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PRIORITY MANAGEMENT FOR URBAN ARTERIALS

TRANSFERABILITY OF TECHNIQUES

HUMBERSTONE/UPPINGHAM ROAD

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ABSTRACT

This paper describes the background and methodology employed in research funded by EPSRC to assess the effect of individual traffic control measures, both in isolation and in combination upon urban arterials. The aim of the project was to test the transferability of the techniques developed in a DRIVE II project, PRIMAVERA, to a range of different types of urban corridor. The techniques concerned can be classed into three broad categories: Congestion Management, Public Transport Priority and Traffic Calming. The scope of these measures is wide, some operating at a junction level whilst others concentrate on the efficient use of road space.

Measures from these areas are applied to a sophisticated microsimulation model of four urban arterial corridors: three in Leeds and one in Leicester. The effects of the application of individual and integrated measures are assessed in terms of their efficiency, environmental and safety impacts using a form of Multi-Criteria Analysis. Travel time and other monetary costs are also taken into consideration.

This paper reports the results for the A47 Humberstone and Uppingham Roads which form the main arterial route to the east of Leicester.

1 DESCRIPTION

The majority of the links within the chosen network have single lanes in each direction with occasional widening at critical junctions to accommodate turning movements. In some places these extra turning lanes are marked on the road whilst in others their use is through convention. The exception to this is the Ring Road which generally has two lanes per link per direction. The arterial has a large number of side streets which give way to traffic on the arterial, especially towards the east.
Starting at timing point 1, in figure 1, there is one general traffic lane in both directions between points 1 (a give way junction) and 2 with the addition of an all-day reserved bus lane in the inbound

direction. This bus lane is fragmented, being broken in a number of places to allow left and right turning vehicles into side streets. This feature means that left turning vehicles will sometimes use the bus lane to pass stationary queues or slow moving traffic in the general traffic lane. The section of roadway from the signalised intersection at timing point 2 through to 4 follows the generalised single lane, local junction widening pattern. Timing points 3 and 4 are signalised as is an intermediate junction between 2 and 3. There is also a single lane in each direction between points 4 and 5, both of which are signalised junctions, and an additional outbound all-day bus lane. This bus lane is more continuous than the inbound bus lane and has less infringement from private vehicles. The inbound approach at point 5 widens from one to two to eventually four lanes at the junction stopline. Beyond point 5 both directions have two lanes of traffic, leading onto a roundabout. There are two Pelican crossings on the arterial, one just inbound of point 1 and the other between points 4 and 5. Some other junctions off the arterial are signalised, mainly where other major roads intersect with the Ring Road.

The bus priority measures described above, some turn bans and one-way side-street regulations are recent additions to the arterial's infrastructure.

In the morning peak there is considerable congestion starting at point 1 and continuing beyond point 5. Some degree of spill-back occurs at point 3. In the outbound direction in the pm peak congestion is largely confined to the 5 to 4 section, since this approach gates the main traffic flow in the rest of the network. Alternative routes to the 5 to 4 section are limited by the existence of a main railway line which bisects this section, on which crossing points are limited.

The land use surrounding the arterial is primarily dense residential with associated retail activities. Some light industrial units exist off the Ring Road to the south of the arterial.

2 MEASURE SELECTION

A meeting was held with five representatives from Leicestershire County Council Area Traffic Control and Engineering Services divisions and two members of the project team. The purpose of the meeting was to select measures appropriate to the corridor from those listed in Clark et al (1995). The short code used in later sections to refer to each selected measure is given at the end of the description.

Autogating (AM). This measure was generally received well and thought worthy of application. A chained application was proposed, starting with an am control of the 4 to 5 link and progressing out to the 1 to 2 link, which would be the last controlled link. The desired space left at the end of the maximum queue should typically start large and decrease towards the final link in the chain. A strong form of gating with large desired space left percentages and low minimum green times and a weak form with lower percentages and higher minimum greens were evaluated. For the pm peak a similar application in the reverse direction was thought inappropriate given the existing gating action on the 5 to 4 link. (AGS - Autogating Strong; AGW - Autogating Weak).

Starting and stopping waves. Currently fixed offsets are used to try to ensure a fixed progression along the arterial but this plan can be adversely affected by excessive queues in the network. It was thus thought that the application of some form of dynamic offset control was appropriate, particularly on short links, in the direction of main flow. (SSW)

Selective vehicle detection. Since relatively high bus flows are present on the arterial, the five signalised intersections on it would be equipped for bus priority in the direction of main flow, inbound during the morning and outbound during the afternoon. (SVD)

Reduced dwell time at bus stops. Some of the mechanisms thought necessary to implement this measure are already in place, particularly the provision of information at bus stops, whilst others (bus passes) are not available. This measure evaluates the effect of a 20% reduction in bus dwell times at stops. (TS)

Coordination for buses. This measure calculates green split and junction offset timings to fit in better with the behaviour of buses as they travel along the arterial. Usually this requires greater offsets between junctions to account for the greater junction to junction journey times which buses experience. The majority of the signalised links on the arterial are short which makes this measure particularly appropriate. (CB)

Calmed side streets. The route to the south of the arterial is a heavily used rat-run for vehicles trying to avoid congestion on the arterial. This large volume of traffic can be problematic since this area is densely residential. Problems include pollution, accident risk to children travelling to and from school and severance caused by queues of traffic. This measure simulates the effect of physical traffic calming measures on this alternative, southern route. This measure is likely to move traffic from the alternative route and onto the arterial. To reflect this shift in the degree of saturation away from the side street signal stages and onto the arterial stages a new TRANSYT base plan, with calmed (reduced) side street flows is used. (CSS)

Reduced green to side-streets. A reduction in the amount of green time given to side street stages may reduce the flows (but not the speeds) on the side streets, without any physical calming measures being necessary. This measure assesses the effect of such an implementation. (RGS)

Double cycling. The criterion necessary for double cycling to be implemented is unlikely to be satisfied during the peak periods so, although all signalised junctions could be nominated as potential candidates, not many will fulfill the necessary criteria for double cycling to take place. There is, however, some scope for application at signalised junctions off the arterial. (DC)

3 MEASURE INTEGRATION

Clearly some of the measures are mutually exclusive and so cannot be considered together in an integrated approach. The two autogating measures (strong and weak) are obviously mutually exclusive, as are the physical calming and reduced green to side street measures. In order to ensure a broad coverage of evaluation results each measure needs to be applied in as wide a variety of circumstances as resources allow. This variety will come from a combination of measures from differing areas (for example from congestion management and from bus priority).
Whichever of the two autogating measures performs better was integrated with the starting and

stopping wave and the selective vehicle detection measures. The application of calming measures is likely to cause a significant change in the distribution of flows within the network. In these circumstances it is worth trying both autogating measures, rather than the better of the two.

4 CALIBRATION RESULTS

Three Automated Traffic Count sites are available. Two are sited west of timing point 5 in figure 1, one for inbound and the second for outbound traffic. The third is for inbound traffic between timing points 1 and 2. The average hourly flow (am peak 0800-0900 and pm peak 1700-1800) for the five day period, week beginning 14/11/94 is used for comparison with the equivalent assigned hourly flow and the simulated hourly flow in table 1.

The level of agreement is good with the possible exception of 1 to 2 in the pm peak. For the five observed days the lowest recorded hourly flow for this period, at this site, is 869 whilst the highest is 1,199.

Site	AM			PM		
	Observed	Assigned	Simulated	Observed	Assigned	Simulated
W of 5 Inbound	1,802	1,834	1,828	1,377	1,394	1,431
W of 5 Outbound	1,110	1,047	1,059	1,554	1,578	1,586
1 to 2	1,046	1,098	1,112	1,069	937	958

Table 1 : Comparison of hourly flows

There is a considerable volume of number plate matching survey data from November 1993, recorded at five points along the A47, for both cars and buses. During simulation a fixed route vehicle was generated every two minutes to cover this same route. Tables 2 and 3 present the comparable inbound journey times (mean, sd and count): Columns headed Obs are the observed journey times and F4 are modelled journey times, both measured in seconds.

Link	1-2		2-3		3-4		4-5		1-5	
AM	Obs	F4	Obs	F4	Obs	F4	Obs	F4	Obs	F4
mean	84	70	116	120	95	99	80	85	397	373
sd	34	20	24	29	37	20	19	7	118	32
n	243	29	44	28	58	30	257	28	281	26

Table 2 : am car inbound journey times

The 1-2 travel time result is disappointing. The standard deviations for the journey times also tend to be lower.

Link	1-2		2-3		3-4		4-5		1-5	
AM	Obs	F4	Obs	F4	Obs	F4	Obs	F4	Obs	F4
mean	99	94	181	183	88	88	110	101	482	456
sd	29	15	38	24	41	23	27	14	83	48
n	34	26	31	25	27	33	28	44	30	20

Table 3 : am bus inbound journey times

There is a reasonable correspondence between means and sample sizes for buses in table 3, though not for the complete route. Once again the standard deviations are lower than observed.

Tables 4 and 5 present similar data for the evening peak.

Link	5-4		4-3		3-2		2-1		5-1	
PM	Obs	F4	Obs	F4	Obs	F4	Obs	F4	Obs	F4
mean	112	118	45	41	194	166	50	28	420	349
sd	45	27	15	23	54	32	13	4	112	41
n	205	28	100	28	99	29	180	27	162	26

Table 4 : pm car journey times

Means for car journey times are reasonable for the sections 5 to 3; but much lower for 3 to 1. The section 2 to 1 is the section with a lower than observed flow in table 1. Standard deviations also tend to be lower. The overall modelled figure is also low, mainly due to the low contribution from the 3 to 1 section.

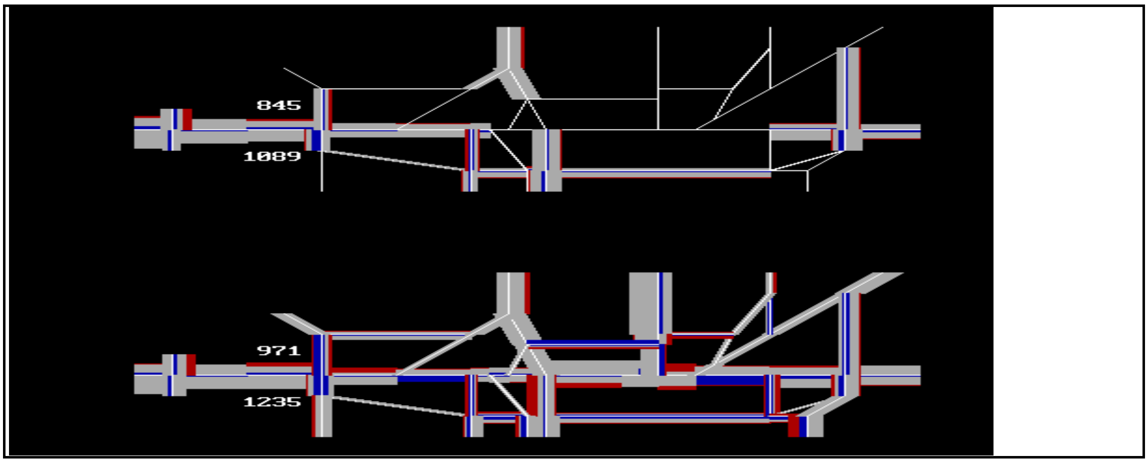
Link	5-4		4-3		3-2		2-1		5-1	
PM	Obs	F4	Obs	F4	Obs	F4	Obs	F4	Obs	F4
mean	90	87	51	67	227	203	70	51	441	417
sd	37	49	13	19	45	30	20	11	71	92
n	11	35	18	34	27	27	31	28	16	28

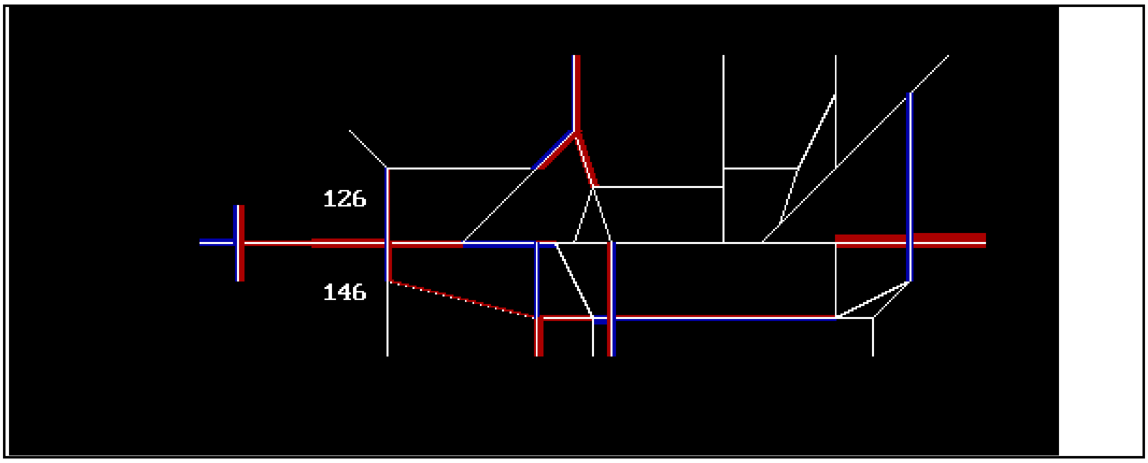
Table 5 : pm bus journey times

Table 5 shows a similar picture to the cars, with lower modelled journey times on the 3 to 1 sections. The overall figure for buses is, however, close to that observed. Note that significantly more bus journeys are recorded on the 5 to 3 section in the simulation model.

At various junctions in the network observed turning counts are available. Also some total link flows can be derived by summing all turning flows into the link. The NEMIS assignment procedure produces a set of comparable turning, demand, flows. The following diagrams attempt to give a graphical representation of the differences between these two sets of flows. There are two sets of three diagrams, one set for the am peak and another for the pm peak. Within each set the first diagram is the observed turning flows (which do not cover the whole network), the second is the assigned turning (demand) flows, and the last is the difference (assigned-observed).

An over assignment is reasonable in places since the assigned flows can be seen as the demand for a movement whilst the observed flows are the flows which can be supplied by the junction. Clearly demand can exceed supply, but not to too large an extent.

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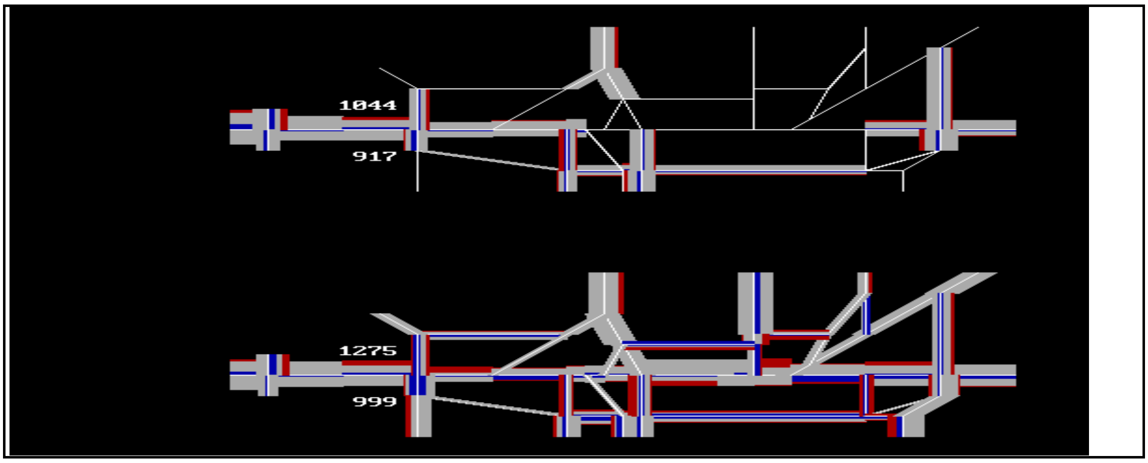
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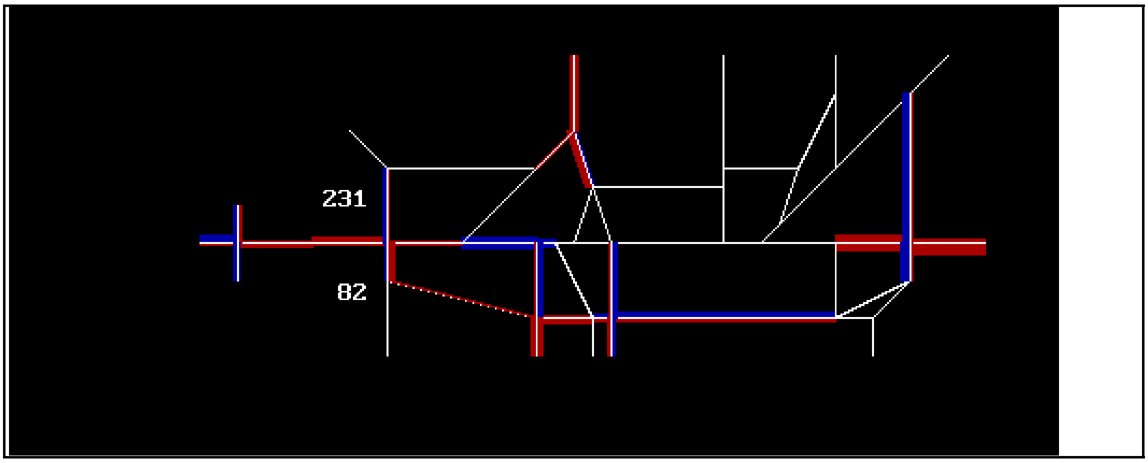
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5 COST BENEFIT ANALYSIS RESULTS

The "cost benefit" analysis results, relative to the base case of a TRANSYT base plan are given in figures 6 and 7.

The corresponding mean Cost Benefit and upper and lower limits are given in table A1 of appendix A. Table A2 of appendix A also lists the individual results. The codes used to denote each measure are given in section 3.

In the discussion which follows a *significant* result is one where the 95% confidence interval for the measure does not overlap with that of the TRANSYT base case. A difference without this qualification term is just an observation on the direction of movement.

The TRANSYT base plan (TRA) produces a significant reduction in the CBA score over the on-street signal plan (LGT). This is to be expected. Both the autogating measures (strong autogating, AGS and weak autogating, AGW) give an increase in the operating cost of the corridor, with AGW giving the smaller increase. This means that AGW will be combined with the other queue management measures. The remaining queue management measure, starting and stopping waves (SSW) produces a not quite significant increase over the base case. Two of the bus priority measures, selective vehicle detection (SVD) and reduced time at stop (TS) produce a reduction in operating costs. The remaining bus priority measure, coordination for buses (CB) gives an increase. The calming of the side-streets (CSS) give a large and significant increase in operating costs. This may be due to the fact that the arterial is already operating near to capacity so any additional flows re-assigned from the side-streets cause a large increase in travel times and congestion. The measure which involves the reduction of green time to the side streets (RGS) also gives an increase in operating costs, although this increase is not significant. The double cycling measure (DC) has shown a slight reduction in operating costs.

Those combined measures which give a significant reduction over the base plan are reduced time at stops with either selective vehicle detection (TS+SVD) or co-ordination for buses (TS+CB). None of these measures is significant by itself but in combination their effect is not so much to reduce the mean cost but to reduce the variability.

The combination of the starting and stopping wave and selective vehicle detection measures (SSW+SVD) has produced a significant increase in the operating cost of the corridor. The SSW measure alone has a not quite significant effect so it would appear that SVD has made matters worse for this measure. This may not in fact be the case since the addition of the SVD measure has actually reduced the mean cost and also the variability. This reduction in variability is what has made the difference significant. Thus the benefit of a reduction in mean level has been lost by a reduction in variability. Any combination which includes the calmed side-street measure has a significant increase in its operating costs.

Concentrating on those individual and combined measures which produce a decrease in cost, the ranking (1= greatest reduction; 6 = least) for the average and individual simulation runs are given in table 6:

Run	1	2	3	4	5	6	7
Average	TS+CB	TS+SVD	TS	SVD	DC		
1	TS+CB	TS+SVD	TS	AGW+SVD	CB		
2	TS+CB	TS+SVD	TS	DC	AGW+SVD		
3	TS+SVD	TS+CB	SVD	AGW	DC	TS	
4	TS+CB	TS	TS+SVD	CB	DC	SVD	SVD+RGS

Table 6: Ranking for improvement in CBA for measures on A47 am peak

This table clearly shows that TS+CB and TS+SVD feature near the top of all the rankings, showing that the effect of this measure is consistent and effective at reducing the operating cost of the corridor. A further simulation of TS+CB+SVD combination was conducted, which gave individual CBAs of 17330; 17321; 17449 and 17322 Ecu and an average of 17356 Ecu and a standard deviation of 62. This measure combination gives a significant decrease on the TRA base, but little different from TS+CB or TS+SVD.

In order to establish whether these features are significant and consistent across all the simulations a regression was conducted of the mean CBA figure on dummy variables indicating whether that particular measure was part of the package. Regression of the cost variable on the measure indicator variables produces the following equation and associated t-ratios:

$$\underset{(176)}{CBA = 17701} + \underset{(8.75)}{1654\,CSS} + \underset{(3.07)}{625\,SSW} + \underset{(2.69)}{748\,AGS} \qquad (1)$$

The explanatory power of this equation is high, with an R^2_{adj} figure of 83.7%. This shows that the CSS, SSW and AGS measures consistently inflate the base cost value of 17701 Ecus by their associated parameter values. Since none of the parameter estimates is negative, the optimal measure combination for the A47 during the morning peak appears to be a TRANSYT base plan, although table 6 suggests that TS+CB and TS+SVD may be worth considering.

The corresponding mean Cost Benefit and upper and lower limits are given in table B1 of appendix B. Table B2 of appendix B also lists the individual results.

The TRANSYT base plan (TRA) produces a reduction in the operating cost of the corridor, although unlike the morning peak case this reduction is not significant. The starting and stopping wave (SSW) measure, as in the morning peak, has produced an increase. All three bus priority measures, selective vehicle detection (SVD), time at stops (TS) and co-ordination for buses (CB) produce a reduction in operating costs, the only difference with the morning peak being that CB gave an increase during the am peak. Both calming measures, calmed side streets (CSS) and reduced green to side streets (RGS) once again produce an increase in costs, with the CSS increase being significant. Double cycling (DC) has, unlike in the morning peak, produced an increase.

Amongst the combined measures, all those that include the calmed side street measure give a significant increase in operating costs. Also the other calming measure, reduced green to side streets, in combination with starting and stopping waves produces a significant increase.

Concentrating on those individual and combined measures which produce a decrease in cost, the ranking (from greatest reduction to least) for the average and individual simulation runs are given in table 7:

Run	1	2	3	4	5	6	7
Average	CB	TS+SVD	TS	TS+CB	SVD		
1	TS	TS+CB	CB	TS+SVD	SVD	SSW	LGT
2	SVD	TS+SVD	TS				
3	CB	TS+SVD	TS+CB				
4	CB	TS+SVD	TS+CB	SVD	TS		

Table 7: Ranking for improvement in CBA measures on A47 pm peak

The individual bus priority measures of CB, TS and SVD all feature at or near the top of at least two of the rankings. A more consistent performance is achieved, however, if two of these measures are combined ie TS+SVD or TS+CB. A further simulation of TS+CB+SVD combination was conducted, which gave individual CBAs of 17621; 17594; 17668 and 17465 Ecu and an average of 17587 Ecu and a standard deviation of 87. This combination is not a significant improvement of the base TRA figure but it has produced the lowest CBA figure of all the pm peak measure combinations.

A corresponding regression equation for the afternoon peak period is:

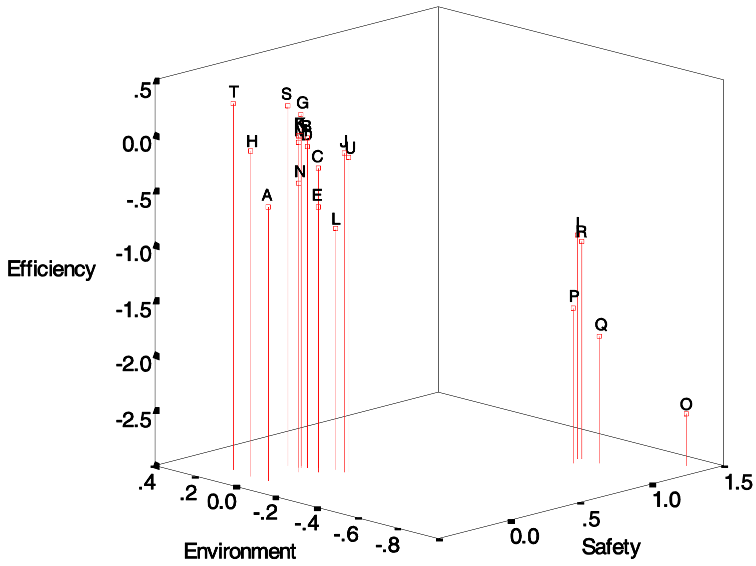
$$CBA = 17892 + 2117\ CSS + 647\ RGS + 338\ SSW + 250\ DC$$
$$(307)\quad (21.92)\quad (5.83)\quad (3.87)\quad (2.59)$$

The explanatory power of this equation is high, with an R^2_{adj} figure of 96.6%. None of the parameter estimates is negative which suggests that none of the measures produces a consistent, significant reduction in the operational cost of the arterial.

6 MCA RESULTS

A 3D scatter plot of each measure's score on the efficiency, environment and safety scales for the am peak produces figure 8. In each case the point plotted is the centroid of the cluster of four points obtained for each measure. The full data set is given in appendix A.

Examination of the individual MCA scores for the measures shows that there is considerable variation in the derived scores, especially for the environmental score.



Key :
A :LGT
B :TRA C :AGS D :AGW E :SSW F :SVD
G :TS H :CB I :CSS J :RGS K :DC
L :AGW+SSW M :AGW+SVD N :SSW+SVD O :AGS+CSS P :AGW+CSS
Q :SSW+CSS R :SVD+CSS S :TS+SVD T :TS+CB U :SVD+RGS

There are two distinct clusters of points, those which are efficient and environmentally positive but less safe and those which are safe but inefficient and environmentally negative. This second cluster is entirely composed of those measures which have calmed side-streets as one of their components.

In a similar manner to the ranking table for the CBA, tables 8, 9 and 10 present the measures ranked for their score on the efficiency, environment and safety impacts in the am peak for each set of simulation runs and the average. Notice that the safety impact is listed as a deterioration, so for the average case LGT is the least safe measure. Hence, for a measure to perform well we would expect it to be listed in tables 8 and 9 but not 10.

Run	1	2	3	4	5	6	7	8
Average	TS+CB	TS+SVD	TS	SVD	DC			
1	TS+CB	TS	TS+SVD	CB	AGW+SVD			
2	TS+CB	TS+SVD	TS	DC	AGW+SVD			
3	TS+SVD	TS+CB	SVD	AGW				
4	TS+CB	TS	TS+SVD	CB	SVD+RGS	DC	SVD	RGS

Table 8: Ranking for improvement in MCA efficiency impact on A47 am peak

For the following two tables the second row continues the rankings beyond rank 6.

Run	1/7	2/8	3/9	4/10	5/11	6
Average	TS+CB/ DC	TS+SVD/ AGW	CB	SVD	AGW+SVD	TS
1	TS+CB	CB	TS+SVD	AGW+SVD		
2	TS+CB	TS	TS+SVD	CB	DC	SSW+SVD
3	TS+CB/ SSW+SVD	TS+SVD/ AGW+SVD	CB	AGW	SVD	DC
4	TS+CB/ LGT	CB/ AGW+SVD	TS/ SSW+CSS	TS+SVD/ AGW	SVD/ SSW	DC

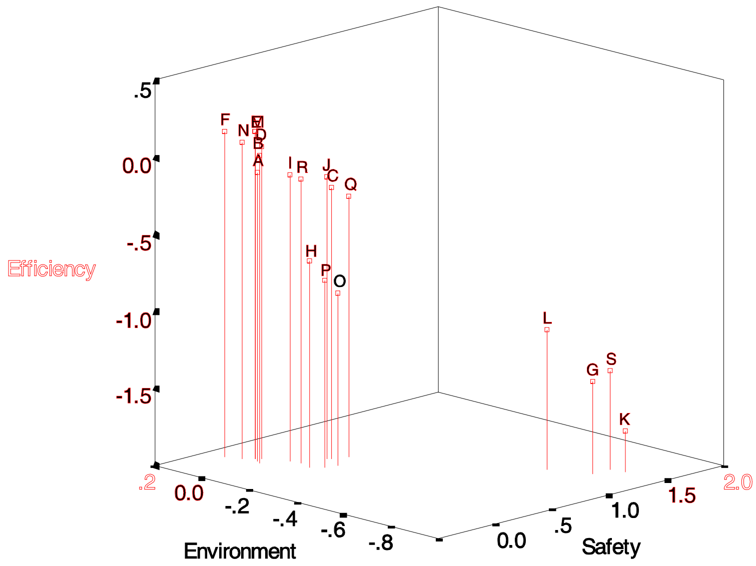
Table 9: Ranking for improvement in MCA environment impact on A47 am peak

Run	1/7	2/8	3/9	4/10	5/11	6/12
Average	LGT/ DC	CB/ AGW+SVD	TS+CB/ SSW	SSW+CSS	TS+SVD	SVD
1	TS+CB/ TS	CB/ SSW+SVD	LGT/ AGW	AGW+SVD	TS+SVD	SVD
2	CB/ TS	LGT/ SVD	TS+CB/ TS+SVD	SSW+SVD/ AGS	DC/ AGW+SSW	SSW/ AGW+SVD
3	LGT/ AGW+SVD	TS+CB/ SVD	CB/ AGW	SSW+SVD/ SSW	TS+SVD/	DC/
4	LGT/ TS	CB/ SSW	TS+CB/ DC	SSW+SVD/ AGW+SVD	SVD/ AGW	TS+SVD

Table 10: Ranking for deterioration in MCA safety impact on A47 am peak

The efficiency and environment assessments appear to be consistent in terms of those measures or combined measures which they rank highly. This may be due to the fact that there is a correlation between low congestion (high efficiency) and low emissions or fuel consumption (high environment). A similar inverse relationship may exist between efficiency/environment and safety, since high speeds may suggest a greater predicted accident rate.

Figure 9 shows the three dimensional plot for the pm peak. Table B1 lists the detailed data.



Key :
A :LGT
B :TRA C :SSW D :SVD E :TS F :CB
G :CSS H :RGS I :DC J :SSW+SVD K :SSW+CSS
L :SVD+CSS M :TS+SVD N :TS+CB O :SSW+RGS P :SVD+RGS
Q :SSW+DC R :SVD+DC S :CSS+DC

Once again two distinct clusters are formed. The safe but inefficient and environmentally negative cluster involves the calming of side-street measure. Another minor cluster exists within the other larger cluster. This sub cluster of points H, O and P tend to have a lower efficiency score than the others in this main cluster. These points have the common feature of involving the reduced green time to side-streets measure.

Once again tables 11, 12 and 13 present the measures ranked for their score on the efficiency; environment and safety impacts for each set of simulation runs and the average. Notice that the safety impact is listed as a deterioration.

Run	1	2	3	4	5	6	7
Average	TS+SVD	TS	CB	TS+CB	SVD		
1	TS	TS+SVD	TS+CB	CB	LGT	SVD	SSW
2	TS+SVD	SVD	TS				
3	CB	TS+CB	TS+SVD				
4	CB	TS+SVD	SVD	TS			

Table 11: Ranking for improvement in MCA efficiency impact on A47 pm peak

Run	1	2	3	4	5	6

Average	CB	TS+CB	TS	SVD	LGT	
1	CB	TS+CB	TS	TS+SVD	LGT	SVD
2	SVD	CB				
3	CB	TS+CB	TS+SVD	TS	LGT	DC
4	CB	TS+CB	TS+SVD	SVD		

Table 12: Ranking for improvement in MCA environment impact on A47 pm peak

Run	1	2	3	4	5
Average	CB				
1	CB	TS+CB	LGT	TS+SVD	TS
2	NONE				
3	CB	TS+CB			
4	CB				

Table 13: Ranking for deterioration in MCA safety impact on A47 pm peak

A similar, but clearer, pattern to that described for the am peak period appears here. Measures which are efficient are also environmentally good but poor on safety.

7 CONCLUSIONS

The introduction of TRANSYT-based signal times produces an improvement in efficiency in both peaks. All other measures have been assessed against this improved base condition. Only the bus priority measures produce a further improvement in efficiency. Not surprisingly, the reduction of dwell time at stops achieves the greatest improvement, with coordination of buses also producing an improvement in the evening peak. These two measures also perform well together, and when combined with selective vehicle detection, but the latter does not achieve efficiency benefits on its own.

None of the congestion management measures improves efficiency, and the use of stopping and starting waves produces a deterioration in the morning peak. Not surprisingly, the calming measures produce significant reductions in efficiency, with calmed side streets having a far greater impact than reduced side street green. The combination of calmed side streets with the congestion management measures aggravates the situation, and produces the worst reductions in efficiency.

The impacts on the environment generally follow those on efficiency, but are less marked. The bus priority measures do not improve the environment, and only the calming of side streets, alone and in combination with congestion management measures, worsens it. These environmental indicators are, however, aggregate ones for the whole network. Calming of side streets inevitably reduces traffic levels on those side streets and improves the environment there whilst increased traffic levels elsewhere reduce this overall benefit effect. However, the deterioration in emissions on the main roads more than offsets the gains there.

The impacts on safety are generally the mirror image of those for efficiency and the environment. Calmed side streets, and the combinations of calming and congestion management measures and calming and selective vehicle detection improve safety. Interestingly, the introduction of stopping and starting wave signal settings also improves safety in the evening peak, on its own and when combined with some calming and congestion management measures. Only the bus priority measures in the morning peak produce any worsening in safety.

Most measures have an impact on the network; the only two which do not on their own are selective vehicle detection and double cycling. Most effects are similar in both peaks (except for autogating, which was only tested in the morning). The only exceptions are reduced green for side streets and double cycling, which only have an impact in the evening peak.

These results are generally as would be expected. The bus priority measures improve efficiency, while the calming measures have the reverse effect. Aggregate environmental impacts follow those for efficiency, since reductions in congestion lead to lower pollution levels. Safety impacts, in a network with largely unchanged overall flows, are primarily affected by increases in speed. The one surprise is the poor performance of the congestion management measures. However, it should be noted that they are being compared against a TRANSYT signal plan which is itself a substantial improvement on the existing timings. Autogating, particularly in its weak form, is itself a substantial improvement on the existing timings.

The synergy between reduced time at stops and coordination for buses noted in the results section may result from the fact that with reduced dwell times at stops, buses behave more like private traffic. Thus the offsets for bus progression in this case will be closer to those for private traffic, so any benefit to buses is not outweighed by dis-benefits to private traffic. Another factor may be that the reduced dwell time will also give a reduced variability in the journey time (if the distribution of dwell times is Poisson, which is likely) for buses along a link, which aids the operation of a fixed set of bus progression offsets.

REFERENCES

Clark, SD, May, AD and Montgomery, FO (1995). "Priority Management for Urban Arterials, Transferability of Techniques, Methodology and Summary". *Working Paper 460*, Institute for Transport Studies, University of Leeds, Leeds.

APPENDIX A : RESULTS FOR AM PEAK

MEASURE	MEAN	STDS	95% LL	95% UL	Eff	Env	Safety
LGT	18634	222	18282	18986	-0.50	-0.03	-0.32
TRA	17677	92	17530	17823	0.00	0.00	0.00
AGS	17963	182	17673	18252	-0.27	-0.03	0.03
AGW	17764	72	17649	17879	-0.08	0.00	0.00
SSW	18352	334	17821	18883	-0.60	-0.06	-0.01
SVD	17624	59	17530	17719	0.02	0.02	-0.03
TS	17446	233	17075	17817	0.20	0.03	0.00
CB	17796	274	17360	18233	-0.05	0.06	-0.31
CSS	18998	214	18658	19339	-0.95	-0.59	1.06
RGS	17946	201	17626	18266	-0.10	-0.13	0.08
DC	17633	144	17404	17861	0.02	0.01	-0.03
AGW+SSW	18573	358	18004	19142	-0.82	-0.08	0.08
AGW+SVD	17683	176	17402	17963	-0.04	0.02	-0.03
SSW+SVD	18097	150	17859	18335	-0.37	-0.02	-0.08
AGS+CSS	20588	464	19850	21326	-2.53	-0.92	1.35
AGW+CSS	19545	262	19127	19962	-1.59	-0.61	1.00
SSW+CSS	19934	338	19396	20472	-1.84	-0.68	1.09
SVD+CSS	19082	228	18719	19444	-1.02	-0.60	1.07
TS+SVD	17357	53	17272	17442	0.28	0.06	-0.05
TS+CB	17293	84	17159	17427	0.35	0.15	-0.30
SVD+RGS	17994	241	17611	18376	-0.15	-0.14	0.10

Table A1: Mean Cost Benefit (Ecu); standard deviation of CBA and mean MCA

MEASURE	CBA	Efficiency	Environment	Safety
LGT	18656	-0.50	-0.05	-0.31
	18735	-0.69	-0.09	-0.30
	18826	-0.58	-0.02	-0.32
	18318	-0.22	0.04	-0.34
TRA	17665	0.00	0.00	0.00
	17560	0.00	0.00	0.00
	17783	0.00	0.00	0.00
	17698	0.00	0.00	0.00
AGS	17881	-0.21	-0.02	0.03
	17755	-0.14	-0.04	-0.02
	18171	-0.38	-0.03	0.03
	18043	-0.33	-0.04	0.09
AGW	17735	-0.06	-0.02	0.00
	17744	-0.14	-0.02	0.03
	17706	0.06	0.03	-0.03
	17870	-0.17	0.02	-0.01
SSW	18415	-0.64	-0.10	0.06
	18108	-0.47	-0.05	-0.06
	18799	-1.00	-0.11	-0.02
	18086	-0.30	0.00	-0.03
SVD	17697	-0.07	-0.01	-0.01
	17602	-0.06	-0.01	-0.03
	17642	0.12	0.03	-0.04
	17557	0.09	0.06	-0.05
TS	17367	0.28	0.00	-0.01
	17422	0.13	0.02	-0.04
	17772	0.00	-0.01	0.07
	17223	0.41	0.10	-0.04
CB	17621	0.10	0.08	-0.32
	17952	-0.29	0.01	-0.31
	18098	-0.22	0.04	-0.30
	17515	0.20	0.13	-0.31
CSS	19254	-1.18	-0.69	1.18
	19044	-1.05	-0.69	1.17

	18737	-0.69	-0.40	0.79
	18959	-0.88	-0.56	1.11
RGS	17846	-0.01	-0.15	0.08
	18042	-0.27	-0.17	0.09
	18174	-0.18	-0.14	0.06
	17722	0.07	-0.07	0.08
DC	17756	-0.08	-0.05	0.02
	17474	0.08	0.01	-0.07
	17752	-0.02	0.03	-0.05
	17547	0.10	0.05	-0.02
AGW+SSW	18863	-1.08	-0.16	0.25
	18150	-0.50	-0.05	-0.01
	18875	-1.08	-0.11	0.05
	18403	-0.62	-0.02	0.05
AGW+SVD	17526	0.07	0.03	-0.07
	17535	0.01	-0.01	-0.01
	17815	-0.06	0.01	-0.04
	17854	-0.21	0.04	-0.01
SSW+SVD	18276	-0.49	-0.11	0.00
	17910	-0.31	0.00	-0.14
	18096	-0.30	0.01	-0.09
	18107	-0.38	0.03	-0.07
AGS+CSS	21132	-3.22	-1.01	1.45
	20807	-2.79	-1.06	1.44
	20282	-2.22	-0.72	1.19
	20132	-1.90	-0.89	1.33
AGW+CSS	19582	-1.72	-0.57	0.89
	19884	-1.93	-0.81	1.25
	19454	-1.37	-0.55	0.99
	19259	-1.35	-0.52	0.88
SSW+CSS	19906	-1.82	-0.66	1.03
	20192	-2.08	-0.86	1.31
	19465	-1.49	-0.45	0.77
	20172	-1.97	-0.77	1.27
SVD+CSS	19382	-1.27	-0.73	1.25

	19126	-1.24	-0.62	1.06
	18862	-0.76	-0.46	0.80
	18956	-0.79	-0.61	1.19
TS+SVD	17344	0.28	0.05	-0.04
	17412	0.14	0.02	-0.03
	17384	0.36	0.07	-0.08
	17289	0.33	0.10	-0.04
TS+CB	17244	0.38	0.16	-0.33
	17294	0.29	0.11	-0.28
	17411	0.34	0.16	-0.32
	17222	0.42	0.19	-0.28
SVD+RGS	17996	-0.21	-0.16	0.08
	18064	-0.29	-0.17	0.12
	18246	-0.26	-0.17	0.11
	17669	0.15	-0.08	0.10

Table A2: Individual Cost Benefit (Ecu) and MCA

APPENDIX B : RESULTS FOR PM PEAK

MEASURE	MEAN	STDS	95% LL	95% UL	Eff	Env	Safety
LGT	18284	55	18197	18371	-0.12	0.01	0.01
TRA	17969	243	17583	18355	0.00	0.00	0.00
SSW	18312	139	18090	18533	-0.24	-0.12	0.39
SVD	17883	237	17505	18260	0.04	0.02	0.06
TS	17782	129	17578	17987	0.13	0.03	0.03
CB	17702	125	17503	17901	0.12	0.12	-0.05
CSS	20189	282	19741	20638	-1.40	-0.79	1.28
RGS	18535	223	18180	18890	-0.66	-0.15	0.14
DC	18161	142	17936	18387	-0.13	-0.06	0.14
SSW+SVD	18182	163	17923	18442	-0.16	-0.12	0.35
SSW+CSS	20465	380	19861	21069	-1.73	-0.85	1.44
SVD+CSS	19777	72	19662	19892	-1.09	-0.67	1.13
TS+SVD	17782	129	17578	17987	0.13	0.03	0.03
TS+CB	17812	47	17738	17886	0.06	0.07	0.00
SSW+RGS	18769	202	18448	19090	-0.87	-0.20	0.28
SVD+RGS	18649	235	18275	19024	-0.78	-0.19	0.19
SSW+DC	18438	242	18053	18824	-0.30	-0.15	0.48
SVD+DC	18231	152	17989	18473	-0.15	-0.09	0.19
CSS+DC	20196	124	19999	20392	-1.35	-0.81	1.40

Table B1: Mean Cost Benefit (Ecu); standard deviation of CBA and mean MCA

MEASURE	CBA	Efficiency	Environment	Safety
LGT	18260	0.15	0.09	-0.07
	18223	-0.21	-0.05	0.03
	18349	-0.28	0.00	0.07
	18304	-0.16	-0.02	0.01
TRA	18314	0.00	0.00	0.00
	17746	0.00	0.00	0.00
	17925	0.00	0.00	0.00
	17890	0.00	0.00	0.00
SSW	18172	0.08	-0.01	0.31
	18221	-0.33	-0.18	0.39
	18472	-0.44	-0.17	0.43
	18381	-0.30	-0.13	0.43
SVD	18060	0.14	0.04	0.03
	17565	0.12	0.04	0.04
	18068	-0.15	-0.01	0.06
	17837	0.03	0.02	0.12
TS	17664	0.51	0.12	-0.03
	17688	0.06	-0.03	0.02
	17935	-0.07	0.04	0.00
	17843	0.03	0.00	0.13
CB	17783	0.29	0.20	-0.12
	17823	-0.13	0.03	0.01
	17653	0.11	0.13	-0.05
	17550	0.21	0.14	-0.06
CSS	20159	-1.07	-0.72	1.22
	20282	-1.67	-0.85	1.44
	19821	-1.16	-0.70	1.11
	20495	-1.71	-0.91	1.37
RGS	18376	-0.17	-0.05	0.12
	18621	-0.92	-0.22	0.18
	18810	-1.04	-0.21	0.17
	18333	-0.52	-0.12	0.10
DC	18345	-0.05	-0.02	0.11
	18140	-0.17	-0.14	0.17

	18000	-0.12	0.00	0.10
	18161	-0.16	-0.09	0.17
SSW+SVD	18335	-0.02	-0.10	0.32
	17995	-0.18	-0.11	0.30
	18301	-0.32	-0.16	0.40
	18098	-0.11	-0.12	0.37
SSW+CSS	19912	-1.04	-0.59	1.21
	20586	-2.03	-0.97	1.60
	20584	-1.87	-0.93	1.45
	20778	-2.00	-0.90	1.49
SVD+CSS	19849	-0.89	-0.57	1.08
	19737	-1.25	-0.75	1.09
	19826	-1.20	-0.65	1.14
	19697	-1.01	-0.71	1.21
TS+SVD	17664	0.51	0.12	-0.03
	17688	0.06	-0.03	0.02
	17935	-0.07	0.04	0.00
	17843	0.03	0.00	0.13
TS+CB	17764	0.35	0.15	-0.08
	17875	-0.15	0.00	0.03
	17795	0.04	0.05	-0.04
	17814	-0.02	0.06	0.08
SSW+RGS	18475	-0.25	-0.05	0.17
	18883	-1.23	-0.33	0.36
	18915	-1.10	-0.22	0.34
	18804	-0.92	-0.22	0.27
SVD+RGS	18786	-0.66	-0.16	0.21
	18544	-0.86	-0.23	0.18
	18894	-1.10	-0.22	0.20
	18373	-0.52	-0.15	0.15
SSW+DC	18781	-0.29	-0.14	0.52
	18297	-0.36	-0.21	0.43
	18241	-0.19	-0.13	0.50
	18435	-0.38	-0.11	0.49
SVD+DC	18450	-0.09	-0.07	0.18

	18217	-0.33	-0.14	0.23
	18112	-0.11	-0.06	0.16
	18146	-0.06	-0.09	0.18
CSS+DC	20207	-1.16	-0.70	1.35
	20362	-1.61	-0.95	1.49
	20074	-1.33	-0.80	1.32
	20138	-1.29	-0.80	1.46

Table B2: Individual Cost Benefits (Ecu) and MCA