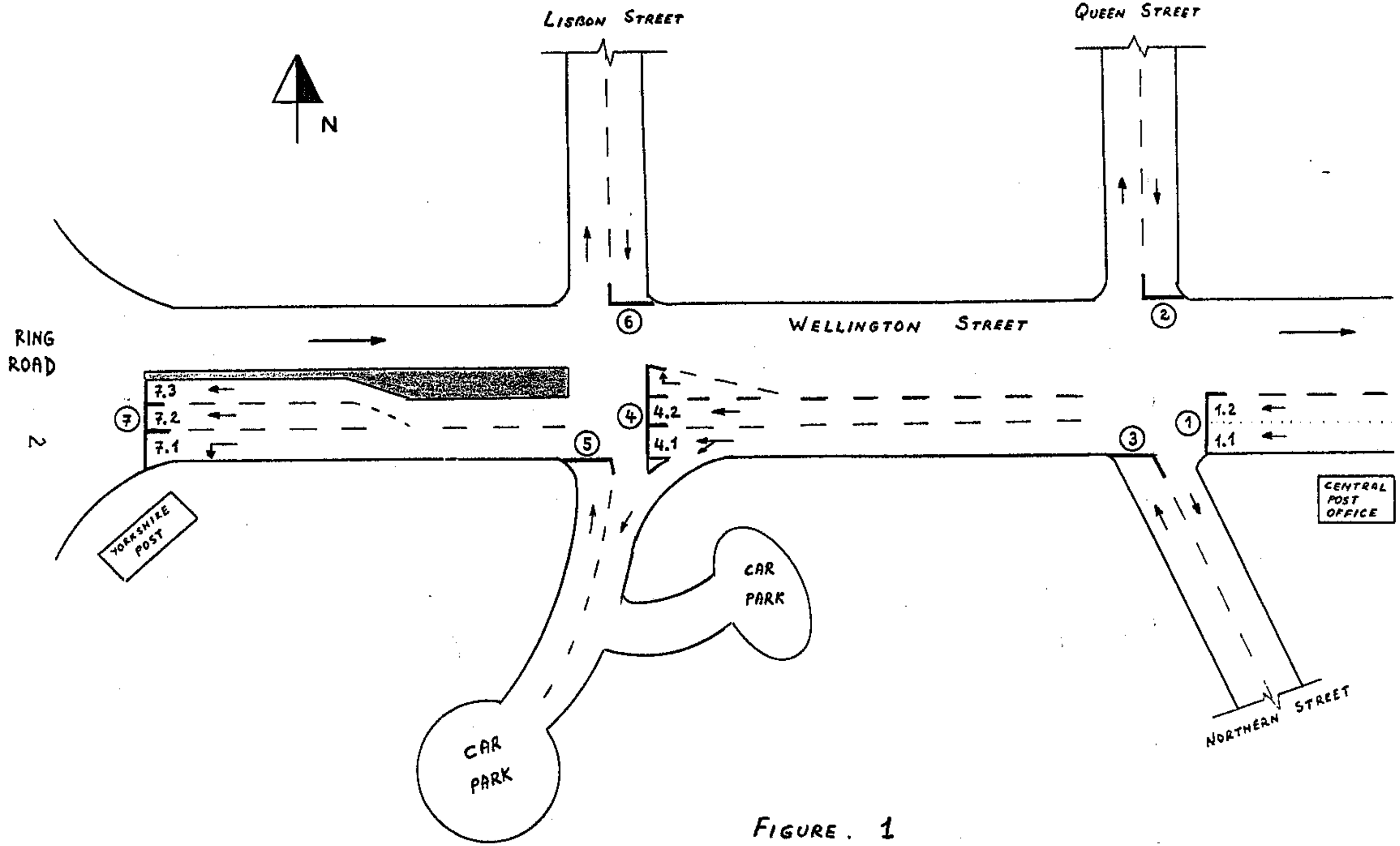

FIGURE. 1
STUDY AREA

appropriate since we are interested in the extreme situation where spill back occurs. The duration of any spill back at upstream junctions, where it occurred, was also used as a calibration measure. The observed values of these measures are given in table 2. Later the vehicle flows at the junction stop lines were also used. These observed values are given in table 3.

File	Link	Lane	Measure	Observed	Spill back
1	7	2	Max	65.3	none
			Red	46.3	
	4	2	Max	40.6	none
			Red	37.3	
2	7	2	Max	56.7	none
			Red	47.6	
	4	2	Max	45.4	none
			Red	39.9	
3	7	2	Max	175+	11s-37s
			Red	121	(10/10)
	4	2	Max	124	5s-37s
			Red	103	(7/10)
4	7	2	Max	175+	17s-40s
			Red	147	(10/10)
	4	2	Max	130+	7s-72s
			Red	90	(10/10)

Table 2 Observed queue lengths (m) and spill back duration(sec)

Note

+ indicates link length exceeded

The ratio in brackets indicates the proportion of cycles with spill back

Link	Lane	File 1	File 2	File 3	File 4
1	1	430	484	508	440
	2	440	544	440	460
2		180	188	196	130
3		330	332	484	450
4	1	516	600	636	645
	2	750	912	884	705
5		270	144	176	290
6		157	176	184	215
7	1	523	500	508	520
	2	660	672	736	780
	3	460	548	660	601

Table 3 Observed flows (v/hr)

4 Calibration stages

4.1 Stage 1

Initially the main result of running the real-world data with the model was that spill back was occurring with all the data files ie in both under and over saturated conditions. These results arose from misrepresentation of the block merging process. When a block of low density traffic merges with a denser block the new block's length was initially taken as the sum of the lengths of the two blocks but the density of the dense block. A block of density 65 v/km and length 100m and a less dense block of density 30v/km and length 50m merged to give a block of density 65v/km and length 150m. Thus the number of vehicles rose from 8 (65 * 0.1 + 30 * 0.05) to 9.75 (65 * 0.15). This increased the volume of traffic in the network artificially and caused the long queues. The code was easily changed once the problem had been pin-pointed. This adapted model was then used to produce the second stage results.

4.2 Stage 2

Table 4 gives the results of the model execution.

File	Link	Lane	Measure	Observed	Modelled	Error
1	7	2	Maximum	65.3	73.1	7.8
			Red	46.3	62.3	16.0
	4	2	Maximum	40.6	49.1	8.5
			Red	37.3	45.1	7.8
2	7	2	Maximum	56.7	52.4	-4.3
			Red	47.6	41.5	-6.1
	4	2	Maximum	45.4	43.5	-1.9
			Red	39.9	37.9	-2.0
3	7	2	Maximum	175+	107.1	-67.9
			Red	121	71.1	-49.9
	4	2	Maximum	124	64.3	-59.7
			Red	103	56.2	-46.8
4	7	2	Maximum	175+	129.8	-46.2
			Red	147	61.8	-85.2
	4	2	Maximum	130+	62.3	-67.7
			Red	90	52.6	-37.4

Table 4 Observed and modelled queue lengths

The results show that the model results were nearly always an under estimate of the queue lengths. This discrepancy was greatest in over saturated conditions (files 3 and 4), which are the conditions of most interest. In order to try to improve the situation attention was paid to relaxing one or two of the constraints in the model specification. In particular the lane split percentages were refined. Initially as traffic left a link, at a junction, to join another link with two or more lanes, the percentage split of the traffic into each receiving lane was the same irrespective of the source direction of the traffic. Thus the percentages used were a combined estimate and not representative of the real observed values. The model was changed to provide source specific lane splits. Thus the percentage split of the traffic entering a multi-laned link depends upon it source.

Two other changes where made. The flow across the stop line during the first two seconds of green time was amended. Initially due to the total flow for these two seconds all took place during the second second and none in the first. The effect of this was a high flow during this second second as traffic left a queue. This high flow meant that the percentage lane splits in the links to receive this traffic had to be near equal, ie a 50-50 split for a two lane link so that each could accommodate this large volume of traffic. This constraint was quite unrealistic where the actual lane splits were quite different. The second change was in how traffic merged and joined with stationary queues. This problem was similar to that experienced with block merging mentioned earlier in section 4.1.

We expected these changes to have the following effects on the modelled queue lengths. The source specific lane splits would increase the amount of traffic in lane two and thus give longer queues. How traffic merged and formed queues would reduce the queue length whilst the flow during the first two seconds would have no effect in itself.

Once these changes had been made the model was re-run to produce another set of results.

4.3 Stage 3

Table 5 gives the results of the model execution

File	Link	Lane	Measure	Observed	Modelled	Error
1	7	2	Maximum	65.3	94.0	28.7
			Red	46.3	76.1	29.8
	4	2	Maximum	40.6	68.4	27.8
			Red	37.3	53.7	16.4
2	7	2	Maximum	56.7	62.4	5.7
			Red	47.6	52.6	5.0
	4	2	Maximum	45.4	57.9	12.5
			Red	39.9	45.3	5.4
3	7	2	Maximum	175+	114.2	-60.8
			Red	121	78.9	-42.1
	4	2	Maximum	124	59.9	-64.1
			Red	103	46.9	-56.1
4	7	2	Maximum	175+	87.0	-88.0
			Red	147	71.5	-75.5
	4	2	Maximum	130+	65.3	-64.7
			Red	90	50.7	-39.3

Table 5 Observed and modelled queue lengths

The results are mixed. In under saturated conditions the model has changed from being an underestimate of queue length to being one of an over estimation. The most disappointing performance was, however, in over saturated conditions. The queue lengths have become an even greater underestimate than previously. Despite this fall in performance the changes described above are still valid and are retained in the model.

At this stage another mis-specification in the model was identified. As traffic left a lane it was immediately added to the appropriate receiving lane(s). This meant that when two movements occurred, eg link 2 to link 4 and link 3 to link 4, one movement would block the other. The model was changed to accumulate all flows into a link before creating the traffic in the receiving lanes. Thus the two flows link 2 to link 4 and link 3 to link 4 created only one block of traffic in each receiving lane.

The next stage was to experiment to see how sensitive the model was to changes in one of its important parameters. The parameter selected was the free-flow speed. It was suggested that one effect of having a congested network was that the speeds at which traffic moves through the network would be reduced. The speeds we were currently using were observed during uncongested conditions. The model was run three times, once with a free flow speed as usual, a second with all the free-flow speeds set at 90% of the original value and a third time with the speeds set at 80%.

4.4 Stage 4

The results of the three model runs are given below in table 6:

File	Link	Measure	Observed	U_f	$0.9U_f$	$0.8U_f$
1	1	Max	65.3	66	65	31
		Red	46.3	50	58	25
	2	Max	40.6	61	39	24
		Red	37.3	39	35	21
2	1	Max	56.7	71	44	39
		Red	47.6	53	33	29
	2	Max	45.4	87	26	29
		Red	39.9	55	23	22
3	1	Max	175+	90	70	52
		Red	121	70	54	39
	2	Max	123	40	37	27
		Red	103	31	30	20
4	1	Max	175+	95	95	86
		Red	147	74	73	63
	2	Max	130+	62	36	44
		Red	90	37	27	35

Table 6 Reduced free-flow speed (U_f)

Once again the results are a disappointment. As the free-flow speed is reduced then so are the queues. In hindsight this is reasonable since if we reduce the speed at the inputs then the flow of traffic into the network is reduced and the queues do not form as rapidly. The idea of improving the calibration of the model by a global reduction in the free-flow speeds was abandoned. The above work did suggest that attention should be paid to flows across stop lines into the network and across internal junctions. The model was adapted to collect flows of vehicles leaving a link and entering Wellington Street. These were input flows (1 to 4), (2 to 4), (3 to 4), (5 to 7) and (6 to 7) along with internal flow (4 to 7) and output flow from (7). These values were then compared with the observed flows for the appropriate 15 minute time period. Both flows were multiplied up to represent flows in vehicles per hour. The results are shown in tables 7 to 10.

Link	Lane	Observed	Model	Error
1	1	430	370	-60
	2	440	423	-17
2		180	121	-59
3		330	154	-176
4	1	516	542	26
	2	750	557	-193
5		270	117	-153
6		157	104	-53
7	1	523	418	-105
	2	660	459	-201
	3	460	137	-323

Table 7 File 1 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	484	351	133
	2	544	426	-118
2		188	119	-69
3		332	148	-184
4	1	600	516	-84
	2	912	571	-341
5		144	148	4
6		176	114	-62
7	1	500	426	-74
	2	672	502	-170
	3	548	206	-342

Table 8 File 2 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	508	468	-40
	2	440	484	44
2		196	111	-85
3		484	161	-323
4	1	636	573	-63
	2	884	550	-334
5		176	123	-53
6		184	127	-57
7	1	508	443	-65
	2	736	452	-284
	3	660	228	-432

Table 9 File 3 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	440	417	-23
	2	460	454	-6
2		130	106	-24
3		450	168	-282
4	1	645	537	-108
	2	705	518	-187
5		290	165	-125
6		215	111	-104
7	1	520	480	-40
	2	780	429	-351
	3	606	245	-361

Table 10 File 4 observed & modelled flows (v/hr)

The results show that the model is an almost consistent under estimate of the observed flows, the worst performer being link 3. Link 3's flow is always less than half the observed value. Since the flows into the network are less than those observed, traffic is not entering the network giving shorter queues and less flow out of link 7. Investigation revealed two possible causes:
1) *Lost traffic* at input links. An arbitrary, but reasonable, link length had been given to the input links. If during a modelled second there was no room in the link for the input traffic then it was not added to the link. Monitoring of the program showed that this was occurring often for the over saturated files. The situation was overcome by making the links as long as reasonably possible. This was especially relevant for link 3 which was observed to regularly have a long queue of traffic waiting to enter Wellington Street. Another method adopted to overcome this problem was to make the input traffic denser, thereby reducing its length so it occupied less space in the link. The amount of traffic was, however, unchanged.
2) Incorrect saturation flow along the input links. The model does not explicitly use measured saturation flow. Instead the condition of saturation flow is derived from free-flow speed, jam density and Greenshield's speed-density relationship. To establish the measure of theoretical saturation flow we were using we have the following equation:

$$q_s = \frac{U_f}{2} * \frac{K_j}{2} = \frac{U_f K_j}{4}$$

This gives the following comparison in table 11

Link	Lane	K_j	U_f	$(U_f K_j)/4$	Observed	Error
1	1	157.8	44.29	1747.2	1580	-167.2
	2	173.8	44.29	1924.4	1600	-324.4
2		200.0	35.03	1751.5	1567	-184.5
3		142.3	37.55	1335.8	1859	523.2
4	1	154.5	46.56	1798.4	1429	-369.4
	2	173.0	46.56	2013.7	1385	-628.7
5		200.0	31.59	1579.5	2190	610.5
6		175.0	32.43	1418.8	1990	571.2
7	1	167.5	50.13	2099.2	1954	-145.2
	2	165.0	50.13	2067.9	1903	-164.9
	3	162.5	50.13	2036.5	1739	-297.5

Table 11 Theoretical and observed saturation flows

This table shows that the theoretical value of saturation flow used by the model is an underestimate of the true saturated flow for input links 3, 5, 6 and an overestimate for 2 and 1. The model is also an overestimate for the flow out of links 4 and 7. To provide additional information the starting wave speeds along links 4 and 7 were calculated. When these wave speeds are doubled another estimate of the free-flow speed is available since the application of Greenshield's speed-density relationship gives $U_f = 2U_m$ and $U_m = - U_{start}$.

Link	Lane	1	2	3
1	1	44	35	
	2	44	36	
2		35		
3		37	49	
4	1	46	33	
	2	46	32	38
5		31	27	
6		32	27	
7	1	50	41	
	2	50	41	41
	3	50	41	

Table 12 Different free-flow speeds (km/hr)

The results are shown in table 12. Method 1 is the observed value. Method 2 is the value of U_f required to achieve the observed saturation flow (using the formula $U_f = (4*q_s)/K_j$). Method 3 is double the starting wave speed along the appropriate link. Methods 2 and 3 are in close agreement where common data exists. This is reasonable since both the saturation flow and the jam density were calculated during over saturated conditions as was the starting wave speed. Thus the appropriate measure of free-flow speed depends upon the conditions. In under saturated conditions the observed free-flow speeds are appropriate. In over saturated conditions the free-flow speeds consistent with the measured saturation flow (methods 2 and 3) are appropriate. To summarise we have that data files 1 and 2 consist of a traffic specification during under saturated conditions whilst files 3 and 4 are for over saturated conditions. The free flow speeds used at the inputs are those which give measured saturation flow (case 2 above). For files 1 and 2 the speeds on the internal links are those which were measured in under saturated conditions(case 1 above). For files 3 and 4 the free flow speeds used are those which are consistent with the observed jam density and saturation flow which were both calculated in over saturated conditions (case 3 above).

This scheme had to be modified in one respect. The free-flow speed on link 1 was constrained by the speed along link 4. If the speed for link 1 was greater than link 4 then link 4 did not have sufficient capacity to accommodate all the traffic leaving link 1. In practice the free-flow speed along link 1 was set at the same as on link 4 ie 38km/h.

4.5 Stage 5

The results are given in tables 13 to 16 (flows) and 17 (queue lengths).

Link	Lane	Observed	Model	Error
1	1	430	348	-82
	2	440	411	-29
2		180	172	-8
3		330	344	14
4	1	516	514	-2
	2	750	698	-52
5		270	204	-66
6		157	154	-3
7	1	523	700	177
	2	660	613	-47
	3	460	405	-55

Table 13 File 1 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	484	458	-26
	2	544	535	-9
2		188	174	-14
3		332	344	12
4	1	600	606	6
	2	912	776	-136
5		144	186	42
6		176	169	-7
7	1	500	851	351
	2	672	626	-46
	3	548	468	-80

Table 14 File 2 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	508	549	41
	2	440	500	60
2		196	170	-26
3		484	378	-106
4	1	636	731	95
	2	884	691	-193
5		176	211	35
6		184	189	5
7	1	508	839	331
	2	736	790	54
	3	660	604	-56

Table 15 File 3 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	440	446	6
	2	460	505	45
2		130	156	26
3		450	387	-63
4	1	645	665	20
	2	705	696	-9
5		290	254	-36
6		215	173	-42
7	1	520	857	337
	2	780	787	7
	3	606	505	-101

Table 16 File 4 observed & modelled flows (v/hr)

File	Link	Lane	Measure	Observed	Modelled	Error
1	7	2	Maximum	65.3	66.0	0.7
			Red	46.3	64.1	17.8
	4	2	Maximum	40.6	46.3	5.7
			Red	37.3	41.8	4.5
2	7	2	Maximum	56.7	72.7	16.0
			Red	47.6	56.6	9.0
	4	2	Maximum	45.4	65.8	20.4
			Red	39.9	57.6	17.4
3	7	2	Maximum	175+	88.3	-86.7
			Red	121	63.1	-57.9
	4	2	Maximum	124	59.9	-64.1
			Red	103	53.9	-49.1
4	7	2	Maximum	175+	103.0	-72.0
			Red	147	70.5	-76.5
	4	2	Maximum	130+	55.2	-74.8
			Red	90	49.1	-40.9

Table 17 Observed and modelled queue lengths

The flow results were an improvement on those obtained during stage 4. The queue length measures were still disappointing. The model seemed unable to give significantly longer queues during over saturated conditions.

Investigations showed that the model had been using the wrong signal duration times. The actual duration of the red/green aspects were used to control the movement of traffic at junctions, rather than the effective red/green. Table 18 gives a comparison of how these two measures compare:

Movement	Actual Green	Effective Green
1 -> 4	38	39
2,3 -> 4	40	41
4 -> 7	64	65
5,6 -> 7	13	14
7 -> out	39	40

Table 18 Actual and effective green times (sec)

This change gives an extra 2 seconds of green time to each junction. These signal changes were made and the model re-run.

4.6 Stage 6

The results of the model run are given in tables 19 to 22 (flows) and 23 (queue lengths).

Link	Lane	Observed	Model	Error
1	1	430	355	-75
	2	440	421	-19
2		180	170	-10
3		330	341	11
4	1	516	496	-20
	2	750	676	-74
5		270	204	-66
6		157	154	-3
7	1	523	686	163
	2	660	614	-46
	3	460	404	-56

Table 19 File 1 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	484	458	-26
	2	544	535	-9
2		188	181	-7
3		332	336	4
4	1	600	600	0
	2	912	780	-132
5		144	186	42
6		176	169	-7
7	1	500	828	328
	2	672	634	-38
	3	548	475	-73

Table 20 File 2 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	508	550	42
	2	440	500	60
2		196	221	25
3		484	347	-137
4	1	636	773	137
	2	884	751	-133
5		176	210	34
6		184	189	5
7	1	508	853	345
	2	736	767	31
	3	660	622	-38

Table 21 File 3 observed & modelled flows (v/hr)

Link	Lane	Observed	Model	Error
1	1	440	446	6
	2	460	505	45
2		130	180	50
3		450	513	63
4	1	645	733	88
	2	705	784	79
5		290	254	-36
6		215	173	-42
7	1	520	891	371
	2	780	784	4
	3	606	509	-97

Table 22 File 4 observed & modelled flows (v/hr)

File	Link	Lane	Measure	Observed	Modelled	Error
1	7	2	Maximum	65.3	51.0	-14.3
			Red	46.3	49.1	2.8
	4	2	Maximum	40.6	53.3	12.7
			Red	37.3	43.8	6.5
2	7	2	Maximum	56.7	43.7	-13.0
			Red	47.6	42.0	-5.6
	4	2	Maximum	45.4	40.8	-4.6
			Red	39.9	38.6	-1.3
3	7	2	Maximum	175+	73.0	-102.0
			Red	121	58.9	-62.1
	4	2	Maximum	124	36.6	-87.4
			Red	103	35.1	-67.9
4	7	2	Maximum	175+	109.7	-65.3
			Red	147	70.1	-76.9
	4	2	Maximum	130+	47.0	-83.0
			Red	90	35.7	-54.3

Table 23 Observed and modelled queue lengths

The flows have changed little over those obtained during stage 5. The queue lengths are also little changed. In order to try and improve the situation one of the model restrictions was removed. The model assumes constant flow at the inputs. Normally we would expect a variation in the input flows within a cycle and between cycles. The model was adapted to use different input flows at different times during the model execution. The observed two minute input flows at each input link were multiplied up to represent input flows in vehicles per hour. These input flows were then used in the model. Tables 24 to 27 give these flows

Link		2	3	6	5	1
4:37-	4:21	300	420	330	360	840
39	23	240	270	150	180	690
41	25	270	330	90	360	450
25	27	360	330	60	390	780
27	29	240	240	270	90	750
29	31	360	450	90	330	810
31	33	240	450	210	270	750
33	35	390	360	180	360	1020
35	37	390	420	270	390	750
37	39	360	600	270	660	840
39	41	240	270	360	300	660
Average		323	390	214	349	795
Uniform		327	387	240	347	793

Table 24 Input flows for file 1 (16:25 to 16:41)

Link		2	3	5	6	1
4:37-	4:39	360	600	270	660	840
39	41	240	270	360	300	660
41	43	330	390	180	360	780
43	45	360	300	300	360	930
45	47	360	540	240	120	870
47	49	480	540	180	150	870
49	51	390	420	150	150	750
51	53	360	510	300	360	1080
53	55	420	150	330	210	1350
55	57	330	540	600	300	1140
57	59	390	450	210	330	960
Average		386	431	289	248	994
Uniform		386	431	289	248	994

Table 25 Input flows for file 2 (16:43 to 16:59)

Link	2	3	5	6	1
4:59-5:01	510	270	330	300	690
01 03	540	420	330	420	960
03 05	390	510	150	360	1080
05 07	450	600	180	300	1200
07 09	510	600	180	330	840
09 11	300	420	330	270	1230
11 13	480	690	300	540	840
13 15	410	540	300	420	1020
15 17	360	450	150	240	1380
17 19	330	600	300	210	900
19 21	360	510	390	330	1100
Average	413	551	266	330	1065
Uniform	540	413	266	338	1065

Table 26 Input flows for file 3 (17:05 to 17:21)

Link	2	3	5	6	1
5:25-5:27	510	360	180	300	960
27 29	360	330	300	210	810
29 31	390	360	270	300	690
31 33	390	630	330	540	1140
33 35	360	600	270	360	750
35 37	450	450	210	480	780
37 39	570	690	360	360	1050
39 41	540	510	330	330	1230
41 43	300	570	450	330	870
43 45	420	540	540	360	930
45 47	240	480	390	330	570
Average	409	559	360	386	915
Uniform	425	570	380	395	970

Table 27 Input flows for file 4 (17:31 to 17:46)

Note
The underline marks the end of the run-in time.
Average is the average flow during the ten cycle study period.
Uniform is the flow assumed previously.

This change also enabled us to run the model over the entire observed period of 15 minutes. The run-in period was set at six minutes (4 cycles) and the run time set at 15 minutes (10 cycles). Now it is not just appropriate that the global maximums of observed and modelled should agree but that there should be close agreement in the growth and decline in queue profiles between observed and modelled throughout the 10 cycle period. Another consideration is that multiplying the flows to get a measure of both observed and modelled flows in terms of vehicles per hour disadvantages the model results. Up to now the observed flows have been the flows during the appropriate 15 minute period multiplied by 4. The modelled flows have been the one cycle flows multiplied by 40. We would expect the flows during a short period to be much more variable than those over a longer period. If this is the case them the models short term variability has been emphasised more then the observed flows by a factor of 100 (since $VAR(aX) = a^2VAR(X)$ and for observed $a = 4$, $a^2 = 16$ and for modelled $a = 40$ and $a^2 = 1600$). The new scheme of having variable flows and a modelled period of 15 minutes will overcome this problem enabling all flows to be measured in units of vehicles per 15 minutes.

4.7 Stage 7

The results using variable flows were very encouraging. Table 28 gives the measures of queue length whilst tables 29-32 give the flow measures.

File	Link	Lane	Measure	Observed	Modelled	Error
1	7	2	Maximum	65.3	54.0	-11.3
			Red	46.3	53.1	6.8
	4	2	Maximum	40.6	50.0	9.4
			Red	37.3	40.2	2.9
2	7	2	Maximum	56.7	60.2	3.5
			Red	47.6	57.5	9.9
	4	2	Maximum	45.4	47.3	1.9
			Red	39.9	39.3	0.6
3	7	2	Maximum	175+	175+	
			Red	121	127.4	-6.4
	4	2	Maximum	124	62.7	-61.3
			Red	103	51.0	-52.0
4	7	2	Maximum	175+	175+	
			Red	147	123.4	23.6
	4	2	Maximum	130+	123.2	6.8
			Red	90	89.0	-1.0

Table 28 Observed and modelled queue lengths

Link	Lane	Obs	Model	χ^2
1	1	107	79	7.3
1	2	110	94	2.3
2		45	36	1.8
3		83	73	1.2
4	1	129	104	4.8
4	2	188	139	12.8
5		68	40	11.5
6		39	25	5.0
7	1	130	137	0.3
7	2	165	130	7.4
7	3	115	70	**17.6**
TOTAL				72.2

Table 29 File 1 Observed & Modelled flows

Link	Lane	Obs	Model	χ^2
1	1	121	103	2.6
1	2	136	118	2.3
2		47	38	1.7
3		83	68	2.7
4	1	150	124	4.5
4	2	228	156	**22.7**
5		36	44	1.7
6		44	34	2.2
7	1	125	170	**16.2**
7	2	168	145	3.1
7	3	137	78	**25.4**
TOTAL				85.5

Table 30 File 2 Observed & Modelled flows

Link	Lane	Obs	Model	χ^2
1	1	127	124	0.0
1	2	110	115	0.2
2		49	40	1.6
3		121	101	3.3
4	1	159	154	0.1
4	2	221	166	13.7
5		44	44	0.0
6		46	37	1.7
7	1	127	171	**15.2**
7	2	184	154	4.8
7	3	165	79	**44.8**
TOTAL				85.8

Table 31 File 3 Observed & Modelled flows

Link	Lane	Obs	Model	χ^2
1	1	110	97	1.5
1	2	115	108	0.4
2		33	39	1.0
3		113	109	0.1
4	1	161	142	2.2
4	2	176	155	2.5
5		73	58	3.0
6		54	38	4.7
7	1	130	168	11.1
7	2	195	155	8.2
7	3	152	80	**34.1**
TOTAL				69.2

Table 32 File 4 Observed & Modelled flows

Note

$\chi^2_{10}(1.0\%) = 24.72$

$\chi^2_{10}(0.5\%) = 26.76$

$\chi^2_{10}(0.1\%) = 31.26$

Considering the queue measure results first we see that for files 1 and 2 there is close agreement between observed and measured. The queue lengths in over saturated conditions (files 3 and 4) have grown especially in the case of link 7. The four flow tables also give the results of a χ^2 test on the flows. Large values for the deviance (greater than 15) are shown in bold. Lane 3 of link 7 is consistently a large underestimate of the flow whilst lane 1 of link 7 is occasionally a under estimate of the flow. The other results are generally all reasonable (except possibly lane 2 of link 4). A possible remedy for the situation at link 7 is to alter the lane split percentages so as to move traffic from lane 1 to lane 2, which subsequently feeds lane 3. Another remedy may be to increase the lane change percentage which determines how much traffic leaves lane 2 and goes into lane 3. This later percentage was measured at 36% which appears low since a near 50/50 split would be expected. When the video tapes of the survey were viewed it was noticed that vehicles, when they are moving freely, only use one of the lanes 2 or 3 and tend not to split. Lane 3 is only full when a queue is forming. This phenomenon is reflected in the low lane change percentage.

The idea of changing the lane split percentages at the entrance to link 7 was investigated for files 3 and 4.

4.8 Stage 8

Table 33 gives the flow and queue length results of a model run on file 3 with various lane split percentages. Table 34 give the corresponding results for file 4. Table 35 Gives the duration of any spill back for each cycle for both files 3 and 4.

Flow Measure						
Link	Lane	Case 1	Case 2	Case 3	Case 4	Observed
1	1	124	118	103	94	127
	2	115	110	98	91	110
2		40	39	39	38	49
3		101	100	98	95	121
4	1	154	144	131	124	159
	2	166	153	138	129	221
5		44	45	46	45	44
6		37	37	37	37	46
7	1	171	166	153	142	127
	2	154	154	154	154	184
	3	79	79	79	80	165
Queue Measure						
7	Max	176	177	177	177	175+
	Red	127	159	168	165	121
4	Max	62	114	138	141	124
	Red	51	96	105	111	103

Table 33 File 3 Flow and Queue Measure with variable lane splits

Note
Case 1 - Original lane splits
Case 2 - Split from lane 4 changed from 45/55 to 44/56
Case 3 - As case 2 but split from lane 6 changed from 35/65 to 30/70
Case 4 - As case 3 but split from lane 5 changed from 57/43 to 53/48

Flow Measure					
Link	Lane	Case 1	Case 2	Case 3	Observed
1	1	97	96	96	110
	2	108	109	408	115
2		39	39	39	33
3		109	109	109	113
4	1	142	143	142	161
	2	155	157	154	176
5		58	58	58	73
6		38	38	38	54
7	1	168	163	164	130
	2	155	150	150	195
	3	80	74	76	152
Link Measure					
7	Max	177	177	177	175+
	Red	143	137	137	175+
4	Max	123	93	129	130+
	Red	89	85	92	90

Table 34 File 4 Flow and Queue Measure with variable lane splits

Note
Case 1 - Original lane splits
Case 2 - Split from lane 6 changed from 28/72 to 25/75
Case 3 - Split from lane 5 changed from 53/47 to 51/49

There is less freedom to alter the lane split percentages for file 4 since the resultant high flow causes the flow density parabola to have complex roots. This restriction was later removed by setting the resultant density to jam density and increasing the length of the block to compensate.

	Entrance of 7										Entrance of 4									
	Cycle										Cycle									
Case	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	2	2	7	4	17	20	0	0	0	0	0	0	2	2	2	2
3	0	0	5	3	2	12	23	23	23	20	0	0	0	0	0	0	2	2	3	2
4	0	2	6	2	4	21	21	21	21	23	0	0	0	2	3	3	4	9	10	11
Obs	Average duration = 27										Average duration = 17									
Case																				
1	0	0	0	0	2	2	5	13	11	3	0	0	0	0	0	2	2	2	3	2
2	0	0	0	0	3	2	5	13	7	2	0	0	0	0	0	0	0	2	2	2
3	0	0	0	0	2	9	2	15	2	2	0	0	0	0	0	0	2	2	2	2
Obs	Average duration = 32										Average duration = 42									

Table 35 Duration of spill back (seconds)

This exercise has not improved the situation in link 7. The flows out of lanes 2 and 3 have hardly changed, whilst the flow out of lane 1 has fallen as the percentage splits have moved in favour of lane 2. The diminished flow out of lane

1 has not been transferred into lane 2 but has given longer queues and longer periods of spill back. The minor change from case 1 to 2 for file 3 has produced a dramatic effect in the queue lengths. Subsequent changes for file 3 in cases 3 and 4 appear to have little additional useful effect. The queue length results for file 4 are unusual. The change from case 1 to 2 has produced a decrease in queue length on link 4. The other results for file 4 appear stable.

The amount of spill back at the junction which is the entrance to link 7 compares favourably with the observed, whilst the spill back at the entrance to 4 does not. For the entrance to link 4, however, in the case of file 3 the spill back only occurred in seven out of ten cycles and for file 4 the variation in the amount of spill back varied considerable between 7 seconds and 72 seconds.

The duration of spill back is encouraging but it does not cover all ten cycles. If the spill back were to start occurring earlier then the knock on effect of this from link 7 to link 4 may be beneficial. To help achieve this the run-in time was extended from 4 to 8 cycles by adding new flows to the start of the period. Stage 9 details these results.

4.9 Stage 9

Table 36 shows the results of increased run-in time for file 3 whilst table 37 shows the same for file 4. Table 38 is the duration of blocking back for both files.

Flow Measure						
Link	Lane	Case 1	Case 2	Case 3	Case 4	Observed
1	1	116	102	78	84	127
	2	105	97	78	84	110
2		40	39	39	38	49
3		97	96	94	94	121
4	1	150	130	115	117	159
	2	159	137	119	121	221
5		50	51	51	51	44
6		48	48	48	48	46
7	1	186	165	145	147	127
	2	166	167	167	167	184
	3	83	85	85	85	165
Queue Measure						
7	Max	177	177	177	176	175+
	Red	126	166	168	168	121
4	Max	68	136	141	142	124
	Red	53	109	111	109	103

Table 36 File 3 Flow and Queue Measure with variable lane splits

Note
Case 1 - Original lane splits
Case 2 - Split from lane 4 changed from 45/55 to 44/56
Case 3 - As case 2 but split from lane 6 changed from 35/65 to 30/70
Case 4 - As case 3 but split from lane 5 changed from 57/43 to 53/48

Flow Measure					
Link	Lane	Case 1	Case 2	Case 3	Observed
1	1	88	89	86	110
	2	100	99	98	115
2		38	38	38	33
3		102	102	102	113
4	1	139	133	134	161
	2	153	149	148	176
5		64	64	63	73
6		42	42	42	54
7	1	177	168	163	130
	2	167	167	167	195
	3	84	85	85	152
Queue Measure					
7	Max	177	177	176	175+
	Red	149	135	137	175+
4	Max	135	134	136	130+
	Red	100	101	103	90

Table 37 File 4 Flow and Queue Measure with variable lane splits

Note
Case 1 - Original lane splits
Case 2 - Split from lane 4 changed from 45/55
Case 3 - As case 2 but split from 5 changed from 53/47 to 50/50 and split from 6 changed from 28/72 to 25/72.

	Entrance of 7										Entrance of 4									
	Cycle										Cycle									
Case	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
1	0	0	0	0	0	2	8	4	2	0	0	0	0	0	0	0	0	0	0	0
2	0	0	6	22	25	23	23	23	22	23	0	0	0	0	2	4	2	8	12	2
3	8	26	26	23	26	25	21	23	25	19	0	0	0	3	2	8	11	12	6	9
4	7	24	21	26	25	26	21	21	26	22	0	0	2	4	7	2	13	5	11	2
Obs	Average duration = 27										Average duration = 17									
1	0	0	0	8	2	11	18	2	13	3	0	0	0	0	0	0	0	0	0	0
2	0	0	10	9	6	12	16	2	11	2	0	0	0	0	0	2	2	3	4	2
3	0	2	12	16	12	12	15	14	10	2	0	0	0	0	2	3	5	5	4	0
Obs	Average duration = 32										Average duration = 42									

Table 38 Duration of spill back (seconds)

For file 3 the queue lengths have grown as have the duration and commencement of any spill back, but not to the extent expected. This could result from the characteristics of the traffic prior to the modelled period. For file 3 the additional input flows for the run-in period were taken from traffic in uncongested conditions during 16:53 to 16:59. This was also the case for file 4. The congestion occurs in the 15 minute period after 17:00, there then follows a decrease in congestion until 17:25 after which time the road becomes congested again. The extra run-in time was taken from the uncongested period 17:19 to 17:25. As a result the effect of including the extra run-in time is visible but not as great as expected.

To test the three alternative signal offset strategies, case 2 of file 3 was selected. The reason for this was that it produced acceptable measures of queue length and significant periods of blocking back. The adjustments made to the lane splits from the observed percentages was minor (from a 10% to a 12% difference between the two receiving lanes). Further adjustments in the side link percentages produces no significant additional benefits.

For the results of trying the four signal offset strategies see Working Paper number 344.

5 Validation

To validate the model another survey was carried out on Wellington Street in April 1991 using the Bangkok signal offset strategy. The data collected in this exercise was used to build two new model specification files (new input flows, turning percentages and lane split percentages), one in uncongested conditions and one in congested conditions. The start and stop times for each of these data files is given in table 39.

File	Time
5	16:43 to 16:59
6	17:05 to 17:21

Table 39 - Model run time

5.1 Observed results

The input flow used are given in tables 40 (file 5) and 41 (file 6).

Link	2	3	5	6	1
4:37-4:39	390	390	210	450	1140
39 41	330	480	150	510	780
41 43	330	480	180	330	1020
43 45	210	570	300	180	1020
45 47	330	510	420	510	960
47 49	390	330	210	210	870
49 51	570	810	450	390	990
51 53	300	420	270	300	900
53 55	480	240	300	390	960
55 57	240	660	180	180	930
57 59	510	540	300	120	840
Average	379	510	304	285	934

Table 40 Input flows for file 5 (16:43 to 16:59)

Link	2	3	5	6	1
4:59-5:01	270	270	300	420	990
01 03	420	630	120	390	1080
03 05	600	510	630	420	1050
05 07	810	690	570	330	930
07 09	540	750	360	360	1110
09 11	270	540	210	510	1020
11 13	540	840	150	420	1020
13 15	180	900	300	180	930
15 17	60	780	210	330	750
17 19	240	450	270	300	1020
19 21	360	720	420	270	570
Average	375	709	311	338	919

Table 41 Input flows for file 6 (17:05 to 17:21)

Note
The underline marks the end of the run-in time.
Average is the average flow during the ten cycle study period.

To asses the validity of the model the usual queue measures were also collected. The queue measure results are given in table 42

File	Link	Lane	Measure	Observed	Spill back
5	7	2	Maximum	175+	7s-36s
			Red	115	(4/10)
	4	2	Maximum	59	none
			Red	52	none
6	7	2	Maximum	175	15s-30s
			Red	126	(7/10)
	4	2	Maximum	130+	18s-25s
			Red	126	(5/10)

Table 42 Observed queue lengths

An unusual feature in the above results is with file 5. Although there is spill back from long queues in link 7 the queues in link 4 are small.

5.2 Model results

Table 43 gives a queue measure comparison between the observed results and the results obtained from the model. Table 44 gives a similar comparison using spill back.

File	Link	Lane	Measure	Observed	Modelled
5	7	2	Maximum	175+	175+
			Red	115	102
	4	2	Maximum	59	60
			Red	52	48
6	7	2	Maximum	175	175
			Red	126	162
	4	2	Maximum	130+	130+
			Red	126	92

Table 43 Observed and Modelled queue lengths

File	Link	Measure	Observed	Modelled
5	7	Duration	7s-36s	2s-4s
		Prop'n	(4/10)	(2/10)
	4	Duration	none	none
		Prop'n	none	none
6	7	Duration	15s-30s	5s-24
		Prop'n	(7/10)	(8/10)
	4	Duration	18s-25s	4s-9s
		Prop'n	(5/10)	(4/10)

Table 44 Observed & Modelled Spill back

The queue measure results are generally good. Once again, however, the spill back produced in the model has been an under estimate of that observed, especially in the case of link 4.

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