TRANSPORT RESEARCH LABORATORY

Monitoring and evaluation of a public transport priority scheme in Southampton

Prepared for Hampshire County Council

Transport Research Laboratory, Transportation Research Group (University of Southampton) and University of Portsmouth

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Executive Summary

This report describes the evaluation of a demonstration scheme using new technology to give priority to buses at three junctions in Southampton. The scheme was implemented and evaluated as part of the ENTRANCE project.

The ENTRANCE project is a European project funded partly by the European Commission’s Directorate-General for Energy (under the THERMIE programme doe promotion of European energy technology) and partly by the cities and other partners involved. The project was launched in February 1994 and is led by nine cities in eight member states. The evaluation in Hampshire is being carried out by TRL, the University of Southampton and the University of Portsmouth, for Hampshire County Council.

The purpose of ENTRANCE is to demonstrate through implementation and assessment various integrated measures for promoting alternatives to car travel and alternative patterns of travel, improving public transport operations and use, and making better use of existing road space in European cities. It is intended that these measures will lead to energy savings and lower emission levels and a better quality of life for residents and visitors. The project targets a number of technologies offering significant improvements to urban public transport, to encourage the use of this mode of travel in preference to private vehicles, but is also concerned with promoting alternative patterns of travel (for example through teleworking and cycling), and with techniques for managing congestion to improve the use of existing road space.

The Hampshire partners aim to raise awareness of energy and environmental issues by demonstrating a number of integrated applications within and in the vicinity of Southampton and Portsmouth. The evaluation aims to assess the energy consumption benefits and the associated environmental benefits due to individual system elements. In addition the evaluation seeks to determine the impacts of the applications in behavioural and economic terms. Although the applications are each evaluated and reported separately in the ENTRANCE study, the full impact of each scheme will not be felt in isolation. For example, in addition to bus priority measures, real-time passenger information could also improve the attractiveness of public transport, while traffic volumes could be reduced through teleworking, thereby improving journey times for bus users.

This report describes the evaluation of the public transport priority application in Southampton. The aim was to reduce delays to buses at traffic signals and to improve the reliability of services, thereby improving the attractiveness of public transport relative to the private car. Benefits for energy consumption and the environment were expected to arise from the reduction in delays to buses.

This was one of three bus priority schemes in Hampshire evaluated in the ENTRANCE study. In Eastleigh, priority at four signal-controlled junctions along a main route was provided by equipping buses with electronic tags to communicate with loop detectors in the road on the approach to the junctions. In Portsmouth, a range of measures including bus lanes and signals at junctions were used to provide bus priority along one major route through the city. The evaluation of these schemes is the subject of other reports in this series.

In this application in Southampton, buses were given priority at three junctions controlled by the SCOOT Urban Traffic Control system, which was already being used to manage traffic in Southampton, by controlling traffic signals. ‘Footprint’ loop detectors were installed in the road on five of the links approaching the three junctions. When buses are detected by the loops, the SCOOT software gives buses priority at the junction either by extending an existing green phase in the traffic signals or by calling up a new green phase. The strategy selected within SCOOT was one that gave buses relatively high priority over other traffic.

‘Footprint’ detector technology is one of a number of methods of vehicle detection available for giving buses priority, and is relatively simple to introduce because it does not involve installing any equipment on buses. This technology is also inexpensive relative to other selective detection technologies that require on-bus equipment. It is particularly suitable for cities where conventional bus fleets predominate, and for sites where the position of buses approaching the signals is predictable and where there is little chance that other vehicles will trigger the priority. Because the system took advantage of existing capabilities in the traffic control software, and did not involve installing any equipment in the buses, the installation costs were modest, at around £5,000 per link.

The application was evaluated from ‘before and after’ surveys which produced data on bus journey times and hence speeds, traffic delays and system operations. Pollutant emissions and fuel consumption were calculated using speed-related factors derived from an emissions database. The economic evaluation was based on the techniques used by the Department of Transport for the economic appraisal of road schemes.

This form of vehicle detection proved successful at the junctions concerned, achieving the objectives of the application. Delays to buses were reduced significantly while delays for other traffic increased. ‘Footprint’ loop detectors proved to be a cost-effective method of detecting buses at the sites concerned.

The bus priority strategies implemented were shown to benefit bus operators and passengers by producing significant reductions in bus delay and fuel consumption. For buses all six major pollutants (i.e. carbon monoxide, carbon dioxide, unburnt hydrocarbons, nitrogen oxides, sulphur and particulate matter) were reduced by between 13% and 25%. However, because of the relatively high priority granted to buses, additional delays to car drivers resulted in an overall increase in fuel consumption and emissions of all pollutants except sulphur, oxides of nitrogen and particulates. The net increases were between 3% and 8% for emissions while fuel consumption increased by 3%. Emissions of oxides of nitrogen and particulates were reduced, which is encouraging, as nitrogen dioxide and particulate concentrations in urban areas are likely to exceed acceptable values without some form of local action.

Considering bus delay savings alone, the application produced an economic benefit which would exceed its implementation costs by a factor of three. The high priority strategies implemented produced small but significant increases in general traffic delay which, using UK standard values for economic assessment of road schemes, outweighed the benefits to buses, so that there was a net increase in overall delay costs amounting to about twice the installation cost.

This assessment excludes any beneficial impacts of modal change, which could be significant in the longer term, particularly if bus priority were applied more widely and linked to other improvements such as better passenger information. The disbenefits to private vehicles (increased journey times, fuel consumption and emissions) could suppress demand for car travel in the longer term, with further savings in bus journey times and consequent savings in fuel consumption and emissions.

The relative impacts of this bus priority application on buses, general traffic and the environment can be controlled by the local authority, according to policy, by implementing the appropriate priority strategy. It is expected that significant net benefits could be achieved, even without modal change, if different priority strategies were adopted that gave lesser priority to buses and did not increase delays to other traffic to the same extent. It could also be argued that rather than adopting the conventional UK approach of assigning lower values of time to bus passengers compared with car passengers, other values of time would be appropriate in the economic assessment in this case, reflecting the policy objective of giving priority to buses at the expense of cars. However while the standard value of time for bus passengers is 27% lower than the value for car passengers, the difference in values of time would have to be considerably greater than this for the application to produce overall net benefits.

In summary, the report concludes that this method of giving priority to buses in Southampton was successful in meeting the objectives of reducing delay, emissions and improving fuel consumption of buses using the priority system. By optimising the priority settings it is anticipated that net benefits in terms of fuel consumption, emissions and costs could be obtained for the other traffic in the area. The application would be suitable for wider implementation in its own right.

1 Evaluation plan

1.1 Description of the application

Bus priority was implemented at three SCOOT controlled junctions in Southampton using selective detection. Five of the links approaching these junctions were equipped with detectors. Two of the junctions were in the city centre, the third was on the east side of the city in Bitterne (Figure 1 and Figure 2).

'Footprint' loops to detect the approach of buses were installed on the five links and connected to the traffic signal controller at the roadside. The detector was tuned to recognise only those vehicles (i.e. buses) which fall within a specified range of inductance values. The software in the signal controller detects the buses by the level of induction caused when they pass over the loop, and triggers the signal controller. Bus priority was provided using the facilities available in SCOOT version 3.1. These enable the green signal to be automatically extended or recalled when a bus is detected, subject to user-defined control parameters. The settings used for the parameters determining bus priority within SCOOT are shown in Appendix A. The most significant parameters are:

- extensions are awarded only if the degree of saturation at the junction is below a specified threshold value (SATE);
- recalls are awarded only if the degree of saturation at the junction is below a specified threshold value (SATR);
- the recovery methods for synchronising SCOOT timings after an extension and recall have been awarded (BEXR and BRER);
- the longest extension permitted (PMAX).

Compared with other possible public transport priority strategies, the strategy adopted offered relatively high priority to buses.

This report concentrates on a summary of the evaluation methodology and findings.

1.2 Evaluation objectives

The general aim of this initiative was to reduce delays to buses at traffic signals and to improve the reliability of services, thereby improving the attractiveness of public transport relative to the private car. A reduction in delays to buses was also expected to provide associated benefits for energy consumption and the environment.

1.3 Expected impacts

It was anticipated that the main impacts of prioritising public transport in Southampton would be reductions in passenger journey times and in fuel consumption for buses due to improved travel speeds. A possible consequence of reducing delays to buses would be a decrease in pollutant emissions from buses.

It was expected that priority for buses might lead to changes in journey times for other traffic, affecting fuel consumption and pollutant emissions. Such changes needed to be balanced with any benefits seen for the buses. In addition it was anticipated that there might be some re-assignment of the non-prioritised traffic to other routes.

The cost of design, implementation and maintenance of priority measures needed to be balanced against the benefits of the scheme within an economic evaluation.

It was hoped that wider application of the priority measures could reduce passenger waiting times, attract new users and lead to an increased use of bus services.

1.4 Experimental plan

1.4.1 Indicators

The indicators required for the evaluation were drawn from the following list:

- traffic flows, average speed and journey times for buses and general traffic within and around the corridor;
- energy consumption of buses and general traffic affected by the scheme;
- pollutant emissions of buses and general traffic affected by the scheme;
- costs of installation and maintenance of the priority measures;
- value in changes in journey times to bus passengers and car drivers.

1.4.2 Measurement method

Bus priority was implemented on five links approaching three SCOOT-controlled junctions. Evaluation was by means of on-street bus journey time measurements and by using SCOOT data to estimate delays to general traffic. Both 'before' and 'after' surveys involved:

- on-site surveyors recording the time when buses passed the detectors and the stop lines. Road side counts were used to obtain average values for bus occupancies;
- concurrent collection of SCOOT data to estimate vehicle flows, stops and delays on all the links entering the junction where priority was provided;
- concurrent automatic collection of system status data concerning bus priority requests and system response.

1.5 Analysis

1.5.1 Energy

Fuel savings were calculated for buses which benefited from the priority system. It was anticipated that delays to other traffic may have resulted in increased fuel usage. Both these elements were calculated using average speeds and suitable fuel consumption factors (see Section 3.1).

1.5.2 Environment

Similarly, it was expected that the amount of emissions may have changed as a result of the priority measures. Bus and car speeds and flows were used to calculate the change in emissions using appropriate factors (see Section 3.1).

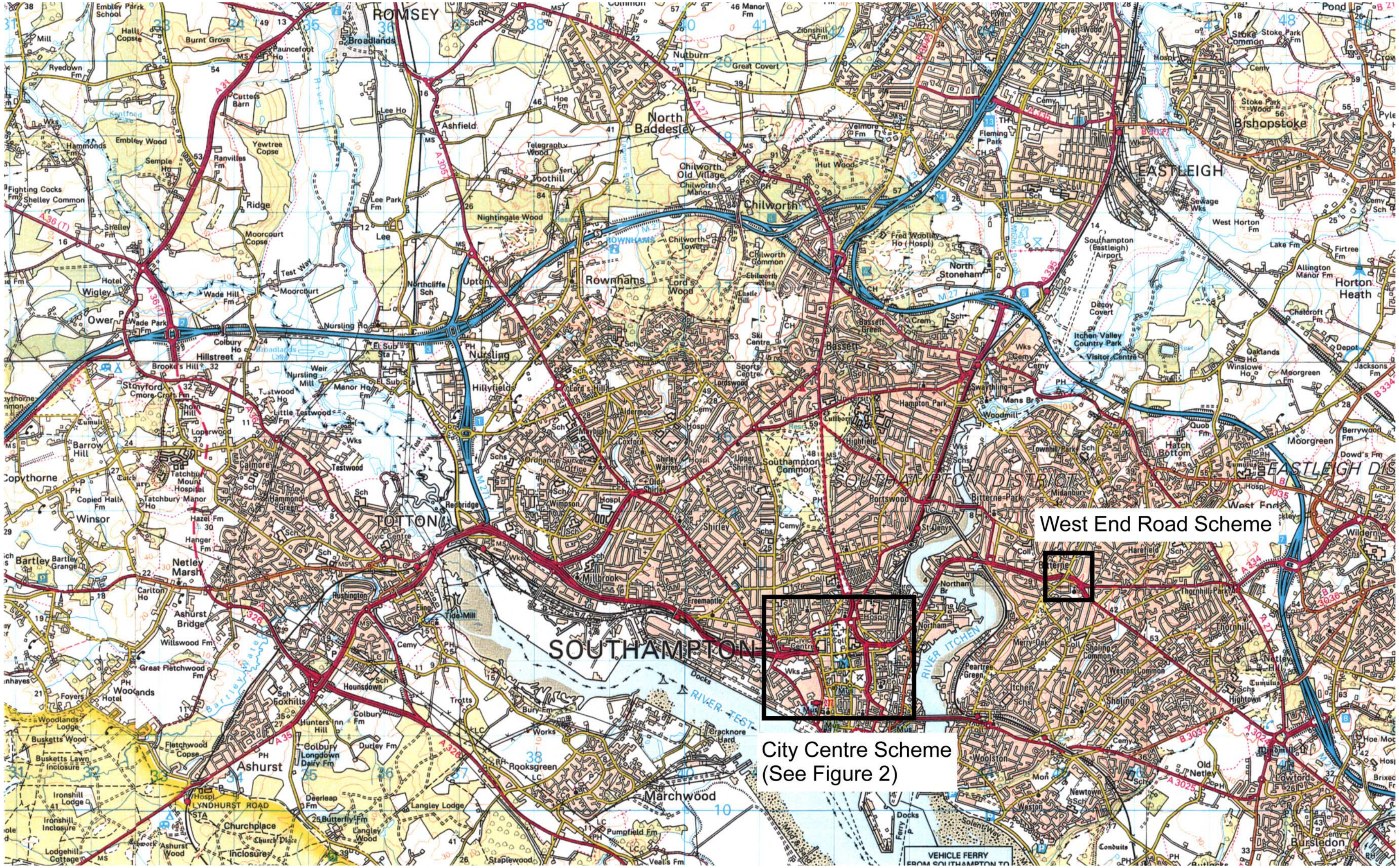

Figure 1 Location of Southampton bus priority

Figure 2 Location of City Centre bus priority measures

1.5.3 Economic

A cost-benefit analysis was undertaken to demonstrate the economic performance of the application, focusing on installation and maintenance costs and benefits resulting from changes in vehicle journey times.

1.5.4 Behaviour

Bus priority may be perceived by the public as increasing the reliability or speed of bus services, thus potentially increasing passenger numbers. Due to the limited extent and impact of the scheme, this was treated in the analysis as an additional potential benefit of the application, particularly if it were implemented more widely. The study did not therefore include 'before and after' counts of passenger numbers.

2 The surveys

2.1 Introduction

The five links in Southampton (see Figure 1 and Figure 2) were surveyed at the following locations:

- Old Northam Road approaching Six Dials;
- New Road approaching Six Dials;
- Commercial Road (westbound) approaching junction with Havelock Road;
- West Park Road (eastbound) approaching junction with Havelock Road;
- West End Road (westbound) slipway.

Surveys took place over a 4 week period between 17th June and 12th July 1996. Each link was surveyed for one week each with and without the priority system operating, to provide a comparison. Surveys were undertaken for the AM peak (0730-0930), AM off-peak (1000-1200), PM off-peak (1330-1530) and PM peak (1600-1800) and covered a total of 36 hours per week. Surveys were not undertaken for the Monday AM peak period and the Friday PM peak period because these peak periods at the start and end of the weekend are not typical of other weekdays. The survey schedule is shown in Table 1.

Table 1 Survey schedule

Site number	*Location*	*Survey dates*	*Priority status*
1	Old Northam Road/ Six Dials	17-21 June 1996 24-28 June 1996	ON OFF
2	New Road/ Six Dials	17-21 June 1996 24-28 June 1996	ON OFF
3	Commercial Road (westbound)	17-21 June 1996 24-28 June 1996	ON OFF
4	West Park Road (eastbound)	17-21 June 1996 24-28 June 1996	ON OFF
5	West End Road (westbound slipway)	1-5 July 1996 8-12 July 1996	OFF ON

2.2 Data collection

At each site, on-street surveyors were positioned at the bus detector and the traffic signal stop line to record the time at which buses passed by. Synchronised palm-top computers were used to enable accurate timing. Buses were identified using their 3-digit identity numbers; a number matching program was then used to obtain bus journey times between passing the detector and clearing the stop line.

To provide information for the economic evaluation on the relative impact of the scheme on bus and car users, average bus occupancies were obtained at each site and for each time period from road-side counts. A sample size of 30 buses was obtained for each measurement. Standard values were available providing the equivalent information on car occupancy.

SCOOT data (M02, M08, M37, B01, B12, B24, B25 and C01 messages) were collected simultaneously with the on-street data. The M02 data were used to estimate for all vehicles, the vehicle flows, stops and delays on all of the links entering the junctions where priority was provided. The other SCOOT messages were collected as useful diagnostic data but were not used in this analysis[1] .

2.3 Survey results

2.3.1 Bus journey times

Bus journey times were calculated for individual buses by matching the bus timing records between passing the detector and clearing the stop line. These journey times were then aggregated and a statistical analysis of significance of the results performed. A full listing of the survey results and an account of the statistical tests performed can be found in Appendix B.

The bus priority measures produced statistically significant average bus journey time savings on each link of between 5.7 and 12.4 seconds as shown in Table 2. A summary of the journey time savings by time of day are shown in Table 3. Savings on New Road in the am off-peak and pm peak were not significant and so are not reported in this table (see Table B3). In general, savings were higher in peak periods when longer cycle times were in operation.

Table 2 Average bus journey time savings over all survey periods

Site	*Average bus journey time savings (seconds)*
Old Northam Road	12.4
New Road	5.7
Commercial Road	8.8
West Park Road	11.3
West End Road	9.4

[1] M08 provides the degree of saturation, M37 the signal stage lengths, the B messages show the bus detection and priority awarded, and C01 provides the cycle time.

Table 3 Average bus journey time savings (seconds) by time of day

Site	*AM peak*	*AM off-peak*	*PM off-peak*	*PM peak*
Old Northam Road	13.3	11.9	15.0	9.5
New Road	10.5	not significant	6.0	not significant
Commercial Road	13.5	5.8	6.2	12.2
West Park Road	15.6	8.1	11.1	10.8
West End Road	11.6	5.8	9.2	12.0

2.3.2 Delay to other vehicles

SCOOT M02 data were used to estimate delays, flows and stops for general traffic on all approach links to the surveyed junctions. Figure 3, Figure 4 and Figure 5 show the junctions, the links and the SCOOT reference numbers used to refer to them in Table 4 to Table 10, and Appendix B.

Free flow journey times between the SCOOT detector and the stop line were measured for each of the links and are shown in Table 4. Data on flows were also collected to check whether delay data would require adjustment to account for significant changes in flow during the survey period. Changes in flow during the surveys varied little (see Appendix B), and so the delays can be directly compared without having to introduce adjustments for variations in flow. There was also no observed change between the 'before' and the 'after' surveys (such as road works) which could have affected flows or delays. Thus changes observed in delays to other vehicles can be attributed to the introduction of bus priority.

Table 5, Table 6 and Table 7 summarise the average daily values for delay per vehicle (DPV) for both priority on and off and where the change in DPV was statistically significant. Decreases in delays as a result of priority are shown as negative. Table 8, Table 9 and Table 10 show the same information by time of day. The full set of data from which these tables are derived are given in Appendix B.

2.3.2.1 Six Dials

Significant additional delays to other traffic as a result of bus priority were seen at 5 of the 7 links approaching Six Dials. The highest of these were an increased delay per vehicle of 13.7 seconds at link 7211E (St. Andrews Road, outside lane) and 16.9 seconds at link 7211H (Kingsway, outside lane. The disbenefits to other traffic on link 7211E and link 7211H were worst during the peak periods. For the latter, in the PM peak period, the delay per vehicle rose by 30.3 seconds.

2.3.2.2 Commercial Road/West Park Road/Havelock Road

A statistically significant increase in the average delay per vehicle in opposing traffic streams of approximately 6 seconds was observed on links 7321A (Havelock Road, northbound, inside lane) and 7321C (Commercial Road, eastbound) and of approximately 10 seconds on link 7321H (Havelock Road, northbound, outside lane). There was also a 10 second increase in average delay per vehicle for other traffic on one of the links with priority: 7321K (Commercial Road, west bound). However, a statistically significant reduction in average delays per vehicle of approximately 10 seconds was observed on the priority link 7321M (West Park Road, eastbound). The greatest disbenefits to other traffic, in terms of delay in seconds per vehicle, tended to occur during the peak periods.

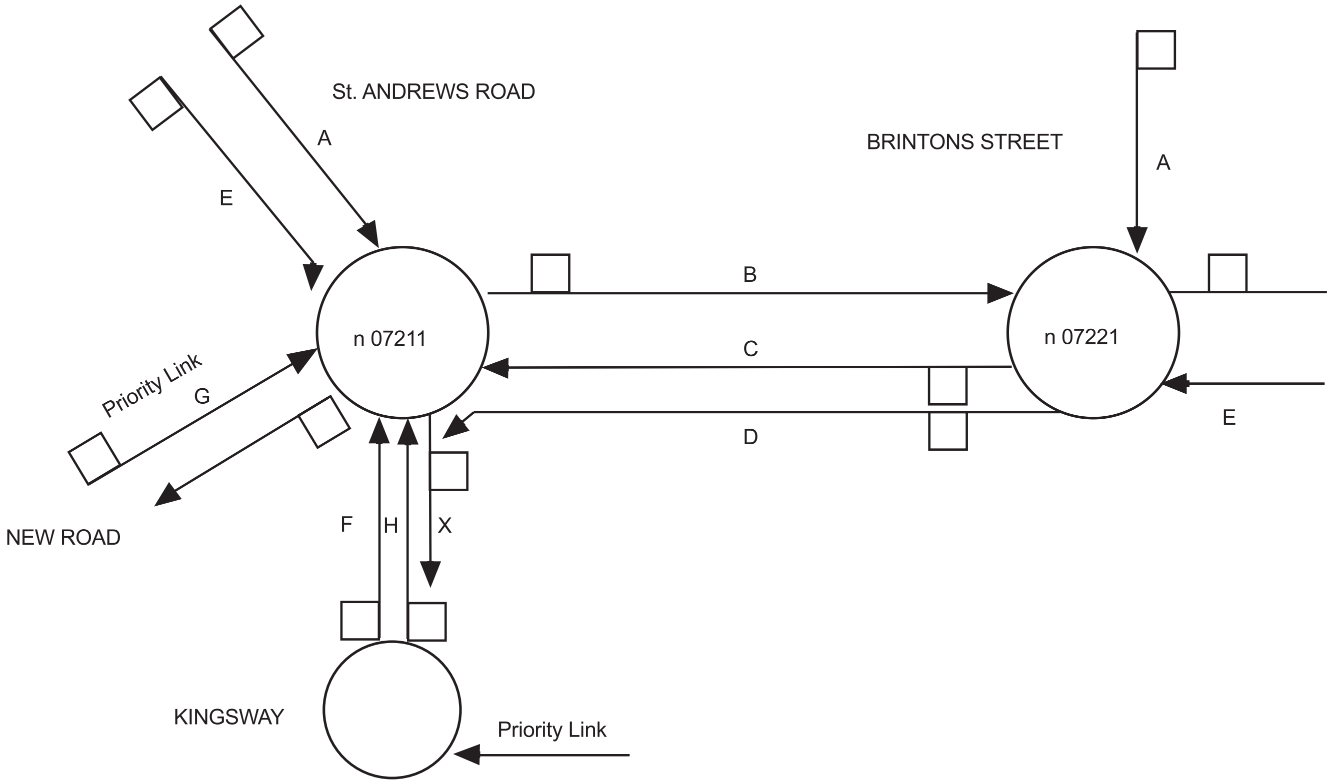

Figure 3 SCOOT links for priority at Six Dials

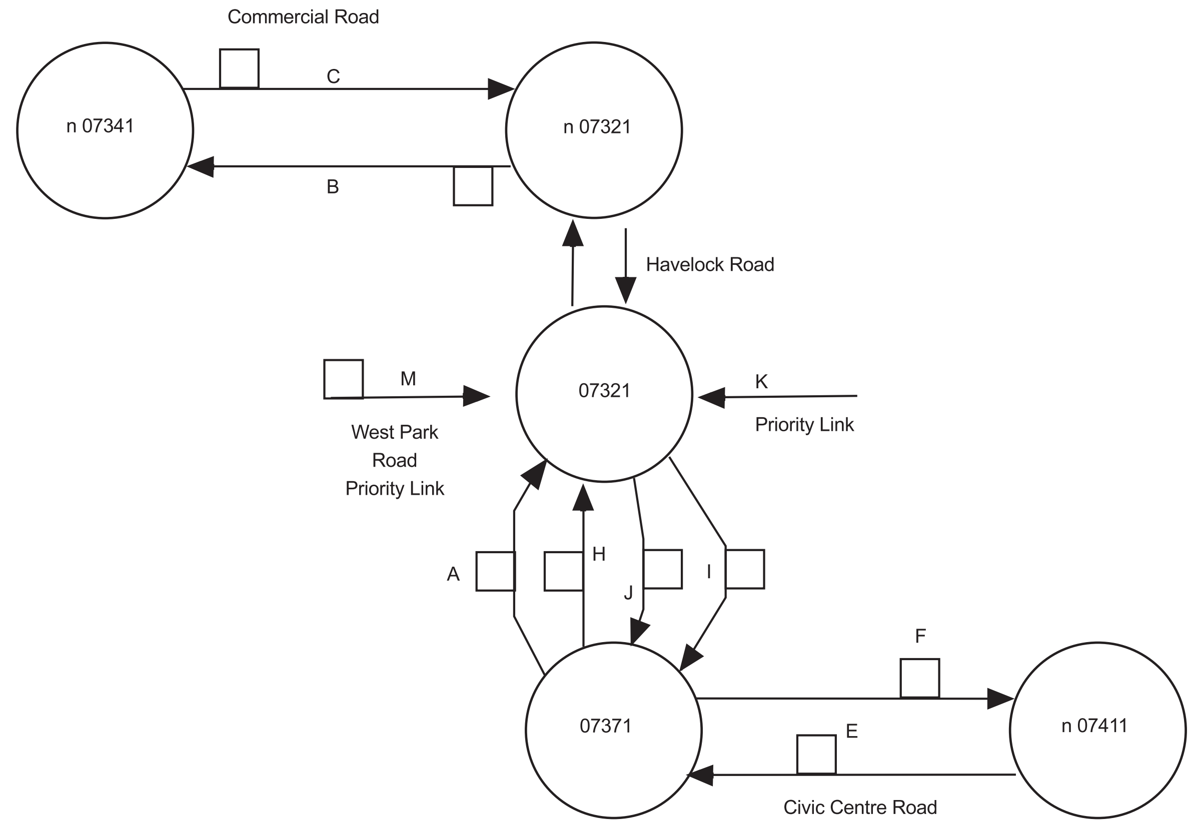

Figure 4 SCOOT links for West Park/Havelock Road priority

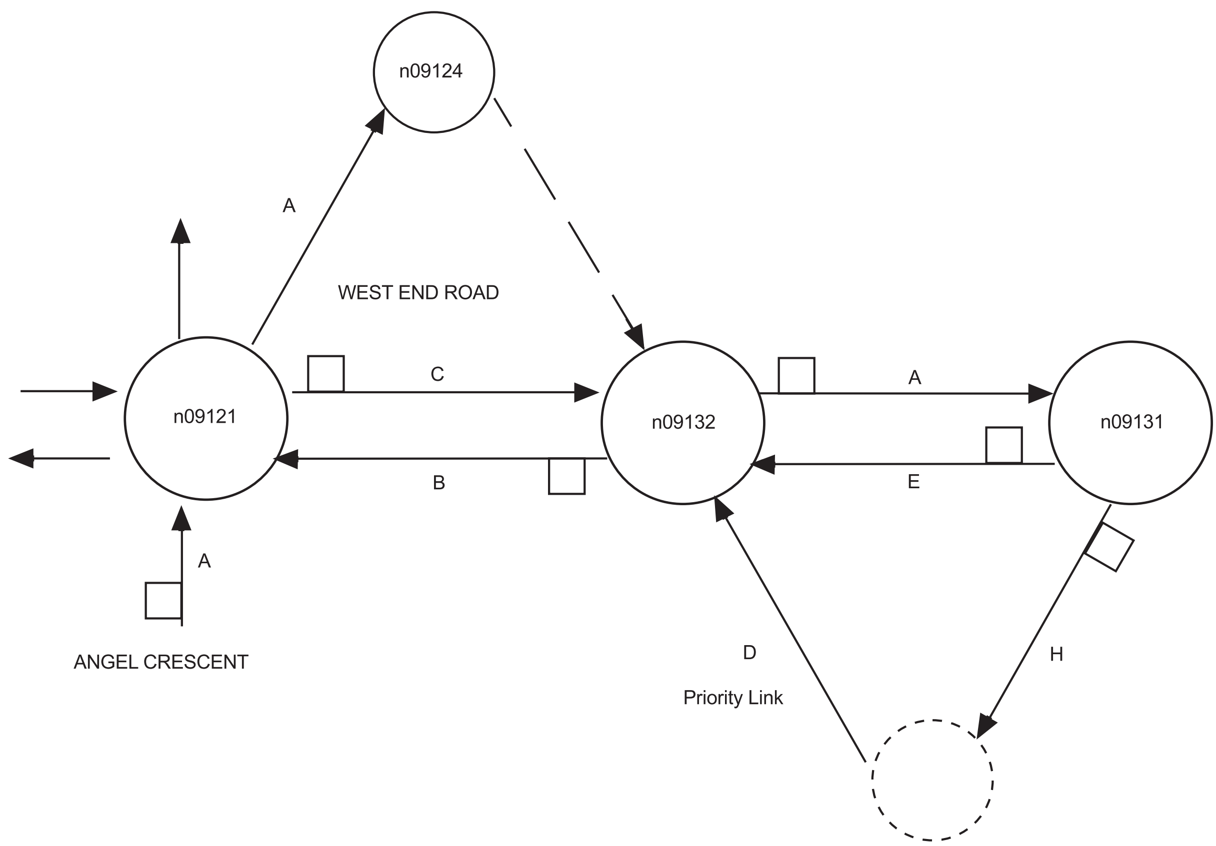

Figure 5 SCOOT links for West End Road priority

Table 4 Free flow journey time for each SCOOT link

Junction	*SCOOT link*	*Free flow journey time(seconds)*
Six Dials	7211A	8
	7211D	7
	7211E	8
	7211F	10
	7211H	10
West Park Road/ Havelock Road	7321A	11
	7321C	21
	7321H	11
	7321K	7
	7321M	7
West End Road slip	9132D	10
	9132E	7

Table 5 Significant changes in delay to other traffic at Six Dials (see Figure 3)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON-OFF)*
7211A	All day	18.4	17.4	1.0
7211D	All day	39.8	37.1	2.7
7211E	All day	56.3	42.6	13.7
7211F	All day	22.4	20.9	1.5
7211H	All day	58.4	41.5	16.9

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

Table 6 Significant changes in delays to other traffic on West Park Road/ Havelock Road (see Figure 4)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON-OFF)*
7321A	All day	15.6	10.0	5.6
7321C	All day	44.8	38.7	6.0
7321H	All Day	44.9	34.6	10.3
7321K	All day	36.8	26.7	10.1
7321M	All day	23.6	33.6	-10.0

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

Table 7 Significant changes in delays to other traffic on the West End Road Slipway (see Figure 5)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON-OFF)*
9132D	All day	26.3	29.2	-2.9
9132E	All day	14.4	11.1	3.3

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

Table 8 Significant changes in delays to other traffic by time of day at Six Dials (see Figure 3)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON - OFF)*
7211A	1000-1200	16.1	14.9	1.2
	1330-1530	18.4	17.1	1.3
7211C	0730-0930	39.4	42.4	-3.0
	1000-1200	29.4	27.4	2.0
7211D	0730-0930	51.8	46.2	5.6
7211E	0730-0930	61.5	44.6	16.9
	1000-1200	47.0	38.5	8.5
	1330-1530	51.5	39.7	11.8
	1600-1800	69.2	51.2	18.0
7211F	1330-1530	23.2	19.9	3.3
	1600-1800	22.5	20.8	1.7
7211G	1000-1200	24.1	27.0	-2.9
7211H	0730-0930	57.8	50.0	7.8
	1000-1200	50.3	39.6	10.7
	1330-1530	57.2	38.0	19.2
	1600-1800	71.2	40.9	30.3

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

Table 9 Significant changes in delays to other traffic by time of day at West Park Road/ Havelock Road (see Figure 4)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON-OFF)*
7321A	0730-0930	18.1	14.4	3.7
	1000-1200	14.6	8.6	6.0
	1330-1530	12.8	9.3	3.5
	1600-1800	17.8	9.0	8.8
7321C	0730-0930	54.4	43.3	11.1
	1330-1530	38.6	34.9	3.7
	1600-1800	52.6	44.6	8.0
7321H	0730-0930	48.6	38.5	10.1
	1000-1200	38.3	31.5	6.8
	1330-1530	39.0	30.8	8.2
	1600-1800	57.1	40.9	16.2
7321K	0730-0930	43.4	29.2	14.2
	1000-1200	33.4	24.8	8.6
	1330-1530	34.5	24.7	9.8
	1600-1800	37.5	29.9	7.6
7321M	0730-0930	26.4	38.6	-12.2
	1000-1200	22.6	31.5	-8.9
	1330-1530	20.4	31.3	-10.9
	1600-1800	25.9	34.8	-8.9

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

Table 10 Significant changes in delays to other traffic by time of day at the West End Road slipway (see Figure 5)

SCOOT link	*Time period*	*Average delay (seconds) per vehicle with Priority ON*	*Average delay (seconds) per vehicle with Priority OFF*	*Difference (ON-OFF)*
9132D	1330-1530	23.8	31.3	-7.5
9132E	0730-0930	12.5	10.2	2.3
	1000-1200	15.4	9.7	5.7
	1600-1800	13.6	10.3	3.3

Statistically significant decreases in delay (with 95% confidence) with bus priority switched on are indicated by negative values in the 'difference' column.

2.3.2.3 West End Road

A statistically significant decrease in delay per vehicle of approximately 3 seconds was observed on the prioritised link 9132D, but an increase of approximately 3 seconds per vehicle was observed for the opposing traffic stream on link 9132E (West End Road, southbound). The greatest benefit to other traffic on link 9132D occurred during the PM off-peak period.

2.3.3 Bus occupancies

Data on bus occupancy were collected so that the changes in journey times for bus passengers could be weighted appropriately in evaluating the relative impact of the scheme on bus passengers and other road users. Estimated average occupancies for buses for each site and for each time period were derived from road-side counts and are shown in Table 11. Bus patronage was not expected to change in the short term as a result of the priority measures, so the evaluation assumed that bus occupancy did not change. Therefore only one set of occupancy data was collected.

Table 11 Average bus occupancies

Site	*Time period*	*Number of buses*	*Average number of passengers*
Old Northam Road/ Six Dials	AM peak	27	27.4
	AM off-peak	26	17.9
	PM off-peak	26	8.6
	PM peak	27	6.7
New Road/ Six Dials	AM peak	21	2.8
	AM off-peak	32	2.7
	PM off-peak	28	17.8
	PM peak	31	21.2
Commercial Road (westbound)	AM peak	25	14.0
	AM off-peak	36	5.9
	PM off-peak	27	24.1
	PM peak	32	21.5
West Park Road (eastbound)	AM peak	31	27.3
	AM off-peak	45	13.8
	PM off-peak	36	11.6
	PM peak	32	10.5
West End Road (westbound slipway)	AM peak	23	27.7
	AM off-peak	23	14.7
	PM off-peak	21	7.4
	PM peak	25	7.2

AM peak = 0800-0900 hrs
AM off peak = 0900-1000 hrs
PM off peak = 1500-1600 hrs
PM peak = 1600-1700 hrs
Bus occupancy surveys took place between 4/11/96 and 6/11/96.

2.4 Summary

Bus priority at traffic signals using loop detectors has been shown to provide delay savings for buses at all 5 of the surveyed links. Average delay savings for buses ranged between 5.7 seconds (New Road) and 12.4 seconds (Old Northam Road). The greatest average delay saving observed was 15.6 seconds on West Park Road during the morning peak.

In general, delay savings for buses were obtained at the expense of traffic in opposing traffic streams, as might have been expected. At Six Dials, an additional average delay of 16.9 seconds per vehicle was found on one link as a result of priority which was exacerbated in the PM peak where an additional delay of 30.3 seconds per vehicle was observed. At Commercial Road/West Park Road/Havelock Road average delay increases of 10 seconds per vehicle were seen on two links but a 10 second decrease in general traffic delay was observed on one of the bus priority links (West Park Road). At West End Road an average delay increase of 3 seconds per vehicle was observed on one link but, also, an average decrease of 3 seconds per vehicle was observed on the bus priority link.

3 Evaluation

3.1 Energy and emissions

3.1.1 Introduction

The combustion of hydrocarbon fuels in an engine leads to the production of carbon dioxide (CO_2), unburnt hydrocarbons (HC), carbon monoxide (CO) and particulates (PM) containing carbon and other contaminants. Sulphur dioxide (SO_2) is produced as a result of sulphur compounds present as impurities in the fuel. Also, at the high temperatures and pressures found in the combustion engine, nitrogen and oxygen in the air combine to produce nitric oxide (NO) and a small amount of nitrogen dioxide (NO_2), collectively known as NO_x.

Within ENTRANCE the evaluation of the applications is concerned with emissions of carbon dioxide, hydrocarbons, carbon monoxide, particulates, sulphur, nitrogen oxides and fuel consumption. Using known relationships between speed and emission rates, changes were calculated using speeds and flows collected in the before and after surveys.

3.1.2 Impact on vehicle speeds

Table 2 indicates that bus journey times with the priority on were less for all links over the whole of the survey period. The journey times and speeds achieved with priority on and off are shown in Table 12. The changes shown were significant for all the links involved.

Similarly, journey times for other vehicles were affected by the priority measures. Generally other traffic was delayed by the bus priority scheme, and this is reflected in the reduced speeds when the SCOOT system was on. Table 13 shows the effect of the priority measures on the speeds of other vehicles. Only those links where the changes are significant are shown; only these links were used in the estimation of the benefits in terms of reduced emissions and fuel consumption.

Table 12 The effect of the priority measures on bus journey time and speed through the prioritised junctions (all survey periods)

	Average journey time (seconds)		*Average speed (km/h)*	
Priority links	*Priority on*	*Priority off*	*Priority on*	*Priority off*
Old Northam Road	33.7	46.1	8.01	5.85
New Road	45.2	50.9	5.58	4.98
Commercial Road	27.4	36.2	6.32	4.70
West Park Road	29.9	41.2	14.14	10.25
West End Road	28.4	37.8	17.67	13.20

Table 13 The effect of bus priority on the speed of other traffic approaching the prioritised junctions (all survey periods)

			Speed (km/h)	
Approach links	*SCOOT link*	*Distance (m)*	*Priority on*	*Priority off*
Six Dials	7211A	101	13.77	14.31
	7211D	89	6.85	7.27
	7211E	101	5.65	7.19
	7211F	127	14.11	14.80
	7211H	127	6.68	8.88
West Park Road/ Havelock Road	7321A	139	18.81	23.83
	7321C	266	14.55	16.04
	7321H	139	8.95	10.97
	7321K	89	7.32	9.51
	7321M	89	10.47	7.89
West End Road slip	9132D	127	12.60	11.66
	9132E	89	14.97	17.70

3.1.3 Bus emissions

In this scheme 90% of the buses affected were double deckers. A combined factor for the affected buses was derived according to the relative proportion of double to single decker buses in the fleet. A fuller explanation of the calculation of bus emission factors can be found in Appendix C.

3.1.4 Passenger car emissions

The passenger cars affected were assumed to be passenger cars with a fleet composition (according to engine size, fuel and emissions control) similar to the national fleet. A combined emission factor for the affected vehicles was derived from the manual on emissions factors (known as the HB-EFA) according to this distribution as described in Appendix C.

3.1.5 Emissions and energy consumption

Using the speeds given in Table 12 and Table 13 and the flows given in Appendix B (Tables B3 and B4) emissions and energy consumption were calculated for the significantly affected traffic. A comparison of the calculated emissions and energy usage with and without priority is shown in Table 14 and summarised in Figure 6, Figure 7 and Figure 8.

Table 14 Comparison of emissions at the prioritised junctions with and without priority

	HC kg	*CO_2 kg*	*CO kg*	*PM kg*	*NO_x kg*	*S kg*	*Fuel kg*
Cars, priority on	11.9	1790	77.5	0.24	5.5	12.2	612
Buses, priority on	0.62	251	1.6	0.27	4.8	4.1	81.7
Total, priority on	12.5	2041	79.1	0.51	10.3	16.3	694
Cars, priority off	11.2	1690	71.3	0.24	5.6	11.6	578
Buses, priority off	0.83	288	2.04	0.34	5.7	4.7	94.0
Total, priority off	12.0	1980	73.3	0.58	11.3	16.3	672
Total on - total off	0.53	58.9	5.7	-0.07	-1.0	0	21.6
% change	4	3	8	-12	-9	0	3

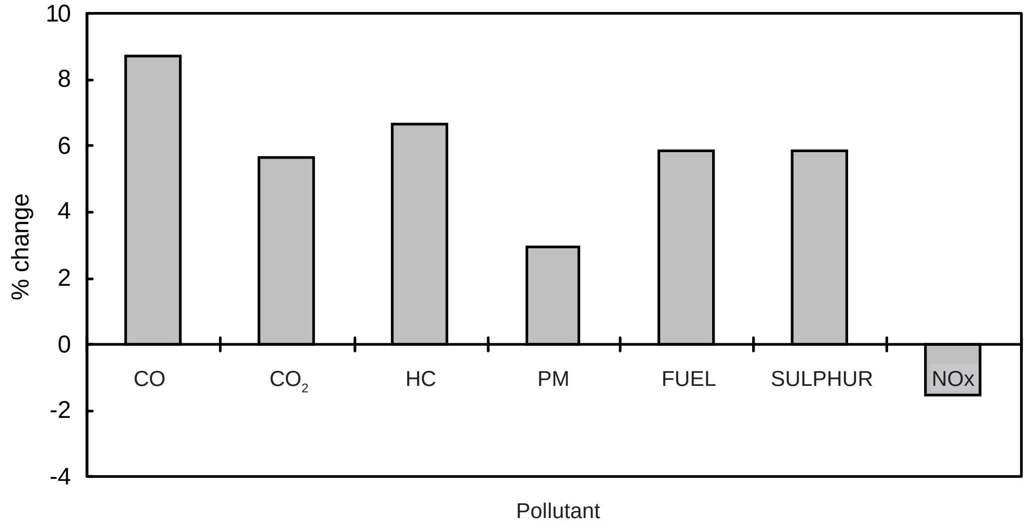

Figure 6 Change in car emissions and fuel consumption at the prioritised junctions (priority on – priority off)

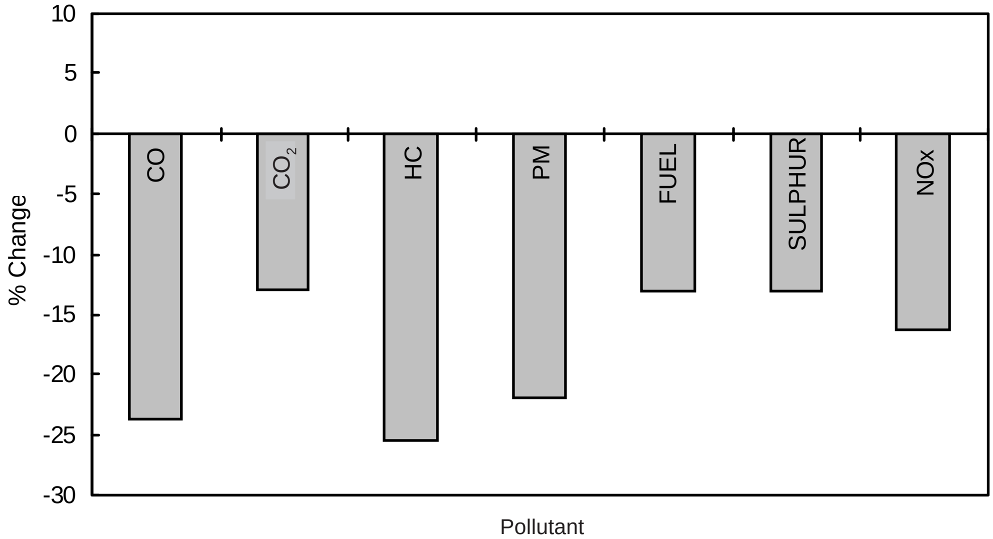

Figure 7 Change in bus emissions and fuel consumption at the prioritised junctions (priority on – priority off)

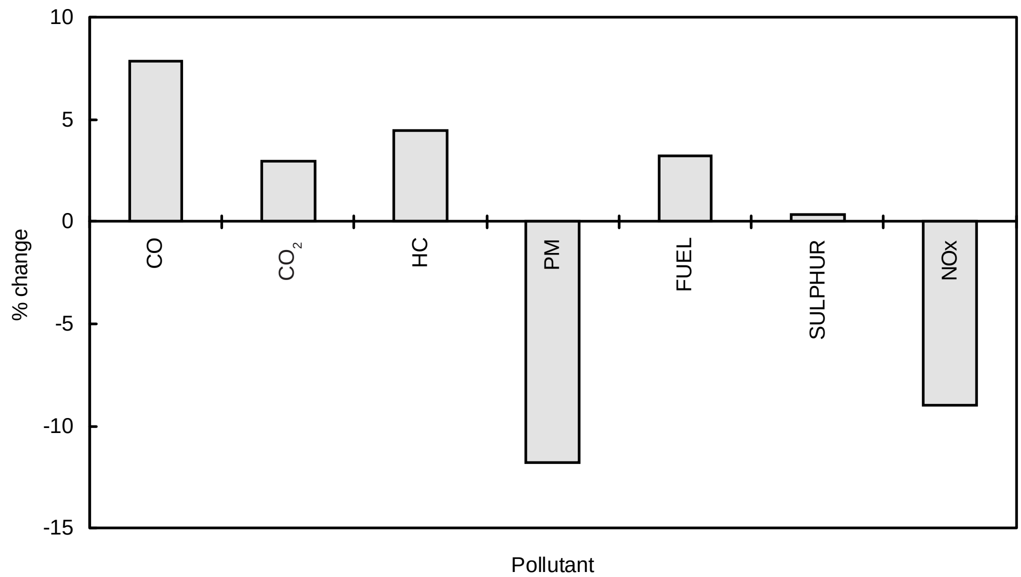

Figure 8 Change in emissions and fuel consumption for all traffic at the prioritised junctions (priority on – priority off)

Table 14 indicates that whilst bus emissions reduced as a result of the priority measures, an overall benefit was seen only for particles and NO_x, and disbenefits were seen for all other pollutants apart from sulphur. On a vehicle-km basis, cars generally have lower emissions than buses. However, because so many more cars were affected than there were buses, overall they make the largest contribution to the total. This means that to achieve a large impact on emissions through changes in bus operation, changes affecting bus operation have to be large, whilst the effects on cars have to be small. The exception is for NO_x and particles, where buses make a much greater contribution because on a vehicle-km basis, emissions of these pollutants are very much higher than for cars. Changes in bus operation can therefore have a relatively greater impact on these two pollutants as is seen here.

At the relatively low speeds encountered at the study sites, pollutant emissions and fuel economy generally increase as vehicle speed reduces. In all but two of the links affected, car speeds were reduced by the bus priority measures, consequently emissions and fuel consumption increased (Table 15). Where speeds were increased on one each of the links affected by the West End Road and Havelock Road measures, pollutant emissions and fuel consumption decreased. This suggests that overall savings are possible if the speed of other traffic is maintained or improved.

Because the savings for buses in emissions and fuel consumption were outweighed by increases for cars, there was an overall disbenefit in terms of emission of pollutants and fuel consumption. It is hoped that the additional delays to cars would discourage car use in the longer term, with consequent reductions in emissions and fuel consumption.

The reduction of NO_x and PM is encouraging. In the National Air Quality Strategy (DoE and Scottish Office, 1996), the Government suggests that emissions of PM and NO_x may be the most difficult to control under existing legislation such that concentrations of nitrogen dioxide and particulates of less than 10µm (PM_{10}) may continue to exceed acceptable values in urban areas. As traffic is a major source of these pollutants in urban areas, the results of this study suggest that it would be worthwhile for local authorities to consider traffic management measures, including bus priority, as a means of reducing emissions.

3.1.6 Summary

The evaluation shows that overall reductions in emissions of NO_x and particulates can be achieved by providing priority for buses at signal controlled junctions. The benefit is however at the expense of emissions of CO, CO_2, hydrocarbons and fuel consumption. Maintaining or improving the speed of other traffic through the affected junctions would reverse this adverse impact of the priority measures.

These results apply only to those links where changes in speed were significant, and the savings are therefore limited to these links.

3.2 Economic

3.2.1 Introduction

The economic evaluation of the Southampton Bus Priority scheme concentrated on the benefits generated from delay savings to buses on priority links and on fuel savings from the increased speed of buses through the links. The impact on other traffic was also examined with regard to potential disbenefits from increased delays at junctions.

In the analysis, monetary values of time and assumptions about average car occupancy were taken from the COBA (cost-benefit analysis) manual for the economic assessment of trunk road schemes including motorways (Department of Transport, 1994). The analysis assumed 1996 prices net of taxes.

3.2.2 Value of time savings

Time savings were calculated based on Table 1 to Table 10 which detail the delays to buses and other traffic on each of the links. Average bus occupancies were taken from Table 11 whilst for cars, the average occupancy was assumed to be 1.65 (from COBA). The evaluation assumed a 12 hour day, 250 days per year.

Table 15 Effect of the measures on other vehicles

			Change in emissions (on - off)						
	Link	*Change in speed (on - off)*	*HC %*	*CO_2 %*	*CO %*	*PM %*	*NO_x %*	*S %*	*Fuel %*
Traffic	7211A	-0.5	1.2	1.0	1.9	0.3	-0.9	1.1	1.1
affected by the	7211D	-0.4	0.5	0.1	1.2	-0.9	-3.6	0.2	0.2
Six Dials	7211E	-1.5	23.9	16.4	21.6	11.8	-0.3	16.9	16.9
priority	7211F	-0.7	1.9	1.7	2.8	0.8	-0.7	1.8	1.8
measures	7211H	-2.2	20.5	21.0	28.0	15.3	2.0	21.5	21.5
Traffic affected	7321A	-5.0	18.0	12.8	19.2	6.2	-0.2	13.2	13.2
by the West Park	7231C	-1.5	3.4	2.6	5.0	0.6	-2.2	2.8	2.8
Road Havelock	7321H	-2.0	8.2	10.3	15.1	6.3	-1.6	10.5	10.5
Road priority	7321K	-2.2	9.9	11.9	18.1	6.9	-4.0	12.3	12.3
measures	7321M	2.6	-18.4	-20.4	-25.0	-16.4	-6.5	-20.7	-20.7
Traffic affected by the West	9132D	0.9	-2.7	-2.9	-4.6	-1.5	1.1	-3.0	-3.0
End Road slip measures	9132E	-2.7	8.7	6.9	11.1	3.2	-1.7	7.2	7.2

The value of time per bus is given by:

Value of time per bus = £(10.60 + 3.46B) per hour (1996 prices)

where B is the bus occupancy.

The value of time per car was taken to be £7.26 per hour, based on an occupancy of 1.65.

It can be seen in Table 16 that overall time savings for buses as a result of the reduced delays were more than outweighed by the disbenefits associated with delays to other traffic. However for the West End Road slipway, time savings for buses outweighed the additional delays to cars; at this junction the delays to other traffic were reduced on the priority link, and delays to other traffic did not increase significantly on one of the other two links.

3.2.3 Fuel savings

The value of fuel savings were calculated from data in Table 14, with the assumptions that the price of fuel (net of taxes) in 1996 was 17.9 p/l and the density of fuel was 750 g/l.

As with the analysis of time savings, Table 17 shows that whilst there were fuel savings from the bus priority measures, the disbenefits in fuel consumption from other traffic were greater.

3.2.4 Summary

Using the assumed values of time, this method of assessment showed the following results. The bus priority strategy implemented at the three junctions in Southampton provided time and fuel savings to buses totalling £76,154 per annum. This on average gives a saving per link of £15,230 per annum which is considerably in excess of the system installation costs which amounted to £5,000 per link. However, the bus priority strategy resulted in costs to other traffic in terms of increased time and fuel costs. The total costs to other traffic were calculated to be £127,822 per annum resulting in a net system cost of £51,668 per annum as shown in Table 18. Although on average there was a 9.5 second per bus delay saving, this was outweighed by the 3.8 second per vehicle disbenefit for other traffic because of the high ratio of car to bus passengers (approximately 5 to 1) and the higher average value of time assumed for car occupants relative to bus passengers (approximately 27% higher).

Table 18 Total savings from Southampton bus priority

Junction	*Annual fuel savings (£)*	*Annual time savings (£)*	*Total savings (£ per annum)*
Six Dials	-631	-28,702	-29,333
West Park Road/ Havelock Road	-637	-24,867	-25,504
West End Road	-20	3,189	3,169
Total	-1,288	-50,380	-51,668

In the longer term, it is expected that disbenefits to car users on the scale seen here would lead to a reduction in car use, and possibly an increase in bus use. Such changes would produce further time savings for buses and change the balance of economic benefits between car and bus users in the assessment. Other changes leading to an increase in bus use, such as improvements in service frequency, could also change this balance of benefits between car and bus users.

3.3 Behaviour

The survey data for this application concentrated necessarily on detailed operational impacts of the bus priority system and its immediate impacts on delay to buses and general traffic. Statistically significant results could then be used with some confidence if wider system

Table 16 Calculations for time savings

	Person-hour savings/annum			*Time savings £/annum*		
Junction	*Buses*	*Cars*	*Total*	*Buses*	*Cars*	*Total*
Six Dials	5,077	-11,388	-6,311	21,412	-50,114	-28,702
West Park Road/ Havelock Road/	10,487	-15,470	-4,983	43,210	-68,077	-24,867
West End Road	2,567	-1,728	839	10,793	-7,604	3,189
Total	18,131	-28,586	-10,455	75,415	-125,795	-50,380

Table 17 Calculations for fuel savings

	Fuel savings grams/day			*Fuel savings £/annum*		
Junction	*Buses*	*Cars*	*Total*	*Buses*	*Cars*	*Total*
Six Dials	3,619	-14,199	-10,580	216	-847	-631
West Park Road/ Havelock Road	6,700	-17,378	-10,678	400	-1,037	-637
West End Road	2,064	-2,390	-326	123	-143	-20
Total	12,383	-33,967	-21,584	739	-2,027	-1,288

implementation were considered. However the limited extent of the application described here precluded a quantitative behavioural analysis of impacts such as changes in bus and car use, and possible switching of traffic to routes without bus priority. The scale of these impacts would clearly be influenced by the implementation scenario in terms of its extent and the level of priority implemented, which influences the relative impacts on buses and general traffic. Also, the ‘before and after’ survey methodology was designed to capture the impacts of primary interest, rather then behavioural elements which would require a longer-term survey.

4 Discussion

This evaluation has shown that the application achieved its objective of reducing delays to buses at junctions. Bus priority at SCOOT-controlled traffic signals can be implemented successfully and cost-effectively using footprint detection. This technology is inexpensive relative to other selective detection technologies which require on-bus equipment. It would appear to be particularly appropriate where conventional bus fleets predominate, where bus positioning on the signal approach is predictable and where the possibility of other vehicles triggering the priority is limited. The technology would be less appropriate where any of these circumstances do not occur and would be inappropriate if more sophisticated priority were required, for example priority related to the ‘adherence to schedule’ of each bus.

The ‘high priority’ control strategy implemented at each site in this study provided relatively large benefits to buses but some disbenefits to general traffic. The ‘optimum’ strategy clearly depends on the objectives. In this short-term evaluation using standard UK values of time for economic appraisal of road schemes, which considered the impacts on all affected, the priority strategies implemented produced an overall net economic and environmental/energy disbenefit, with the exception of S, NO_X and particulate emissions. Emissions of NO_X and particulates were reduced, which is encouraging as there is evidence that these pollutants may be the most difficult to control under existing legislation. This suggests that it may be worthwhile to use traffic management measures, including bus priority, to control these pollutants.

It could also be argued that rather than adopting the conventional UK approach of assigning lower values of time to bus passengers compared with car passengers, different monetary values given to time delays would be appropriate in the economic evaluation in this case, reflecting the policy to encourage public transport use and deter car use. However while the standard value of time for bus passengers is 27% lower than the value for car passengers, the difference in values of time would have to be considerably greater than this for the application to produce overall net benefits.

There is also strong evidence from evaluations in London (Hounsell et al, 1996) that a lower priority strategy could provide worthwhile delay savings to buses whilst producing no statistically significant disbenefits to other traffic. For the sites in Southampton, it is estimated that this strategy could provide a delay saving to buses of approximately 4 seconds per junction, giving overall time savings of £6,100 per annum per link. Fuel savings from this scenario would be very small at approximately £60 per annum per link. However, whilst the implementation of a lower priority strategy for buses may provide a better economic performance in the short term, this strategy may affect the longer term objective of achieving a migration of journeys to public transport. It may therefore be prudent to give a higher priority to buses which, whilst incurring net costs initially, should then encourage a more rapid shift from car to bus travel, giving improved economic benefits in the longer term.

Although there is insufficient evidence from this study on the modal changes as a result of reduced delays to buses, wider implementation in Southampton could significantly improve the results of economic evaluation. If wider implementation increased journey speeds on entire routes, as well as through individual junctions, this could significantly increase time and fuel savings to buses and therefore its economic viability. Moreover in the longer term, the disbenefits experienced by car drivers (in the form of increased journey times, higher fuel consumption and increased emissions) would be expected to suppress demand for car use (and possible increasing use of buses), resulting in further time savings for buses, thus improving the economic viability of the application.

5 Summary and recommendations

5.1 Summary

The bus priority measures implemented here benefited bus operators and passengers by producing significant reductions in bus delay and fuel consumption. Emissions of all six major pollutants were reduced for buses. Savings in bus delay alone produced an economic benefit in the first year some three times higher than the implementation cost. Thus the objectives of the scheme, namely to reduce delays to buses at traffic signals, were achieved successfully and in a cost-effective way using ‘footprint’ vehicle detection.

However, the high priority strategies implemented here produced small but significant increases in general traffic delay so that, assuming no modal change, there was a net increase in overall delay costs, pollutant emissions and fuel consumption in an evaluation using the values assumed in conventional economic appraisal of UK road schemes. Use of other monetary values, more consistent with the policy of giving priority to bus users, could produce different evaluation results, although the values would have to be considerably different for the application to result in overall net benefits with this level of bus priority.

Although most pollutant emissions increased overall, there were encouraging reductions in NO_x and particulate emissions; these may be the pollutants which are most difficult to control under existing legislation. This suggests that it may be worthwhile to use traffic management measures, including bus priority, to control NO_x and particulate emissions.

The application is considered to have substantial potential as the relative impact to buses and general traffic can be controlled by the user, according to policy, by adopting the appropriate priority strategy. This application is consistent with current transport policies and would be expected to be viewed positively by the city authority, bus operators and passengers alike.

Table 19 summarises the key results from this evaluation.

5.2 Recommendations

Bus priority at traffic signals contributes directly to policies of improving bus services and encouraging modal change. Against this background, and results obtained in this study, it is recommended that:

i bus priority at traffic signals is implemented more widely in Southampton, using the most appropriate technology. This could include footprint detection, subject to comparisons of costs and benefits with other technologies, including automatic vehicle location;

ii further research is carried out to evaluate potential longer term impacts, including modal change, which could justify higher priority strategies than would appear appropriate based on short-term economic and energy calculations;

iii benefits for bus passengers resulting from bus priority measures should be balanced with possible disbenefits to other road users, according to local transport policy objectives.

6 References

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Table 19 Summary of impacts

Impact	*Units*	*Buses*	*Other traffic*	*Overall*
Delay	Seconds/vehicle/ junction (% change)	-9.5 (-30)	3.8 (14)	
Delay	Person hrs/annum	-18,131	28,586	10,455
Cost of delay	£ /annum	-75,415	125,795	50,380
Cost of fuel	£ /annum	-739	2,027	1,288
Overall cost	£ /annum	-76154	127,822	51,668
Emissions during survey period				
CO	kg (% change)	-0.44 (-24)	6.2 (9)	6 (8)
CO_2	kg (% change)	-37 (-13)	96 (6)	59 (3)
HC	kg (% change)	-0.21 (-25)	0.7 (7)	0.5 (4)
S	kg (% change)	-0.6 (-13)	0.7 (6)	0 (0)
NO_x	kg (% change)	-0.9 (-16)	-0.1 (-2)	-1.0 (-9)
PM	kg (% change)	-0.07 (-22)	0.01 (3)	-0.07 (-12)
Fuel	kg (% change)	-12.3 (-13)	34 (6)	22 (3)

Appendix A: SCOOT Bus priority parameter settings

The bus priority parameter settings in SCOOT which were used to give bus priority in this application are listed below and explained in the key.

Bus priority parameter settings

	SCOOT link				
	7211G	*7211M*	*7321M*	*7321R*	*9132D*
Node-based parameters					
BEXR	MIN_STG	MIN_STG	MIN_STG	MIN_STG	DEG_SAT
BRER	DEG_SAT	DEG_SAT	DEG_SAT	DEG_SAT	DEG_SAT
BRSL	200%	200%	200%	200%	200%
SATE	110%	110%	150%	150%	150%
SATR	150%	150%	110%	110%	150%
PMAX	28 sec	28 sec	28 sec	28 sec	28 sec
EXTD	15 sec	15 sec	24 sec	24 sec	20 sec
BSEL	All	All	All	All	All
Link-based parameters					
BASP	20 kph	30 kph	15 kph	30 kph	20 kph
BCTU	1 sec	5 sec	1 sec	3 sec	2 sec
BOTT	0 mins	0 mins	0 mins	0 mins	0 mins
BSLT	-2 mins	-2 mins	-2 mins	-2 mins	-2 mins
BLAT	-4 mins	-4 mins	-4 mins	-4 mins	-4 mins
BVLT	-8 mins	-8 mins	-8 mins	-8 mins	-8 mins
BPFL	All	All	All	All	All
DAVL	127 sec	127 sec	127 sec	127 sec	127 sec
BJNY	7 sec	6 sec	13 sec	5 sec	9 sec

KEY for bus priority parameter settings: (refer to system documentation for a more detailed description of terms used)

BEXR Bus extension recovery type (Nothing, MIN_STG, LONG_STG, DEG_SAT)
BRER Bus recall recovery type (Nothing, MIN_STG, LONG_STG, DEG_SAT)
BRSL Bus recovery saturation level
SATE Saturation level for extensions
SATR Saturation level for recalls
PMAX Priority maximum extension allowed
EXTD Extension duration (0 - PMAX)
BSEL Selection (None, Multi, Queue, Hold, Mqueue, Mhold, Qhold, All)
BASP Bus approach speed
BCTU Bus cruise time uncertainty
BOTT Bus on-time threshold
BSLT Bus slightly late threshold
BLAT Bus late threshold
BVLT Bus very late threshold
BPFL Bus priority flag status (All, Late buses)
DAVL Discard AVL time
BJNY Bus cruise journey time

Appendix B: Survey results

The following tables show journey time, the standard deviation, sample size and Z statistic for each site and compare results between priority ON and priority OFF. In the tables the Z statistic is used to test for statistical significance (with 95% confidence):

$$Z = (av_1 - av_2) / SQRT(sd_1^2/n_1 + sd_2^2/n_2)$$

where

SQRT is square root,
av_1, sd_1, n_1 are the average, standard deviation and sample size for bus journey times with priority on and,
av_2, sd_2, n_2 are the corresponding values with priority off.
If the Z value is less than -1.96 then the reduction in bus journey time, effected by bus priority, is significant at the 95% level.

Table B1 Overall analysis of bus journey times (seconds) over all survey periods

Site	*Average time (seconds)*	*Standard deviation*	*Sample size*	*Priority Status*	*Z statistic*
Old Northam Road/	33.7	20.4	776	ON	-10.8
Six Dials	46.1	27.5	981	OFF	
New Road/	45.2	28.2	714	ON	-3.9
Six Dials	50.9	29.4	833	OFF	
Commercial Road	27.4	21.4	1341	ON	-9.6
(westbound)	36.2	26.9	1471	OFF	
West Park Road	29.9	20.0	1334	ON	-12.8
(eastbound)	41.2	26.4	1447	OFF	
West End Road	28.4	17.4	845	ON	-10.3
(westbound slipway)	37.8	19.7	810	OFF	

Table B2 Analysis of bus journey times (seconds) by time of day

Site	Time period	Average time (seconds)	Standard deviation	Sample size	Priority status	Average bus flow (buses/hr)	Z statistic
Old Northam Road/ Six Dials	0730-0930	34.2	18.0	139	ON	25	-5.2
		47.5	29.2	201	OFF		
	1000-1200	34.1	19.7	208	ON	28	-5.6
		46.0	27.7	281	OFF		
	1330-1530	30.6	19.6	216	ON	28	-7.3
		45.6	26.0	275	OFF		
	1600-1800	36.0	22.8	213	ON	28	-3.9
		45.5	27.5	224	OFF		
New Road/ Six Dials	0730-0930	47.6	29.0	141	ON	21	-3.1
		58.1	30.2	171	OFF		
	1000-1200	44.9	28.2	220	ON	25	-1.8
		49.4	26.7	248	OFF		
	1330-1530	39.0	20.9	200	ON	27	-2.5
		45.0	27.9	207	OFF		
	1600-1800	51.7	33.5	153	ON	27	-0.3
		52.8	31.7	207	OFF		
Commercial Road (westbound)	0730-0930	29.0	22.6	289	ON	36	-6.1
		42.5	30.5	301	OFF		
	1000-1200	27.0	21.0	339	ON	42	-3.5
		32.8	25.0	430	OFF		
	1330-1530	27.6	21.1	406	ON	42	-3.9
		33.8	24.2	418	OFF		
	1600-1800	25.8	21.1	307	ON	40	-6.2
		38.0	28.1	322	OFF		
West Park Road (eastbound)	0730-0930	31.6	22.5	317	ON	40	-7.3
		47.2	31.2	324	OFF		
	1000-1200	29.1	17.6	324	ON	40	-5.3
		37.2	23.7	402	OFF		
	1330-1530	29.0	19.0	401	ON	40	-7.3
		40.1	23.4	393	OFF		
	1600-1800	30.5	20.9	292	ON	40	-5.6
		41.3	26.9	328	OFF		
West End Road (westbound slipway)	0730-0930	27.5	18.9	185	ON	23	-5.8
		39.1	19.2	175	OFF		
	1000-1200	27.0	14.2	241	ON	24	-4.2
		32.8	15.9	232	OFF		
	1330-1530	28.4	21.6	186	ON	23	-5.4
		37.6	21.9	182	OFF		
	1600-1800	31.2	21.6	186	ON	23	-5.3
		43.2	21.9	182	OFF		

Changes where the Z statistic is greater than 1.96 were statistically significant.
Bus flows were obtained from matched journey time records.

Table B3a Effect of priority on other traffic at Six Dials over all survey periods

Data item	*SCOOT link*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z Statistic*
DPV	7211A	18.4	17.4	1.0	2.1
Flow		260.1	262.3	-2.2	-0.5
Stops		169.3	160.3	9.0	1.9
DPV	7211C	34.2	33.4	0.8	1.2
Flow		548.1	582.5	-34.4	-3.3
Stops		462.9	466.6	-3.7	-0.4
DPV	7211D	39.8	37.1	2.7	2.8
Flow		159.2	165.0	-5.8	-1.3
Stops		147.8	149.6	-1.8	-0.4
DPV	7211E	56.3	42.6	13.7	9.0
Flow		292.9	293.3	-0.4	-0.05
Stops		287.1	279.3	7.8	0.9
DPV	7211F	22.4	20.9	1.5	3.9
Flow		244.6	246.0	-1.4	-0.2
Stops		179.6	168.6	11.0	2.3
DPV	7211G	31.55	32.0	-0.5	-0.5
Flow		417.2	404.1	13.1	1.8
Stops		347.6	357.7	-10.1	-1.2
DPV	7211H	58.4	41.5	16.9	13.4
Flow		197.5	193.3	4.2	0.7
Stops		194.1	183.4	10.7	1.7

Delay per vehicle (DPV) units are seconds; flow units are vehicles per hour; stops units are number of stops per hour.

See Figure 3, Figure 4 and Figure 5 for locations of SCOOT links.

Reductions in delay are indicated by a negative value in the 'difference' column, increases in delay are indicated by a positive value.

Changes where the Z statistic is greater than 1.96 were statistically significant.

Table B3b Effect of priority on other traffic at West Park Road/Havelock Road over all survey periods

Data item	*SCOOT link*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z statistic*
DPV	7321A	15.6	10.0	5.6	12.1
Flow		460.3	455.6	4.7	0.6
Stops		251.9	219.4	32.5	4.8
DPV	7321C	44.8	38.7	6.0	6.6
Flow		641.2	654.2	-13.0	-1.2
Stops		610.2	602.2	8.0	0.7
DPV	7321H	44.9	34.6	10.3	12.4
Flow		381.8	386.9	-5.1	-0.8
Stops		352.8	335.5	17.3	2.5
DPV	7321K	36.8	26.7	10.1	15.0
Flow		432.2	449.5	-17.3	-2.9
Stops		344.6	315.8	28.8	5.9
DPV	7321M	23.6	33.6	-10.0	-13.0
Flow		196.4	210.6	-14.2	-2.8
Stops		148.2	177.3	-29.1	-6.0

Delay per vehicle (DPV) units are seconds; flow units are vehicles per hour; stops units are number of stops per hour.

See Figure 3, Figure 4 and Figure 5 for locations of SCOOT links.

Reductions in delay are indicated by a negative value in the 'difference' column, increases in delay are indicated by a positive value.

Changes where the Z statistic is greater than 1.96 were statistically significant.

Table B3c Effect of priority on other traffic at West End Road slipway over all survey periods

Data item	*SCOOT link*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z statistic*
DPV	9132C	10.0	9.8	0.2	0.6
Flow		622.3	622.0	0.3	0.03
Stops		312.6	287.8	24.8	2.1
DPV	9132D	26.3	29.2	-2.9	-2.5
Flow		352.8	349.6	3.2	0.5
Stops		326.2	325.2	1.0	0.1
DPV	9132E	14.4	11.1	3.3	6.9
Flow		689.8	697.9	-8.1	-0.8
Stops		610.9	603.9	7.0	0.6

Delay per vehicle (DPV) units are seconds; flow units are vehicles per hour; stops units are number of stops per hour.

See Figure 3, Figure 4 and Figure 5 for locations of SCOOT links.

Reductions in delay are indicated by a negative value in the 'difference' column, increases in delay are indicated by a positive value.

Changes where the Z statistic is greater than 1.96 were statistically significant.

Table B4a Effect of priority on other traffic at Six Dials by time of day

Data item	*SCOOT link*	*Time period*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON- OFF)*	*Z statistic*
DPV	7211A	0730-0930	13.7	12.7	1.0	1.6
Flow			239.3	251.6	-12.3	-1.5
Stops			130.5	127.0	3.5	0.5
DPV	7211A	1000-1200	16.1	14.9	1.2	2.2
Flow			237.0	239.7	-2.7	-0.4
Stops			148.6	139.0	9.6	1.7
DPV	7211A	1330-1530	18.4	17.1	1.3	2.0
Flow			259.0	257.3	1.7	0.2
Stops			168.7	160.6	8.1	1.2
DPV	7211A	1600-1800	26.2	26.4	-0.2	-0.2
Flow			312.8	317.0	-4.2	-0.4
Stops			236.6	228.6	8.0	0.6
DPV	7211C	0730-0930	39.4	42.4	-3.0	-2.0
Flow			736.6	712.1	24.5	1.5
Stops			611.4	546.4	65.0	3.4
DPV	7211C	1000-1200	29.4	27.4	2.0	2.6
Flow			519.8	560.0	-40.2	-3.0
Stops			426.8	432.2	-5.4	-0.4
DPV	7211C	1330-1530	31.7	31.7	0.0	0.0
Flow			471.3	577.7	-106.4	-4.7
Stops			397.5	483.5	-86.0	-3.8
DPV	7211C	1600-1800	38.2	36.6	1.6	1.1
Flow			489.0	496.5	-7.5	-0.6
Stops			440.6	422.6	18.0	1.2
DPV	7211D	0730-0930	51.8	46.2	5.6	2.1
Flow			238.1	245.1	-7.0	-0.9
Stops			225.1	226.7	-1.6	-0.2
DPV	7211D	1000-1200	33.6	32.1	1.5	1.5
Flow			165.2	167.9	-2.7	-0.5
Stops			150.8	150.9	-0.1	-0.01
DPV	7211D	1330-1530	34.8	35.1	-0.3	-0.3
Flow			131.9	134.0	-2.1	-0.5
Stops			121.9	120.2	1.7	0.4
DPV	7211D	1600-1800	41.6	38.7	2.9	1.5
Flow			105.5	120.2	-14.7	-2.7
Stops			97.8	108.5	-10.7	-2.0
DPV	7211E	0730-0930	61.5	44.6	16.9	5.9
Flow			445.8	441.4	4.4	0.2
Stops			439.2	419.9	19.3	0.9
DPV	7211E	1000-1200	47.0	38.5	8.5	6.0
Flow			250.4	274.2	-23.8	-2.6
Stops			243.7	259.1	-15.4	-1.6
DPV	7211E	1330-1530	51.5	39.7	11.8	7.2
Flow			257.0	262.9	-5.9	-0.7
Stops			251.2	250.6	0.6	0.1
DPV	7211E	1600-1800	69.2	51.2	18.0	3.4
Flow			236.5	216.9	19.6	2.3
Stops			232.5	209.5	23.0	2.7
DPV	7211F	0730-0930	21.8	22.2	-0.4	-0.4
Flow			206.1	208.6	-2.5	-0.3
Stops			149.9	137.8	12.1	1.7

Continued over ....

Table B4a Continued

Data item	*SCOOT link*	*Time period*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON- OFF)*	*Z statistic*
DPV	7211F	1000-1200	22.1	20.9	1.2	1.5
Flow			207.4	222.7	-15.3	-2.4
Stops			153.0	154.5	-1.5	-0.2
DPV	7211F	1330-1530	23.2	19.9	3.3	4.8
Flow			241.9	252.7	-10.8	-1.5
Stops			182.0	175.9	6.1	0.9
DPV	7211F	1600-1800	22.5	20.8	1.7	2.1
Flow			335.8	313.4	22.4	1.4
Stops			241.6	213.6	28.0	1.9
DPV	7211G	0730-0930	43.1	44.1	-1.0	-0.4
Flow			406.9	403.8	3.1	0.2
Stops			369.4	369.3	0.1	0.01
DPV	7211G	1000-1200	24.1	27.0	-2.9	-2.6
Flow			362.7	348.4	14.3	1.6
Stops			297.1	300.4	-3.3	-0.3
DPV	7211G	1330-1530	23.5	25.8	-2.3	-1.8
Flow			403.1	408.3	-5.2	-0.5
Stops			308.0	357.3	-49.3	-4.2
DPV	7211G	1600-1800	39.3	36.3	3.0	1.1
Flow			516.1	491.3	24.8	1.4
Stops			441.2	442.2	-1.0	-0.05
DPV	7211H	0730-0930	57.8	50.0	7.8	2.2
Flow			127.1	128.9	-1.8	-0.3
Stops			124.8	124.9	-0.1	-0.01
DPV	7211H	1000-1200	50.3	39.6	10.7	6.0
Flow			165.2	157.7	7.5	1.3
Stops			161.3	148.8	12.5	2.2
DPV	7211H	1330-1530	57.2	38.0	19.2	11.0
Flow			198.7	210.3	-11.6	-1.5
Stops			195.0	201.2	-6.2	-0.8
DPV	7211H	1600-1800	71.2	40.9	30.3	11.2
Flow			310.2	295.1	15.1	1.0
Stops			306.8	276.6	30.2	1.9

Delay per vehicle (DPV) units are seconds.
Flow units are vehicles per hour.
Stops units are number of stops per hour.
See Figure 3 for location of SCOOT links.
Reductions in delay are indicated by a negative value in the ‘difference’ column, increases in delay are indicated by a positive value.
Changes where the Z statistic is greater than 1.96 were statistically significant.

Table B4b Effect of priority on other traffic at West Park Road/Havelock Road by time of day

Data item	*SCOOT link*	*Time period*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z statistic*
DPV	7321A	0730-0930	18.1	14.4	3.7	3.2
Flow			460.2	457.0	3.2	0.1
Stops			259.5	254.1	5.4	0.3
DPV	7321A	1000-1200	14.6	8.6	6.0	9.2
Flow			419.8	422.9	-3.1	-0.3
Stops			230.9	186.7	44.2	4.7
DPV	7321A	1330-1530	12.8	9.3	3.5	5.4
Flow			464.3	452.7	11.6	1.1
Stops			259.3	228.2	31.1	3.0
DPV	7321A	1600-1800	17.8	9.0	8.8	8.1
Flow			507.6	512.6	-5.0	-0.3
Stops			261.7	228.1	33.6	2.0
DPV	7321C	0730-0930	54.4	43.3	11.1	4.6
Flow			802.3	783.6	18.7	0.6
Stops			772.1	731.0	41.1	1.2
DPV	7321C	1000-1200	37.2	35.5	1.7	1.8
Flow			560.2	578.2	-18.0	-1.5
Stops			522.1	522.7	-0.6	-0.04
DPV	7321C	1330-1530	38.6	34.9	3.7	3.3
Flow			575.2	616.1	-40.9	-3.3
Stops			545.2	567.3	-22.1	-1.7
DPV	7321C	1600-1800	52.6	44.6	8.0	4.0
Flow			664.8	700.8	-36.0	-1.9
Stops			640.9	651.5	-10.6	-0.5
DPV	7321H	0730-0930	48.6	38.5	10.1	5.4
Flow			324.4	342.2	-17.8	-1.1
Stops			299.9	296.6	3.3	0.2
DPV	7321H	1000-1200	38.3	31.5	6.8	6.6
Flow			352.8	342.4	10.4	1.1
Stops			317.7	286.7	31.0	3.1
DPV	7321H	1330-1530	39.0	30.8	8.2	8.2
Flow			413.3	433.6	-20.3	-1.9
Stops			382.9	386.9	-4.0	-0.3
DPV	7321H	1600-1800	57.1	40.9	16.2	8.2
Flow			437.9	445.5	-7.6	-0.8
Stops			414.0	389.2	24.8	2.6
DPV	7321K	0730-0930	43.4	29.2	14.2	9.0
Flow			447.2	473.2	-26.0	-1.7
Stops			350.8	315.4	35.4	3.6
DPV	7321K	1000-1200	33.4	24.8	8.6	8.2
Flow			424.3	446.3	-22.0	-2.0
Stops			350.2	317.9	32.3	3.3
DPV	7321K	1330-1530	34.5	24.7	9.8	11.4
Flow			449.1	454.1	-5.0	-0.6
Stops			364.9	327.9	37.0	4.4
DPV	7321K	1600-1800	37.5	29.9	7.6	4.3
Flow			405.2	425.5	-20.3	-1.5
Stops			305.1	297.5	7.6	0.7
DPV	7321M	0730-0930	26.4	38.6	-12.2	-6.2
Flow			173.4	172.5	0.9	0.1
Stops			126.1	142.5	-16.4	-1.9

Continued over ....

Table B4b Continued

Data item	*SCOOT link*	*Time period*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z statistic*
DPV	7321M	1000-1200	22.6	31.5	-8.9	-7.4
Flow			189.7	200.7	-11.0	-1.3
Stops			144.1	167.1	-23.0	-3.0
DPV	7321M	1330-1530	20.4	31.3	-10.9	-8.2
Flow			175.2	218.3	-43.1	-4.1
Stops			138.6	186.8	-48.2	-4.9
DPV	7321M	1600-1800	25.9	34.8	-8.9	-5.4
Flow			256.4	255.7	0.7	0.1
Stops			188.7	216.7	-28.0	-2.7

Delay per vehicle (DPV) units are seconds.

Flow units are vehicles per hour.

Stops units are number of stops per hour.

See Figure 4 for location of SCOOT links.

Reductions in delay are indicated by a negative value in the ‘difference’ column, increases in delay are indicated by a positive value.

Changes where the Z statistic is greater than 1.96 were statistically significant.

Table B4c Effect of priority on other traffic at West End Road slipway by time of day

Data item	*SCOOT link*	*Time period*	*Average with Priority ON*	*Average with Priority OFF*	*Difference (ON-OFF)*	*Z statistic*
DPV	9132C	0730-0930	6.0	6.2	-0.2	-0.2
Flow			567.3	572.0	-4.7	-0.3
Stops			*168.9*	129.7	39.2	2.6
DPV	9132C	1000-1200	11.6	10.7	0.9	1.8
Flow			609.5	612.6	-2.9	-0.1
Stops			342.6	318.0	24.4	1.5
DPV	9132C	1330-1530	10.6	9.8	0.8	1.8
Flow			626.0	618.2	7.8	0.4
Stops			339.8	307.9	31.9	2.0
DPV	9132C	1600-1800	11.0	12.1	-1.1	-1.3
Flow			689.0	689.3	-0.3	-0.02
Stops			380.8	381.2	-0.4	-0.01
DPV	9132D	0730-0930	35.1	37.1	-2.0	-0.6
Flow			279.5	281.1	-1.6	-0.1
Stops			264.7	266.2	-1.5	-0.1
DPV	9132D	1000-1200	19.9	20.7	-0.8	-1.0
Flow			396.4	388.3	8.1	0.7
Stops			358.1	353.7	4.4	0.4
DPV	9132D	1330-1530	23.8	31.3	-7.5	-2.7
Flow			377.4	378.9	-1.5	-0.1
Stops			352.9	359.2	-6.3	-0.5
DPV	9132D	1600-1800	29.0	29.8	-0.8	-0.4
Flow			336.3	330.6	5.6	0.5
Stops			310.1	304.3	5.8	0.5
DPV	9132E	0730-0930	12.5	10.2	2.3	2.2
Flow			772.6	789.6	-17.0	-0.6
Stops			660.6	666.7	-6.1	-0.1
DPV	9132E	1000-1200	15.4	9.7	5.7	7.4
Flow			628.3	610.6	17.7	1.4
Stops			564.8	522.6	42.2	2.6
DPV	9132E	1330-1530	15.4	13.8	1.6	1.4
Flow			675.7	725.0	-49.3	-2.7
Stops			617.1	659.8	-42.7	-1.9
DPV	9132E	1600-1800	13.6	10.3	3.3	4.5
Flow			706.0	687.9	18.1	0.9
Stops			613.1	579.1	34.0	1.4

Delay per vehicle (DPV) units are seconds.

Flow units are vehicles per hour.

Stops units are number of stops per hour.

See Figure 5 for location of SCOOT links.

Reductions in delay are indicated by a negative value in the 'difference' column, increases in delay are indicated by a positive value.

Changes where the Z statistic is greater than 1.96 were statistically significant.

Appendix C: Calculation of energy and emissions

C1 Background

This appendix sets out the approach to the evaluation of the energy and environmental impact of the Southampton bus priority application. The approach is common for all the applications, except those involving the alternative fuels buses where direct measurements of pollutant emissions and energy consumption are made. Within ENTRANCE the evaluation of the applications is concerned with emissions of carbon dioxide (CO_2), hydrocarbons (HC), carbon monoxide (CO), particulates (PM), sulphur (S), nitrogen oxides (NO_x) and fuel consumption. Using known relationships between speed and emission rates, changes can be calculated using speeds and flows collected in the before and after surveys.

C2 Emission and fuel consumption factors

C2.1 Sources of data

The choice of pollutant emission factors was largely determined by the availability of data for the relatively low speeds at which some of the affected vehicles travelled. There is little data on emissions from UK buses, particularly at speeds less than 15 km/h, the most comprehensive source being the Workbook on Emission Factors for Road Transport in Germany and Switzerland (FEA, 1995), known as HB-EFA. Whilst there is a lot more information on emissions from UK passenger cars travelling at low speeds there is a need to be consistent with the bus emissions calculations. Therefore the HB-EFA were used to calculate passenger car emissions also.

C2.2 Buses

In a comparison of emissions data from German/Swiss and UK buses, the absolute values are different largely because of the size of buses used in these countries. Double decker buses are uncommon outside the UK: larger single decker buses are common in continental Europe, but not often seen in the UK. Although there are differences in terms of the absolute values, the trend of the relationship between speed and emission was found to be similar as shown in Figure C1. It was therefore judged acceptable to use the HB-EFA data where the result required is essentially a comparison of ‘before’ and ‘after’ situations as in this study.

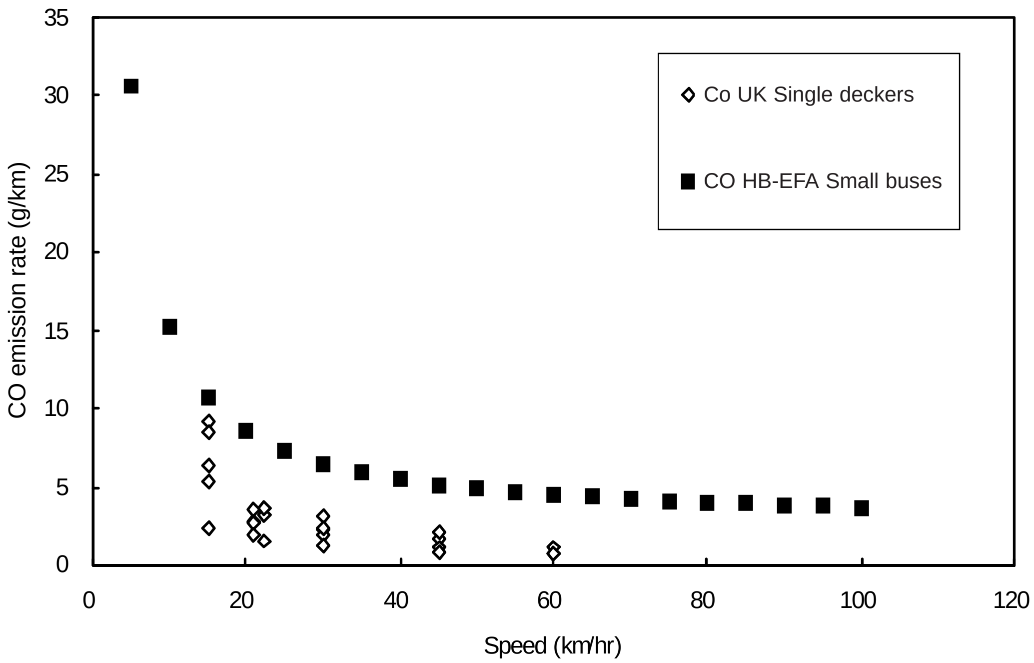

Figure C1 Comparison of emission factors for German and UK buses

C2.3 Passenger cars

There is more conformity between Swiss/German and UK passenger cars, and that combined with the common emission standards means that the HB-EFA data is quite similar to UK data as shown in Figure C2.

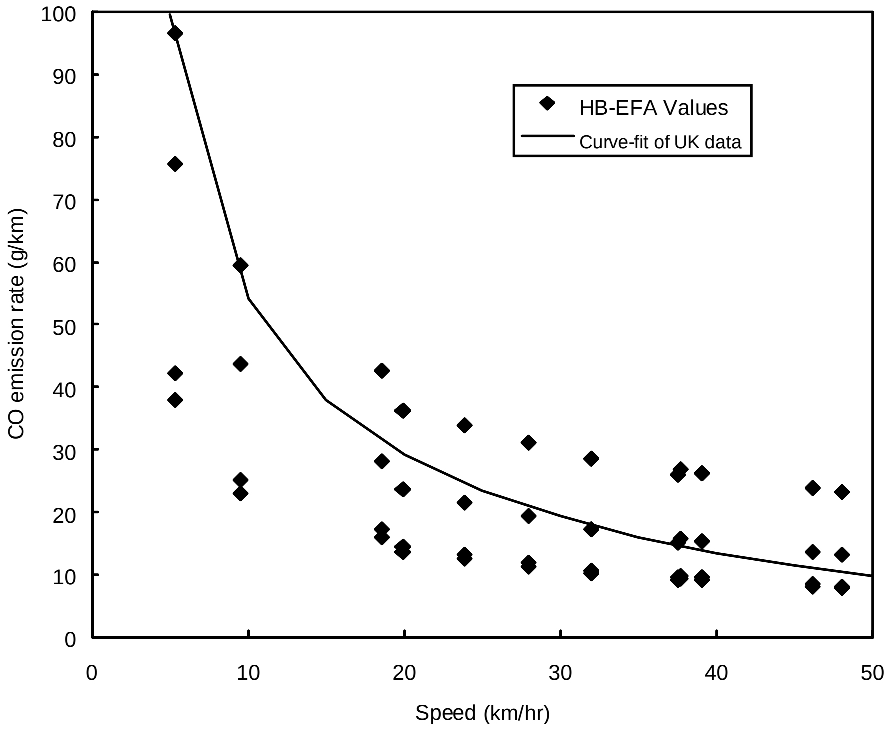

Figure C2 Comparison of CO emission factors for non-catalyst passenger cars

Each passenger car type is required to conform to different emissions standards according to relevant emissions control legislation (when it was registered), size of engine and fuel type. To simplify the calculations a combined relationship between speed and emissions is required, which accounts for all the different types of vehicles in the traffic stream.

In this study passenger cars were assumed to fall into ten categories according to fuel type, engine size and emissions control. It was also assumed that the traffic in Southampton was of a similar composition in terms of the proportion of vehicles in each category, to that of the national fleet. According to the number of vehicles and their annual mileage (Table C1), a weighted distribution of the proportion to which each vehicle category contributes to traffic emissions as a whole was calculated (Figure C3). This distribution was then used to calculate a combined speed-emission factor from the rates for the individual categories.

Table C1 UK vehicle car fleet composition

Passenger car category (fuel, EC emissions control category and engine capacity)	*Total number in each category*	*Total mileage in each category*
All diesel, >2 l	562805	47662.89
All diesel, <2 l	375203	40107.64
All petrol, 15.01/02	34734	12579.44
All petrol, 15.03	3493517	9918.50
All petrol, 15.04, < 1.4 l	5197438	15119.52
All petrol, 15.04, 1.4 - 2 l	5277574	15119.52
All petrol, 15.04, > 2 l	468741	13168.20
All petrol, 91/441, <1.4 l	3161603	20986.82
All petrol, 91/441, 1.4 - 2 l	3210350	20986.82
All petrol, 91/441, >2 l	1096278	19121.87
All categories	22878243	

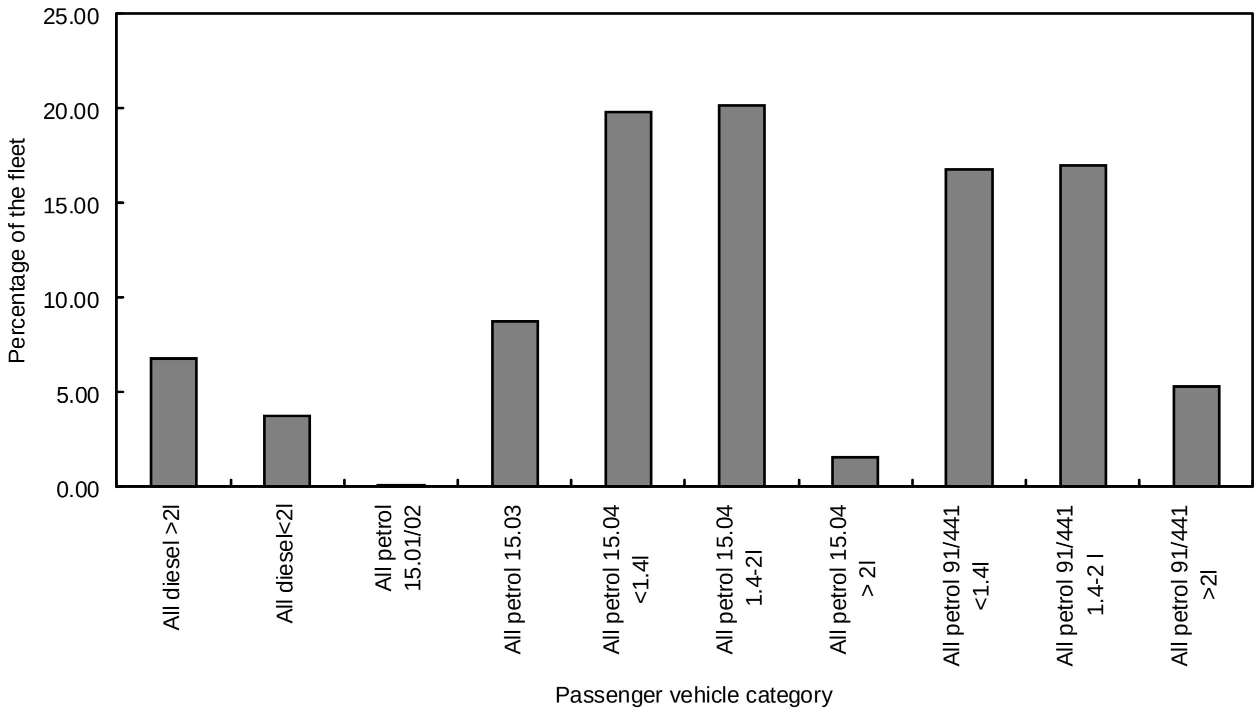

Figure C3 Distribution of passenger cars in the national fleet

C2.4 Calculation of speed-emission curves

HB-EFA allows the determination of speed-emission curves for CO, CO_2, HC, PM and NO_x from a knowledge of the type of vehicle. Using the distributions of types of passenger cars and buses (the latter locally derived) a combined speed-emission curve for each pollutant was derived according to the proportion of each vehicle type in the traffic stream.

Fuel consumption was derived from a mass balance of carbon atoms in the exhaust. The mass emissions of CO, CO_2, HC and PM found using the factors derived above were in turn used in the following equation to calculate the mass of fuel consumed (Eggleston et al. 1993).

$$M_{FUEL} = (12.011 + 1.008 \times r_{H/C}) \times \left(\frac{M_{CO2}}{44.011} + \frac{M_{CO}}{18.011} + \frac{M_{HC}}{13.85} + \frac{M_{PM}}{12.011} \right)$$

where:

M denotes the mass of fuel, CO_2, CO, HC and PM;
$r_{H/C}$ is the ratio of hydrogen to carbon atoms in the fuel (1.8 for petrol, 2.0 for diesel).

Emissions of sulphur were estimated by assuming that all the sulphur in the fuel is emitted e.g.

$$M_S = k_s \times M_{FUEL}$$

where k_S is the sulphur content of the fuel. For petrol this is 200 ppm for diesel 500 ppm.

Abstract

This report describes the evaluation of a demonstration scheme using new technology to give priority to buses at three junctions in Southampton. The scheme was implemented and evaluated as part of the ENTRANCE project.

This report describes the evaluation of the public transport priority application in Southampton. The aim was to reduce delays to buses at traffic signals and to improve the reliability of services, thereby improving the attractiveness of public transport relative to the private car. Buses were given priority at three junctions controlled by the SCOOT Urban Traffic Control system. ‘Footprint’ loop detectors were installed in the road on five of the links approaching the three junctions. When buses are detected by the loops, the SCOOT software gives buses priority at the junction either by extending an existing green phase in the traffic signals or by calling up a new green phase. The strategy selected within SCOOT was one that gave buses relatively high priority over other traffic.

The report concludes that this method of giving priority to buses in Southampton was successful in meeting the objectives of reducing delay, emissions and improving fuel consumption of buses using the priority system. By optimising the priority settings it is anticipated that net benefits in terms of fuel consumption, emissions and costs could be obtained for the other traffic in the area.

Related publications

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