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QUEUE MANAGEMENT PROJECT: RESULTS OF TESTING ALTERNATIVE STRATEGIES

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Situations in which a queue grows so as to block the entrance to the link at an upstream junction can cause various problems, including loss of junction capacity, increased driver stress and hazards to pedestrians crossing at the junction. In the worst case the spill-back may grow so as to produce grid-lock within a network. This paper describes work conducted in order to assess how the coordination of junction offsets in a congested network may help to minimise this disruption. A computer model was produced which used traditional speed-flow theory to represent traffic behaviour, eg traffic speeds, merging of traffic and queue evolution. Two test sites were selected for simulation purposes. The first is a three junction linear network whilst the second is a seven junction grid network. These simulation runs attempted to establish which stage at the upstream junction should be disrupted, given that spill-back was to occur. Results from a field trial on the linear network will be presented to show how the techniques can be applied on-street. The work described here was sponsored by the SERC, but also forms an input to the DRIVE II project, PRIMAVERA.

<u>Introduction</u>. While advances in traffic signal optimisation have increased the capacity of urban networks, growth in demand has meant that such networks continue to operate at close to saturation. Once over-saturation occurs and queues extend to block upstream junctions, the delay costs increase dramatically. A number of techniques have been proposed for the alleviation of these delay costs, by managing the queues in such a way that as little disruption as possible is caused to upstream junctions. Some of these techniques have been tested only in simulation of idealised networks, whereas others have been field tested, but only at one specific site. There was therefore a need to develop a generalised description of the various strategies, and to compare them on a common base. These were two of the objectives of the SERC project 'Queue Management Strategies for Urban Traffic Control Systems' from which this paper derives.
The comparison of strategies (the development and characterisation of which is reported in May (1991)), was carried out using a specially developed graphical model. This was macroscopic in nature, to provide speed of operation, and the primary output was a set of time-space diagrams showing the queues and shock waves on each link.

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Modelling methodology. The program models traffic flow through a one-way signalised network of multi-laned links (Clark, 1992). The arrangement of the network may be one-dimensional, ie linear, or two-dimensional, such as a grid. Each junction in the network may have up to four approaches or exits, labelled north, south, east and west for convenience. Traffic within the network is modelled as blocks of vehicles of a given length and density. Behaviour of these blocks is determined by rules expressed in hydrodynamic traffic flow theory. This theory provides us with:

- The density of traffic at input approaches;
- The speed of blocks of traffic;
- The speed of a shock wave between blocks of traffic;
- The speed of queue stopping waves;
- The speed of queue starting waves;
- The density of traffic leaving a queue.

A number of functional forms are available to provide these quantities (Gerlough and Huber, 1975), the relationship adopted for this study, being the simplest, is that suggested by Greenshields. The forms of each of these quantities are:

Speed of a block of density k

$$u = u_f \left(1 - \frac{k}{k_j}\right) \qquad (1)$$

Speed of a shock wave between two blocks of density k_a and k_b. This is given by

$$u_{shock} = \frac{q_a - q_b}{k_a - k_b} \qquad (2)$$

Where q_a, q_b are the rate of flow in each block. Applying the fundamental relationship ($q=uk$) to each block, we obtain:

$$u_{shock} = \frac{u_a\, k_a - u_b\, k_b}{k_a - k_b} \qquad (3)$$

Application of Greenshields relationship (1) then yields

$$u_{shock} = u_f \left(1 - \left(\frac{k_a}{k_j} + \frac{k_b}{k_j}\right)\right) \qquad (4)$$

Speed of a stopping wave given a block of density k.

$$u_{stop} = u_f \left(\frac{k}{k_j}\right) \qquad (5)$$

Speed of a starting wave

$$u_{start} = \frac{u_f}{2} \tag{6}$$

Where k_j is the link's jam density
and u_f is the link's free flow speed.

In addition it is necessary to have an expression for the conversion of input and output flows to densities. For a given flow, q, the required density, k, is the solution of:

$$0 = -\frac{u_f}{k_j}k^2 + u_f k - q \tag{7}$$

Clearly this equation has, under certain conditions, two roots and therefore two densities per given flow. These flows correspond to the free flow and forced flow conditions. Input and output conditions are assumed to be free flow, and the lower of these two densities is thus used within the computer model.

Model data requirements. In order to model a network the following data are required. Some items of data are supplied on a global network basis whilst other data are link specific.

- Time information.
    - Simulation run time (sec);
    - Time to reach equilibrium within the model (sec);
    - Network cycle time (sec).

- Physical information.
    - Junction number and name;
    - Number of lanes per link (0,4);
    - Link lengths (m);
    - Junction widths (m).
- Traffic information.
    - Link jam density (veh/km);
    - Link free flow speed (km/hr);
- Turning information
    - Proportion of right and left turning traffic (%);
    - Proportional split of traffic between lanes on entry to links (%).
- Signal information
    - Junction offset in a network cycle time (sec);
    - Stage description;
    - Stage duration (sec).
- Traffic input flows (veh/hr).

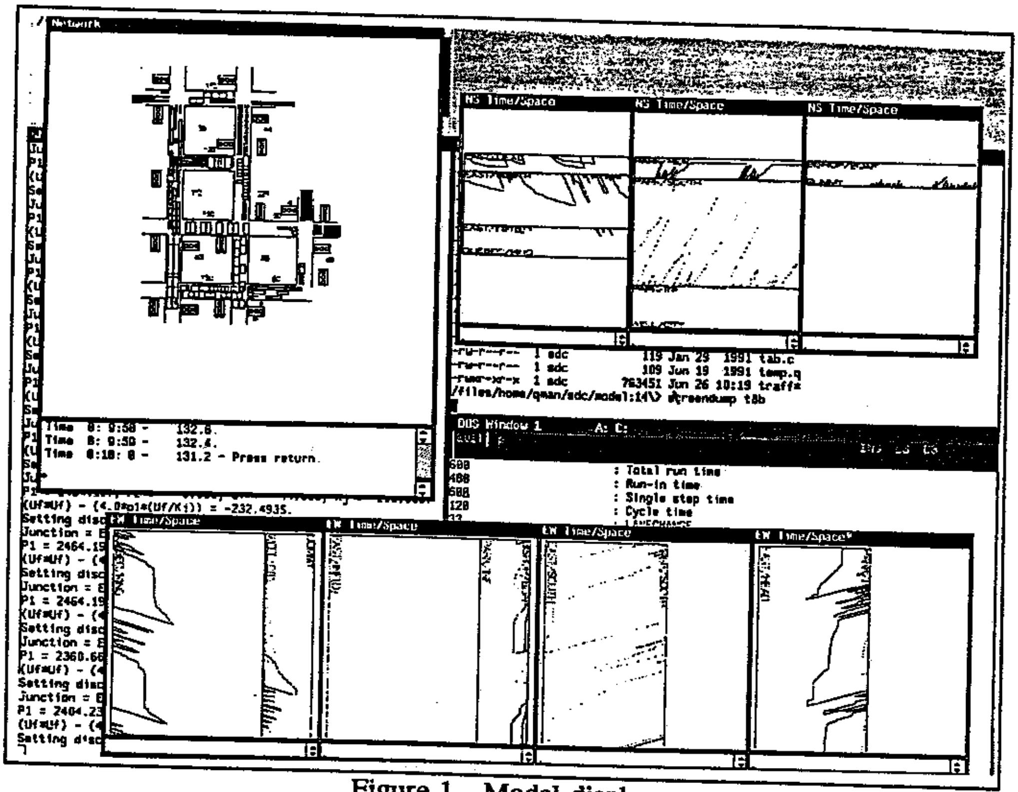

Figure 1 - Model display

Model outputs. The computer model produces two distinct types of output, graphical and textual. The graphical output displays, on a second by second basis, the state of the traffic network as well as time/distance diagrams showing queue evolution. Extensive use is made of the graphical facilities of the Sun386i computer to display each image in its own window, which may then be manipulated to enhance the understanding of the behaviour of traffic within the network. Figure 1 shows a typical arrangement of network and time/distance window views. Textual output consists of: mean and variance of queue length; overall maximum queue rear; maximum queue rear at end of red; input and output flows from each link; and the amount of lost time on this link due to spill-back. This information can then be combined to produce other evaluation measures. Loss of capacity on a link can be calculated as the duration of the entry link blockage, during green, multiplied by the link's saturation flow. The delay on a link is given by the average queue length (in vehicles) divided by the flow into the link.

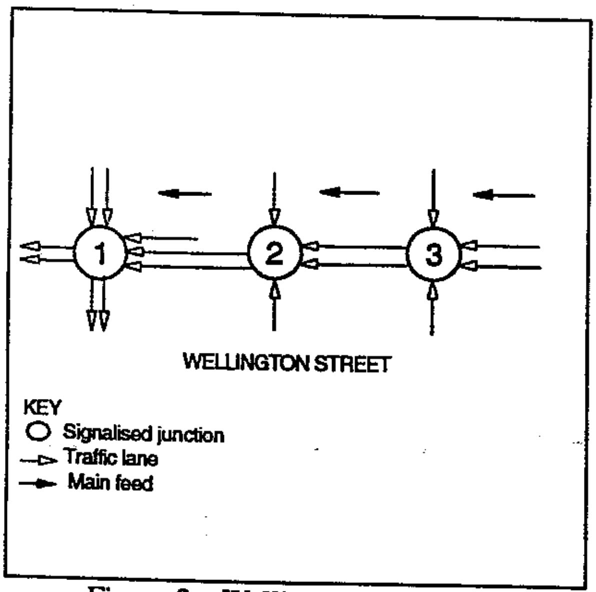

Figure 2 - Wellington St network

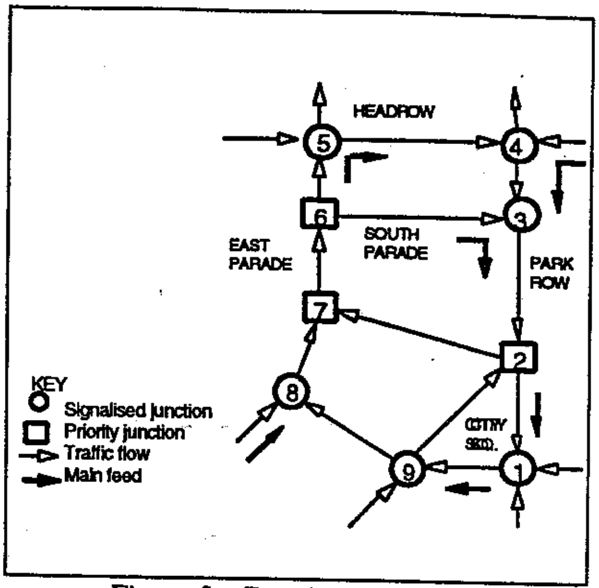

Figure 3 - Park Row network

Test networks. Two test networks are used in this study. The first is a linear network of three nodes, very closely modelled on a stretch of Wellington Street in Leeds. This test site was used to calibrate and validate the computer model (Clark and Montgomery, 1992) and to test the result on-street. See figure 2 for a diagrammatic representation of this network. The second network is loosely modelled on the East Parade/Park Row/City Square one-way system in the centre of Leeds (see figure 3). This network was used to assess how a more complicated set of junctions interacted.

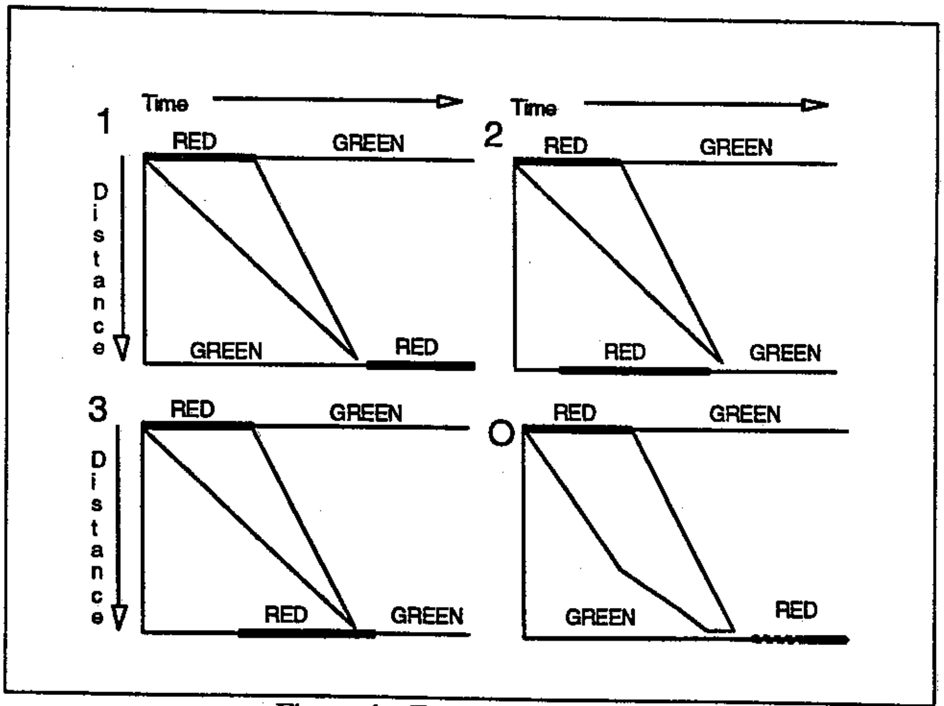

Figure 4 - Four offset strategies

Four strategies. In essence, each strategy involved devising a set of signal offsets which ensured that when spill-back occurred it would obstruct a nominated stage at a nominated time in that stage (May, 1991). Wherever possible, upstream of each junction, main and minor feed stages were nominated. Given information on link lengths and starting wave speeds, offsets were calculated to ensure that the starting wave reached the upstream junction at the following positions in the cycle for each strategy.

Strategy	Position in cycle
1	End of main stage green
2	Start of main feed green
3	End of minor feed stage green
O	Original offset

Table 1 - Offset Strategies

In addition the existing signal offsets were adopted as strategy four. Figure 4 gives a diagrammatic representation of the four strategies.

Modelled results. The results from four simulation results on the two test networks are given in tables 2a and 2b. Within these tables, the top section refers to the Park Row network, whilst the lower section refers to the Wellington Street network. Mean queue length is the sum of the mean queues on all lanes within the appropriate link. One maximum queue measure is presented. This is the maximums of the maxima observed in each lane. Delay is given as delay per vehicle per cycle. Lost capacity is the duration of any spill back each cycle, multiplied by the saturation flow of the entry link. Table 3 ranks the strategies, best first, according to three performance measures from tables 2a and 2b.

Measure	Park Row	Wellington Street
Mean Queue	3 O 1 2	1 3 O 2
Delay	3 O 1 2	1 O 3 2
Lost Capacity	1 3 O 2	3 O 1 2

Table 3 - Offset strategy rankings

The results are contradictory on a number of measures, but a number of points emerge. The results on a link by link basis from strategies (2) and (3) are similar. This is to be expected since the nominated times for spill back to occur at an upstream junction are close to each other in time (ie end of minor feed green and start of main feed green are separated only by an inter-green).

Link	Mean Queue (in lane metres)				Maximum Queue rear (m)			
	1	2	3	O	1	2	3	O
1-2-3	41	44	46	43	258	268	266	282
3-4	28	40	13	33	28	35	28	33
4-5	18	29	23	14	27	64	30	33
3-6	33	21	29	25	84	64	84	83
5-6-7-8	72	77	76	72	117	127	124	98
8-9	12	7	12	12	28	28	28	28
9-1	31	31	31	32	90	86	83	74
W1-W2	145	158	155	158	180	179	179	180
W2-W3	45	49	44	45	146	96	129	140

Table 2a - Link queue performance measures

Link	Delay (per vehicle per cycle)				Lost capacity (vehicles)			
	1	2	3	O	1	2	3	O
1-2-3	0.30	0.33	0.34	0.31	27	27	30	24
3-4	0.34	0.50	0.16	0.38	8	43	25	32
4-5	0.15	0.23	0.19	0.11				
3-6	0.44	0.28	0.39	0.34				
5-6-7-8	0.30	0.32	0.32	0.31		8	3	3
8-9	0.12	0.07	0.12	0.12				
9-1	0.23	0.23	0.23	0.23	15	15	12	14
W1-W2	0.66	0.71	0.71	0.70	8	12	8	8
W2-W3	0.25	0.24	0.22	0.22	3			2

Table 2b - Link congestion performance measures

Taking the Wellington Street results first, strategy (1) emerges with the lowest delay. Although the differences from the next best strategy (3) are small in absolute terms (only 0.05 seconds per vehicle on link W1-W2), this represents a difference in total delay (and hence mean queue length) of 7%. In terms of lost capacity, strategy (3) outperforms the others. Clearly for a field trial either strategy (1) or (3) should be adopted. A final decision was to adopt strategy (1) for testing in the field trial. The results from the Park Row network are more complex to interpret. It appears that links 8-9 and 9-1 were quite insensitive to the different strategies, probably because they were the farthest upstream from the critical junction, No 1. The biggest effect on any link in terms of delay is that on link 3-4 with strategy (3), where there is a reduction of 58% over the base condition. This strategy slightly increases delays on all other links except 8-9 and 9-1, however these increases are not large enough to outweigh the benefits on link 3-4, so that in terms of overall network delay this strategy is the best. Strategy (2) appears to increase delay overall, with the largest effects occurring on links 3-4 and 4-5. Strategy (1) appears to produce a slight overall increase in delay, with small improvements on links 1-2-3, 3-4 and 5-6-7-8 being slightly outweighed by increased delays on links 4-5 and 3-6. In terms of lost capacity however, strategy (1) appears to perform best. The main effect is on link 3-4, where blockage during green causes a potential loss of flow into this link of only 8 vehs/cycle compared to between 25 and 43 for the other strategies. This large difference is due to the fact that with this strategy, as shown on Figure 4, any spillback on link 1-2-3 will block the long link 3-6 rather than the short link (and main feed) 3-4. Strategy (1) therefore slightly improves the capacity of the main links in the network, but at the expense of longer queues and delays on an internal link.

Field trials. A number of evaluation exercises were carried out on the selected field trial site of Wellington Street. The first exercise was a survey of the site to collect both before data and data for the model calibration purposes. This survey took place in September, 1990 and is reported in Quinn and Topp, 1991. A further survey was also carried out to refine some of the model parameters in October of the same year (Argüello and Torres). In April of 1991, strategy 1 was implemented on-street and after survey data collected. The primary measure used in evaluating the effect of the strategies was the average journey time on each of the two links. Table 4 shows the journey times observed both before and after for both links. When examining table 4 it should also be borne in mind that a 3% to 7% increase in the flows was observed between the two surveys.

Link Journey Times	Sample Size		Sample Mean		Sample Variance	
	O	1	O	1	O	1
W1-W2	57	59	42.1	40.6	13.9	10.3
W2-W3	57	60	22.2	16.2	9.1	2.4

Table 4 - Field trial survey results

Although there is a reduction in both the mean and variance of travel time by using strategy 1, this difference cannot be shown to be statistically significant at the 5% level of a two sample t-test. In addition to the journey time information collected those measures used during the calibration stage of the computer model were also collected. A comparison of these on-street surveys and the models predicted measures can be found in Clark and Montgomery, 1992.

Conclusions. The results demonstrate that queue management strategies have the potential to reduce queue propagation and disruption, and hence to reduce travel times. It should be noted however that the model employed in these tests was of a deliberately simple specification, and the test networks were idealised in certain respects. However field trials on the Wellington St network confirmed the model predictions fairly well. It will also be noted that both the simulations and the field trials were based on fixed time systems. Increasingly traffic control is moving towards vehicle responsive systems such as SCOOT or SPOT, however the ability of such systems to deal with oversaturated links is still at an early stage of development. Moreover online prediction of the position of the back and front of the stationary queue on a link is still an inexact science, and further research is required in this area.

As part of a current DRIVE project (V2016 -Primavera) and in an associated SERC project, we are simulating (using the Italian microsimulation model NEMIS), the effects of a number of queue management strategies, and how they might interact with public transport priority measures, and measures to reduce maximum speeds. It is expected that these projects will help to further improve understanding of the operation of signalised networks under oversaturated conditions.

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References.

Argüello, R. and Torres, M.."*Queue Management Project, Measurement of traffic parameters on Wellington Street*", Nov 1990. ITS Technical Note 296.

Bretherton R.D.. "*SCOOT Urban traffic control system - Philosophy and evaluation*". IFAC Symposium on control, Control in Transportation (1989), Paris pp237-239.

Clark, S.D.. "*Queue Management Project, User and Programme Documentation*", Jan 1992. ITS Working Paper 343.

Clark, S.D. and Montgomery, F.O.. "*Queue Management Project, Calibration of the Traffic Model*", Jan 1992. ITS Working Paper 347.

Gerlough, D.L. and Huber, M.J.. "*Traffic Flow Theory*", 1975. TRB Special Report 165.

Mauro, V. and Di Tarranto, C.. "*SPOT-UTOPIA*". CCCT'89 - AFCET Proceedings, Paris.

Mauro, V.. "*Evaluation of dynamic network control : simulation results using NEMIS urban microsimulator*".. Transportation Research Board annual meeting (1991). Washingto DC.

May, A.D.. "*Queue Management Project, Strategies for the Management of Queues at Upstream Junctions*", December 1991. ITS Working Paper 348.

Quinn, D.J. and Topp, C.F.E.."*Queue Management Project, Testing strategies using the Model*", Dec 1991. ITS Working Paper 332.

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