Performance of bus priority measures in Shepherd's Bush

by A J Astrop and R J Balcombe

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TRL Report 140

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TRL REPORT 140

PERFORMANCE OF BUS PRIORITY MEASURES IN SHEPHERD'S BUSH

by A J Astrop and R J Balcombe

Prepared for: **Project Record:** **UG14 Innovative Bus Priority Measures**
Customer: **Driver Information and Traffic Management Division, DOT (Mr C N Cheney)**

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EXECUTIVE SUMMARY

The subject of this study, which is one of a series undertaken on behalf of the Department of Transport, is a bus priority scheme in Shepherd's Bush. It was introduced by Hammersmith and Fulham Council as part of the London Bus Priority Initiative's South & West London Bus Priority Demonstration Project, and is one part of a package designed to reduce congestion by making public transport a reliable and attractive alternative to car travel.

The scheme incorporated three major changes to the road network around Shepherd's Bush Common:

- a 24 hour bus lane along some sections of carriageway on Shepherd's Bush Green;
- a pre-signal, on the main carriageway just before the end of the bus lane, controlling non-priority traffic. It is red for most of the red phase of the main signal, during which time buses are free to proceed to the main stop line and take their preferred lanes in an area which is otherwise clear. Shortly before the main signal turns green, non-priority traffic is released by the pre-signal to allow full use to be made of the main signal's green phase, during which buses emerging from the bus lane may have to give way to non-priority traffic.
- a cut-through at the Eastern end of Shepherd's Bush Common, connecting Uxbridge Road and Shepherd's Bush Green, was converted to a "bus gate", for exclusive use by buses. Buses are able to emerge from this bus gate into Shepherd's Bush Green, during the pedestrian phase of a new pelican crossing just upstream of the bus gate.

Surveys were conducted before and after the scheme was implemented. Measurements were made of journey times of buses and other traffic between various pairs of points in the system, and passenger loads on buses.

The results of these surveys demonstrate substantial benefits, in the form of time savings, to bus passengers, which can be attributed to the combination of the changes. Other road users are enjoying smaller benefits on the South side of Shepherd's Bush Common but North-South travellers are suffering disbenefits, because of the greater distance and complication of their journeys. Nevertheless, the former number substantially more than the latter, so there is an overall nett benefit to non-bus traffic. While benefits cannot be determined with precision, the total annual benefit appears comparable with the capital costs of implementing the scheme.

The overall scheme may therefore be judged a success, to which the pre-signal has almost certainly contributed. We cannot however discriminate between the effects of the pre-signal itself, and those of the other measures which formed part of the package. Nor can we assess how much of the improvement may have been due to better compliance with parking regulations, which could in principle have been achieved by other means. We therefore need to complete our monitoring and assessment of other pre-signal installations before making recommendations about the general applicability of this device in "typical" locations.

PERFORMANCE OF BUS PRIORITY MEASURES IN SHEPHERD'S BUSH

ABSTRACT

A number of bus priority measures were introduced in Shepherd's Bush in 1993 by Hammersmith and Fulham Council as part of the London Bus Priority Initiative's South & West London Bus Priority Demonstration Project. These measures comprised: a 24 hour bus lane along some sections of carriageway on Shepherd's Bush Green; a pre-signal, on the main carriageway just before the end of the bus lane, controlling non-priority traffic and allowing buses free passage into a "bus advance area" where they can position themselves correctly at the main stop line; and a "bus gate", in place of a former cut-through at the Eastern end of Shepherd's Bush Common, connecting Uxbridge Road and Shepherd's Bush Green.

Surveys were conducted before and after the scheme was implemented. Measurements were made of journey times of buses and other traffic between various pairs of points in the system, and passenger loads on buses. The results of these surveys demonstrate substantial benefits, in the form of time savings, to bus passengers, which can be attributed to the combination of the changes. There are also nett benefits to other road, despite the fact that North-South travellers now have longer journeys through the area. While benefits cannot be determined with precision, the total annual benefit appears comparable with the capital costs of implementing the scheme.

It is not possible at this stage to quantify the contribution of the pre-signal to the overall benefits of the scheme, but further monitoring and assessment of other pre-signal installations should provide guidance on the general applicability of this device in "typical" locations.

1. INTRODUCTION

Concern about the environmental impact of heavy traffic flows and the time and fuel wasted by congestion has lead to the desire to reduce traffic levels, particularly in town and city centres. If this is to be achieved without reducing the amount of travel, people have to be persuaded to use public transport rather than cars. Many Local Authorities are now investing in schemes to raise the profile of public transport, and to make it more attractive to car users.

A variety of different types of schemes designed to benefit public transport users are currently in operation in various parts of the country; these range from low cost initiatives, such as dedicating a lane on a dual carriageway to buses, through to high cost schemes such as the Manchester light rail. However, due to the high initial costs of light rail, most Local Authorities have looked to raising the profile and attractiveness of buses.

The study reported here is one of a series undertaken on behalf of the Department of Transport in order to assess the effectiveness of various innovative bus priority measures.

2. BACKGROUND TO THE SCHEME

The subject of this study is a scheme in Shepherd's Bush which was introduced by Hammersmith and Fulham Council as part of the London Bus Priority Initiative's South & West London Bus Priority Demonstration Project, and is one part of a package designed to reduce congestion by making public transport a reliable and attractive alternative to car travel. The objectives of the scheme were to "... help reduce congestion - thereby improving the local environment and thus securing safer, and healthier conditions for vulnerable road users, including cyclists, pedestrians and people with disabilities" (London Borough of Hammersmith and Fulham, 1993). Figure 1 is a plan of the area affected by the scheme, showing the original road layout.

The scheme incorporated three major changes to the road network around Shepherd's Bush Common (shown in more detail in figure 2). Firstly, a 24 hour bus lane[1] has been introduced along some sections of carriageway on Shepherd's Bush Green. It was not possible to introduce a bus lane along the entire length of this road because of restricted width and vehicles turning at the junction between Shepherd's Bush Green and Goldhawk Road.

To allow buses to keep any advantage they gain from using the bus lane, and to allow right-turning buses to manoeuvre appropriately, the second major feature of the scheme, a pre-signal, was placed on the main carriageway just before the end of the bus lane. This pre-signal controls non-priority traffic and is red for most of the red phase of the main signal (at the end of Shepherd's Bush Green), during which time buses are free to proceed to the main stop line and take their preferred lanes in an area which is otherwise clear. Shortly before the main signal turns green, non-priority traffic is released by the pre-signal to allow full use to be made of the main signal's green phase, during which buses emerging from the bus lane may have to give way to non-priority traffic.

1 This bus lane is open to pedal cyclists, but not taxis.

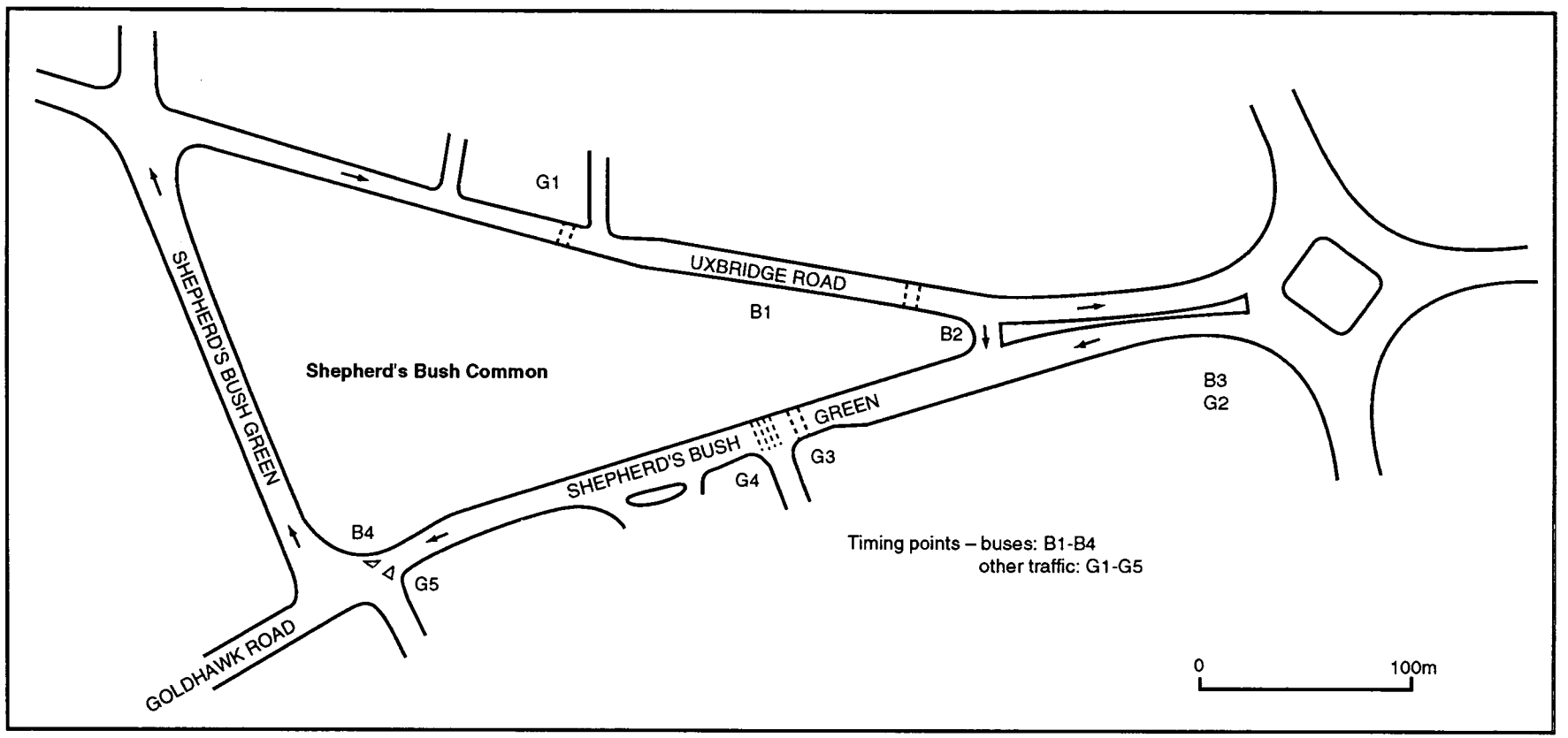

Fig. 1 Road layout before bus priority scheme
(Based, with permission, on a plan produced by the London Borough of Hammersmith and Fulham)

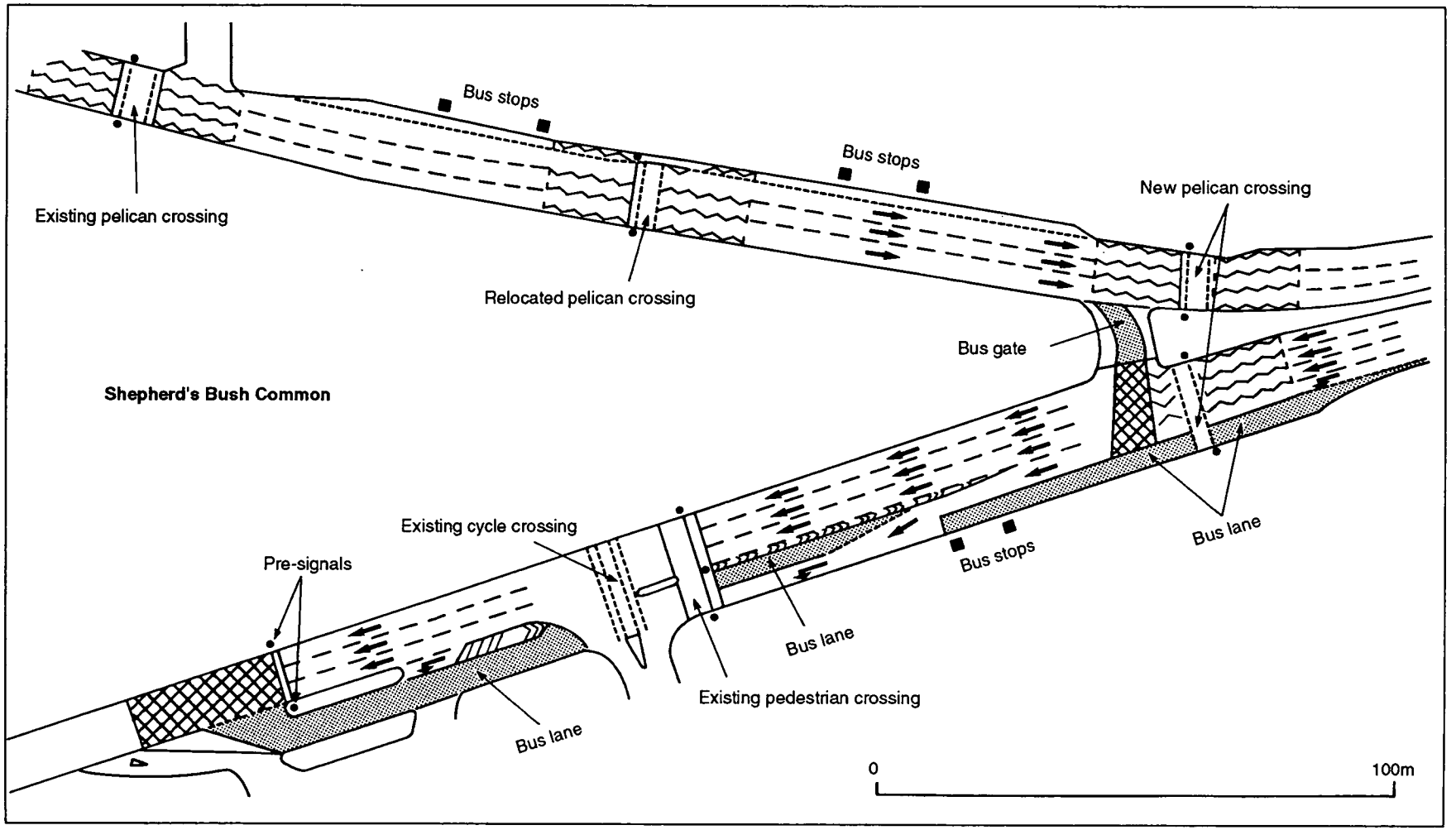

Fig. 2 Details of bus priority measures
(Based, with permission, on a plan produced by the London Borough of Hammersmith and Fulham)

The third major change to the layout of the area has been the dedication of the cut-through from Uxbridge Road and Shepherds Bush Green to buses: this is referred to as a "bus gate". To enhance the pedestrian facilities, a new pedestrian crossing has been installed to the east of the bus gate. During the pedestrian phase, which may be advanced when a bus is detected entering the gate, buses are able to cross the give way line at the bus gate exit and to move across a new yellow box to the bus lane without being obstructed by the general traffic. Conversely, between pedestrian phases, general traffic can proceed along Shepherd's Bush Green without being blocked by buses crossing the carriageway from the bus gate to the bus lane, or other drivers attempting to force their way out of the cut-through into the main stream.

3. METHOD

The purpose of this study was to discover whether the objectives of the scheme i.e, the decrease in bus journey times, improved reliability and increased bus occupancy have been met.

A 'before' survey was carried out to record journey times for buses and general traffic, traffic flows and bus occupancy levels. This survey was carried out between 21 and 28 November 1992 and. The corresponding 'after' survey was carried between 9 and 16 October 1993.

The survey times for data collection on both weekdays and Saturdays are listed below:

1200 to 1330 hours
1430 to 1600 hours
1630 to 1830 hours
1900 to 2000 hours

These times included the evening peak period, and as much as practicable of the time preceding and following the peak. In order to keep survey costs within acceptable limits, no morning observations were made. Since the scheme mainly affects West-bound traffic, it was assumed that the morning peak would be less pronounced and therefore of less interest than the evening peak.

The NOPCOP number plate comparison program (Lucas 1986), which matches partial numberplates between designated origin and destination points, was used to calculate both bus and car journey times. Observers were positioned at a number of locations (shown in figure 1) around the system to record partial registration plates (i.e numbers and year letters) and the times at which they passed.

All buses were recorded, and their service numbers were also noted. However, it was not necessary to record information on all other vehicles as the network is subject to heavy traffic flows, particularly in the peak periods. Instead, it was decided to record data for a random sample of vehicles; this could then be grossed up to provide an estimate of traffic flows. The observers were briefed to select vehicles with registration numbers ending with 1, 2 or 3.

In order to measure vehicle flows through the system, an observer was positioned on Shepherd's Bush Green just to the East of the bus gate to record all vehicles by type.

Bus occupancy surveys were undertaken between the bus stops on Shepherd's Bush Green near the bus gate, for all services stopping there (i.e. routes 237, 295, 72, 260, 49, 220 and 12) and the pre-signals. Roadside observations were judged to be insufficiently accurate for this purpose, so enumerators boarded buses to count passengers. To limit the cost of this exercise, counts were made on a sample of buses. In the after survey, it was estimated that around 80 per cent of all required buses were surveyed, and there is no reason to suppose that this was different in the before survey.

4. JOURNEY TIMES

4.1 BUSES

Mean bus journey times between the origin-destination pairs (O-D pairs) shown in figure 1 for each survey period for each survey day are displayed in table 1. Despite considerable variation from day to day and between times of day (the implications of which are discussed later), there have been significant reductions in mean journey times for all three O-D pairs. The overall mean time saving for buses travelling around two sides of Shepherd's Bush Common (from B1 to B4) is 57.8s, almost identical with the 57.5s saving for buses travelling the whole length of Shepherd's Bush Green (B3-B4).[2]

The time savings between B1 and B2 may be attributed to the creation of the bus gate and the measures associated with it, described in section 2. Buses travelling between O-D pairs B2-B4 and B3-B4 have clearly benefited from the combination of the advanced bus area and the bus lane. Prior to the installation of the bus priority scheme, buses stopping to allow passengers to board or alight were frequently obstructed by vehicles parked on bus stops near the shopping facilities on Shepherd's Bush Green. Creation of the bus lane seems to have encouraged better compliance with parking regulations, which has to a large extent

2 B1-B4 time saving = (69.5 +121.9) - (33.8+ 99.8) = 57.8s;
B3-B4 time saving = 185.3-127.8 = 57.5s

TABLE 1

Bus journey times (Seconds)

	B1-B2									
	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	33.6	32.9	64.6	44.8	62.9	26.4	24.7	27.2	35.6	27.2
1430-1600	40.2	89.0	95.2	39.0	52.6	33.7	44.2	27.1	32.3	52.6
1630-1830	116.8	89.0	98.0	30.6	41.4	33.8	31.3	29.2	28.1	29.6
1900-2000	224.0	77.9	99.0	26.6	32.4	61.8	44.4	36.2	26.3	25.0
mean			69.5					33.8		
st. error			10.0					2.1		
	B2-B4									
	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	90.7	102.6	134.8	99.7	165.9	84.1	84.6	100.6	93.8	91.3
1430-1600	80.6	129.3	155.0	107.8	166.7	87.6	106.4	109.8	95.2	107.8
1630-1830	188.8	132.2	124.5	83.8	135.9	113.8	104.4	105.8	114.4	87.8
1900-2000	148.7	113.1	136.1	61.7	79.7	106.9	105.9	96.4	101.1	97.7
mean			121.9					99.8		
st. error			7.4					2.1		
	B3-B4									
	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	121.5	136.4	205.7	132.7	356.9	95.9	101.4	119.3	123.4	122.3
1430-1600	125.5	200.0	233.0	164.4	299.6	160.2	119.6	163.7	119.4	118.8
1630-1830	239.7	186.1	200.2	100.4	199.4	144.4	131.0	157.9	161.6	124.1
1900-2000	223.5	184.2	215.8	94.3	86.9	157.2	107.8	119.7	123.6	87.1
mean			185.3					127.9		
st. error			15.0					5.1		

removed this problem and consequently buses are able to travel unhindered.

A small minority (about 8 per cent) of buses were observed not to be using the bus lane during the 1993 survey. These were timed separately; their journey times are compared with those for buses using the bus lane in table 2. There are no significant differences between the average journey times, but this does not imply that use of the bus lane saves no time. Only buses not scheduled to stop on the South side of Shepherd's Bush Common are likely to remain in the main traffic stream rather than the bus lane. It would therefore appear that the saving forgone by avoiding the bus lane is approximately cancelled out by the time saved by not having to stop for passengers. Although there is no statistical evidence (no observations were made of whether buses stopped) it is reasonable to suppose that non-stopping buses gain as much by using the bus lane as stopping buses, and the majority of drivers choose their routes accordingly.

4.2 NON-PRIORITY TRAFFIC

Mean journey times for non-priority traffic between the O-D pairs shown in figure 1 are presented in table 3, for each survey period in each survey day. As Rockley Road was closed during the first two time periods on the 2nd Saturday in the before study, no data has been recorded for journeys between G1-G3 and G2-G3 during these times.

These journey times, like those recorded for buses in table 1, vary greatly between days and survey periods, and the implications of this variation are discussed later. Neverthe-

TABLE 2

Effect of bus lane on journey times

	Bus journey times B2-B4 (Seconds) 1993									
	Buses using bus lane					Buses not using bus lane				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	84.6	85.1	100.4	93.0	93.8	80.0	70.0	102.3	96.8	73.2
1430-1600	86.8	101.7	111.8	101.3	109.1	93.7	141.2	57.5	65.4	98.2
1630-1830	114.2	104.1	106.5	107.8	89.7	109.4	113.0	90.7	122.6	78.1
1900-2000	105.5	105.5	95.0	100.0	97.4	110.2	85.7	108.0	105.1	98.8
mean			99.8					95.0		
st. error			1.9					4.5		
	Bus journey times B3-B4 (Seconds) 1993									
	Buses using bus lane					Buses not using bus lane				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	97.9	100.7	117.6	125.2	121.0	80.0	110.3	129.5	116.6	130.0
1430-1600	161.2	119.1	163.6	121.1	119.7	153.6	125.0	166.0	105.3	113.6
1630-1830	133.9	131.1	154.5	160.9	123.5	174.4	130.0	217.0	165.3	129.0
1900-2000	160.4	107.8	123.9	124.0	88.4	98.3	-	105.4	117.0	78.5
mean			127.8					128.7		
st. error			4.8					7.6		

less, comparison of overall means reveals some significant changes.

The greatest volume of traffic, that travelling from G2 to G5, has mainly enjoyed reductions in journey times, with the overall mean decreasing by about three-quarters of a minute, or 25 per cent. A number of factors appear to have contributed to this improvement. Firstly, traffic (including buses) leaving the cut-through before it became a bus gate impeded Westbound traffic on Shepherd's Bush Green. Buses crossing the carriageway to the bus stops, and traffic turning left into Rockley Road, contributed disproportionately to delay at this junction.

Secondly, although traffic may experience some delay at the signals to the east of the bus gate, these signals have been linked with the signals at the Rockley Road/ Shepherd's Bush Green and the Shepherd's Bush Green/ Goldhawk Road junctions. This allows a platoon of vehicles to build up and then proceed through these junctions without delay.

Thirdly, prior to the introduction of the bus lane, there were five traffic lanes on the Eastern part of Shepherd's Bush Green. Traffic merging and changing lanes caused delays. Now, with the reduced number of lanes, traffic is tending to manoeuvre into the correct lanes earlier, thereby reducing delays.

Fourthly, improved compliance with parking regulations has reduced the number of vehicles parking in what is now the bus lane. The need for buses to double park at the stops, hindering the flow of traffic, arises less often (see table 10).

The overall mean journey time for the somewhat smaller volume of traffic between O-D pair G1-G5 has increased by just over one minute, or 35 per cent. Two changes have contributed to this increase. The cut-through from Uxbridge Road to Shepherd's Bush Green has been closed to general traffic, necessitating a detour via a major roundabout and possible delay at the new signalised pedestrian crossing. However, this traffic no longer queues to use the cut-through, where the capacity was limited by the flow of Westbound traffic on Shepherd's Bush Green, and this may partially have offset the delay caused by the detour.

The effect on minor volumes of traffic between points G1 and G3 has been broadly similar. This traffic, much of which is bound for the car park off Rockley Road, was subject to the same causes of delay as that between G1 and G5, and may have been affected by buses crossing its path as they moved from the first section of the bus lane to the second.

The effect on traffic in and out of Rockley Road (between G2 and G3, and G4 and G5) has been broadly neutral.

TABLE 3

Non-priority traffic journey times (Seconds)

G1-G5

	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	110.1	124.7	200.6	108.6	229.7	235.4	211.7	247.4	227.3	219.6
1430-1600	106.1	236.3	237.7	122.0	233.7	209.6	240.2	310.9	208.6	226.4
1630-1830	316.8	269.8	218.0	85.6	161.6	327.7	230.9	360.5	262.0	231.5
1900-2000	440.2	225.5	249.3	70.3	89.8	417.0	267.4	298.1	217.3	211.0
mean			191.8					258.0		
st. error			20.2					12.4		

G2-G5

	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	94.4	98.2	181.2	119.8	278.9	110.3	97.4	165.3	104.3	94.3
1430-1600	85.4	200.9	222.9	130.7	237.4	112.1	106.8	165.3	104.6	105.5
1630-1830	249.4	193.7	221.5	60.7	166.7	172.1	114.9	211.6	149.6	112.6
1900-2000	291.3	190.7	235.5	52.7	67.9	234.0	128.2	125.9	75.6	69.3
mean			171.1					128.0		
st. error			16.6					9.3		

G1-G3

	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	69.7	67.3	139.5	75.9	-	145.9	151.3	141.4	151.7	160.8
1430-1600	65.1	153.5	168.8	73.7	-	157.9	160.6	260.0	141.2	157.3
1630-1830	171.5	183.5	153.6	59.1	63.8	195.1	132.8	249.6	161.3	158.2
1900-2000	381.6	137.1	135.6	53.1	51.8	403.3	157.1	230.4	249.3	155.5
mean			122.5					186.0		
st. error			18.3					14.1		

G2-G3

	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	41.3	40.6	106.1	41.5	-	41.2	33.4	60.6	41.1	94.3
1430-1600	40.3	69.4	103.4	42.8	-	42.1	41.1	59.8	36.1	44.1
1630-1830	112.5	66.7	75.9	29.5	29.8	56.5	41.0	68.2	48.5	48.9
1900-2000	82.8	65.4	74.1	27.7	24.6	59.1	42.6	47.7	27.7	34.4
mean	59.7	48.4								
st. error	6.5	3.3								

G4-G5

	1992					1993				
	Wed	Thu	Fri	Sat1	Sat2	Wed	Thu	Fri	Sat1	Sat2
1200-1330	85.2	98.8	151.9	160.5	276.0	133.4	120.6	136.7	182.1	149.4
1430-1600	108.0	165.1	178.2	145.4	170.5	135.7	126.3	246.1	142.4	151.8
1630-1830	173.7	139.8	181.0	99.6	245.8	151.2	126.3	228.3	157.1	131.9
1900-2000	213.7	135.7	176.4	67.6	67.2	258.3	135.7	123.1	101.0	127.9
mean			152.0					153.3		
st. error			12.0					9.3		

4.3 JOURNEY TIME VARIATIONS

The journey time variations in tables 1 and 3 appear to have a large random element, but it is worth searching for any systematic components in order to gain a full understanding of the effects of the bus priority scheme, and to facilitates comprehensive evaluation.

Factors which may affect speeds of all traffic are flows through the road links under investigation, flows in neighbouring parts of the road network, traffic signal timings, changes in capacity, due to parking, roadworks, breakdowns or accidents. In practice some of these factors cannot be monitored continuously, and the scope of monitoring is limited by considerations of cost. We have therefore been able to quantify only the first factor - the main traffic flow along Shepherd's Bush Green - and this is shown in table 4.

Bus journey times are also affected by the amount of time they have to wait at stops while passengers board and alight. Dwell times and numbers of boarding and alighting passengers were not included in this study, but the mean bus occupancy (see section 9.1) increased by just under one passenger per bus between the before and after surveys, which would have had the effect of increasing mean bus journeys times by a small, probably undetectable, amount (see, for example York 1993).

The relationship between journey times for buses and other traffic, and traffic flows along Shepherd's Bush Green is illustrated in figures 3 to 7. The most remarkable result is that substantial time savings have been achieved, except for G1-G5 traffic for reasons discussed above, while traffic flows have increased substantially (37 per cent overall). Further, statistical analysis reveals no significant dependence of journey times on traffic flows in either 1992 or 1993.

Further analysis is limited by the lack of quantifiable data on other factors which might influence journey times. It is possible however to search for dependence on "dummy variables", which indicate the time of day or the day of the week on which the observations were made. The rationale for this approach is that there may be some relationship between factors which may be important (e.g. volume of on-street parking in the area, traffic signal settings) and

TABLE 4

Traffic counts (All vehicles, Shepherd's Bush Green)

	1200-1330		1430-1600		1630-1830		1900-2000		TOTAL	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Wednesday	2561	2949	2070	3441	2488	4986	1428	2299	8547	13675
Thursday	2688	3137	2570	3424	3308	5127	1628	2363	10194	14051
Friday	2760	3273	2560	3347	3018	3772	1680	2086	10018	12478
1st Saturday	3122	3221	2377	3031	3393	4243	1211	2221	10103	12716
2nd Saturday	2227	3271	1927	3130	3387	4241	1714	2166	9255	12808

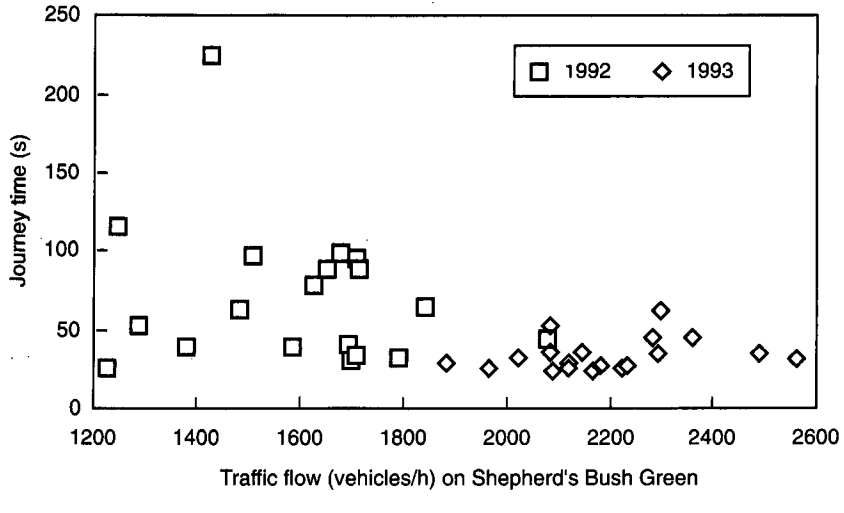

Fig. 3 Bus journey times B1-B2

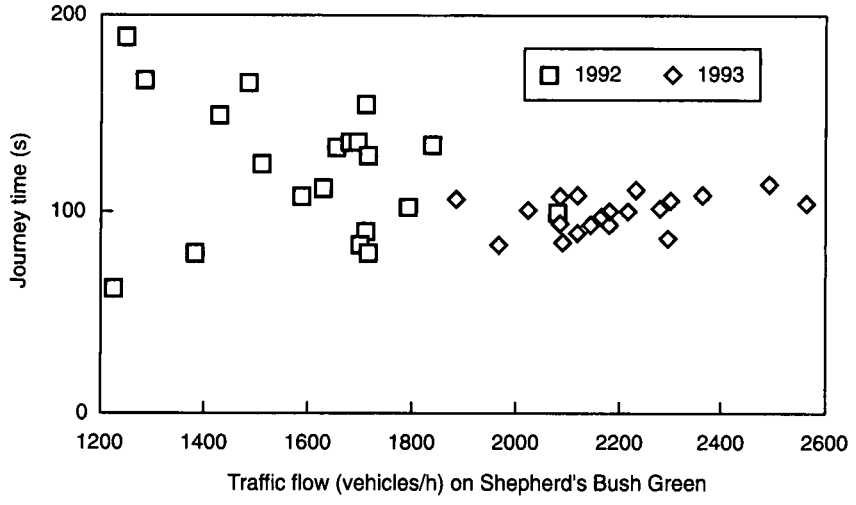

Fig. 4 Bus journey times B2-B4

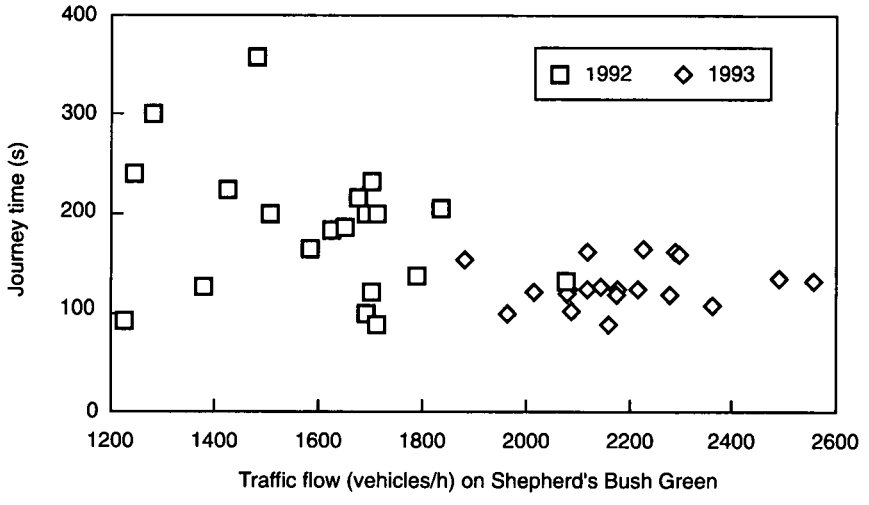

Fig. 5 Bus journey times B3-B4

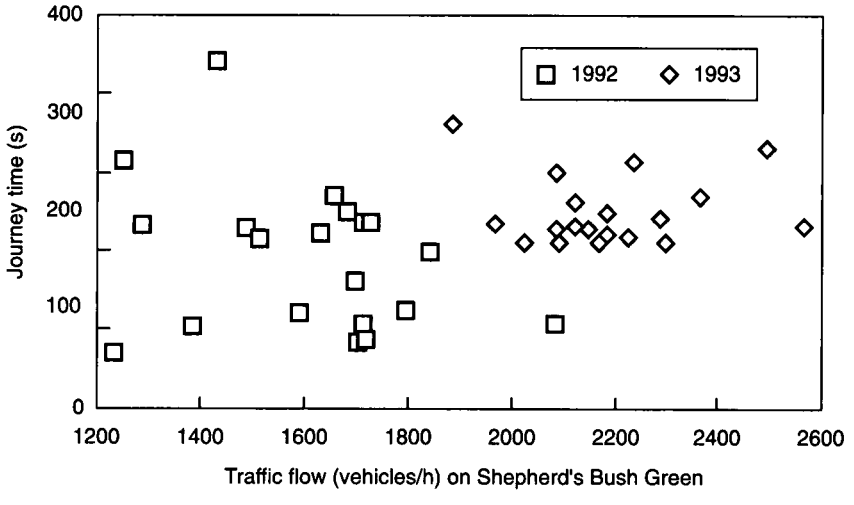

Fig. 6 Non-priority traffic journey times G1-G5

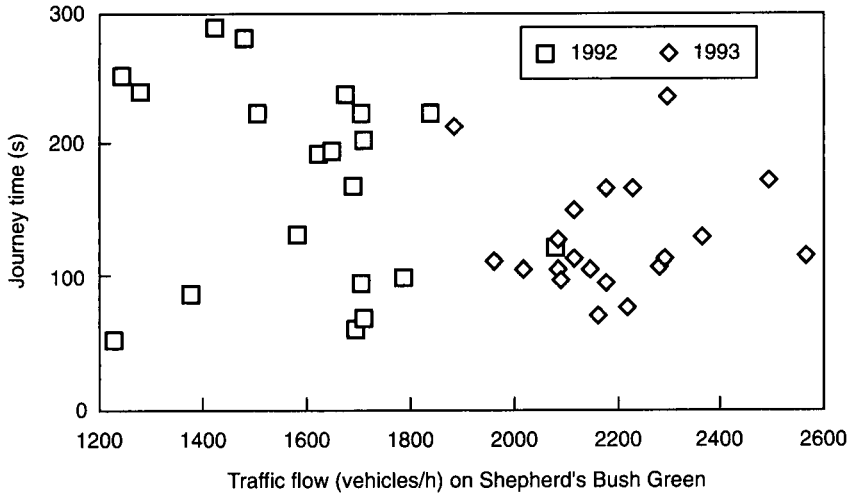

Fig. 7 Non-priority traffic journey times G2-G5

time of day, or day of the week. The weakness is that the results may be affected by unknown random events occurring on particular survey days.

Full results of the regression analysis using these dummy variables are set out in appendix A. They are somewhat confusing and not entirely convincing. They suggest that in 1992 journey times for buses between B1 and B2, and other traffic between G1 and G5 (most of which would have used the cut-through) were somewhat less on Saturdays than other days. There was no significant variation between the other days or by time of day. The 1993 results hint at some variation by time of day: buses between B2 and B4 (but not other O-D pairs) seem quicker between 1200 and 1330 than at other times, while other traffic between G2 and G5 seems slower between 1630 and 1830 than at other times. Non-priority traffic between G1 and G5 and G2 and G5 seems quicker on Thursday and Saturday.

It is impossible to be sure whether these apparent dependencies are real, or the product of random fluctuations in conditions affecting traffic. For example, it is reasonable to suppose that parking behaviour might be differ between Saturdays and weekdays, but it is not clear why Thursday in 1993 should be different from Wednesday and Friday, or why it should affect car but not bus journey times. Further speculation along these lines seems unproductive. Nevertheless, in assessing the benefits of the scheme (section 9) the possibility that these relationships are valid is taken into account.

5. BUS PASSENGER NUMBERS

The numbers of scheduled buses during both surveys, on weekdays and Saturdays, at different times of day, are shown in table 5. Separate figures are given for buses approaching Shepherd's Bush from the North or West (B1-B4) and from the East (B3-B4).

For each survey period the number of scheduled buses has been multiplied by the observed number of passengers per bus (based on the samples described in section 3)

to give an estimate of the total number of passengers carried on each group of buses. These estimates are also shown in table 5.

6. ADHERENCE TO BUS TIMETABLES

If bus priority measures can reduce variability in bus running times, benefits accrue to both operators (because in principle, buses can be scheduled more efficiently) and passengers (who will find services more reliable and average waiting times shorter).

Bus departure times at the bus stops in Shepherd's Bush Green were recorded and compared with the scheduled times. The results of this exercise are shown in table 6.

Overall, the buses are running more closely to their timetables (in 13 out of 20 observations). There is also less variability in departure times, as indicated by the reductions in standard deviations. However, since the Shepherd's Bush priority measures affect only small fractions of the routes of the buses that use them, it is impossible (without measurements over complete routes) to determine how much of the observed changes are due to these priority measures, and how much to variability in the cumulative effects of delays over other parts of routes.

TABLE 5

Buses and passengers

	scheduled buses		estimated passengers				
	weekdays	saturdays	Wed	Thu	Fri	Sat1	Sat2
			1992: B1-B4				
1200-1330	68	69	947	967	964	838	872
1430-1600	67	69	448	910	924	757	830
1630-1830	93	101	1473	1464	1571	1247	1007
1900-2000	35	34	509	360	463	267	329
			1992: B3-B4				
1200-1330	45	53	457	611	556	638	658
1430-1600	50	53	570	656	662	548	773
1630-1830	69	64	937	907	1087	673	842
1900-2000	29	23	366	413	389	286	236
			1993: B1-B4				
1200-1330	68	69	787	904	934	925	937
1430-1600	67	68	1039	884	895	744	872
1630-1830	95	99	1604	1392	1457	1143	1315
1900-2000	36	36	593	415	573	344	388
			1993: B3-B4				
1200-1330	45	52	608	500	461	829	553
1430-1600	50	52	747	753	813	1016	604
1630-1830	77	63	1084	1274	925	920	852
1900-2000	31	23	411	517	335	316	248

7. BUS PRIORITY VIOLATIONS

The benefits to be gained by buses using the bus lanes may be reduced if these lanes are used by other forms of road traffic. To monitor compliance with the bus lane regulations, observers recorded levels of non-priority traffic using the bus gate and the bus lane.

Table 7 shows the number of bus lane violations for each survey period and time band. On average, there are 19 violations per hour at the bus gate and 24 in the bus lane. The latter figure is an underestimate, as it includes only those vehicles travelling over the whole length of the bus lane between Rockley Road and the pre-signal: a number of vehicles were also observed using the bus lane to gain access to the petrol station positioned West of Rockley Road, even though there is provision for access from the general traffic lanes.

It is possible that some drivers have been confused by the layout and consequently inadvertently travelled in the bus lane, but it is reasonable to suppose that the bus lane has been in use for a sufficient length of time for regular users of this network to understand the regulations. Many drivers appear to be making deliberate use of the bus lane in order to bypass the traffic queue at the pre-signals.

Tables 8 and 9 show how many buses per hour were recorded using the bus lane and cut-through. Comparison with table 7 shows that in some time periods, the amount of non-priority traffic using the bus gate and bus lane is in excess of the number of buses using them. It has not been possible to ascertain whether bus journey times have been affected by bus lane violations, but it is possible that journey times could be further reduced if there were stricter enforcement of the bus lane regulations.

In response to the high number of bus lane violations, the Local Authority has subsequently modified the road markings at the Rockley Road junction in order to discourage motorists from entering the bus lane.

Video surveys were made on Shepherd's Bush Green between 1200 and 1600 on 26 November 1992 (before) and between 1200 and 2000 on 13 October 1993 (after). These provided some indication of the number of buses affected by cars parking in the bus lane. Table 10 shows the results of video analysis of recordings between 1200 and 1600 in both surveys.

TABLE 6

Adherence to bus timetables

Period	mean difference between actual and scheduled departure times (seconds)		standard deviations (seconds)	
	1992	1993	1992	1993
		1200-1330		
Wed	172	106	234	192
Thu	193	240	204	510
Fri	136	157	256	218
Sat1	238	107	270	173
Sat2	54	24	272	218
		1430-1600		
Wed	85	79	407	211
Thu	135	99	238	243
Fri	132	59	317	193
Sat1	203	32	305	175
Sat2	179	125	648	209
		1600-1830		
Wed	173	80	184	389
Thu	168	211	239	222
Fri	138	156	257	189
Sat1	177	77	236	205
Sat2	209	148	246	234
		1900-2000		
Wed	39	192	292	311
Thu	142	166	302	274
Fri	153	142	284	242
Sat1	163	122	249	349
Sat2	166	169	270	236

TABLE 7

Bus priority violations (Vehicles per hours)

	Sat 1	Wed	Thu	Fri	Sat 2
Time			Bus gate		
1200-1330	31.3	19.3	10.7	31.3	26.7
1430-1600	15.3	18.7	17.3	18.0	21.3
1630-1830	18.0	18.0	20.5	18.0	19.5
1900-2000	18	35	21	26	25
Time			Bus lane		
1200-1330	19.3	16.0	8.0	22.0	22.0
1430-1600	12.0	10.0	14.0	28.0	41.3
1630-1830	34.0	15.5	13.0	13.0	36.5
1900-2000	57	45	33	38	46

The results show that fewer buses are having to double park to allow passengers to board and alight. This would suggest that fewer cars are being parked at the bus stops.

However, in the after survey, a greater number of buses were forced to double park at the bus stops because of the presence of other buses. It would appear that sometimes, even when there is no illegal parking, there is inadequate space at the stops for all the buses using them (a problem which might be alleviated to some extent by rescheduling). This would have been less apparent in the before survey when the dominant problem was obstruction of the stops by illegal parking.

In both surveys, a number of bus drivers chose not to use the bus stop even though there appeared to be adequate space. This maybe because the drivers were concerned that heavy traffic flows would cause them to be blocked in.

8. SAFETY

The safety of road users was an important consideration in the design of the Shepherd's Bush priority system, and associated pedestrian facilities. So far, there have been no suggestions from the public that the area has become more dangerous, but insufficient time has elapsed to make a proper statistical evaluation of any change in accident rates.

However, as an interim measure, we have obtained accident statistics for the roads adjacent to Shepherd's Bush Common and associated junctions for the three years before the implementation of the scheme, and for the first two and a half months since the scheme has been operational. These statistics are shown in table 11.

Examination of eight hours of video recording during the after survey revealed no dangerous traffic conflicts resulting from the priority measures. In principle, pedestrians crossing Shepherd's Bush Road at the pre-signals during red general traffic phases may be vulnerable to buses, as well as (quieter) cyclists and illicit traffic, emerging from the bus lane. In practice only a tiny minority (less than one per cent) of pedestrians choose to cross the road at this point, as it is not a convenient route for them. Attention will be paid to this possible safety implication in studies of other pre-signal arrangements.

9. BENEFITS OF THE SCHEME

9.1 BUS PASSENGERS

The results in section 4 indicated considerable savings in journey times through the system for most buses, which in turn have produced time savings for bus passengers. In order to quantify these savings, total numbers of passengers

TABLE 8

Number of buses per hour using the bus gate

	Wednesday	Thursday	Friday	Saturday 1	Saturday 2
1992					
1200-1330	29.3	32.0	31.3	35.3	24.7
1430-1600	29.3	24.0	28.0	24.0	20.7
1630-1830	17.0	22.0	21.5	24.5	17.0
1900-2000	10.0	21.0	14.0	23.0	23.0
1993					
1200-1330	31.3	34.0	30.0	28.0	29.3
1430-1600	31.3	29.3	34.7	29.3	30.0
1630-1830	34.0	38.5	33.0	28.0	25.5
1900-2000	11.0	30.0	25.0	25.0	28.0

TABLE 9

Number of buses per hour using the bus lane

	Wednesday	Thursday	Friday	Saturday 1	Saturday 2
1992					
1200-1330	56.0	58.0	54.0	59.3	56.7
1430-1600	62.6	48.0	52.7	48.7	44.0
1630-1830	39.0	52.0	44.5	44.5	42.5
1900-2000	35.0	47.0	29.0	33.0	40.0
1993					
1200-1330	52.0	60.7	46.0	45.3	45.3
1430-1600	52.6	52.0	57.4	46.0	48.7
1630-1830	62.0	64.5	59.5	48.5	38.0
1900-2000	31.0	45.0	42.0	40.0	41.0

TABLE 10

Results of the video survey

	Before	After
Buses double parked at the bus stop because of parked vehicles	129	22
Buses double parked because other buses were using the bus stop	2	20
Buses double parking, even though adequate space at the bus stop	18	9
Bus able to use the bus stop without difficulty	38	137
Total number of buses observed	187	188

TABLE 11

Accidents at Shepherd's Bush

	1990	1991	1992	1993 before[3]	1993 after[4]
Fatal	0	1	1	0	0
Serious	10	10	6	10	0
Slight	85	93	77	43	9

3 To 15 July 1993

4 16 July to 30 September 1993

travelling through different parts of the system during different periods have been estimated using observations of bus occupancy made on a sample of buses (table 5). In each period the total number of passengers is multiplied by the mean saving in bus journey times to produce an estimate of the total passenger time savings.

The simplest procedure is to ignore the variation in journey times discussed in section and to take the time savings for each O-D pair as the differences between the overall means shown in table 1: these are 57.8s for passengers between B1 and B4, and 57.5s between B3 and B4. The resulting savings over the 30 hours surveyed in each year are 283.3 and 208.0 passenger hours respectively.

It is then necessary to expand these results first to compute savings at times not surveyed, then for days of the week not surveyed, and then for the rest of the year. This involves making a number of assumptions which are set out in detail in appendix B; they are, we believe, plausible but there is considerable uncertainty and we have therefore been deliberately conservative. The results obtained, which are shown in table 12 (in the column labelled "high estimate"), should therefore be regarded as order of magnitude estimates rather than precisely computed quantities.

To allow for the possibility that the variation in journey times described in section may be real, even if not totally explicable, we have made alternative estimates. For this purpose we have taken time savings as the differences between journey times computed from the regression models described in appendix A. Where such estimates vary over the day, we have assumed that the minimum value applies to all times of day not surveyed. These calculations are explained in detail in appendix B, and the results are summarised in table 12. (Note that for buses there are no differences between the "central" and "low" estimates[5]; the differences apply only to other road users and are explained in section 9.3 and appendix A.)

The improved adherence to bus timetables may in principle have benefited passengers boarding buses at Shepherd's Bush Green and possibly at subsequent stops along the routes. It is not possible to quantify this benefit without knowing numbers of passengers boarding at affected stops, how many of them plan their arrivals so as to catch buses at advertised times (rather than arriving randomly), and how far along the routes the effects of the Shepherd's Bush improvements are sustained.

It is interesting to note that mean occupancy rose by about 8 per cent (from 12.9 to 13.8 passengers per bus) between the surveys, while there was an increase of about 1.5 per cent in scheduled service frequency. The possibility that bus service improvements resulting from the priority measures may have contributed to this increase in demand cannot be discounted, it must be recognised that many other factors, not identified or measured in the course of this study, may also have influenced demand.

9.2 BUS DRIVERS

Bus drivers' time savings are estimated in a manner completely analogous to those for passengers: the estimated delays per bus for each survey period is simply multiplied by the appropriate number of scheduled buses and the results aggregated. The same assumptions are made to expand the results to give daily, weekly and annual estimates and both methods of calculation (using average and variable journey times) have been used. The results (table 12) are then used to estimate the value of drivers' time savings and savings in operating costs (see sections 9.4 and 9.5).

9.3 OTHER ROAD USERS

The results in section 4 indicated that while journey times for some non-priority traffic have increased, others have decreased. In this section we quantify the resulting benefits and disbenefits to non-priority road users, in much the same way as that adopted in the previous section for bus passengers. Numbers of vehicles using different parts[7] of the system have been estimated by expansion of the numbers of vehicles timed at various points, using expansion factors which match estimated and observed flows along Shepherd's Bush Green Road. In the absence of observations on non-priority vehicle occupancies, we have assumed an average occupancy of 1.32 people per vehicle, taken from the London Area Transport Survey 1991 (London Research Centre 1994).

5 The terms "high", "central" and "low" applied to these estimates relate to total time savings for all road users, and hence to total benefits of the scheme. Estimates for "other road users" (section 9.3) are more sensitive to the assumptions made than those for bus passengers, so that the "high" estimate includes lower benefits to bus passengers than the "central" or "low" estimates.

7 Separate calculations have not been made for traffic entering and eventually leaving Rockley Road, from which there is no other exit. Flows to G3 and from G4 are vary small compared with those of the main streams, and the measurements of journeys time changes are not statistically reliable. Instead, it has been assumed that journey time changes for this traffic are broadly the same as those for the main streams, and are included in the results for G1-G5 and G2-G5.

TABLE 12

Total benefits

Time savings (thousands of person hours per annum)		high[6] estimate	central estimate	low estimate
Bus passengers	B1-B4	43.3	50.9	50.9
	B3-B4	33.3	33.3	33.3
	total	76.6	84.1	84.1
Bus drivers	B1-B4	3.3	3.9	3.9
	B3-B4	2.5	2.5	2.5
	total	5.8	6.3	6.3
Other road users	G1-G5	-18.7	-16.7	-15.6
	G2-G5	94.8	74.1	36.7
	total	76.1	57.4	21.2
All road users		158.5	147.9	116.4
Value of time savings (£k per annum)				
Bus passengers		174	191	191
Bus drivers		41	45	45
Other road users		173	130	48
All road users		388	366	284
Vehicle operating cost savings (£k per annum)				
Buses		13	14	14
Other vehicles		30	23	8
All vehicles		43	37	22
Total benefits (£k per annum)		431	403	306
Total cost of scheme (£k)			326	

6 See sections 9.1, 9.3 and 13 for explanations of alternative estimates

As for buses, we have made alternative estimates assuming average journey times and allowing for journey time variation in accordance with the regression models described in appendix A. Average journey times over all days and survey periods are used for the "high" estimate. The low estimate depends on the pattern of journey times revealed by regression analysis (appendix A), including all the factors that appear to be statistically significant, even if inexplicable (table 12). The central estimate uses regression coefficients derived when marginal significant and inexplicable factors are excluded (these are shown in table A.2 where they are different). All three estimates indicate that savings to non-priority traffic between G2 and G5 outweigh losses between G1 and G5 (table 12), but there are considerable differences between them, especially for traffic between G2 and G5.

9.4 VALUE OF TIME SAVED

The annual time saving for bus passengers has been conservatively estimated at between 76.5k and 84.1k person hours. The proportion of this time which falls in working hours is unknown, but likely to be small. As a conservative estimate we therefore take the 1993 value of non-working time (£2.27 per hour) from the COBA9 Manual (Department of Transport 1989), assuming low growth between 1989 and 1993, and deduce the value of this time saving to be between about £174k and £191k per annum.

Savings in bus drivers' time amount to between 5.8k and 6.3k hours per annum, which at £7.09 per hour (from the COBA9 manual), assuming low growth between 1989 and 1993, is worth between £41k and £45k per annum.

The value of time savings of other road users are obtained using the same value of non-working time as for bus passengers. This ignores the higher rates applicable to goods vehicle drivers and car drivers travelling in working time, which would increase the benefits of the scheme. The size of this effect is likely to be relatively small, since such drivers are likely to be only a small minority of the other road users, but their numbers are unknown.

There may also be second-order effects on traffic using neighbouring parts of the road network, as a result of West-bound drivers altering their routes to include Shepherd's Bush Green, and South-bound drivers avoiding it. In practice the costs of mounting surveys to quantify such changes in sufficient detail for evaluation would have been prohibitive. However, discounting the possibility that the scheme has generated or suppressed traffic (which seems unlikely in view of the journey time changes observed) it would appear that the net effect of the scheme may have been a transfer of traffic from other routes to Shepherd's Bush Green, which may have made a marginal contribution to easing congestion elsewhere.

9.5 SAVINGS IN OPERATING COSTS

The COBA9 manual expresses vehicle operating costs as:

$$\text{cost/km} = a+b/v+cv^2$$

where v is speed in km/hour. This equation may be manipulated to show that under the traffic conditions observed in this study reductions in costs are, to a sufficient degree of accuracy, the product of the parameter b and the time savings.

For cars, the vehicle time savings are those shown in table 12 divided by the occupancy of 1.32, i.e. 16.1k, 43.5k and 57.7k hours for the low, central and high estimates. The parameter b is £0.52/h, and the resulting reductions in operating costs are between £8k and £30k per annum.

For buses b is £2.20 per hour, giving an annual cost reduction of between £13k and £14k.

No separate estimates are possible for goods vehicles, which were not distinguished from cars in the surveys.

9.6 TOTAL BENEFITS

Summation of the benefits discussed in the previous sections produces annual totals in the range £306k to £431k per annum. These figures must be treated with caution, in view of the assumptions used in their estimation, and the omission of proper allowances for goods vehicles and people driving cars during working time, and possible reductions in bus passenger waiting times. There is no doubt however that the overall annual benefit is positive, and large, comparing very favourably with the total costs of £326k of planning and implementing the Shepherd's Bush bus priority measures.

It should be noted that the benefits from the various improvements in Shepherd's Bush which combine to produce these totals cannot be identified separately. Some are directly related to the new measures (bus advance area, bus lane, bus gate) while others might perhaps have been achieved on the former road layout (by, for example, more rigorous parking enforcement, relocation of pedestrian crossings).

10. CONCLUSIONS

Interpretation of some of the results presented in this report is not entirely clear cut. This arises from unexplained variations in journey times through the area affected by the priority measures. It is tempting to dismiss these variations as random fluctuations, and rely on average journey times for assessment of the scheme, but such a course could not be justified without comparison with an alternative method. Unfortunately alternative methods of estimation require a number of assumptions and judgements which, even if plausible, cannot be fully justified. For this reason a deliberate attempt has been made to bias assumptions so as to produce conservative estimates of the benefits of the scheme. Even so, the "high" estimate, based on ignoring all the observed variations, may be too optimistic. Conversely, the "low" estimate, which makes maximum allowance for variation, may be close to the limits of statistical credibility and consequently too pessimistic. The "high" and" low" estimates are therefore offered as a representation of the range of uncertainty in the central estimate.

There are clearly substantial benefits, in the form of time savings, to bus passengers, which can be attributed to the combination of the changes. Other road users are enjoying smaller benefits on the South side of Shepherd's Bush Common but North-South travellers are suffering disbenefits, because of the greater distance and complication of their journeys. Nevertheless, the former number substantially more than the latter, so there is an overall nett benefit to non-bus traffic. While benefits cannot be determined with precision, the total annual benefit appears comparable with the capital costs of implementing the scheme.

The overall scheme may therefore be judged a success, to which the pre-signal has almost certainly contributed. We cannot however discriminate between the effects of the pre-signal itself, and those of the other measures which formed part of the package. Nor can we assess how much of the improvement may have been due to better compliance with parking regulations, which could in principle have been achieved by other means. We therefore need to complete

our monitoring and assessment of other pre-signal installations before making recommendations about the general applicability of this device in "typical" locations.

11. ACKNOWLEDGEMENTS

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APPENDIX A: ANALYSIS OF JOURNEY TIME VARIATION

The results presented in tables 1 and 3 show big variations in journey times for buses and other traffic between all O-D pairs in the area, in both 1992 and 1993 surveys. There are differences in journey times from day to day, and at different times of day. The purpose of the analysis reported here is to determine whether any of this variation is systematic (that is, can it be related to other factors?), and how much is simply random fluctuation which is discounted in the usual processes of averaging results.

A number of variable factors which might be expected to influence traffic speed were discussed in section . The only one of these which could be measured in the course of the surveys was the flow of traffic along Shepherd's Bush Green. Figures 3 to 7 suggest a complete lack of any dependence of journey times on this flow of traffic. We have therefore sought to relate journey time variation to "dummy variables" representing days of the week, and different survey periods during the day, using step-wise regression analysis, the results of which are shown in table A.1. In several cases this process revealed no statistical dependence (at the 5 per cent level of confidence) on either traffic flow or on any of the dummy variables. In other cases one or more of the dummy variables, but not traffic flow, appeared to be significant. The resulting values of R^2, even where non-zero, are low, indicating that only a small part of the observed variation is accounted for by the regression models, and this is outweighed by the random element.

The dummy variable which appears most relates to Saturdays, indicating that journey times tend to be faster on Saturdays than other days. This is perhaps due to a difference in traffic patterns (but not volumes) on Saturdays. There is possibly less loading and unloading by commercial vehicles along the stretch of Shepherd's Bush Green near the shops on Saturdays, allowing traffic to move more freely. The reduction in bus times between B2 and B4 in period 1 may perhaps be similarly explained: there may be a lull in commercial activity at lunch time. However, it is less plausible that commercial activity would be more intense in the evening peak, and it is not clear why traffic should flow more freely on Thursdays (in 1993 than on Wednesdays or Fridays. However, the confidence levels for these factors are somewhat marginal, and it is arguable that they could be ignored. Exclusion of these variables from the regression analysis slightly modifies the coefficients of the more significant factors, as shown in table A.2.

These modified regression models "explain" less of the observed variation than the previous ones but they have the merit of less complication and, more importantly, contain only factors whose influence can be understood and therefore seem more plausible. We therefore use these modified models as the basis of our central estimates of time savings and benefits.

It is arguable that if conditions on weekdays and Saturdays are sufficiently different to produce different journey times then the dependence of journey times on time of day may also be different. To test this possibility, separate regression analyses were made of journey times against traffic flow and time period for weekdays and Saturdays in 1992 and 1993. The resulting coefficients, with confidence levels, are shown in table A.3.

In view of the small data sets on which these models are based (having separated the weekday and Saturday data) it is not surprising that the results are inconclusive. For 1992 the only significant variable (at the 5% level or better) is period 1 (1200-1330) for journey times between G2 and G5 on weekdays. Such a model suggests that at other times of day (periods 2-4) buses move more quickly over the same stretch of road (B3-B4) in spite of having to stop and having no priority. This is not credible and suggests that the apparent variation is spurious. It also casts doubt on the

TABLE A.1

Journey time regression model coefficients

O-D	constant	flow	Wed	Thu	Fri	Sat	Per1	Per2	Per3	Per4	R^2
1992											
B1-B2	88.4					-47.1 (2%)					0.22
B2-B4	121.9										0
B3-B4	185.3										0
G1-G5	227.9					-90.3 (3%)					0.20
G2-G5	169.0										0
1993											
B1-B2	33.8										0
B2-B4	102.6						-11.2 (1%)				0.28
B3-B4	127.8										0
G1-G5	300.8			-63.3 (4%)		-74.5 (0.5%)					0.33
G2-G5	148.7			-45.3 (3%)		-55.4 (0.25%)			34.7 (5%)		0.45

Note: times in seconds; confidence levels in brackets; Per1 = 1200-1330; Per2 = 1430-1600; Per 3 = 1630-1830; Per4 = 1900-2000

TABLE A.2

Modified regression model coefficients

O-D	constant	flow	Wed	Thu	Fri	Sat	Per1	Per2	Per3	Per4	R^2
1993											
G1-G5	279.7					-53.4 (3.5%)					0.18
G2-G5	142.2					-40.2 (3%)					0.19

credibility of the models suggested for 1993, where the confidence levels are similar, and there is little consistency between the various O-D pairs.

For the sake of completeness overall time savings and benefits have been derived from these models, along the lines described in appendix B. Annual benefits amount to some £250k per annum, rather less than the low estimate given in table 12, but still positive and comparable with the cost of the scheme. The reason for the difference lies in the assumption that time each day savings during unsurveyed periods are equal to the smallest time savings during survey periods. Any spurious variation with time of day will therefore lead to underestimation. We therefore regard the low estimate in table 12 as being more realistic.

APPENDIX B: ESTIMATION OF TIME SAVINGS

Estimation of total time savings from the models described in appendix A and data on passenger numbers is straightforward in principle but involves quite complicated detail. It is therefore best described by way of example.

TABLE A.3

Weekday and Saturday regression models

O-D	Weekdays const	flow	Per1	Per2	Per3	Per4	Saturdays const	flow	Per1	Per2	Per3	Per4
1992												
B1-B2	88.4						41.3					
B2-B4	128.0						112.7					
B3-B4	189.3						179.3					
G1-G5	227.9						137.7					
G2-G5	210.1		-85.5 (4%)				139.4					
1993												
B1-B2	30.8					16.6 (1%)	28.6			13.8 (5%)		
B2-B4	103.3		-13.7 (4%)				99.0					
B3-B4	139.5		-34.1 (2.5%)				123.0					
G1-G5	279.7						219.5				27.2 (3.5%)	
G2-G5	142.2						102.2				28.9 (4.5%)	-29.7 (4%)

First, estimates of journey times must be made for each time period each day. For buses travelling between B1 and B2 in 1992, table A.1 indicates no variation by time of day: the mean journey time on weekdays is 88.4s, and on Saturdays 41.3s (88.4 - 47.1). The corresponding journey time in 1993 is simply 33.9s for all days and periods. The time savings are therefore 54.5s (88.4 - 33.9) on weekdays, and 7.4s (41.3-33.9) on Saturdays.

For B2-B4 the estimated mean journey time for all days and periods in 1992 is 121.9s. In 1993 the corresponding time is 102.6s, except during period 1 (1200-1330) when it is 91.4s (i.e. 11.2s less). So the savings for this journey are 19.3s, except for period 1, when they are 30.5s.

Combining these results yields estimates of savings between B1 and B4:

weekdays 85.0s per bus (period 1) and 73.8s per bus (periods 2 to 4)

Saturdays 38.0s per bus (period 1) and 26.7s per bus (periods 2 to 4).

Numbers of passengers[8] are obtained simply by multiplying the mean[9] number of passengers observed during each survey period by the number of scheduled buses, and are shown for B1-B4 in table B.1. The mean of the 1992 and 1993 numbers is then multiplied by the time saving per bus, derived as explained above. The total saving in passengers' time for each day, over the survey periods, is shown in the last column of table B.1.

It is now necessary to make assumptions about times of day for which there is no direct evidence from surveys. The number of passengers per hour in the morning (0600 - 1200) is assumed to be equal to that between 1430 and 1600 (i.e. off-peak afternoon). This is probably conservative since it ignores the morning peak (which however may be less pronounced than the evening peak for Westbound centrifugal passengers), but this may be compensated in part by lower demand before the morning peak. The number of passengers per hour for the last two hours of the day is assumed to be equal to the lowest observed during the day. For each intermediate time, the number of passengers per hour is assumed equal to the lower of those observed in the periods immediately before and after. In table B.1 the last

8 Averages of passengers numbers observed during the two Saturdays in each of the surveys are shown in table A.3.

9 This is equivalent, where passengers have increased, to the conventional "rule of one half", which attributes the whole time saving to the original number of passengers, and half the time saving to the additional passengers, on the ground that the benefit accruing to new passengers must be more than zero (or they would not have transferred to these buses) but less than the full benefit of the reduced journey time (otherwise they would have used these buses before). The same arithmetical device also applies when journey times increase and passenger numbers decrease.

TABLE B.1

Time savings for buses B1-B4 (low and central estimates)

day, period	time (h)	passengers 1992	passengers 1993	mean	pass /hour	saving /bus (s)	total saving (pass.h)
Wednesday							
1200-1330	1.50	947	787	867.0	578.0	85.0	20.5
1430-1600	1.50	448	1039	743.5	495.7	73.8	15.2
1630-1830	2.00	1473	1604	1538.5	769.3	73.8	31.5
1900-2000	1.00	509	593	551.0	551.0	73.8	11.3
0600-1200	6.00			2974.0	495.7	73.8	61.0
1330-1430	1.00			495.7	495.7	73.8	10.2
1600-1630	0.50			247.8	495.7	73.8	5.1
1830-1900	0.50			275.5	551.0	73.8	5.6
2000-2200	2.00			991.3	495.7	73.8	20.3
					Totals (survey times)		78.5
					(16 hours)		180.7
Thursday							
1200-1330	1.50	967	904	935.5	623.7	85.0	22.1
1430-1600	1.50	910	884	897.0	598.0	73.8	18.4
1630-1830	2.00	1464	1392	1428.0	714.0	73.8	29.3
1900-2000	1.00	360	415	387.5	387.5	73.8	7.9
0600-1200	6.00			3588.0	598.0	73.8	73.6
1330-1430	1.00			598.0	598.0	73.8	12.3
1600-1630	0.50			299.0	598.0	73.8	6.1
1830-1900	0.50			193.8	387.5	73.8	4.0
2000-2200	2.00			775.0	387.5	73.8	15.9
					Totals (survey times)		77.7
					(16 hours)		189.5
Friday							
1200-1330	1.50	964	934	949.0	632.7	85.0	22.4
1430-1600	1.50	924	895	909.5	606.3	73.8	18.6
1630-1830	2.00	1571	1457	1514.0	757.0	73.8	31.0
1900-2000	1.00	463	573	518.0	518.0	73.8	10.6
0600-1200	6.00			3638.0	606.3	73.8	74.6
1330-1430	1.00			606.3	606.3	73.8	12.4
1600-1630	0.50			303.2	606.3	73.8	6.2
1830-1900	0.50			259.0	518.0	73.8	5.3
2000-2200	2.00			1036.0	518.0	73.8	21.2
					Totals (survey times)		82.7
					(16 hours)		202.5
Saturday							
1200-1330	1.50	855	931	893.0	595.3	38.0	9.4
1430-1600	1.50	794	808	800.8	533.8	26.7	5.9
1630-1830	2.00	1127	1229	1178.0	589.0	26.7	8.7
1900-2000	1.00	298	366	332.0	332.0	26.7	2.5
0600-1200	6.00			3203.0	533.8	26.7	23.8
1330-1430	1.00			533.8	533.8	26.7	4.0
1600-1630	0.50			266.9	533.8	26.7	2.0
1830-1900	0.50			166.0	332.0	26.7	1.2
2000-2200	2.00			664.0	332.0	26.7	4.9
					Totals (survey times)		26.6
					(16 hours)		62.5
					Weekly total		1017
					Annual total		50850