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# PRIORITY MANAGEMENT FOR URBAN ARTERIALS

# TRANSFERABILITY OF TECHNIQUES

# OTLEY/KIRKSTALL 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. Measures 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 affect the whole network.*

*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 describes the study of two neighbouring arterials to the west of Leeds, the Otley and Kirkstall Roads. These arterials have been considered together since they are geographically close to each other. The Otley Road is the main arterial to the north west of Leeds City Centre, linking the Outer Ring Road to the Centre and is approximately 5km in length. The Kirkstall Road is to the south of the Otley Road, running west to east. The section of Kirkstall Road chosen for inclusion in this combined corridor is 3.5 km in length. The land use surrounding each corridor is primarily residential although near the city centre on the Kirkstall Road there are light industrial units. A popular district shopping centre exists halfway along the Otley Road.*

## 1 DESCRIPTION

Figure 1 gives a schematic diagram of the network used in this study. The junction of the A660 Otley Road with the Outer Ring Road is a roundabout with three lanes on each approach. Travelling inbound towards the city centre, the Otley Road has two lanes in each direction until timing point 3, which is a signalised junction. During the morning peak period one of the inbound lanes operates as a reserved bus lane between points 1 and 2, point 2 being the end of the bus lane setback at point 3. Between points 3 and 4 the inbound direction has two lanes, one of which is a dedicated right turning lane at the signals at point 4. The outbound direction starts as one lane but widens to two lanes at point 3. From point 4 to 6 each direction has a single lane, although these lanes are wider than is usual. Between 6 and 7 (which is signalised) both directions have two lanes. Between 7 and 8, the edge of the network, the road is predominantly two lanes inbound. Similarly the outbound section from 8 to 7 has two lanes, although a reserved bus lane, with a set-back, does operate during the evening peak period.

The whole of the modelled section of the A65 Kirkstall road is single carriageway. Timing points 9 and 10, are both signalised junctions. There is a degree of lane widening to three lanes at point 10, inbound and point 9, outbound. The section between points 10 and 11 has two lanes in both directions.

Another significant route into the city centre, Burley Road; (points 12-13-14) runs parallel to the Kirkstall Road, along all of its length. The road has single lanes with some lane widening to two lanes at signalised junctions. The remaining roads in the network have one lane in each direction.

As can be expected, significant queues develop in the direction of main flow on the Otley Road, Kirkstall Road and Burley Road. During the morning peak there is an almost continuous queue downstream of point 8 and continuing beyond point 1. The Kirkstall Road is almost as congested but there is some degree of free-flowing for a short section of road inbound of point 9. A similar situation exists on Burley Road with long queues of traffic, upstream of the junction which corresponds with point 13. Beyond this junction the traffic is largely free-flowing.

## 2 MEASURE SELECTION

A meeting took place with three members of the project team and two representatives of Leeds City Council (LCC). The purpose of the meeting was to select measures appropriate to the corridor from those listed in Clark et al (1995). The only long term plans for these two corridors are the installation of a Light Rapid Transit line along the whole of the section of Otley Road considered in this study and the possibility of a guided busway on the Kirkstall or Burley Road.

The Outer Ring Road is managed by the Highways Agency. Thus there is a constraint that any measures employed on the A660 should not adversely affect the Ring Road.

The measures considered suitable for application to this corridor are presented below. Two time periods are considered in this study; the am and pm peaks. Where a time period is explicitly mentioned then the measure is only suitable for that time period, otherwise it is considered in both. The short code used in later sections to refer to a measure is given at the end of the description for the measure.

Double cycling. Given the degree of saturation on the two arterial roads it is unlikely that the circumstances appropriate for the use of double cycling will arise. Therefore double cycling is only appropriate on off-arterial signalised junctions. Most of these junctions operate on a low cycle time, typically 50 seconds, so after any lost time is accounted for in a 25 second cycle time, little is left for green time. The only junction which runs a high cycle time, 100 seconds, is on the road which joins points 4 and 9. This is the only junction for which double cycling is feasible. (DC)

Starting and stopping waves. The application of this measure is appropriate on short links, signal controlled at both ends, and which have the potential to cause spillback at the upstream junction. Only three links in the network fulfill this criterion. One is the congested link between points 3 and 4, the second is the section between points 7 and 8, with the third being a section between 8 and the end of the arterial. The maximum allowed movement in the offsets was taken as 10 seconds. (SSW)

Metering traffic (AM). The purpose of this measure is to hold back traffic from the environmentally sensitive area between points 12 and 13 by changing the green split at points 9 10, 12 and 13. The green times given to the through movements along Burley Road at points 12 and 13 are reduced by 5 seconds to make this route less attractive and hold back traffic at point 12. The green splits at points 9 and 10 are changed in favour of through traffic, making the Kirkstall Road a more attractive option than the Burley Road. (MTR)

Reduced green to side streets (AM). This measure is the conceptual opposite of the metering measure discussed above. The side street green is reduced in favour of the through route. This will have the effect of reducing the degree of saturation (and hence queues) on the through routes at the expense of the side streets. (RGS)

Two lanes. The section of the Otley Road between points 4 and 6 currently has a single lane in each direction. The road width would, however, allow three lanes in total along most of its length. Figure 2 shows how the existing road layout could be changed to allow two lanes in certain directions. In each direction of main flow, the section starts with a single lane until it reaches a Pelican crossing. This crossing is converted into a staggered crossing beyond which the main direction of flow changes to two lanes until the next signalised junction. (2LA)

Bus lanes. Using the same philosophy as the two lanes strategy, the additional road lane created is used as a reserved bus lane in the appropriate time period, ie inbound during the morning and outbound during the evening. This approach is depicted in figure 2. (2BU)

Selective vehicle detection. The approach in the main direction of flow to four junctions in the network was equipped for selective bus detection. (SVD)

Move bus stop (AM). In the congested section of road between points 3 and 4 there is a pelican and a bus stop with a layby and long dwell times. In the inbound direction the bus stop is currently upstream of the Pelican. This can give rise to the situation where general traffic is stopped by the pelican, creating a queue which impedes buses from leaving the layby. If the bus stop is moved downstream of the Pelican then the bus can leave the layby in the shadow of the Pelican's pedestrian green stage. (MBS)

Coordination for buses. There is only limited scope for application of this strategy in the network. Either the signalised intersections are too far apart to make coordination effective or those short signalised sections of road which are suitable only have low bus flows. The exception to this is the section between points 3 and 4. Here a manual calculation of the appropriate offsets as a function of distance, travel time and dwell time is made to attempt coordination for buses. (CB)

Reduced time at stop. A 20% reduction in the dwell time at every stop in the network is implemented. (TS)

Queenswood Drive calming. The western link on junction 15 in the network is used by large volumes of traffic rat-running to avoid congestion on the A660. This causes annoyance and disruption to the residents on this link. A reasonable proposal would be to calm this link by implementation of signalling strategies which reduce the green time for vehicles leaving and entering this link, coupled with physical calming measures. These calming measures are applied both on Queenswood Drive and Burley Road, until timing point 13. As is to be expected, the result of this is to move traffic from Burley Road onto Kirkstall Road. (QWD)

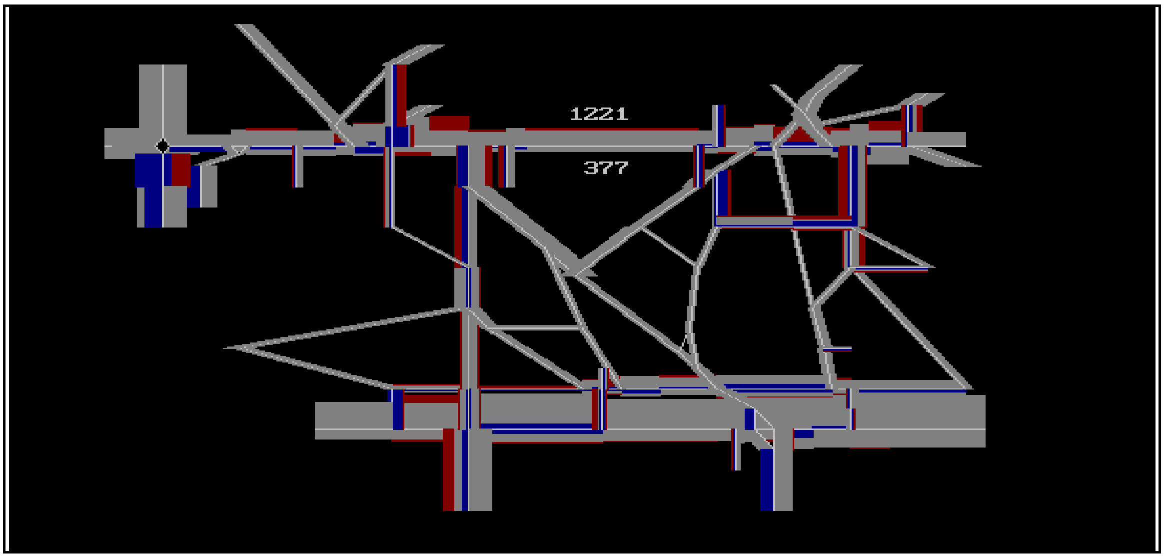
## 3 MEASURE INTEGRATION

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). Clearly some of the strategies are mutually exclusive and so can not be considered in an integrated approach. The various measures which operate to the north west of the Kirkstall Road (metering traffic, reduced green to sidestreets and calming Queenswood Drive) are mutually incompatible.

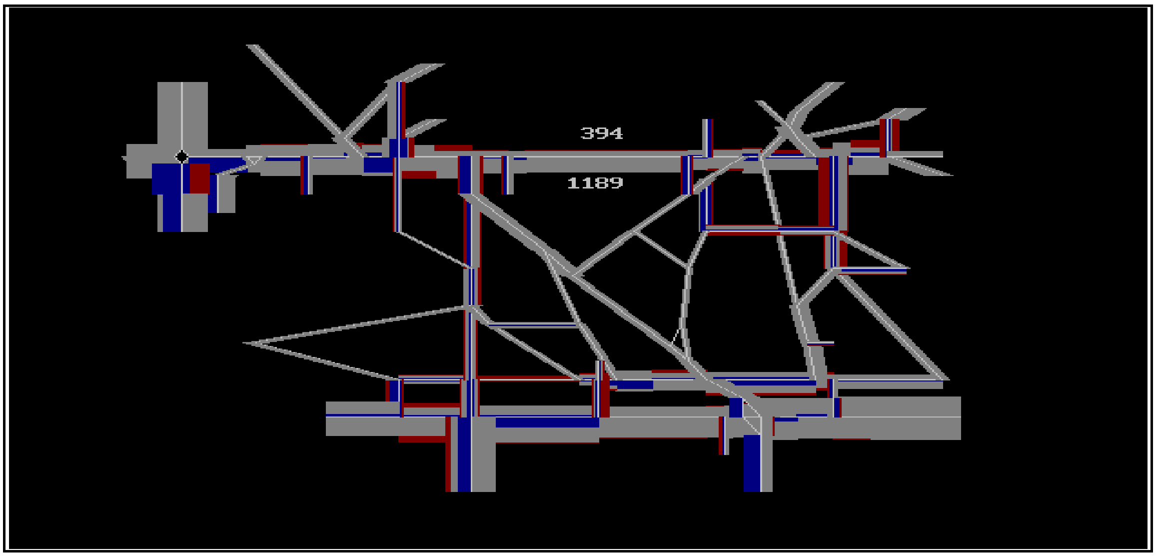
## 4 CALIBRATION RESULTS

For the am period the ½ hour *warm-up* phase represents 0730-0800, and the 1 hour *evaluation* phase, 0800-0900. For the pm period the corresponding periods are 1630-1700 and 1700-1800.

Automatic Traffic Counts (ATC) are available for a number of links on both the arterials and also some of the connecting network. Figure 1 shows the approximate locations for these sites. From the




simulation two sets of flows are available:




Assigned : These are the flows taken from the OD matrix and assigned, according to Wardrop's equilibrium assignment principle, to the links in the network. These flows can be thought of as the demand flows. The assigned flows along every link in the corridor are presented in figure 3 for the am peak period and figure 4 for the pm peak period. The numbers associated with some links denote the hourly assigned flow in vehicles per hour on the link. In both periods (but especially so the am peak) the Kirkstall Road carries, by far, the most traffic into the City Centre.

Simulation : These are the actual outflows which occur on each link during the simulation. These flows can be less than the assigned (capacity less than demand) or more than the assigned (unmet demand in the ½ period being processed in the following 1 hour).

Figure 5 shows the correspondence between Observed; Assigned and Simulated flows for the am peak period. The level of agreement is good, with a slight tendency for the simulated flows to underestimate the observed flows.

Figure 6 shows the correspondence between Observed; Assigned and Simulated flows for the PM peak period. The level of agreement is good, with less of a tendency for the simulated flows to underestimate the observed flows.

The quantity of private vehicle journey time information is limited. The main source is a set of am peak number plate matching and observation surveys carried out by MSc students during October 1991 and October 1992. Figure 1 shows the various timing points for selected journeys. Journeys between points 2→6 and 5→7 are taken from a number plate matching exercise whilst journeys between 3→4 are from an elevated observer. A single journey during the AM peak is also available from a DoT survey in 1994 for the A65. In the simulator a number of fixed route vehicles were generated and their journey times are used for comparison.

The comparison of journey times for the AM Peak are given in table 1.

| CAR journey times | Observed **mean**, n | Modelled **mean**, (sd), n |
|---:|---:|---:|
| 2→6 | **343**, 70 | **353** (48) 12 |
| 5→7 | **314**, 25 | **224** (29) 12 |
| 3→4 | **76**, 22 | **73** (26) 13 |
| 9→10 | **298** | **303** (69) 8 |
| 10→11 | **242** | **99** (6) 8 |
| 11→10 | **131** | **120** (38) 8 |
| 10→9 | **250** | **271** (108) 8 |

**Table 1 : Observed vs modelled am car journey times (seconds)**

With two exceptions the level of agreement is good. The journey 5→7 is underestimated in the model by a significant amount. Attempts were made to improve this figure but with only limited success. The journey 10→11 is also underestimated in the model. This could be because the single journey was unrepresentative or because of a mis-match in timing points between the observed and modelled journeys. Indeed when use is made of the corresponding bus journey survey (see table 3) we see that buses were observed to take only 127 seconds and 145 seconds to make this same journey, suggesting that a modelled journey time of 99 seconds for a car is acceptable.

Unfortunately even less journey time data is available for the PM peak period. What results exist, are presented in table 2.

| CAR journey times | Observed **mean** | Modelled **mean**, (sd), n |
|---:|---:|---:|
| 6→2 | | **479** (153) 9 |
| 7→5 | | **395** (182) 9 |
| 4→3 | **52** | **38** (22) 10 |
| 9→10 | | **158** (20) 9 |
| 10→11 | | **133** (21) 8 |
| 11→10 | | **117** (17) 9 |
| 10→9 | | **183** (19) 8 |

**Table 2 : Observed vs Modelled PM Car journey times (seconds)**

Little can be said about these results other than that the modelled journey times are plausible.

A recent and comprehensive set of bus journey time data is available from May 1994. A number plate matching exercise was carried out at three points on each corridor (A660 and A65) over two days (D1 & D2).

Table 3 presents the results for the AM Peak period.

| Bus journey times | Observed (D1) **mean**, (sd), n | Observed (D2) **mean**, (sd), n | Modelled **mean**, (sd), n |
|---:|---:|---:|---:|
| 1→3 | **242** (76) 26 | **344** (67) 17 | **242** (18) 14 |
| 3→8 | **560** (127) 27 | **536** (86) 18 | **511** (48) 17 |
| 9→10 | **416** (48) 7 | **345** (59) 13 | **405** (85) 15 |
| 10→11 | **145** (29) 9 | **127** (30) 9 | **164** (8) 20 |

**Table 3 - Observed vs modelled am bus journey times (seconds)**

The only anomalous point is the increased number of modelled bus journeys made on the 10→11 route which is in excess of the observed frequency.

A similar table for the pm peak period gives rise to table 4.

| Bus journey times | Observed (D1) **mean**, (sd), n | Observed (D2) **mean**, (sd), n | Modelled **mean**, (sd), n |
|---|---|---|---|
| 8→3 | **585** (99) 31 | **600** (60) 34 | **590** (118) 11 |
| 3→1 | **350** (63) 22 | **166** (48) 32 | **196** (9) 15 |
| 11→10 | **138** (43) 6 | **179** (165) 20 | **165** (49) 20 |
| 10→9 | N/A | **285** (61) 16 | **241** (18) 9 |

**Table 4 - Observed vs modelled pm bus journey times (seconds)**

Perhaps the most striking point in this table is the disparity in the observed 3→1 journey time between the two days. This feature, along with other disparities between the two days, suggests that a considerable degree of day to day variability in network performance may exist.

## 5 CBA RESULTS

The cost benefit analysis results, relative to the base case of the on-street base plan (LGT) is given in figure 7 for the am peak.

The corresponding mean Cost Benefit and MCA scores and upper and lower limits are given in table A1 of appendix A. Table A2 of appendix A also lists the individual results.

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 on-street base case. All but two of the individual measures produce a reduction in the overall operational cost of this corridor. The only one which produces a significant reduction is the calming measure associated with Queenswood Drive (QWD). This measure has diverted traffic away from the Burley Road and onto the parallel Kirkstall Road. The only other measure which has caused a substantial decrease is the reduced dwell time at bus stops (TS). The poor performance of the additional lane of general traffic on the A660 (2LA) in relation to the current single lane case is disappointing. The metering of traffic to the west of the corridor using signals (MTR) has produced the largest increase in cost. The only other increase in cost is from the addition of a new extra reserved bus lane on the A660.

Any combined measure which involves the calming of Queenswood Drive produces a significant reduction in operating costs. Reductions are also possible from a combined application of co-ordination for buses and reduced dwell time at stop (CB+TS). The combined measures of selective vehicle detection with metering (SVD+MTR) or an additional reserved bus lane (SVD+2BU) cause a significant increase in operating costs.

Concentrating on the top seven of 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 5. In total 16 measures gave an average reduction in cost; 13 gave a reduction in cost for simulation run one; 14 for run two; 18 for run three and 15 for run four.

| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | TS+QWD | QWD | QWD+MBS | CB+QWD | 2LA+QWD | CB+TS | TS |
| 1 | QWD+MBS | QWD | CB+QWD | 2LA+QWD | TS+QWD | CB+TS | DC |
| 2 | TS+QWD | CB+QWD | QWD | 2LA+QWD | CB+TS | QWD+MBS | SSW |
| 3 | TS+QWD | QWD | 2LA+QWD | QWD+MBS | CB+QWD | CB+TS | TS |
| 4 | QWD+MBS | TS+QWD | CB+QWD | QWD | CB+TS | 2LA+QWD | TS |

**Table 5: Ranking for improvement in CBA for measures on A660 am peak**

The dominant effect of the Queenswood Drive measure can clearly be seen in the above table. Examination of the change in flows and costs between Burley Road and Kirkstall Road when calming is implemented shows that 200 inbound vehicles in the peak hour transfer from Burley Road to Kirkstall Road. The corresponding changes in costs are a 3,000 Ecu reduction on Burley Road but only a 150 Ecu increase on Kirkstall Road. This suggests that Kirkstall Road has spare capacity in the inbound direction during the morning peak, which can accommodate additional traffic, with only a consequent small increase in costs.

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

$$\underset{(651)}{CBA = 53870} - \underset{(-15.28)}{2484\,QWD} - \underset{(-6.37)}{1260\,TS} + \underset{(6.56)}{1562\,MTR} + \underset{(4.29)}{1023\,2BU} \tag{1}$$

The explanatory power of this equation is high, with an $R^2_{adj}$ figure of 94.8%. Only the QWD and TS measures are predicted to give a significant and consistent reduction in the CBA figure. This combination has been simulated, with a cost of 50,344 against a prediction of 50,126 from equation (1). The MTR and 2BU measures produce an increase in the operating cost of the corridor.

Figure 8 shows the similar results for the PM peak. The only measure which has produced a significant result is the calming of Queenswood Drive with a two lane layout on the A660 which increases costs. The addition of an outbound bus lane on the A660 (2BU) has produced the greatest reduction, but due to its corresponding large variance, this reduction is not significant. The result for the calming of Queenswood Drive contradicts the result found in the morning peak. Calming has moved approximately 150 outbound vehicles from Burley Road onto Kirkstall Road as in the morning peak. The costs are however little changed on Burley Road at 700 Ecu but much larger by 2,000 Ecu on Kirkstall Road. This suggest that Kirkstall Road is unable to accommodate this modest increase in outbound vehicles during the evening peak without causing a significant deterioration in its performance.

Concentrating on the 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 6.

| Run | 1/8 | 2/9 | 3/10 | 4/11 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | 2BU | 2BU+CB | 2BU+SSW | TS | DC+SVD | DC | CB+TS |
| 1 | 2BU | 2BU+CB | DC | | | | |
| 2 | CB+TS | 2LA | 2BU | DC+SVD | TS | SVD | DC |
| 3 | SSW/ CB+TS | 2BU | DC+SVD | 2BU+CB | 2BU+SSW | TS | SVD |
| 4 | 2BU/ DC | 2BU+SSW | 2BU+CB | CB | TS | SVD | SVD+TS |

**Table 6: Ranking for improvement in CBA for measures on A660 pm peak**

The pattern is less easy to discern for this set of results. The various bus priority measures appear to feature in the top measures, either individually or in combination. The double cycling of off-arterial roads also features well.

A corresponding regression equation for the pm peak period is

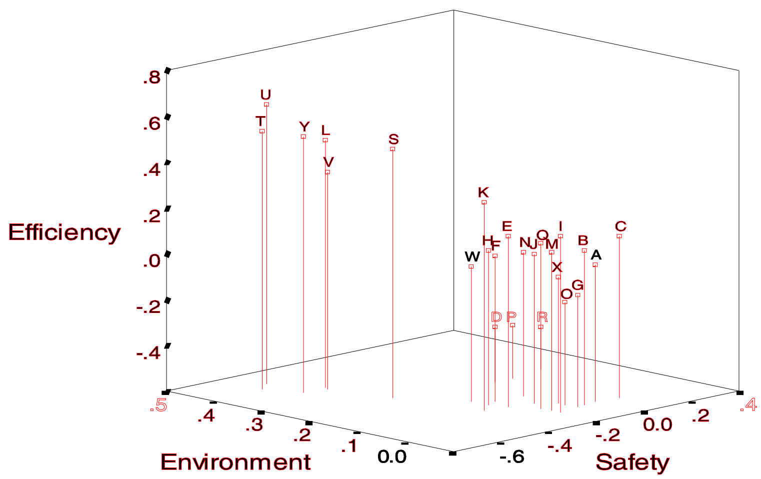
$$CBA = 46318 + 1588\ QWD - 1269\ (2BU) + 958\ SSW\ + 710\ (2LA)$$
$$(435)\quad (8.34)\quad (-6.04)\quad (5.54)\quad (3.86)$$

(2)

The explanatory power of this equation is high at 89.2%. The only significant and consistent effect on the operating cost of the arterial is from a two lane layout with a bus lane which gives a reduction in costs.

## 6 MCA RESULTS

Figure 9 plots the MCA results for the three performance dimensions for the am peak.




```
A: LGT
B: DC         C: SSW       D: MTR       E: RGS       F: 2LA       G: 2BU
H: SVD        I: MBS       J: CB        K: TS        L: QWD       M: DC+SSW
N: 2LA+SSW    O: 2BU+SSW   P: SVD+MTR   Q: SVD+RGS   R: SVD+2BU   S: CB+TS
T: CB+QWD     U: TS+QWD    V: 2LA+QWD   W: 2LA+RGS   X: MBS+2LA   Y: QWD+MBS
```

The cluster in the top left of the graph is composed of points with the calming of Queenswood Drive measure.

The ranking of the top seven measures on each of the three MCA impacts is given in tables 7, 8 and 9.

In total 17 measures gave a positive average efficiency score; 18 gave a positive score for simulation run one; 17 for run two; 15 for run three and 11 for run four.

| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | TS+QWD | CB+QWD | QWD+MBS | CB+TS | QWD | 2LA+QWD | TS |
| 1 | TS+QWD | QWD | QWD+MBS | CB+QWD | CB+TS | TS | DC |
| 2 | QWD+MBS | TS+QWD | QWD | CB+TS | 2LA+QWD | CB+QWD | TS |
| 3 | TS+QWD | CB+QWD | QWD+MBS | QWD | 2LA+SSW | DC | TS |
| 4 | CB+TS | TS+QWD | CB+QWD | CB | 2LA+QWD | RGS | SSW |

**Table 7: Ranking for positive scores on efficiency for first seven measures on A660 am peak**

In total 21 measures gave a positive average environment scores; 23 gave a positive score for simulation run one; 22 for run two; 19 for run three and 15 for run four.

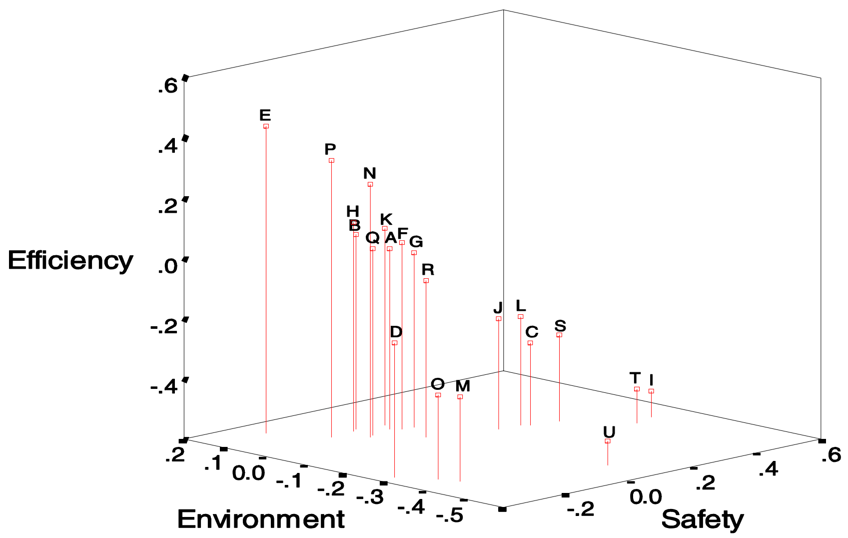
| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | TS+QWD | CB+QWD | QWD+MBS | QWD | 2LA+QWD | CB+TS | SVD+2BU |
| 1 | TS+QWD | QWD+MBS | CB+QWD | 2LA+QWD | CB+TS | SVD+MTR | MTR |
| 2 | TS+QWD | QWD | 2LA+QWD | CB+QWD | QWD+MBS | SVD+MTR | 2LA+RGS |
| 3 | CB+TS | CB+QWD | 2LA+QWD | SVD+2BU | QWD | QWD+MBS | TS+QWD |
| 4 | CB+QWD | QWD+MBS | QWD | TS+QWD | 2LA+QWD | DC+SSW | MTR |

**Table 8: Ranking for positive scores on environment for first seven measures on A660 am peak**

| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | SVD+2BU | SSW | SVD+MTR | | | | |
| 1 | MTR | SSW | 2LA | SVD+2BU | | | |
| 2 | SVD+2BU | SVD+MTR | SSW | 2LA+SSW | | | |
| 3 | SVD+MTR | 2BU+SSW | DC | SSW | | | |
| 4 | SVD+2BU | MBS+2LA | 2LA+SSW | 2BU | DC | 2LA+QWD | MTR |

**Table 9: Ranking for positive scores on safety for first seven measures on A660 am peak**

Figure 10 shows similar results for the evening peak.




```
A:  LGT
B:  DC          C:  SSW       D:  2LA       E:  2BU       F:  SVD       G:  CB
H:  TS          I:  QWD       J:  DC+SSW    K:  DC+SSW    L:  SSW+SVD   M:  2LA+SSW
N:  2BU+SSW     O:  2LA+CB    P:  2BU+CB    Q:  CB+TS     R:  SVD+TS    S:  QWD+DC
T:  QWD+SVD     U:  QWD+2LA
```

The ranking of the top seven measures on each of the three MCA impacts is given in tables 10, 11 and 12.

| Run | 1/8 | 2/9 | 3/10 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | 2BU/ SVD | 2BU+CB | 2BU+SSW | TS | DC+SVD | DC | CB+TS |
| 1 | DC+SVD | 2BU | 2BU+CB | DC | SVD | CB | |
| 2 | 2BU+SSW | 2BU+CB | TS | SVD | 2BU | CB+TS | DC+SVD |
| 3 | 2BU/ DC | 2BU+CB | 2BU+SSW | CB | TS | SVD+TS | 2LA |
| 4 | 2BU/ SVD | 2BU+CB/ SVD+TS | 2LA/ DC | CB+TS | TS | 2BU+SSW | 2LA+CB |

**Table 10: Ranking for positive scores on efficiency for first seven measures on A660 pm peak**

| Run | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Average | 2BU | DC | TS | 2BU+CB | DC+SVD | | |
| 1 | 2BU | DC+SVD | SVD | CB+TS | DC | | |
| 2 | DC | 2BU+CB | SVD+TS | TS | | | |
| 3 | 2BU | CB | TS | 2BU+CB | DC | | |
| 4 | 2BU+CB | CB+TS | 2BU | DC+SVD | | | |

**Table 11: Ranking for positive scores on environment for measures on A660 pm peak**

| Run | 1/8 | 2/9 | 3/10 | 4/11 | 5/12 | 6/13 | 7 |
|---|---|---|---|---|---|---|---|
| Average | QWD/ CB | QWD+SVD/ DC+SVD | QWD+DC/ SVD | SSW/ SVD+TS | SSW+SVD/ LGT | DC+SSW | QWD+2LA |
| 1 | QWD/ SVD+TS | QWD+DC/ QWD+2LA | SSW | QWD+SVD | SSW+SVD | DC+SSW | CB |
| 2 | QWD+SVD/ DC+SSW | QWD/ DC+SSW | SSW+SVD | SSW | QWD+DC | CB | QWD+2LA |
| 3 | QWD/ DC+SVD | QWD+SVD/ QWD+2LA | QWD+DC | SVD+TS | SVD | SSW+SVD | DC+SSW |
| 4 | QWD/ QWD+2LA | QWD+SVD/ SVD | DC+SSW/ CB | SSW+SVD/ DC+SVD | QWD+DC/ TS | SSW/ SVD+TS | DC |

**Table 12: Ranking for positive scores on safety for first seven measures on A660 pm peak**

# 7 CONCLUSIONS

The impacts of the measures are markedly different in the morning and evening peaks. In the morning, the only measures which improve efficiency are the calming of Queenswood Drive and the reduction of bus dwell time at stops, and the combination of these with some of the other bus priority measures. Metering of traffic (a calming measure) and additional bus lanes worsen efficiency. In the evening peak, the calming of Queenswood Drive worsens efficiency, as do stopping and starting wave signal timings and a second lane on the Otley Road, while an additional bus lane improves efficiency.

The environmental impacts to some extent reflect the efficiency ones, but are less pronounced. In the morning peak, the calming of Queenswood Drive and, in this case, metering of traffic, and their combination with bus priority measures, improve conditions. Reduced dwell time at stops has little effect, and no measures have an adverse impact. In the evening peak, the calming of Queenswood Drive and the introduction of a second lane on Otley Road, together with their combinations with some bus priority measures, have an adverse effect; no measures improve the environment.

The safety impacts are to some extent the mirror image of the efficiency ones. In the morning peak, the calming of Queenswood Drive, selective vehicle detection, reduced time at stops and a second lane on Otley Road all worsen safety, as do certain combinations of these measures (particularly with bus coordination); only one combination improves it. In the evening peak, the calming of Queenswood Drive, the use of stopping and starting waves to set signals, and certain combinations of these measures improve safety, while the introduction of a second lane, or an additional bus lane, on Otley Road worsen it.

Most measures have an impact in either one or both peaks. The only exceptions are double cycling, the reduction of green time for side streets, and moving of bus stops. This is not surprising, since the opportunities for implementing these were limited. The use of stopping and starting waves has no real impact in the morning, presumably because the signals at which it can be applied are more critical in the evening peak. Selective vehicle detection and reduced dwell time at stops have little impact in the evening peak. The latter in particular seems surprising.

However, the most unexpected results are the opposing impacts of several measures in the two peaks. This is particularly true of the calming of Queenswood Drive, and the second lane or the additional bus lane on Otley Road. The first of these appears to be explained by differing levels of spare capacity on Kirkstall Road in the two peaks. The last two may be explained by the relatively limited reallocation of road space to outbound traffic; in retrospect it may have been more interesting to test a full tidal treatment.

## 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 | 53939 | 437 | 53244 | 54635 | 0.00 | 0.00 | 0.00 |
| DC | 53652 | 993 | 52071 | 55232 | 0.08 | -0.01 | -0.07 |
| SSW | 53680 | 538 | 52823 | 54536 | 0.11 | -0.01 | 0.08 |
| MTR | 55442 | 289 | 54982 | 55903 | -0.36 | 0.20 | -0.02 |
| RGS | 53905 | 570 | 52998 | 54812 | 0.15 | 0.06 | -0.25 |
| 2LA | 53842 | 310 | 53349 | 54334 | 0.04 | 0.10 | -0.22 |
| 2BU | 54351 | 993 | 52770 | 55932 | -0.11 | -0.01 | -0.10 |
| SVD | 53722 | 321 | 53211 | 54233 | 0.08 | 0.09 | -0.27 |
| MBS | 53657 | 268 | 53232 | 54083 | 0.17 | -0.02 | -0.19 |
| CB | 53696 | 480 | 52932 | 54459 | 0.06 | 0.05 | -0.16 |
| TS | 52928 | 371 | 52338 | 53518 | 0.31 | 0.07 | -0.33 |
| QWD | 51128 | 494 | 50342 | 51915 | 0.48 | 0.35 | -0.43 |
| DC+SSW | 53959 | 121 | 53766 | 54153 | 0.09 | 0.00 | -0.19 |
| 2LA+SSW | 53791 | 350 | 53235 | 54347 | 0.03 | 0.10 | -0.10 |
| 2BU+SSW | 54455 | 716 | 53316 | 55593 | -0.15 | 0.01 | -0.11 |
| SVD+MTR | 55423 | 362 | 54847 | 56000 | -0.37 | 0.20 | 0.05 |
| SVD+RGS | 54064 | 727 | 52907 | 55220 | 0.12 | 0.02 | -0.19 |
| SVD+2BU | 55436 | 461 | 54703 | 56170 | -0.41 | 0.21 | 0.19 |
| CB+TS | 52076 | 304 | 51592 | 52560 | 0.49 | 0.23 | -0.39 |
| CB+QWD | 51254 | 301 | 50775 | 51733 | 0.53 | 0.41 | -0.58 |
| TS+QWD | 50344 | 607 | 49378 | 51310 | 0.62 | 0.43 | -0.52 |
| 2LA+QWD | 51741 | 803 | 50463 | 53019 | 0.35 | 0.34 | -0.44 |
| 2LA+RGS | 54248 | 380 | 53642 | 54853 | -0.01 | 0.13 | -0.26 |
| MBS+2LA | 53791 | 304 | 53307 | 54275 | -0.05 | 0.03 | -0.10 |
| QWD+MBS | 51205 | 1049 | 49536 | 52875 | 0.52 | 0.35 | -0.52 |

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

| Measure | CBA | EFF | ENV | SAFETY |
|---|---|---|---|---|
| LGT | 53421 | 0.00 | 0.00 | 0.00 |
| | 53734 | 0.00 | 0.00 | 0.00 |
| | 54282 | 0.00 | 0.00 | 0.00 |
| | 54320 | 0.00 | 0.00 | 0.00 |
| DC | 52648 | 0.55 | -0.05 | -0.21 |
| | 53236 | 0.32 | 0.10 | -0.34 |
| | 53740 | 0.28 | -0.03 | 0.09 |
| | 54983 | -0.81 | -0.05 | 0.19 |
| SSW | 53042 | -0.02 | 0.08 | 0.15 |
| | 53460 | 0.27 | -0.07 | 0.22 |
| | 53956 | 0.14 | 0.03 | 0.06 |
| | 54261 | 0.05 | -0.10 | -0.10 |
| MTR | 55044 | -0.22 | 0.26 | 0.24 |
| | 55440 | -0.16 | 0.18 | -0.34 |
| | 55567 | -0.62 | 0.25 | -0.02 |
| | 55719 | -0.43 | 0.10 | 0.06 |
| RGS | 53197 | 0.41 | 0.20 | -0.19 |
| | 53736 | 0.05 | 0.11 | -0.35 |
| | 54172 | 0.00 | 0.10 | -0.20 |
| | 54516 | 0.13 | -0.18 | -0.25 |
| 2LA | 53526 | 0.12 | 0.08 | 0.06 |
| | 53626 | 0.27 | 0.08 | -0.41 |
| | 54099 | -0.20 | 0.16 | -0.46 |
| | 54116 | -0.02 | 0.09 | -0.10 |
| 2BU | 53660 | 0.29 | 0.03 | -0.35 |
| | 53851 | 0.23 | 0.08 | -0.14 |
| | 54074 | 0.21 | -0.21 | -0.11 |
| | 55820 | -1.15 | 0.06 | 0.19 |
| SVD | 53454 | 0.17 | 0.13 | -0.23 |
| | 53526 | -0.15 | 0.11 | -0.26 |
| | 53738 | 0.25 | 0.11 | -0.20 |

| | | | | |
|---|---|---|---|---|
| | 54169 | 0.04 | -0.01 | -0.38 |
| MBS | 53382 | 0.32 | 0.13 | -0.28 |
| | 53535 | 0.40 | -0.17 | -0.22 |
| | 53706 | -0.02 | 0.09 | -0.25 |
| | 54006 | -0.03 | -0.10 | 0.00 |
| CB | 53014 | 0.42 | 0.13 | -0.11 |
| | 53795 | -0.12 | 0.01 | -0.02 |
| | 53834 | -0.25 | 0.12 | -0.33 |
| | 54139 | 0.21 | -0.05 | -0.19 |
| TS | 52390 | 0.55 | 0.08 | -0.14 |
| | 52977 | 0.43 | 0.02 | -0.44 |
| | 53151 | 0.25 | 0.07 | -0.40 |
| | 53194 | 0.02 | 0.10 | -0.36 |
| QWD | 50625 | 0.80 | 0.23 | -0.63 |
| | 50783 | 0.59 | 0.55 | -0.41 |
| | 51541 | 0.51 | 0.33 | -0.49 |
| | 51564 | 0.02 | 0.30 | -0.19 |
| DC+SSW | 53831 | 0.30 | -0.11 | -0.43 |
| | 53883 | 0.23 | 0.08 | -0.14 |
| | 54041 | -0.00 | -0.06 | -0.07 |
| | 54083 | -0.17 | 0.11 | -0.13 |
| 2LA+SSW | 53459 | -0.01 | 0.23 | -0.59 |
| | 53675 | 0.09 | 0.19 | 0.00 |
| | 53746 | 0.29 | -0.08 | -0.29 |
| | 54282 | -0.25 | 0.04 | 0.47 |
| 2BU+SSW | 53580 | 0.35 | 0.06 | -0.47 |
| | 54168 | 0.16 | -0.01 | -0.16 |
| | 54958 | -0.33 | 0.03 | 0.12 |
| | 55114 | -0.77 | -0.05 | 0.05 |
| SVD+MTR | 55035 | -0.47 | 0.29 | -0.04 |
| | 55337 | -0.31 | 0.24 | 0.25 |
| | 55412 | -0.43 | 0.22 | 0.18 |
| | 55909 | -0.28 | 0.04 | -0.20 |

| | | | | |
|---|---|---|---|---|
| SVD+RGS | 52994 | 0.48 | 0.12 | -0.05 |
| | 54302 | -0.09 | 0.09 | -0.47 |
| | 54340 | 0.07 | -0.03 | -0.28 |
| | 54618 | 0.03 | -0.11 | 0.05 |
| SVD+2BU | 55101 | -0.17 | 0.25 | 0.03 |
| | 55109 | -0.17 | 0.15 | 0.39 |
| | 55452 | -0.53 | 0.34 | -0.21 |
| | 56083 | -0.76 | 0.09 | 0.54 |
| CB+TS | 51674 | 0.65 | 0.29 | -0.27 |
| | 52018 | 0.57 | 0.14 | -0.35 |
| | 52247 | 0.24 | 0.38 | -0.49 |
| | 52365 | 0.50 | 0.10 | -0.46 |
| CB+QWD | 50828 | 0.69 | 0.43 | -0.73 |
| | 51268 | 0.48 | 0.40 | -0.56 |
| | 51407 | 0.65 | 0.37 | -0.37 |
| | 51513 | 0.31 | 0.46 | -0.68 |
| TS+QWD | 49778 | 0.81 | 0.56 | -0.55 |
| | 49889 | 0.63 | 0.63 | -0.94 |
| | 50683 | 0.69 | 0.28 | -0.51 |
| | 51025 | 0.36 | 0.24 | -0.09 |
| 2LA+QWD | 50991 | 0.60 | 0.39 | -0.91 |
| | 51151 | 0.50 | 0.40 | -0.50 |
| | 52160 | 0.15 | 0.35 | -0.51 |
| | 52662 | 0.17 | 0.20 | 0.16 |
| 2LA+RGS | 53593 | 0.16 | 0.25 | -0.12 |
| | 54421 | -0.25 | 0.23 | -0.50 |
| | 54438 | 0.21 | 0.11 | -0.45 |
| | 54539 | -0.14 | -0.07 | 0.01 |
| MBS+2LA | 53522 | -0.18 | 0.21 | -0.37 |
| | 53663 | 0.21 | 0.03 | -0.12 |
| | 53756 | 0.14 | -0.09 | -0.44 |
| | 54224 | -0.36 | -0.01 | 0.53 |

| | | | | |
|---|---|---|---|---|
| QWD+MBS | 50221 | 0.76 | 0.47 | -0.60 |
| | 50610 | 0.77 | 0.27 | -0.69 |
| | 51391 | 0.57 | 0.32 | -0.29 |
| | 52600 | -0.00 | 0.36 | -0.52 |

**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 | 46217 | 579 | 45297 | 47138 | 0.00 | 0.00 | 0.00 |
| DC | 46080 | 655 | 45037 | 47122 | 0.04 | 0.05 | -0.05 |
| SSW | 47665 | 1190 | 45772 | 49558 | -0.33 | -0.15 | 0.25 |
| 2LA | 46934 | 1076 | 45222 | 48645 | -0.15 | -0.29 | -0.35 |
| 2BU | 44857 | 1085 | 43131 | 46583 | 0.42 | 0.13 | -0.23 |
| SVD | 46243 | 484 | 45473 | 47013 | 0.02 | -0.02 | 0.01 |
| CB | 46498 | 804 | 45219 | 47776 | -0.02 | -0.02 | 0.05 |
| TS | 45938 | 382 | 45330 | 46547 | 0.09 | 0.04 | -0.07 |
| QWD | 48260 | 879 | 46861 | 49659 | -0.51 | -0.26 | 0.49 |
| DC+SSW | 47280 | 586 | 46347 | 48213 | -0.23 | -0.14 | 0.16 |
| DC+SVD | 46075 | 828 | 44757 | 47392 | 0.05 | 0.03 | 0.02 |
| SSW+SVD | 47300 | 624 | 46306 | 48293 | -0.24 | -0.14 | 0.23 |
| 2LA+SSW | 47812 | 611 | 46839 | 48784 | -0.32 | -0.39 | -0.27 |
| 2BU+SSW | 45760 | 1097 | 44015 | 47505 | 0.24 | -0.02 | -0.09 |
| 2LA+CB | 47525 | 734 | 46358 | 48692 | -0.32 | -0.35 | -0.29 |
| 2BU+CB | 45485 | 955 | 43965 | 47005 | 0.32 | 0.03 | -0.15 |
| CB+TS | 46166 | 441 | 45465 | 46867 | 0.02 | -0.01 | -0.07 |
| SVD+TS | 46674 | 487 | 45899 | 47448 | -0.08 | -0.09 | 0.00 |
| QWD+DC | 47450 | 835 | 46122 | 48778 | -0.32 | -0.16 | 0.33 |
| QWD+SVD | 48238 | 1033 | 46595 | 49882 | -0.49 | -0.27 | 0.43 |
| QWD+2LA | 48386 | 118 | 48198 | 48575 | -0.52 | -0.49 | 0.07 |

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

| Measure | CBA | Eff | Env | Safety |
|---|---|---|---|---|
| LGT | 46077 | 0.00 | 0.00 | 0.00 |
| | 46674 | 0.00 | 0.00 | 0.00 |
| | 45456 | 0.00 | 0.00 | 0.00 |
| | 46661 | 0.00 | 0.00 | 0.00 |
| DC | 46531 | 0.12 | 0.00 | -0.06 |
| | 46023 | -0.04 | 0.08 | -0.09 |
| | 45174 | 0.05 | 0.12 | -0.15 |
| | 46590 | 0.02 | -0.01 | 0.09 |
| SSW | 48651 | -0.47 | -0.23 | 0.36 |
| | 48696 | -0.41 | -0.26 | 0.45 |
| | 46359 | -0.05 | -0.02 | 0.00 |
| | 46954 | -0.38 | -0.10 | 0.18 |
| 2LA | 48445 | -0.75 | -0.46 | -0.22 |
| | 46613 | -0.15 | -0.23 | -0.43 |
| | 46770 | 0.05 | -0.29 | -0.35 |
| | 45906 | 0.25 | -0.17 | -0.39 |
| 2BU | 44052 | 0.40 | 0.18 | -0.20 |
| | 46297 | 0.21 | 0.00 | -0.14 |
| | 43989 | 0.55 | 0.26 | -0.39 |
| | 45090 | 0.53 | 0.09 | -0.21 |
| SVD | 45602 | 0.09 | 0.10 | -0.08 |
| | 46152 | 0.27 | -0.07 | -0.02 |
| | 46698 | -0.32 | -0.10 | 0.08 |
| | 46521 | 0.04 | 0.00 | 0.05 |
| CB | 46877 | 0.09 | -0.07 | 0.07 |
| | 47285 | -0.12 | -0.08 | 0.23 |
| | 45418 | 0.16 | 0.15 | -0.15 |
| | 46412 | -0.22 | -0.07 | 0.04 |
| TS | 45827 | -0.14 | -0.01 | -0.05 |

| | | | | |
|---|---|---|---|---|
| | 45866 | 0.28 | 0.04 | -0.04 |
| | 45581 | 0.13 | 0.15 | -0.19 |
| | 46480 | 0.09 | -0.01 | 0.01 |
| QWD | 49239 | -0.55 | -0.43 | 0.51 |
| | 47648 | -0.58 | -0.20 | 0.52 |
| | 48755 | -0.69 | -0.30 | 0.47 |
| | 47398 | -0.23 | -0.11 | 0.45 |
| DC+SSW | 47002 | -0.37 | -0.17 | 0.12 |
| | 47016 | -0.04 | -0.05 | 0.11 |
| | 46945 | -0.27 | -0.03 | 0.07 |
| | 48159 | -0.25 | -0.29 | 0.36 |
| DC+SVD | 45243 | 0.44 | 0.15 | -0.08 |
| | 46443 | 0.08 | -0.02 | 0.10 |
| | 47055 | -0.26 | -0.07 | 0.05 |
| | 45557 | -0.06 | 0.05 | 0.03 |
| SSW+SVD | 46760 | -0.03 | -0.01 | 0.13 |
| | 48104 | -0.27 | -0.25 | 0.45 |
| | 46854 | -0.17 | -0.08 | 0.07 |
| | 47481 | -0.51 | -0.22 | 0.26 |
| 2LA+SSW | 48412 | -0.57 | -0.45 | -0.22 |
| | 47052 | -0.37 | -0.33 | -0.28 |
| | 48183 | -0.21 | -0.48 | -0.23 |
| | 47600 | -0.13 | -0.31 | -0.37 |
| 2BU+SSW | 47280 | -0.01 | -0.15 | -0.05 |
| | 45608 | 0.45 | -0.02 | -0.02 |
| | 44665 | 0.44 | 0.13 | -0.25 |
| | 45486 | 0.08 | -0.03 | -0.06 |
| 2LA+CB | 48378 | -0.77 | -0.46 | -0.18 |
| | 47821 | -0.28 | -0.35 | -0.32 |
| | 47216 | -0.30 | -0.28 | -0.39 |

| | | | | |
|---|---|---|---|---|
| | 46686 | 0.07 | -0.33 | -0.26 |
| 2BU+CB | 46709 | 0.14 | -0.09 | -0.08 |
| | 45366 | 0.29 | 0.07 | -0.18 |
| | 45487 | 0.51 | 0.00 | -0.21 |
| | 44377 | 0.32 | 0.16 | -0.15 |
| CB+TS | 46452 | -0.13 | 0.01 | -0.05 |
| | 46611 | 0.10 | -0.10 | -0.02 |
| | 45934 | -0.11 | -0.08 | -0.06 |
| | 45667 | 0.23 | 0.13 | -0.17 |
| SVD+TS | 47134 | -0.36 | -0.23 | 0.04 |
| | 45992 | -0.03 | 0.05 | -0.15 |
| | 46850 | 0.06 | -0.11 | 0.11 |
| | 46719 | 0.03 | -0.05 | 0.01 |
| QWD+DC | 48223 | -0.30 | -0.29 | 0.40 |
| | 47469 | -0.38 | -0.16 | 0.30 |
| | 47823 | -0.32 | -0.15 | 0.36 |
| | 46287 | -0.26 | -0.05 | 0.25 |
| QWD+SVD | 46933 | -0.11 | -0.08 | 0.32 |
| | 47918 | -0.70 | -0.22 | 0.59 |
| | 49241 | -0.51 | -0.43 | 0.44 |
| | 48862 | -0.67 | -0.33 | 0.37 |
| QWD+2LA | 48402 | -0.60 | -0.48 | 0.02 |
| | 48542 | -0.79 | -0.56 | 0.18 |
| | 48337 | -0.38 | -0.42 | 0.03 |
| | 48264 | -0.32 | -0.51 | 0.05 |

**Table A2: Individual Cost Benefit (ECU) and MCA**