TRANSPORT RESEARCH LABORATORY

The impacts of the Safer City Project on road traffic emissions in Gloucester: 1996–1998

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P G Boulter

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Executive Summary

In 1995 the Department of the Environment, Transport and the Regions (DETR) embarked on a 'Safe Town Initiative', in which towns around the country were invited to compete for £5m to treat a whole town in a strategic manner, with road safety integrated into other town development policies. The city of Gloucester was chosen as the location for the initiative, renamed the 'Safer City Project'. Appropriate measures are being introduced in stages over a five year period. These include changes to the road hierarchy, traffic redistribution, measures for vulnerable road users, traffic management, education, and publicity.

As part of a general programme of research into the environmental impacts of urban traffic management and safety schemes, the Charging and Local Transport Division of DETR commissioned the Transport Research Laboratory to monitor the environmental effects of the Safer City Project. TRL is monitoring the effects on vehicle and road traffic emissions, air quality, vehicle and traffic noise, vibration, and the public perception of the environment. It is intended that the results from the work will help local authorities to determine the likely benefits and drawbacks of planned traffic management schemes in relation to their effects on the environment.

This report deals with the effects of the different traffic management and safety elements of the Safer City Project on vehicle and road traffic emissions. Detailed annual surveys of passenger car driving cycles, traffic flow, and traffic composition have been undertaken to assess the changes in emissions along a sample of roads in Gloucester which are likely to be affected. The Report presents the results of the first three surveys, conducted in November of 1996, 1997, and 1998.

A link-based approach was used to examine the evolution of the speeds, flows, and exhaust emissions of road traffic in Gloucester. The bulk of the experimental work involved the determination of representative driving cycles on 76 links covering most of the main roads in the city. The speed data were collected using an instrumented car which was driven in the traffic. Traffic flows were also measured on around half of the links. The links were grouped according to the main (or only) type of traffic management or traffic safety measure that was implemented during 1996-97. The measures investigated were anti-skid surfacing, gateways, a roundabout, speed cameras, pedestrian refuges, and carriageway narrowing combined with a cycle lane. On Cheltenham Road, measures were introduced during both the 1996-97 and 1997-98 periods, with a broad range of traffic calming and traffic management measures appearing during the latter period. These included a raised pedestrian crossing, a set of speed cushions, cycle lanes, a bus lane, and re-phasing of traffic signals. Consequently, the results for the two affected links were treated as a separate 'Cheltenham Road' category. A sample of links on which no traffic management measures had been introduced was also considered. Changes in the overall mean speed and traffic flow were determined for each link and link type.

For the calculation of emissions vehicles were separated into two generic groups: (i) light-duty vehicles (LDVs), which included passenger cars, light-duty goods vehicles, and medium-size goods vehicles; (ii) heavy-duty vehicles (HDVs), which included all heavy goods vehicles and buses. The calculation covered four pollutants: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), and carbon dioxide (CO_2). Consideration was only given to 'hot' exhaust emissions (*i.e.* those emissions produced when an engine is at its normal operational temperature); the study did not account for exhaust emissions due to cold starts or evaporative emissions.

The calculation of emissions on each link was either a one-step or two-step process, depending upon the level of information available. For all 76 links where driving cycles had been recorded, emissions from LDVs in each year of the study were estimated using the cycles as an input to the MODEM model. Emissions from HDVs were calculated using empirical emission functions for heavy goods vehicles relating to average link speed. For the sub-sample of links where traffic flow and composition had been recorded, weekday emissions from traffic were estimated by weighting the emissions from LDVs and HDVs by the traffic flow and composition.

In general, the changes in mean speed along most individual links were quite small; during both the 1996-97 and 1997-98 periods the change in mean speed was less than 5.0 km/h (3.1 mph) on more than three quarters of the links studied. Following the introduction of any type of measure, there was a decrease in the overall mean speed recorded on the affected links. On links where either anti-skid surfacing, a gateway, a roundabout, pedestrian refuges, or carriageway narrowing with a cycle lane had been introduced during 1996-97, the resulting speed reduction was maintained during 1997-98. The extent of the speed reduction effected by the introduction of measures was dependent upon the type of measure used. Link speeds were reduced by around 2 km/h (1 mph) where the measures were least severe (*i.e.* the anti-skid surfacing, the gateways, and the pedestrian refuges), and by around 6-8 km/h (4-5 mph) where the measures were either more severe or occupied long sections of road (*i.e.* the roundabout, the carriageway narrowing with a cycle lane, and the measures introduced on Cheltenham Road).

During 1996-97 it was found that there was also a decrease in mean speed of 1.8 km/h (1.1 mph) along unaffected links, and during the 1997-98 period the mean speed on unaffected links increased by 0.8 km/h. If these general changes in speed on unaffected links were to be taken into account when considering the effects of the measures introduced on other links, it could be argued that during 1996-97 the net reductions in speed would only have been substantial on the links with a roundabout and the links where carriageway narrowing was combined with a cycle lane. During 1997-98 a substantial reduction in speed was only observed on the Cheltenham Road links.

On the links affected by the introduction of speed cameras the reduction in mean speed during 1996-97 was only slight, and was actually followed by an increase in speed during 1997-98. However, in this study the links on which the cameras were installed were several kilometres long. A more localised speed-reduction effect may have occurred, but this would have had little impact on the mean speed over an entire link.

During both the 1996-97 and 1997-98 periods the change in flow was less than 10% on around two thirds of the links where it had been recorded. For the various link types, changes in traffic flow of more than 10% were only observed in a few cases; on links with pedestrian refuges there was a 15% decrease in flow between 1997 and 1998, and on the Cheltenham Road links there was an 11% decrease in flow between 1997 and 1998. Overall traffic flow on links with no measures hardly changed during the study.

The changes in driving pattern effected by the introduction of traffic management and traffic safety measures on a link tended to result in increases in emissions of CO, HC, and CO_2 *per LDV*, with NO_x emissions changing only slightly. There was also a tendency for emissions of all four pollutants *per HDV* to increase after the introduction of measures. The largest increases in emissions per vehicle coincided with the largest speed reductions. Consequently, the largest increases in emissions per vehicle were observed for the links with a roundabout and links with carriageway narrowing combined with a cycle lane during 1996-97, and the Cheltenham Road links during 1997-98.

On the links with a roundabout and the links with carriageway narrowing combined with a cycle lane during 1996-97, emissions of CO per LDV increased by 9% and emissions of HC per LDV increased by 11-13%. NO_x emissions per LDV decreased by 1-3%, and CO_2 emissions per LDV increased by 4%. On links with a roundabout CO emissions per HDV increased by 27%, and on links with carriageway narrowing combined with a cycle lane CO emissions per HDV increased by 19%. On the two types of link, emissions of HC per HDV increased by around 20%, and emissions of NO_x and CO_2 per HDV increased by around 10%.

During the 1996-97 period the changes in driving pattern on the unaffected links resulted in increases in CO and HC emissions per LDV of 4% and 5% respectively, a decrease in NO_x emissions per LDV of 1%, and an increase in CO_2 emissions per LDV of 2%. On the same links, emissions of CO and HC per HDV increased by 6%, and emissions of NO_x and CO_2 per HDV increased by 3%. As with vehicle speed, it could be argued that the net effects on emissions per vehicle of the anti-skid surfacing, gateways, speed cameras, and pedestrian refuges installed during this period were similar to the effects on the unaffected links, and therefore negligible. Similar reasoning would also suggest that the effects of the roundabout and the carriageway narrowing combined with a cycle lane on emissions per LDV were small for CO and HC, and negligible for NO_x and CO_2. The net effects of the roundabout and carriageway narrowing with a cycle lane on emissions of CO and HC per HDV were larger than those for LDVs, but the net effects on emissions of NO_x and CO_2 per HDV were similar to those for LDVs.

For the Cheltenham Road links during the 1997-98 period, emissions of CO and HC per LDV increased by 10%. Emissions of NO_x per LDV decreased by 2%, and emissions of CO_2 per LDV increased by 6%. For HDVs, emissions of CO and HC per vehicle increased by 18% and 22% respectively, NO_x emissions per vehicle increased by 11%, and CO_2 emissions per vehicle increased by 13%. During the same period the driving pattern effects on links with no measures were negligible.

In spite of the increases in emissions per vehicle on the links where traffic management measures had been installed and, in some cases, increases in traffic flow, total emissions of CO, HC, and NO_x from traffic on the different types of link decreased by between 1% and 13% during 1996-1997, and by between 4% and 20% during 1997-1998. The general reductions in total emissions of CO, HC, and NO_x were mainly due to the changes that had occurred in the composition of the LDV fleet, although the decreases in emissions were amplified on the types of link where large reductions in traffic flow had occurred. The emission characteristics of the LDV fleet are changing rather dramatically at present. Emissions from catalyst-equipped LDVs are typically an order of magnitude lower than those from non-catalyst LDVs, and during the course of a year a significant proportion of older vehicles are replaced by newer ones. This alone results in a general reduction in the absolute emissions of CO, HC, and NO_x, and a slight increase in CO_2 emissions, from traffic on all roads. For example, during 1996-97 total city-wide weekday emissions of CO from traffic decreased by 4% during 1996-97, and decreased by a further 8% during 1997-98. City-wide emissions of both HC and NO_x decreased by 6% during each period. Total emissions of CO_2 increased by 2.3% during 1996-97, but during the 1997-98 period emissions decreased by 1%. Currently, the outcome is that unless traffic flow on any given road increases markedly, or driving patterns are changed so radically that a large increase in emissions per vehicle occurs, there will usually be a reduction in emissions of CO, HC, and NO_x from traffic over the course of the year. However, driving pattern and traffic flow effects may become more important in the future, when catalyst-equipped vehicles will dominate the fleet.

1 Introduction

1.1 The Gloucester Safer City Project

In 1995 the Road Safety Division of the Department of the Environment, Transport and the Regions (DETR) embarked on a 'Safe Town Initiative', in which towns around the country were invited to compete for £5m of funding to spend on road safety improvements and traffic management. It was intended that the award would be used to treat the road network of the chosen town in a strategic manner, with safety integrated into other town development policies. In December 1995 the city of Gloucester (population *c.*100,000) was chosen from 29 contenders as the preferred location for the initiative, renamed the 'Gloucester Safer City Project'.

The objective of the Safer City Project is to reduce the number of road casualties by implementing a coherent range of actions for improving road safety according to a well-defined strategy. The first stage of the Project involved the development of an appropriate strategic framework. Two main elements to the overall safety strategy were defined: management of the different modes of travel to achieve a safer distribution around the road network, and management of speed to achieve a safer circulation.

Appropriate measures are being introduced in stages over a five year period, starting in the financial year 1996/7. These measures include:

- changes to the road hierarchy;
- traffic redistribution;
- area-wide traffic calming;
- speed-reduction measures on main routes;
- bus and cycle lanes;
- new pedestrian facilities;
- education and publicity.

1.2 The environmental assessment of the Safer City Project

The primary concerns of traffic management are to reduce congestion and/or accidents. However, in addition to the safety and congestion benefits that might be available, traffic management may also influence the environmental impact of traffic. Detailed reviews of previous case studies of traffic management schemes, and appraisals of their likely benefits and drawbacks, have been compiled by Abbott *et al.* (1995) and Cloke *et al.* (1997).

As part of a more general programme of research into the environmental impacts of urban traffic management and safety schemes, the Charging and Local Transport Division of DETR has commissioned the Transport Research Laboratory (TRL) to monitor the environmental effects of the Gloucester Safer City Project. The monitoring started in 1996, and will continue for at least one year after the completion of the Safer City Project. In a separate Project (S204I) for the Road Safety Division of DETR, TRL is also advising on the safety strategy to be adopted, as well as monitoring accident and casualty occurrence, traffic distribution and speed, and public responses. Project S204I commenced in September 1995 and is due to be completed in March 2001.

In Project UG106, TRL is monitoring the effects of the Safer City Project on vehicle emissions, air quality, vehicle and traffic noise, vibration, and the public's perception of the environment. It is intended that the results from the work will help to provide local authorities with a framework to determine the likely benefits and drawbacks of selected traffic management schemes in relation to their effects on the environment.

The safety and traffic management measures are being introduced incrementally, so not only is there a need to assess the environmental impact of the Safer City Project as a whole during its lifetime, there is also a need to assess the impact of individual safety and traffic management measures as they are introduced. In view of this, some of the environmental surveys will be city-wide and repeated throughout the life of the project, whilst others will be more local and tailored to assess specific schemes.

The main objective of the work in the air pollution area is to achieve an understanding of the effects on emissions of the different safety and traffic management elements of the Safer City Project. In addition, measurements of ambient pollutant concentrations will be made in order to relate changes in emissions to changes in local air quality. The pollutants that will be measured are nitrogen dioxide (NO_2), benzene, and PM_{10} [1].

Detailed surveys of passenger car driving cycles, traffic flow, and traffic composition are being undertaken to assess the changes in exhaust emissions from road traffic along a sample of roads in Gloucester which are likely to be affected by the safety or traffic management measures. These surveys are being repeated at annual intervals, and this Report presents the results of the first three. These surveys were conducted in November of 1996, 1997, and 1998. The 1999 survey has also been completed but the results are not yet available. Further surveys are planned for 2000, 2001, and 2002.

1.3 Safety and traffic management measures implemented

The measures that were implemented between November 1996 and November 1998 are listed in Table 1 and Table 2.

During the period between the 1996 and 1997 driving cycle surveys a range of measures were introduced in various parts of the city. The measures were generally small in scale and typified by localised effects on traffic. The main exception was an area-wide traffic calming scheme in Elmbridge. However, because the measures in Elmbridge were installed on residential and local distributor roads they were not covered during the TRL surveys. The other measures that were introduced during the first year of the study but were not located on the main routes are indicated in Table 1.

During the 1997-98 period, work on the Safer City Project concentrated on two main schemes: an area-wide traffic calming scheme in the Longlevens area, and the pedestrianisation of Northgate and Southgate in the town centre.

Some of the measures that are listed in Table 1 are also illustrated in Figures 1-5. For each of the measures illustrated, the year of implementation is given in brackets. The anti-skid surfacing identified in Table 1 was a surface

Table 1 Measures implemented between November 1996 and November 1997

Description	*Started* [1]	*Finished* [1]	*Location*
Anti-skid surfacing [2]	3/97	3/97	Cheltenham Road
Anti-skid surfacing [2]	11/96	11/96	Metz Way
Anti-skid surfacing [2]	11/96	12/96	Eastern Avenue/Metz Way
Anti-skid surfacing [2]	11/96	11/96	Eastern Avenue/Coney Hill
Anti-skid surfacing [2]	2/97	3/97	Eastern Avenue/Painswick
Anti-skid surfacing [2]	3/97	3/97	Parkend Road/Trier Way
Carriageway narrowing/ cycle lane [3]	7/97	9/97	Finlay Road
Gateway [4]	4/97	9/97	Bristol Road
Gateway	4/97	9/97	Stroud Road
Gateway	6/97	9/97	Painswick Road
Gateway	6/97	9/97	Hucclecote Road
Gateway	6/97	9/97	Cheltenham Road
Gateway [4]	5/97	9/97	Innsworth Lane
Gateway [4]	5/97	9/97	Longford Lane
Gateway	5/97	9/97	Tewksbury Road
Speed camera	2/97	4/97	Bristol Road/Linden Road
Speed camera	2/97	4/97	Bristol Road/Philip Street
Speed camera [4]	2/97	4/97	Stroud Road
Speed camera	2/97	4/97	Eastern Avenue/Metz Way
Speed camera	2/97	4/97	Eastern Avenue/Carne Place
Signal modifications	2/97	5/97	Painswick Road/Heron Way
Area-wide scheme [4]	3/97	9/97	Elmbridge
Pedestrian refuges	10/96	3/97	London Road
Toucan [4]	2/97	4/97	Severndale Drive
Roundabout [5]			St. Oswald's

[1] Start and finish dates are approximate for each scheme. Finish dates are when the scheme was regarded as operational.

[2] Installed only at the approaches to traffic lights or junctions.

[3] Narrowing of carriageway for motor vehicles achieved through installation of hatching, central refuges, and cycle lane.

[4] Not on routes covered by TRL driving cycle surveys (see Section 2.1).

[5] Although the roundabout was installed at the entrance to a new supermarket, and was therefore not a part of the Safer City Project, its effects were monitored coincidentally.

Table 2 Measures implemented between November 1997 and November 1998

Description	*Started* [1]	*Finished* [1]	*Location*
Area-wide traffic calming	11/97	7/98	Longlevens (Cheltenham Road) [3]
Various traffic calming [2, 4]	2/98	6/98	Tredworth Road
Pedestrianisation [5]	4/98	5/99	Northgate/Southgate

[1] Start and finish dates are approximate for each scheme. Finish dates are when the scheme was regarded as operational.

[2] Not on routes covered by TRL driving cycle surveys (see Section 2.1).

[3] Only the traffic calming introduced on Cheltenham Road was covered in this assessment.

[4] Measures included flat-top road humps, speed cushions, a fake hump, red surfacing, and a cycle lane.

[5] Prior to the pedestrianisation, Gouda Way and Black Dog Way were connected to form an inner relief road that allowed traffic to flow around the city centre.

dressing of high-friction material that was introduced at traffic lights and junctions as a remedial measure against accidents, rather than as a measure specifically designed to affect driver behaviour.

1.4 Assessment of road traffic emissions

A link-based approach was used to examine the evolution of exhaust emissions from road traffic in the city of Gloucester. Emissions from vehicles and traffic on the links studied were estimated for a typical weekday in November of 1996, 1997, and 1998. Consideration was only given to 'hot' exhaust emissions (*i.e*. those emissions produced when an engine is at its normal operational temperature). The study did not account for exhaust emissions due to cold starts or evaporative emissions, both of which are likely to be significant in an urban area such as Gloucester. It would have been beyond the scope of the study to measure the parameters that would enable either of these emission sources to be evaluated. Furthermore, changes in overall cold start and evaporative emissions mainly arise as a result of changes in the number of trips by private passenger car. It was considered unlikely that the measures introduced in Gloucester would have resulted in a net change in this number.

Emissions from light-duty vehicles were estimated using the MODEM model. The reasons for using an emission model, and for selecting MODEM specifically, were identical to those presented in a previous TRL report describing a similar study in the Leigh Park area of Havant (Cloke *et al*., 1999). The model accounts for the vehicle-to-vehicle variability of emissions by relying on databases constructed from tests on a large number of cars. However, MODEM does not explicitly account for the variations in driver behaviour which could affect emissions. Consequently, the main experimental work in Gloucester involved the determination of a range of driving cycles that were representative of driver behaviour on the selected links.

The accuracy of the Gloucester emission estimates hinges mainly on the accuracy of the MODEM model. Although some limitations concerning MODEM's accuracy have been identified (notably by Joumard *et al.*, 1998), it remains a state-of-the-art model that is specifically designed to evaluate the changes in emissions associated with detailed changes in driving pattern. It is one of only a few such tools available.

MODEM does not calculate emissions from heavy-duty vehicles, and so the emission rates for these vehicles were calculated using functions relating to average speed.

In order to calculate the daily emission rate of traffic on a link, information was also required on the daily traffic flow and composition. This information was available for around half of the links covered during the driving cycle surveys.

2 Method

2.1 Driving cycle measurements

Representative driving cycles, which described vehicle speed as a function of time, were measured on most of the main

Figure 1 Gateway, Painswick Road (1996-97)

Figure 2 Toucan crossing and cycle lane. Cheltenham Road (1997-98)

Figure 3 Carriageway narrowing (central hatching and refuges) and cycle lane, Finlay road (1996-97)

roads in the Gloucester City area. The speed data were collected during two-week surveys in which an instrumented car was driven in the traffic (often referred to as the ‘floating vehicle’ method). A PC-based data acquisition system was fitted inside the passenger compartment of the car to enable its road speed to be logged every second. The experimental method employed, and the vehicles used to obtain the speed measurements, were similar to those described in the report by Cloke *et al*. (1999). The main differences concerning the

Figure 4 Cycle lane and speed cusions, Cheltenham Road (1997-99)

Figure 5 Bus and cycle lane, Cheltenham Road (1997-98)

Gloucester work, apart from the obvious differences relating to the routes driven, were the smaller number of drivers and the use of local residents as navigators. The first three surveys in the Project were conducted in November of 1996, 1997, and 1998.

During the 1996 survey two members of TRL staff were employed to drive the instrumented car along eight predetermined routes through the city. Prior to the survey the drivers were instructed to drive as normally as possible along the routes, and in such a way that their speeds reflected those of the surrounding traffic.

The routes covered roads on which future modifications to the management of traffic were likely to occur. The logging of speeds on the routes was confined to two sessions on each day (07:00-11:00 and 15:00-19:00), and the routes were driven in both directions (designated *A* and *B)*. In the first session of the survey the driver started on route *A1* and completed the remaining routes in direction *A* in ascending numerical order. On completing route *A8*, the driver arrived back at the start of route *A1,* from where the session continued. The number of routes completed in the session was determined solely by the time available. In each subsequent session with the same driver, the starting route was changed so that peak traffic flows were encountered on the different routes. The same procedure was applied to the second driver, except that the routes were driven in direction *B*, and in descending numerical order. However, as the routes were driven in succession, the natural variability of the traffic speeds in the city dictated that no exact controls could be exercised on the time of day at which each link was driven. During the 1997 and 1998 surveys, four drivers were used. Two drivers followed the routes in direction *A*, and the other two followed those in direction *B.*

To compliment the logged data, an information sheet was also completed for each trip. The sheet included details of the time and date, the driver's name, the route number, the logged file number, and any comments regarding the route (adverse weather conditions, congestion, road works, *etc*.).

Prior to the driving cycles being used in conjunction with the MODEM model, the speed measurements were isolated for particular links covered by the routes. These links were identified by assigning letters of the alphabet to the start and end points of the routes, as well as the points where routes intersected. The roads covered by the routes, and the start, end, and intersection points, are shown in Figure 6. For example, Kingsholm Road formed the links **FG** (southbound) and **GF** (northbound). The resulting links, and the main traffic management measure that was introduced on each link, are listed in Table 3. On a number of links more than one traffic management measure was introduced. For example, on the two links where carriageway narrowing (hatching and pedestrian refuges)

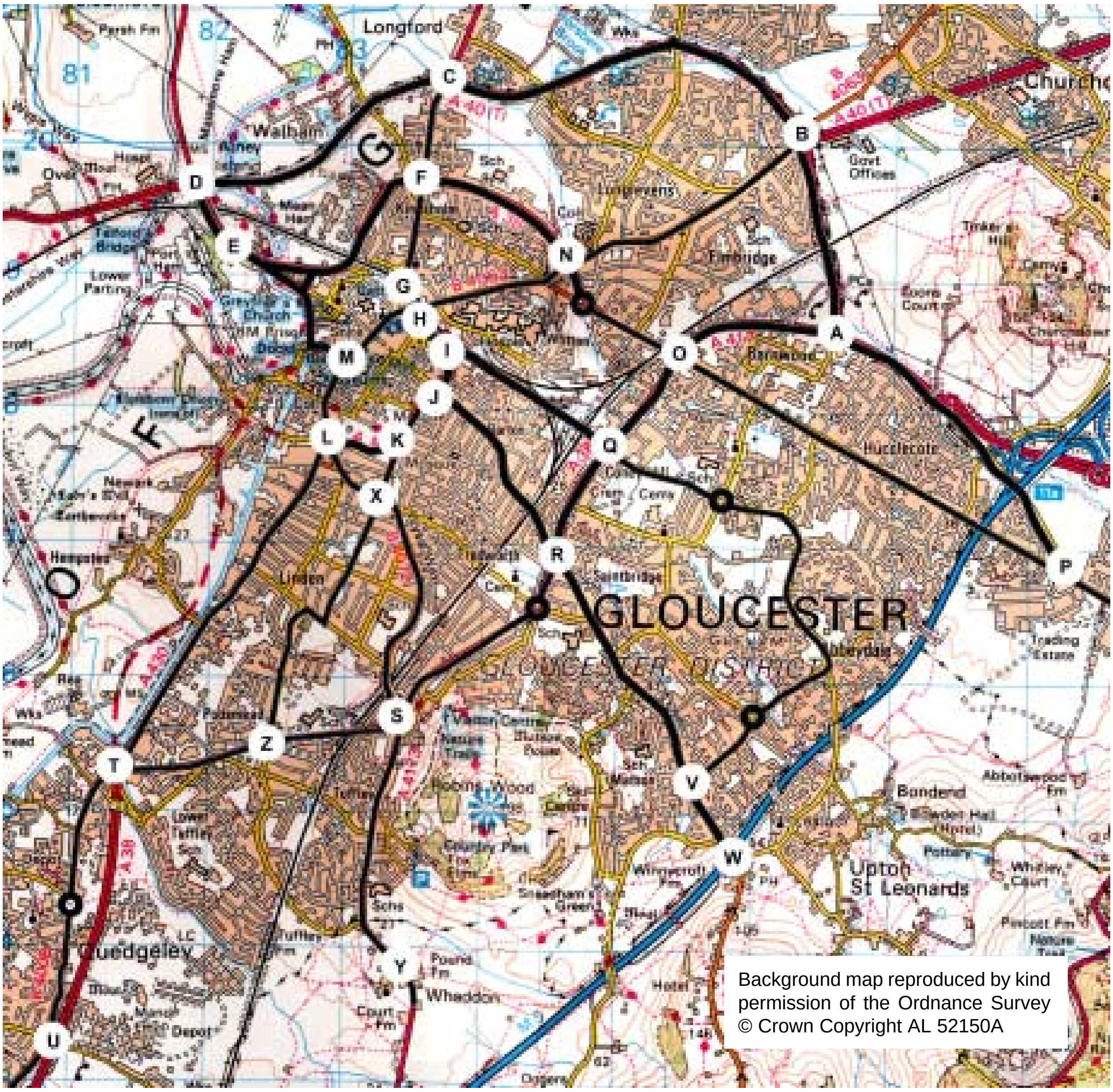


Figure 6 Roads and links covered during driving cycle surveys

Table 3 The links covered, including the traffic management measures introduces and the presence of road works

		Main traffic management measure introduced		*Road works (% of trips affected)*		
Link	*Road(s) covered*	*1996-97*	*1997-98*	*1996*	*1997*	*1998*
AB	Barnwood Link Road	None	None			
AO	Barnwood Bypass	None	None			
AP	Barnwood Bypass	None	None			
BA	Barnwood Link Road	None	None			3
BC	Gloucester Northern Bypass	None	None			
BN	Cheltenham Road	Gateway [1,2,3]	Various [7]			
CB	Gloucester Northern Bypass	None	None			
CD	Gloucester Northern Bypass	None	None			
CF	Tewkesbury Road	Gateway [1,2]	None			
DC	Gloucester Northern Bypass	None	None			
DF (via E)	Over Causeway/St.Oswald’s	Roundabout	None			
EM	Over Causeway/The Quay/Commercial Road	None	None			
FC	Tewkesbury Road	Gateway [1]	None			
FD (via E)	St.Oswald’s/Over Causeway	Roundabout	None			
FG	Kingsholm Road/Worcester Street	None	None			
FN	Estcourt Road	None	None	9		
GF	Worcester Street/Kingsholm Road	None	None			2
GH	Black Dog Way	None	None			
GM	Northgate Street/Southgate Street	None	Pedestrianisation [8]			
HG	London Road	None	None	3		
HI	Bruton Way	None	None			
HN	London Road	Pedestrian refuges	None			
IH	Bruton Way	None	None			
IJ	Bruton Way	None	None			
IQ	Metz Way	Anti-skid surfacing	None			
JI	Bruton Way	None	None			
JK	Trier Way	Anti-skid surfacing	None			
JR	Barton Street/Painswick Road	Anti-skid surfacing	None			
KJ	Trier Way	None	None			
KL	Trier Way	None	None			
KX	Park End Road	None	None			
LK	Trier Way	None	None			
LM	Southgate Street	None	None			
LT	Bristol Road	Speed camera	None			
LX	Stroud Road	None	None			
MD (via E)	The Quay/Over Causeway	None	None			
MG	Southgate Street/Northgate Street	None	Pedestrianisation [8]			6
ML	Southgate Street	None	None			
NB	Cheltenham Road	Gateway [1,3]	Various [7]			
NF	Estcourt Road	None	None			
NH	London Road	Pedestrian refuges	None			
NO	Barnwood Bypass	None	None			
OA	Barnwood Bypass	None	None			
ON	Barnwood Bypass	None	None			
OP	Barnwood Road/Hucclecote Road	Gateway [1]	None			19
OQ	Eastern Avenue	Speed camera [3]	None			
PA	Barnwood Bypass	None	None			
PO	Barnwood Road/Hucclecote Road	Gateway [1,2]	None			11
QI	Metz Way	None	None			
QO	Eastern Avenue	Speed camera [3]	None			
QR	Eastern Avenue	Anti-skid surfacing	None			
QV	Metz Way/Abbeymead Avenue/Wheatway	Anti-skid surfacing	None	8		
RJ	Painswick Road/Barton Street	Anti-skid surfacing	None			
RQ	Eastern Avenue	Speed camera [3]	None			
RS	Eastern Avenue/Finlay Road	Carriageway narrowing and cycle lane[3,4,5]	None			
RV	Painswick Road	Anti-skid surfacing [6]	None			
SR	Finlay Road/Eastern Avenue	Carriageway narrowing and cycle lane [3,4,5]	None			
SX	Stroud Road	None	None	8		
SY	Stroud Road	Gateway [3]	None			
SZ	Southern Avenue	None	None			
TL	Bristol Road	Speed camera	None		5	
TU	Bristol Road	None	None			
TZ	Cole Avenue	None	None			

Continued over

Table 3 Continued

Link	Road(s) covered	Main traffic management measure introduced 1996-97	1997-98	Road works (% of trips affected) 1996	1997	1998
UT	Bristol Road	None	None			
VQ	Wheatway/Abbeymead Avenue/Metz Way	Anti-skid surfacing	None	25		
VR	Painswick Road	Anti-skid surfacing [6]	None			
VW	Painswick Road	Gateway [1]	None			
WV	Painswick Road	Gateway [1,2]	None		4	
XK	Park End Road	None	None		6	
XL	Stroud Road	None	None			
XS	Stroud Road	None	None			
XZ	King Edward's Av./The Oval/Tuffley Av./Podsmead Rd.	None	None			
YS	Stroud Road	Gateway [1,2,3]	None	4	4	
ZS	Southern Avenue	None	None			
ZT	Cole Avenue	None	None			
ZX	Podsmead Rd./Tuffley Av./The Oval/King Edward's Av.	None	None			

[1] *Red surfacing also introduced.*

[2] *Dragons' teeth and roundel also introduced.*

[3] *Anti-skid surfacing also introduced.*

[4] *Pedestrian refuges also introduced.*

[5] *Speed cameras also introduced.*

[6] *Modifications also made to traffic signals.*

[7] *The measures introduced on Cheltenham Road during 1997-98 were advanced stop lines, a set of speed cushions, dummy road humps, a bus lane, cycle lanes, a raised Toucan crossing, an entry treatment, and re-phasing of traffic signals.*

[8] *Alternative route taken in 1998 because of town-centre pedestrianisation works.*

was combined with a cycle lane, **RS** and **SR**, speed cameras and anti-skid surfacing were also introduced. The identification of the 'main' measure was therefore somewhat subjective in a number of cases.

The presence of road works on a particular link may have been an important factor governing the mean speed on the link. Therefore, for each link in Table 3 there is also an indication of the percentage of trips affected by road works. These values were derived solely from the notes made by the navigators during the surveys.

During the 1996 and 1997 surveys 76 links were covered. During the 1998 survey a section was added to routes *A4* and *B4*, approximately half way between nodes **R** and **S**, to include an area of Barton/Tredworth were a traffic calming scheme was to be implemented. This addition required the division of links **SR** and **RS**, and so for each of these links the results reported here are average values for the two new sections. The results for the additional Barton/Tredworth section will be presented in a subsequent TRL report. The pedestrianisation of the city centre meant that the routes followed between points **G** and **M** had to be altered. Consequently, the speed and emission results for links **GM** and **MG** obtained in the 1998 survey cannot be compared with those obtained during the earlier surveys.

2.2 Traffic flow measurements

Automatic traffic flow measurements and 12-hour (07:00-19:00) manual classified counts were made by TRL and Gloucester City Council (on behalf of TRL) at a number of locations in the area. These locations are shown in Appendix A. In total, traffic flow measurements were available for 44 of the links covered by the 1996 and 1997 driving cycle surveys, and 41 of the links covered by the 1998 survey (since no counts were made on the pedestrianised links). The traffic counts were mostly conducted during a two week period in November of each year which coincided with the timing of the driving cycle surveys. Average 24-hour flows were determined for weekdays, and the manual classified counts were used to determine the heavy-duty vehicle proportion of the traffic flow.

2.3 Analysis of speed and traffic flow data

The mean speed of each driving cycle on a link was calculated from the length of the link and the time taken to travel along it. The resulting values were again averaged to give an overall mean speed for the link

The links studied were arranged into the following groups according to the main (or only) type of traffic safety or traffic management measure that was implemented between the 1996 and 1997 surveys:

- Links with anti-skid surfacing alone.
- Links with a gateway.
- Links with a roundabout.
- Links with a speed camera.
- Links with pedestrian refuges.
- Links with carriageway narrowing combined with a cycle lane.

On two links, **BN** and **NB** on Cheltenham Road, measures were introduced during both the 1996-97 and 1997-98 periods. Particularly during the latter period, a broad range of measures appeared. Consequently, the results for these links have been reported in a separate 'Cheltenham Road' category. A sample of links on which no traffic management measures had been introduced was also considered.

For each type of link the changes in overall mean speed between the survey years were calculated. The 'stop time' (*i.e.* the length of time that a vehicle is stationary as a result of waiting at traffic lights, waiting for pedestrians, or involvement in conflicts with other vehicles) was also calculated for each link and link type. This aids the understanding of the effects of different traffic management measures, as well as the possible influence of factors that cannot be controlled.

As a further aid to understanding the changes in speed on different links, the effects of congestion were considered. Congestion effects were assessed semi-quantitatively. Firstly, the data sheets completed by the navigators were examined to determine how many of the trips on each link had been affected by congestion. Secondly, the driving cycle measured on each trip was inspected to see if congestion could be identified. During this latter analysis, congestion was deemed to have occurred on a link if the instrumented car had been driven in a 'stop-start' fashion with the speed not exceeding 20 km/h for a distance of around 250m or more.

The annual changes in city-wide speed and traffic flow have also been estimated. A simple arithmetic average of all recorded mean link speeds is a poor descriptor of the mean speed of traffic in the city during each survey year, since it does not account for the numbers of vehicles travelling at each speed. A better measure would incorporate both the average speed and average flow of the traffic on each link, and a 'speed index' was formulated on this basis to provide a more accurate estimate. The index took the form:

$$SI_y = \frac{\sum_{l=1}^{l=44} \left(S_{l,y} \cdot F_{l,y} \right)}{\sum_{l=1}^{l=44} F_{l,y}}$$

Where: $\boldsymbol{SI_y}$ = speed index for year $\boldsymbol{y}$.

$\boldsymbol{S_{l,y}}$ = mean link speed index on link $\boldsymbol{l}$ in year $\boldsymbol{y}$.

$\boldsymbol{F_{l,y}}$ = mean weekday traffic flow on link $\boldsymbol{l}$ in year $\boldsymbol{y}$.

2.4 Emission modelling

In order to determine the overall effect on emissions of the changes in the traffic conditions encountered on each link, it was necessary to account for changes in traffic flow and the vehicle fleet, as well as changes in the emissions performance of vehicle types resulting from changes in driving pattern. For example, new vehicles must be fitted with emission control systems to enable them to comply with emission limits that are more stringent than those that were applied to older vehicles. In each new year of the study a proportion of the latter will be replaced by the former.

However, the limited availability of emissions data for some vehicle categories (*e.g.* buses and light-duty goods vehicles) imposed restrictions on the estimation of emissions from traffic. Vehicles were therefore simply separated into two generic groups:

- *Light-duty vehicles (LDVs)*. For the purposes of this study this group included passenger cars, light-duty goods vehicles, and medium-size goods vehicles (gross vehicle weight less than 3.5 tonnes).
- *Heavy-duty vehicles (HDVs)*. These included all heavy goods vehicles (gross vehicle weight more than 3.5 tonnes) and all buses.

The calculation of emissions on each link was either a one-step or two-step process, depending upon the level of information available:

Step 1: For all 76 links where driving cycles had been recorded, emissions from LDVs in each year were estimated using the driving cycles measured in those years as an input to the MODEM model. For 1996 and 1997 the composition of the LDV fleet was determined from national registration statistics. The proportion of LDVs in each category during 1998 was estimated by extrapolating the trend in the registration statistics between 1996 and 1997. Emissions from HDVs were calculated using empirical emission functions for heavy goods vehicles relating to average link speed (Hickman, 1996).

Step 2: For the sub-sample of around 40 links where traffic flow and composition had been recorded, daily emissions from traffic during each year of the study were estimated by weighting the emissions from LDVs and HDVs by the traffic flow and composition.

These two steps are described in more detail in the following sections.

2.4.1 Emissions from LDVs and HDVs

Light-duty vehicles

Emissions from light-duty vehicles were estimated using the MODEM model. The model calculates emissions of carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), and carbon dioxide (CO_2) from twelve categories of passenger car using the second-by-second speed of a given driving cycle. From the driving cycle the program evaluates the average speed and acceleration between each pair of adjacent speed readings, and the corresponding emission factor for each vehicle category is then referenced from a database. The emission factors are summated to give an emission (in grammes) for the driving cycle.

As the MODEM model provides results for twelve different vehicle categories (*e.g.* those with a catalyst and those without a catalyst, those running on petrol and those running on diesel), large amounts of emission data can rapidly be generated. In order to simplify the presentation of the emission rates of LDVs in these different emission categories, a ‘composite’ vehicle was defined. This composite vehicle reflected the composition of the LDV fleet in terms of the categories of emission control, fuel type, and engine size used in MODEM. The emission rate of the composite vehicle on each link was determined by weighting the predicted emission rate for each MODEM category by the proportion of the national LDV fleet in the same category.

The MODEM model categories and fleet composition for the three years of the study are shown in Table 4. The proportion of LDVs in each category during 1996 and 1997 was determined from the national vehicle registration statistics for the respective years (SMMT, 1997; SMMT, 1998). This was the most up-to-date information available. The exhaust emission legislation that effectively required most passenger cars in the UK to be fitted with a catalyst (91/441/EEC) came into effect on January 1 1993. It was therefore assumed that all petrol LDVs registered after January 1 1993 were equipped with a catalyst. It was also assumed that the proportion of diesel LDVs in each engine size category was the same as the proportion used for each engine size for petrol cars. The proportion of LDVs in each category during 1998 was estimated by extrapolating the trend in the registration statistics between the reference years 1996 and 1997. The registration statistics for 1991 to 1998 are illustrated in Figure 7. In order to test the general validity of this extrapolation, a similar extrapolation was conducted for the 1997 fleet composition using the 1995-96 data. When compared with the actual 1997 composition, it was found that the estimated composition resulted in negligible errors in the estimation of emissions.

The gradual phasing-in of catalyst-equipped petrol vehicles is apparent from the data presented in Table 4 and Figure 7. In 1996 these vehicles formed 24% of the LDV fleet, and by 1997 the proportion had risen to 30%. By extrapolating the 1996-97 registration data it was estimated that by 1998 around 36% of LDVs were equipped with a catalyst. These changes in the proportion of vehicles equipped with a catalyst are mirrored by changes in the proportion of non-catalyst petrol vehicles. The proportion of diesel vehicles has increased from 9% to 11% between 1991 and 1998.

The accuracy with which these national statistics reflect the composition of the LDV fleet in Gloucester is not known. A study is currently underway at TRL to develop a classification of traffic composition by area and location type. This study should provide more accurate information on the composition of the traffic in Gloucester, and the effects on the emission estimates of using this information will be assessed when it becomes available.

For every link on which driving cycles had been measured, the emission rate of a given pollutant from the composite LDV was determined using the following equation:

$$E_{LDV,l,y} = \sum_{v=1}^{v=12} e_{l,v,y} \cdot x_{v,y}$$

Where:
- $\boldsymbol{E_{LDV,l,y}}$ = emission (g) for a composite LDV on link $\boldsymbol{l}$ in year $\boldsymbol{y}$ of the study.
- $\boldsymbol{e_{l,v,y}}$ = emission (g) on link $\boldsymbol{l}$ for LDV category $\boldsymbol{v}$ in year $\boldsymbol{y}$ of the study.
- $\boldsymbol{x_{v,y}}$ = proportion of LDVs in vehicle category $\boldsymbol{v}$ in year $\boldsymbol{y}$ of the study.

For each link the value for $\boldsymbol{e_{l,v,y}}$ was obtained by processing all the measured driving cycles through MODEM and averaging the resulting emission rates.

Heavy-duty vehicles

MODEM does not calculate emissions from heavy-duty vehicles, and so the emission rates for these vehicles on each link in each survey year were calculated using the following empirical emission functions for heavy goods vehicles relating to average link speed $\boldsymbol{S_l}$ (Hickman, 1996):

$$CO(g/km) = 6.52 - (0.109S_l) + (5.84x10^{-6}S_l^3) + \left(\frac{55.1}{S_l}\right) - \left(\frac{150}{S_l^2}\right)$$

$$HC(g/m) = 0.652 - (6.3\times10^{-5}S_l^2) + (6.4\times10^{-7}S_l^3) + \left(\frac{16.3}{S_l}\right) - \left(\frac{4.86}{S_l^2}\right)$$

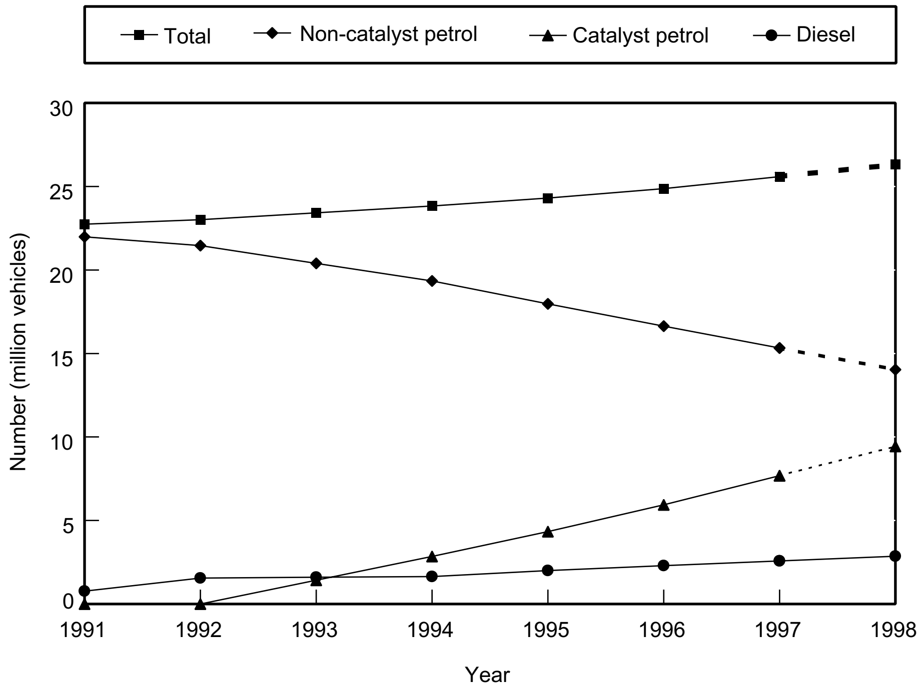
$$NO_X(g/km) = 10.8 - (0.00301S_l^2) + (2.95\times10^{-5}S_l^3) + \left(\frac{182}{S_l}\right) - \left(\frac{510}{S_l^2}\right)$$

Table 4 Proportion of LDVs in each category

	Petrol, non-catalyst (MODEM layers[1] 1-6[2]) Engine size			*Petrol, catalyst (MODEM layers 7-9) Engine size*			*Diesel (MODEM layers 10-12) Engine size*		
Reference year	*<1.4 l*	*1.4-2.0 l*	*>2.0 l*	*<1.4 l*	*1.4-2.0 l*	*>2.0 l*	*<1.4 l*	*1.4-2.0 l*	*>2.0 l*
1996	0.29	0.33	0.05	0.10	0.12	0.02	0.04	0.04	0.01
1997	0.25	0.30	0.05	0.13	0.14	0.03	0.04	0.05	0.01
1998 (Extrapolated)	0.22	0.27	0.04	0.15	0.18	0.03	0.04	0.06	0.01

[1] *The word ‘layer’ is used in MODEM to distinguish between different categories.*

[2] *Two layers are contained within each engine size band for non-catalyst petrol vehicles. These two layers relate to compliance with ECE15/03 (EC Directive 78/665/EEC) and ECE 15/04 (EC Directive 83/351/EEC) emission-control legislation.*



Solid lines represent the actual number of registrations in each year.
Dotted lines represent the predicted values for 1998.
(source: SMMT 1992-98)

Figure 7 LDV fleet composition by year

$$CO_2(g/km) = 2269 + (73.9S_l) - (1.07S_l^2) + \left(\frac{64593}{S_l}\right) - \left(\frac{3.82\times10^5}{S_l^2}\right) + \left(\frac{8.21\times10^5}{S_l^3}\right)$$

The values of $\boldsymbol{S_l}$ used were the mean link speeds measured during the driving cycle surveys.

2.4.2 Traffic emissions

Traffic flow and composition were measured during each year of the study on a sub-sample of around 40 links. The daily emissions from road traffic[2] on each of these links were estimated by weighting the emissions from LDVs and HDVs by the recorded flow and composition. For each link, the total emission rate of a given pollutant during a normal weekday in a particular year of the study was determined using the following equation:

$$E_{Traffic,l,y} = \left[\left(E_{LDV,l,y}\cdot x_{LDV,l,y}\right) + \left(E_{HDV,l,y}\cdot x_{HDV,l,y}\right)\right]\cdot F_{l,y}$$

where:

$E_{traffic,l,y}$	=	total emission rate (g/day) of traffic on link ***l*** in year ***y***.
$E_{LDV,l,y}$	=	emission (g) for a 'composite' LDV on link ***l*** in year ***y***.
$x_{LDV,l,y}$	=	LDV proportion of traffic along route ***l*** in year ***y***.
$E_{HDV,l,y}$	=	emission (g) for a typical HDV on link ***l*** in year ***y***.
$x_{HDV,l,y}$	=	HDV proportion of traffic along route ***l*** in year ***y***.
$F_{l,y}$	=	mean weekday traffic flow on link ***l*** in year ***y.***

Where it had not been measured directly, the proportion of heavy-duty vehicles in the flow was assigned a default value of 0.05 (*i.e*. 5%). The actual proportion of heavy vehicles on these roads may have been greater or less than 5%, but the same default value was applied to the data for each year and this assumption should not have resulted in any large errors in the calculation.

2.4.3 Assessment of factors contributing to changes in traffic emissions

For each type of link, an assessment has been made of the relative importance of different factors contributing to the changes in traffic emissions.

For light-duty vehicles, three factors contributed to the predicted overall changes in emissions between each survey year. Two of these factors, changes in driving pattern and changes in the LDV flow, were recorded during each survey. For the purposes of this assessment, it was assumed that the values related to these parameters did not vary with time, but did vary with the types of traffic management measures that were introduced. The third factor, the change in the composition of the LDV fleet, was estimated from annual registration statistics. This did vary with time as a result of improvements in emission control technology, but should not have been affected by the traffic management measures that were introduced. In this study, the impact of changes in the composition of the LDV fleet was considered over the one-year period between the surveys.

For heavy-duty vehicles it was assumed that the composition of the fleet did not change with time. This is not likely to be the case, since there are also ongoing improvements in the control of emissions from these vehicles. However, the lack of emission data for newer technology heavy-duty vehicles, as well as any detailed information of HDV fleet composition, dictated that these changes could not be assessed.

2.4.4 City-wide emissions

In order to examine the evolution of emissions from traffic on a city-wide basis, the daily emissions of each pollutant were summated over the links where flow was measured.

3 Link speed and traffic flow

The results of the driving cycle surveys and traffic flow measurements conducted during the first three years of the study are presented in this Chapter of the Report.

The total times and distances logged in each driving cycle survey are shown in Table 5. The figures in the table show that the three surveys yielded large quantities of continuous speed data. For example, 85.7 hours equates to over 300,000 individual speed measurements. It is only recently that improvements in computing power have allowed a study of this size to be undertaken. Previously, the processing of this quantity of such a large set of data would have been prohibitively slow.

Table 5 Total time and distance logged in each driving cycle survey

Year	*Total time (hours)*	*Total distance (km/miles)*
1996	68.2	2226/1383
1997	67.4	2263/1406
1998	85.7	2783/1730

An equipment failure during the 1996 survey resulted in irregularities in the driving cycle measurements along certain links, and the loss of around 5% of the logged data. A ‘moving average’ smoothing function was applied to the remaining driving cycle data in order to remove the irregularities. The smoothing function took the form:

$$s_t^{'} = \frac{\left(s_{t-1} + \left(2s_t\right) + s_{t+1}\right)}{4}$$

where: s_t = the recorded speed at time ***t***

s'_t = the smoothed speed at time ***t***

There were occasionally slight differences between the lengths of corresponding links (*e.g.* **AB**=1.44km, whilst **BA**=1.56km). This was caused by differences in the driving distances between nodal points on some corresponding links. For example, a link involving a roundabout would require an extra distance to be driven in one direction than in the alternate direction.

Examples of the driving cycles measured on a selected route (route *A4* comprising links **PA**, **AO**, **OQ**, **QR**, **RS**, **SZ**, **ZT**, and **TU**) during the three surveys are shown in Figures 8, 9, and 10. The link names are shown at the top of each graph. These figures are only included to indicate the type and quantity of information collected in the surveys, and typical changes in driving patterns.

The mean speed recorded on each of the 76 links covered in the three survey years, and the changes in mean speed between successive surveys, are presented in relation to each of the link types in Appendix B. Overall mean speeds for the link types are also shown. The mean stop times for each link and link type are presented in Appendix C, any congestion effects are noted in Appendix D, and the traffic flows on each link where they were measured are given in Appendix E.

Summaries of the overall results for each link type are provided in the following sections.

3.1 Speed and flow by link type

3.1.1 Links with anti-skid surfacing

Anti-skid surfacing, and no other traffic management measure, was introduced on a total of nine links during the 1996-97 period. The overall mean speeds for these links during each year of the study are shown in Figure 11. The error bars in the figure indicate the 95% confidence intervals on the means.

There was a 1.6 km/h (1.0 mph) decrease in mean link speed between 1996 and 1997 on the nine links. A paired sample *t*-test showed that this change was not significant at the 95% confidence level. The 7.0 km/h (4.4 mph) increase in mean speed on link **JK** (Trier Way) and the 8.1 km/h (5.0 mph) decrease in mean speed on link **RV** (Painswick Road) were the only significant changes on single links.

No further traffic management measures were introduced on the nine links during 1997-98, and there was no change in overall mean speed during the period. None of the changes in speed on individual links during this period were found to be statistically significant.

The changes in the overall mean stop time on the nine links during the two survey periods were small and not statistical significant, although there were large changes in the stop time on some links. For example, the statistically significant reduction in the mean stop time on link **JK** (Trier Way) during 1996-97 coincided with the observed increase in mean speed. Large changes in stop time were recorded on link **RJ** (Painswick Road/Barton Street) during both periods, with highest mean values recorded in the 1996 and 1997 surveys. These high values coincide with an apparently high incidence of congestion, and this suggests that the results for this link may not provide a particularly accurate impression of the effects of the anti-skid surfacing.

Traffic flows also changed only slightly on most of the links with anti-skid surfacing. The only change that was greater than 5% was the increase of 16% on link **IQ** (Metz Way) during 1996-97. This change in flow was larger than

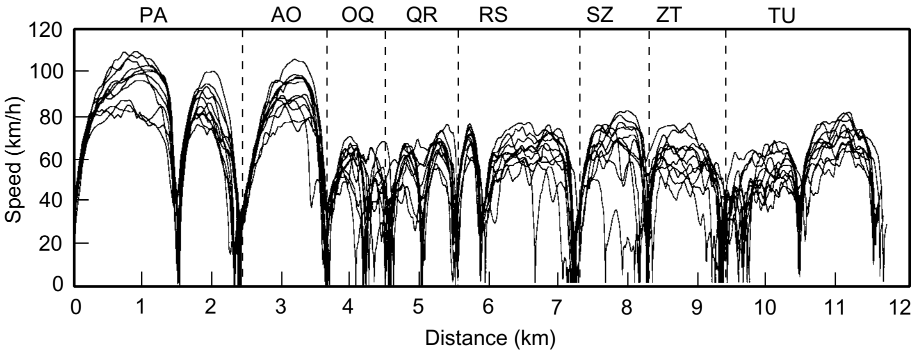


Figure 8 Driving cycles measured on route A4 during the 1996 survey

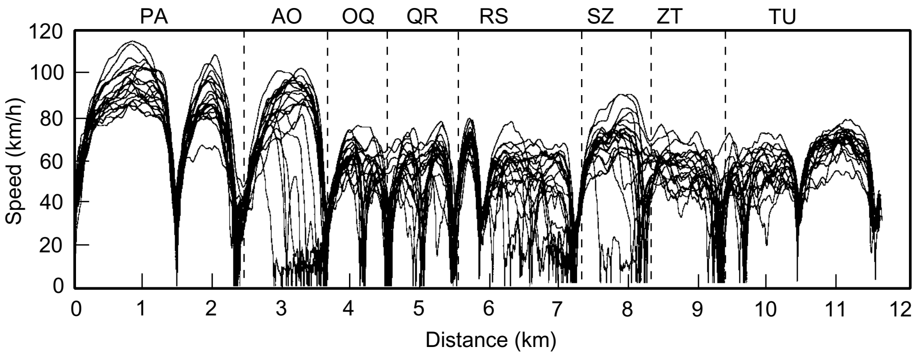


Figure 9 Driving cycles measured on route A4 during the 1997 survey

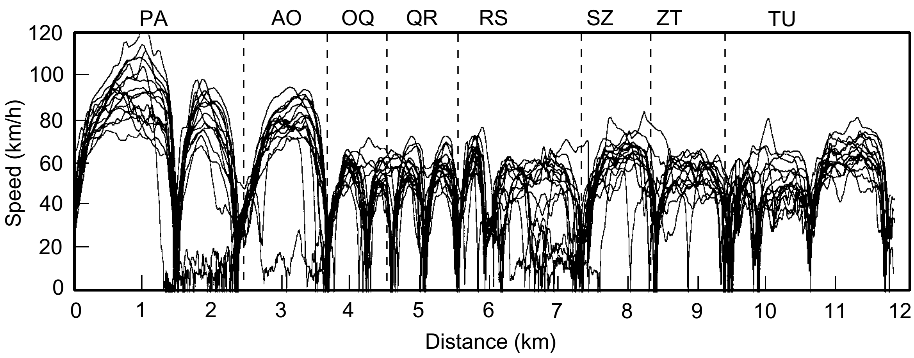


Figure 10 Driving cycles measured on route A4 during the 1998 survey

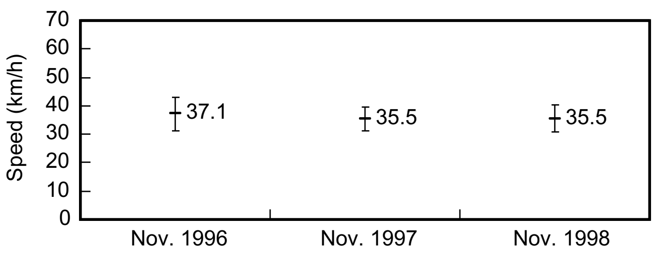


Figure 11 Mean speed: links where anti-skid surfacing was introduced

the typical errors associated with traffic counts (see Appendix E), which suggests that it was probably significant. However, it is not likely that the change was due to the introduction of the anti-skid surfacing.

3.1.2 Links with a gateway

For the eight links featuring a gateway, the overall mean speeds during each year of the study are shown in Figure 12. A gateway was also introduced on Cheltenham Road, but since a variety of traffic management measures were introduced on this road during 1997-98 the results have been treated separately.

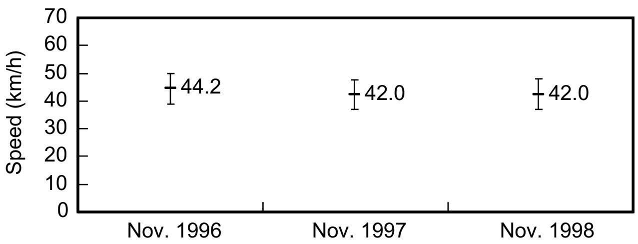


Figure 12 Mean speed: links where a gateway was introduced

Between the 1996 and 1997 surveys the overall mean speed on these links was reduced by 2.2 km/h (1.4 mph). On no individual link was the change in speed either greater than 5.0 km/h (3.1 mph) or statistically significant. The mean link speed remained unchanged between 1997 and 1998, again reflecting the fact that no further traffic management measures had been installed during this period.

Although at the gateways a red surface colouring was applied across the full width of the carriageway, the gateway signs were erected to that they could only be read in one direction of travel (*i.e.* entering the city). Roundels and 'dragons' teeth'[3] were also introduced on the inbound carriageway. It was therefore appropriate to separate the eight links according to the direction of travel. It was found that during the 1996-97 period the speed reduction on the inbound links (3.0 km/h / 1.9 mph) was slightly greater than that on the outbound links (1.5 km/h / 0.9 mph). However, during the 1997-98 period the speed on the outbound links dropped by a further 1.2 km/h (0.7 mph), whilst that on the outbound links increased by 1.3 km/h (0.8 mph).

Elsewhere, gateways have produced substantial speed reductions. For example, speed reductions ranging from 3mph to 13mph have been measured at gateways to villages on major roads (Wheeler and Taylor, 1999). However, downstream from the gateway these reductions can quickly be lost if other measures are not installed. Thus, the reductions in mean speed along the links featuring a gateway are not necessarily a reflection of the speed reductions achieved at the gateways in Gloucester.

There was little change in the overall mean stop time on these links between the 1996 and 1998 surveys. The largest stop times occurred on link **PO** (Barnwood Road/ Hucclecote Road), and again these high values coincided with a high incidence of congestion.

Traffic flows were recorded on four of the eight links. During 1996-97 the changes in flow ranged from 6% decrease on link **SY** (Stroud Road) to a 8% increase on link **PO**, though the average change was just +1%. No overall change in traffic flow on the four links was observed for the 1997-98 period.

3.1.3 Links with a roundabout

Between the 1996 and 1997 surveys, a roundabout was introduced on St. Oswald's in order to provide access to a new superstore. The roundabout was not a feature of the Safer City Project, but vehicle speeds on the link were measured coincidentally. The overall mean speeds for the two affected links during each year of the study are shown in Figure 13.

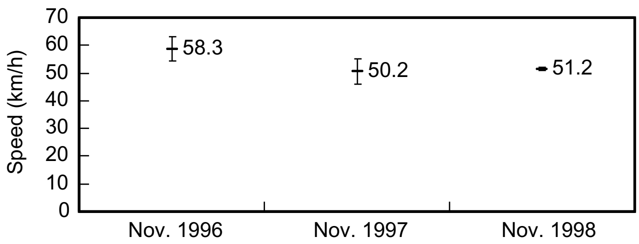


Figure 13 Means speed: links where a roundabout was introduced

As would be expected, the mean speed on the links dropped significantly after the introduction of the roundabout. The link speed recorded during in 1997 was 8.1 km/h (5.0 mph) lower than that recorded in 1996 survey, though the installation of temporary traffic lights on link **DF** (Over Causeway/St. Oswald's) during the 1997 survey may have enhanced the speed reduction. The change in speed was significant on both links. By the time of the 1998 survey the mean link speed had increased from the 1997 level by 1.0 km/h (0.6 mph), but this increase was not statistically significant.

The absolute changes in mean stop time on the two links were negligible, and no congestion was observed in any of the three surveys. No record of the traffic flow was obtained for the links affected.

3.1.4 Links with a speed camera

Speed cameras were activated on a total of five links, at locations on Bristol Road and Eastern Avenue, between February and April of 1997. The overall mean speeds for these links during each year of the study are shown in Figure 14. There was little overall change in mean link speed (-0.5 km/h / -0.3 mph) during the first period, and on no link was the change in speed significant. The mean speed on these links actually increased during the second year of the study. Although this increase was not statistically significant, it suggests that any localised speed reduction that the cameras might have effected had little impact on the mean speed over the entire links. Again, there was little absolute overall change in stop time on the five links between 1996 and 1998.

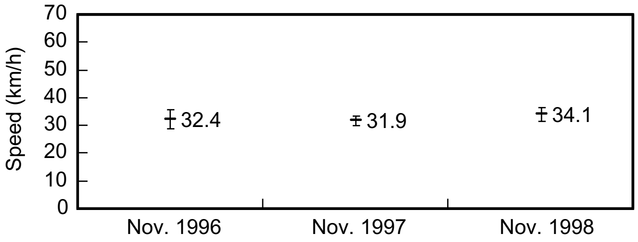


Figure 14 Mean speed: links where a speed camera was introduced

Although the mean overall stop time on the five links was low in each survey, larger changes in stop time were observed for individual links. Also, a small proportion of the links were affected by congestion in 1997 and 1998. Consequently, the actual effect of the cameras on vehicle speed was unclear.

Traffic flows were recorded on three of the five links. Between 1996 and 1997 there was a mean increase in flow of 3%, with little subsequent change in flow on the same links during the following year.

3.1.5 Links with pedestrian refuges

Pedestrian refuges were introduced on London Road (links **HN** and **NH**) between October 1996 and March 1997. The overall mean speeds for the two links during each year of the study are shown in Figure 15.

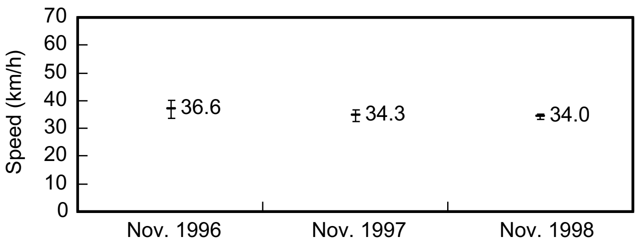


Figure 15 Mean speed: links where pedestrian refuges were introduced

There was a reduction in speed of 2.2 km/h (1.4 mph) on these links during 1996-97, and a slight further reduction during 1997-98. Neither of these changes in speed was statistically significant. Once again, stop time on the links was hardly affected and congestion effects were only slight.

Notable reductions in traffic flow were observed on link **NH** during both periods. The traffic flow recorded in 1997 was 13% lower than that recorded in 1996, and the flow was reduced by a further 24% in 1998. Both these changes are well outside the margin of error associated with traffic counts, but the reasons for the changes are not clear.

3.1.6 Links with carriageway narrowing combined with a cycle lane

The introduction of hatching, central refuges, and a cycle lane on Finlay Road in September 1997 resulted in the narrowing of the carriageway for motor vehicles. For the links **SR** and **RS,** which included Finlay Road, the effects on link speed are presented in Figure 16. During the 1996-97 period, anti-skid surfacing and speed cameras were also installed on these links.

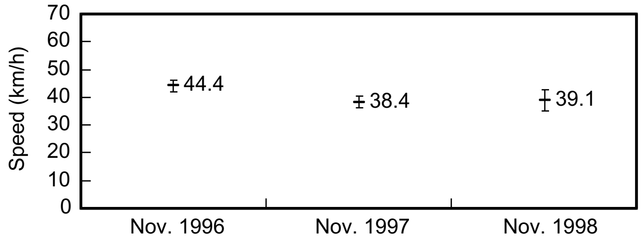


Figure 16 Mean speed: links where carriageway narrowing and a cycle lane were introduced

An average decrease in mean speed of 6.0 km/h (3.7 mph) was recorded for the two links, with the change in link speed being significant for **SR** but not for **RS**. The results presented in section 3.1.5 suggest that the refuges may have been responsible for around one third of this decrease. There was a small increase in speed in 1998. The stop time on each link was comparatively low in all three surveys, although on link **RS** congestion was observed on around 10% of the trips during 1997, and around 20% of the trips during 1998. This congestion will have contributed slightly to the speed reductions observed on the link during the two periods.

Traffic flow on the two links was reduced, on average, by around 4% in the first year of the study, and by a further 2% during the second year.

3.1.7 Links on Cheltenham Road

In March 1997 anti-skid surfacing was laid on Cheltenham Road. This was followed in September by the construction of a gateway. Between November 1997 and July 1998 a range of traffic calming and traffic management measures were introduced on the road. The measures included a raised pedestrian crossing, a set of speed cushions, a bus lane, cycle lanes, and modifications to traffic signals. The overall mean speeds for the two affected links, **BN** (inbound) and **NB** (outbound), measured during each year of the study are shown in Figure 17.

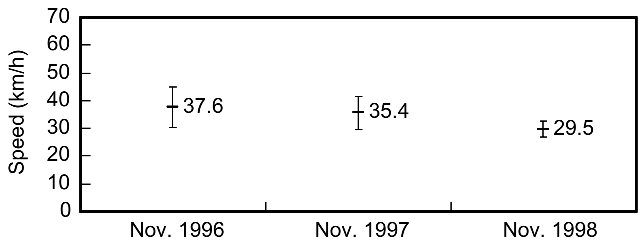


Figure 17 Mean speed: links on Cheltenham Road

On both links there was a substantial reduction in link speed between the first and third surveys. By the time of the 1998 survey, the mean link speed on **BN** had been reduced by around 10.4 km/h (6.5 mph) compared with the 1996 speed. On link **NB** the reduction in speed over the same period was 5.8 km/h (3.6 mph). The speed reductions were larger during the 1997-98 period than during the 1996-97 period. However, the changes in link speed between consecutive years were not significant at the 95% confidence level except for link **BN** during 1997-98. It is interesting to note that the speed reduction of 2.2 km/h (1.4 mph) during 1996-97, when a gateway was introduced, was identical to the mean speed reduction on other links featuring a gateway during the same period.

There were probably three main factors contributing to the larger speed reduction during the 1997-98 period:

- The introduction of more measures than during 1996-97.
- The introduction of measures that tend to have a larger speed-reduction effect (i.e. speed cushions and a raised pedestrian crossing) than those introduced during the 1996-97 period.
- The introduction of a pedestrian phase and conversion to 3-phase working at the traffic lights at the junction with Old Cheltenham Road.

In contrast with all the other types of link during the two study periods, a large overall increase in stop time was observed on the Cheltenham Road links during 1997-98. It appears that these increases in stop time contributed significantly to the reduction in mean link speeds. The stop time on the westbound link, **BN**, which tended to be small in 1996 and 1997, increased greatly (by 41 seconds) during 1997-98. On the eastbound link, **NB**, there was a more gradual increase in stop time (*i.e.* 8 seconds during 1996-97 and 12 seconds during 1997-98). It is likely that the increases in stop time on both links were mainly due to the changes to the traffic lights at the junction with Old Cheltenham Road. On the westbound link, changes in the road layout at the same junction, which included the introduction of a bus lane, may also have contributed to the sharp increase in stop time.

As with link speed and stop time, the changes in traffic flow were larger during the 1997-98 period than during the 1996-97 period. During the 1997-98 period traffic flow on each of the two links decreased by 11%. During the earlier period there was little change at all in traffic flow. The reduction in traffic flow during the 1997-98 period may have been due to drivers adopting alternative routes to avoid the traffic calming measures on Cheltenham Road.

3.1.8 Links with no measures

Between 1996 and 1998, no traffic management measures were installed on 46 of the links covered by the driving cycle surveys. The overall mean speeds for these links are shown in Figure 18.

During the 1996-97 period there was an overall reduction in mean link speed of 1.8 km/h (1.1 mph). A paired sample *t*-test showed this difference to be significant at the 95% confidence level. This reduction may be attributable, in part, to the publicity campaign to

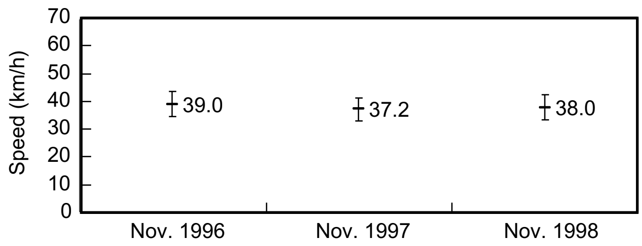


Figure 18 Mean speed: links with no measures

raise awareness of the Safer City Project. The magnitude of the changes ranged from a decrease of 10.6 km/h (6.6 mph) on link **CD** (Gloucester Northern Bypass), to a 6.3 km/h (3.9 mph) increase on link **KL** (Trier Way), although for these two links the changes in speed were not statistically significant. The links where significant changes in overall mean speed had occurred were **AP** (Barnwood Bypass), **DC** (Gloucester Northern Bypass), **GH** (Black Dog Way), and **XS** (Stroud Road).

During the 1997-1998 period there was an overall increase in mean link speed of 0.8 km/h (0.5 mph). This change was not significant at the 95% confidence level. The changes ranged from a decrease of 8.3 km/h (5.2 mph) on link **HG** (London Road), to a 20.6 km/h (12.8 mph) increase on link **CB** (Gloucester Northern Bypass). For these two links the changes in speed were statistically significant. Other links where significant changes in overall mean speed had occurred were **AP** (Barnwood Bypass), **HI** (Bruton Way), **JI** (Bruton Way), **KJ** (Trier Way), and **LK** (Trier Way).

If the general changes in speed on unaffected links were to be taken into account when considering the net effects of the traffic safety or traffic management measures on other links, it could be argued that speeds were only reduced substantially on the links where the measures were either relatively severe or occupied long sections of road. That is to say, during 1996-97 substantial reductions only occurred on links with a roundabout and links with carriageway narrowing combined with a cycle lane, and during 1997-98 substantial reductions in speed only occurred on the Cheltenham Road links.

Congestion and stop time effects were important on only a small proportion of the links.

Traffic flows were recorded on 22 of the 46 links during 1996 and 1997, and 20 links during 1998. During 1996-97 the changes in flow ranged from a 21% increase on **GF** (Worcester Street/Kingsholm Road) to a 21% decrease on **ON** (Barnwood bypass). On average, there was 1% increase in traffic flow. During 1997-98 there was again an overall average increase in traffic flow of just 1%. The largest change (+44%) was again on link **ON**. This suggests that the 1997 traffic count on this link may have been erroneous.

3.2 City-wide speed and traffic flow

The evolution of overall traffic speed in the Gloucester was estimated using the speed index described in Section 2.3. The results for link **ON** were excluded from the calculation because of reason cited above. The use of this index revealed that the overall speed in the city decreased from 35.4 km/h (22.0 mph) in 1996 to 34.1 km/h (21.2 mph) in 1997, and then decreased slightly again in 1998 to 33.9 km/h (21.0 mph).

An estimate of the overall changes in traffic volume in the city of Gloucester during the three years of the study was obtained by summating the traffic flow measurements for the links were it had been recorded in every year of the study. The flows on links **MG** and **GM** were not recorded in 1998 because of pedestrianisation, and therefore these two links were not included in this analysis. As with speed index, link **ON** was also excluded.

There was found to be little overall change in the total traffic flow recorded. During the 1996 survey the total daily flow on all the links was 433,653, and in 1997 it was 428,683. This represented an overall decrease of 1.1% during 1997. The level of traffic recorded during the 1998 survey was 428,088, which equated to a further decrease of just 0.1% on the 1997 level.

4 Emissions

This Chapter of the Report contains the results of the emission modelling exercise. The calculation of emissions on a given link was either a one-step or two-step process, depending upon the level of information available. For all 76 links where driving cycles had been recorded, emissions from LDVs in each year were estimated using the cycles measured in those years as an input to the MODEM model. For 1996 and 1997 the composition of the LDV fleet was determined from national registration statistics. The proportion of LDVs in each category during 1998 was estimated by extrapolating the trend in the registration statistics between 1996 and 1997. Emissions from HDVs were calculated using empirical emission functions for heavy goods vehicles relating to average link speed (Hickman, 1996). For the sub-sample of 41 links where traffic flow and composition had been recorded, daily emissions from traffic during each year of the study were estimated by weighting the emissions from LDVs and HDVs by the traffic flow and composition.

The weekday emissions from traffic on the 41 links where flow was recorded in the three survey years, and the changes in mean speed between successive surveys, are presented for each of the link types in Appendix F. In order to provide a broad impression of how emissions from traffic in the city are changing, the emissions on these links have been summated. The changes in city-wide emissions are presented in Section 4.1. The results are presented by link type in Section 4.2. In addition, the relative contributions of changes in driving pattern, changes in traffic flow, and changes in vehicle fleet composition to the overall changes in emissions from LDVs and HDVs were estimated for each link type, pollutant, and period.

For the 34 links where driving cycles were recorded but no traffic counts were conducted, no estimate of emissions from traffic could be made. Emissions per LDV and per HDV on these links were analysed by link type, though the links mainly covered roads where no measures had been introduced. In fact, in terms of the overall effects of changes in driving pattern and LDV fleet composition on emissions for each link type, there were no major differences between the results for these links and the results for the links where flow was recorded.

4.1 City-wide emissions from traffic

Figures 19 to 22 show the total weekday emissions of CO, HC, NO_x, and CO_2 from traffic on 41 of the 42 links where flow was recorded in each year of the study. Link **ON** was again excluded from the calculation. The LDV and HDV contributions to each total are also indicated.

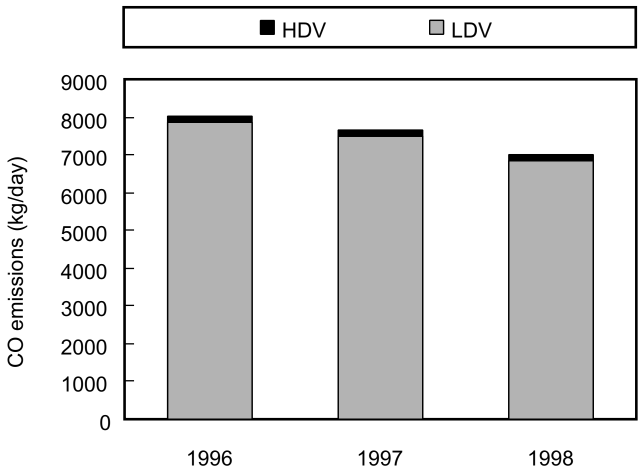


Figure 19 Total weekday emissions of CO on selected links in the city of Gloucester

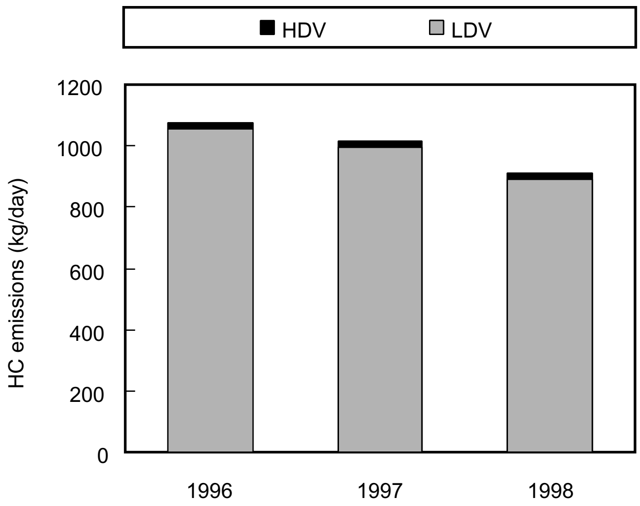


Figure 20 Total weekday emissions of HC on selected links in the city of Gloucester

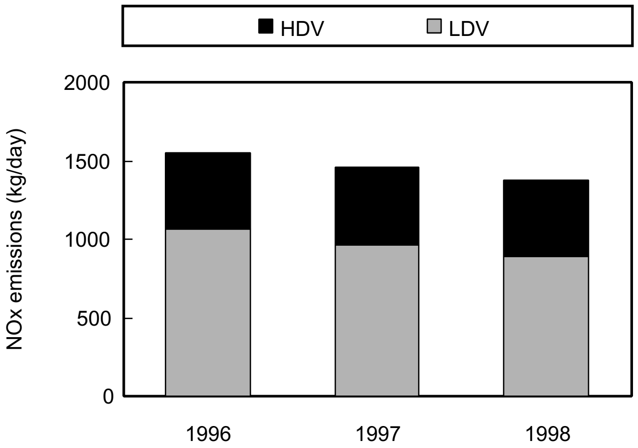


Figure 21 Total weekday emissions of NO_X on selected links in the city of Gloucester

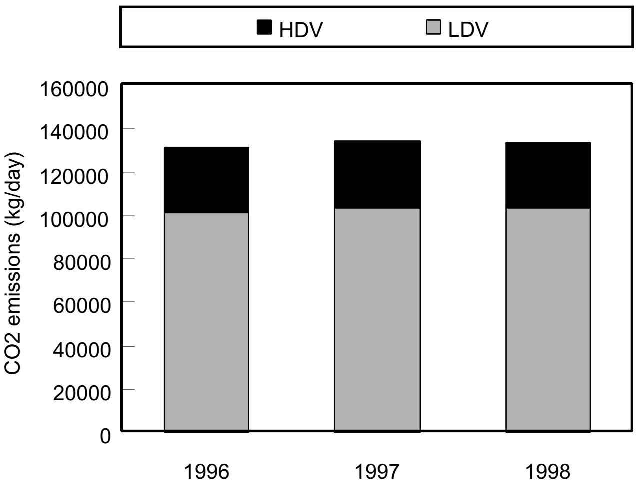


Figure 22 Total weekday emissions of CO_2 on selected links in the city of Gloucester

It was reported in Section 3.2 that the total recorded volume of traffic in the city fell slightly between 1996 and 1998. However, it can be seen from Figures 19 to 21 that, despite the small changes in traffic flow, emissions of CO, HC, and NO_x decreased noticeably between 1996 and 1998. This was due principally to the introduction of more catalyst-equipped vehicles into the light-duty fleet.

During the 1996-97 period, total weekday emissions of CO on the 41 links were reduced by 360 kg/day. This equated to an average reduction in weekday CO emissions of 4%. The equivalent absolute and percentage reductions in emissions of HC and NO_x during the same period were 60 kg/day (6%) and 88 kg/day (6%) respectively. During the 1997-98 period emissions of CO were reduced from the 1997 level by a further 8%. Emissions of both HC and NO_x were reduced from their 1997 levels by a further 6%.

Total emissions of CO_2 were 2973 kg/day higher in 1997 than in 1996, though this equated to an increase of less than 2.3%. During the 1997-98 period, emissions of CO_2 decreased by around 1%.

From Figures 19-22 it is clear that heavy-duty vehicles were responsible for a large proportion of NO_x and CO_2 emissions (around 34% for NO_x and 23% for CO_2) but only a small proportion (around 2%) of CO and HC emissions. HDVs are generally powered by heavy-duty diesel engines, which tend to have relatively low CO and HC emissions. Given that HDVs formed only between 3% and 5% of the traffic flow on most links, it is not surprising that they contributed only a small fraction of the total emissions of these pollutants. On the other hand, heavy-duty engines consume large amounts of fuel and therefore emit much more CO_2 than light-duty engines. They also operate under relatively high loads, which tends to result in elevated levels of NO_x. As a result, the HDV contributions to total CO_2 and NO_x emissions were disproportionately large.

4.2 Emissions from traffic by link type

4.2.1 Links with anti-skid surfacing

The mean changes in weekday emissions from vehicles and traffic on links with anti-skid surfacing are shown in Table 6.

Table 6 Mean changes in weekday emissions on the nine links with anti-skid surfacing during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo-sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-4**	+3	+6	+1	+5	-7
HC	**-5**	+4	+5			-9
NO_x	**-4**	-2	+3			-8
CO_2	**+4**	+1	+2			+1
1997-98						
CO	**-7**	-1	0	+1	+2	-8
HC	**-8**	0	+5			-9
NO_x	**-4**	0	0			-8
CO_2	**+2**	-1	+1			+1

NB *Shading indicates the period during which the measures were introduced.*

The numbers in the table require some explanation. The mean overall change in emissions of each pollutant from traffic on links of this type is shown in bold alongside the pollutant. This mean value is calculated only for the links where traffic flow was recorded. Between 1996 and 1997, emissions of CO, HC, and NO_x from traffic on links with anti-skid surfacing decreased, on average, by 4-5%, and emissions of CO_2 increased by 4%. Between 1997 and 1998 emissions of CO, HC, and NO_x were reduced by a further 7%, 8%, and 4% respectively. CO_2 emissions increased by 2% from their 1997 level.

The values in the columns to the right of the 'mean change' column relate to the estimated impacts of the observed changes in driving pattern, vehicle flow, and fleet composition on emissions per LDV and HDV. These values provide a rough estimate of the extent to which changes in each of these factors contributed to the overall changes in traffic emissions. The values are unweighted for the numbers of LDVs and HDVs present, and so they must be considered in the context of their relative source strengths (*i.e.* HDVs were responsible, on average, for 2% of CO and HC emissions, 34% of NO_x emissions, and 23% of CO_2 emissions). The effects of driving pattern and fleet composition have been calculated as mean values for all links of the type considered, not just those where traffic flow was recorded.

For example, emissions of CO from traffic on links with anti-skid surfacing were 7% lower in 1998 than in 1997. During the same period, emissions of CO from LDVs would have been reduced by 1% just as the result of the changes in driving pattern. This 1% change relates to a hypothetical situation where the LDV fleet composition[4] and traffic flow remained stable during the year. For HDVs, the changes in driving pattern alone had no effect on CO emissions from these vehicles. The 1% increase in the flow of LDVs would have translated directly to a 1% increase in CO emissions from LDVs, and the same principle applies to the 2% increase in the flow of HDVs. The last column represents the change in LDV emissions that resulted solely from the changes in LDV fleet composition (*i.e.* the introduction of more catalyst-equipped vehicles). This relates to a situation (again hypothetical) where the driving cycles[5] and traffic flow did not change during the year. Clearly, the 8% decrease in LDV CO emissions resulting from changes in the fleet was the main determinant of the overall change in CO during the period. The composition of the HDV fleet was assumed to have remained stable during the study, and therefore there is no corresponding column for these vehicles.

In general, during the 1996-97 period the changes in driving pattern and traffic flow would have tended to cause emissions to increase slightly. However, for CO, HC, and NO_x the changes in the composition of the LDV fleet outweighed these factors and resulted in a net overall decrease. A similar trend can be observed in the results for the 1997-98 period. However, the driving pattern effects were generally negligible. This is not surprising, since no change was observed in the overall mean speed for this link type during the 1997-98 period.

4.2.2 Links with a gateway

The mean changes in weekday emissions from traffic on four links with a gateway are shown in Table 7. The results were similar to those for links with anti-skid surfacing. For LDVs the effect on changes in driving patterns on emissions of each pollutant was never greater than 3%, and traffic flow hardly changed at all. The reductions in emissions of CO, HC, and NO_x during 1997-98 were again due principally to the introduction of newer technology vehicles.

4.2.3 Links with a roundabout

Traffic flows were not recorded for the two links on the road where the roundabout was installed. Consequently, daily emission rates from traffic are not available. The changes in emissions from LDVs and HDVs are presented in Table 8.

Between 1996 and 1997 the introduction of the roundabout had a notable impact on emissions from HDVs.

Table 7 Mean changes in weekday emissions on the four links with a gateway during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo-sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-4**	+2	+7	+1	+1	-7
HC	**-5**	+3	+7			-9
NO_x	**-5**	-2	+4			-8
CO_2	**+1**	0	+4			+1
1997-98						
CO	**-10**	+1	-4	0	0	-8
HC	**-11**	+1	-4			-9
NO_x	**-6**	0	-2			-8
CO_2	**+5**	0	-3			+1

NB *Shading indicates the period during which the measures were introduced.*

Table 8 Mean changes in weekday emissions on the two links with a roundabout during1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo-sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**N/A**	+9	+27	N/A	N/A	-7
HC	**N/A**	+13	+21			-9
NO_x	**N/A**	-1	+10			-8
CO_2	**N/A**	+4	+11			+1
1997-98						
CO	**N/A**	0	-3	N/A	N/A	-7
HC	**N/A**	-1	-2			-9
NO_x	**N/A**	+1	-1			-8
CO_2	**N/A**	-1	-1			+1

NB Shading indicates the period during which the measures were introduced.

N/A = Not available.

The reduction in speed on the two links resulted in increases in CO and HC emissions per heavy-duty vehicle of more than 20%, though the data presented in Figures 19 and 20 suggest that this would not have affected emissions of these pollutants from traffic significantly. On the other hand, the increases in NO_x and CO_2 of around 10% may have had a significant impact on emissions of these pollutants from traffic. The reduction in speed had a smaller impact on LDV emissions, though CO and HC emissions per vehicle increased by 9% and 13% respectively.

Between 1997 and 1998 the change in the composition of the LDV fleet was a probably more significant factor than changes in the driving patterns in terms of the overall effect on emissions of CO, HC, and NO_x.

4.2.4 Links with a speed camera

The mean changes in weekday emissions from traffic on links with a speed camera are shown in Table 9.

Table 9 Mean changes in weekday emissions on the three links with a speed camera during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo -sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-2**	+2	+5	+3	+7	-7
HC	**-3**	+2	+6			-9
NO_x	**-1**	0	+3			-8
CO_2	**+7**	+2	+4			+1
1997-98						
CO	**-12**	-3	-4	0	-7	-8
HC	**-14**	-4	-5			-9
NO_x	**-8**	-1	-3			-8
CO_2	**-5**	-3	-3			+1

NB Shading indicates the period during which the measures were introduced.

The speed cameras had little effect on link speed, and this is reflected in the small changes in emissions associated with driving pattern effects during the relevant period. Between 1996 and 1997 emissions of CO, HC and NO_x from traffic on the affected links were reduced by 1-3%. This was due mainly to the change in LDV fleet composition.

During 1997-98, the combined effects of reduced emissions per vehicle, reduced or stabilised traffic flow, and changes in LDV fleet composition resulted in overall reductions in the emissions of CO, HC, NO_x, and CO_2 of 12%, 14%, 8% and 5% respectively.

4.2.5 Links with pedestrian refuges

The mean changes in weekday emissions from traffic on links with pedestrian refuges are shown in Table 10. These two links were associated with some of the largest changes in traffic emissions during both periods of the study. This was due to the reductions in emissions arising from an increase in the proportion of catalyst-equipped LDVs being coupled with reductions in traffic flow. Driving pattern effects were less important.

4.2.6 Links with carriageway narrowing combined with a cycle lane

The mean changes in weekday emissions from traffic on the two links incorporating both carriageway narrowing (hatching/central refuges) and a cycle lane are shown in Table 11.

Table 10 Mean changes in weekday emissions on the two links with pedestrian refuges during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo -sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-11**	+4	+7	-7	-7	-8
HC	**-13**	+4	+7			-9
NO_x	**-12**	-1	+4			-8
CO_2	**-4**	+3	+4			+1
1997-98						
CO	**-19**	+2	+1	-15	-15	-8
HC	**-20**	+3	+1			-10
NO_x	**-19**	0	+1			-8
CO_2	**-13**	+1	+1			+1

NB Shading indicates the period during which the measures were introduced.

Table 11 Mean changes in weekday emissions on the two links with carriageway narrowing combined with a cycle lane during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo -sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-2**	+9	+19	-2	-20	-7
HC	**-1**	+11	+19			-9
NO_x	**-13**	-3	+10			-8
CO_2	**-2**	+4	+11			+1
1997-98						
CO	**-8**	+1	+2	-2	+1	-8
HC	**-9**	+1	+3			-9
NO_x	**-9**	-2	+2			-8
CO_2	**-2**	-1	+2			+1

NB Shading indicates the period during which the measures were introduced.

The changes in driving pattern during the 1996-97 period caused emissions of CO and HC per LDV to increase by 9% and 11% respectively, with NO_x and CO_2 being affected to a lesser extent. For HDVs the changes in driving pattern resulted in increases in CO and HC emissions of almost 20%, and increases in NO_x and CO_2 emissions of around 10%. For CO and HC it appears that these changes in emissions per LDV and HDV were effectively cancelled out by the change in LDV fleet composition over the period. Although the flow of HDVs was reduced by 20%, this appears to have had little effect on emissions of these pollutants from traffic. However, the reduction in HDV flow may well have been a significant contributor the 13% reduction in NO_x emissions from traffic. The effects on emissions of changes in driving pattern were considerably smaller during 1997-98, and the most significant changes in emissions of CO, HC, and NO_x again resulted from the changes in the LDV fleet.

4.2.7 Links on Cheltenham Road

The mean changes in weekday emissions from traffic on links on Cheltenham Road are shown in Table 12.

Table 12 Mean changes in weekday emissions on the two links on Cheltenham Road during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow*		*LDV fleet compo -sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-5**	+2	+7	+1	-1	-7
HC	**-6**	+3	+7			-9
NO_x	**-7**	-3	+4			-8
CO_2	**+1**	0	+4			+1
1997-98						
CO	**-9**	+10	+18	-11	+1	-8
HC	**-11**	+10	+22			-9
NO_x	**-11**	-2	+11			-8
CO_2	**-1**	+6	+13			+1

NB Shading indicates the periods during which the measures were introduced.

The results for Cheltenham Road stand out since the adverse impacts of changes in driving pattern on CO and HC emissions during the 1997-98 period were greater than for any other link type. Emissions of CO and HC per LDV increased by 10%, and emissions of CO_2 per LDV increased by 6%. Emissions of NO_x per LDV were not affected substantially. For HDVs, emissions of CO and HC per vehicle increased by 18% and 22% respectively, NO_x emissions per vehicle increased by 11%, and CO_2 emissions per vehicle increased by 13%. Nevertheless, these changes were outweighed by the combined effects of changes in the LDV fleet and a reduction in traffic flow.

4.2.8 Links with no measures

The mean changes in weekday emissions from traffic on links with no measures are shown in Table 13. In the calculation of mean vehicle flows, link **ON** was excluded due to suspect traffic counts, and links **GM** and **MG** were excluded because no data existed for 1997-98 due to the pedestrianisation of the town centre.

These results give a broad indication of the changes in emissions that would probably have occurred on most other links if no measures had been introduced. As with the speed results presented in the previous Chapter, the results for the unaffected links could be used to indicate the sensitivity of the method used.

Table 13 Mean changes in weekday emissions on the nineteen links with no measures during 1996-97 and 1997-98 periods

		Contributing factors (% impact on emissions for vehicle type)				
	Overall mean change in emissions	*Driving pattern*		*Vehicle flow[1]*		*LDV fleet compo -sition*
Pollutant	*(%)*	*LDV*	*HDV*	*LDV*	*HDV*	
1996-97						
CO	**-5**	+4	+6	0	-2	-7
HC	**-7**	+5	+6			-9
NO_x	**-6**	-1	+3			-8
CO_2	**+2**	+2	+3			+1
1997-98						
CO	**-6**	+2	0	-1	+2	-8
HC	**-8**	+1	+1			-9
NO_x	**-3**	+2	0			-8
CO_2	**+3**	+1	+1			+1

*1 Excluding links **ON, GM**, and **MG.***

For example, for the 1996-97 period the changes in driving pattern alone on links with no measures resulted in increases in CO and HC emissions per LDV of 4% and 5% respectively, a decrease in NO_x emissions per LDV of 1%, and an increase in CO_2 emissions per LDV of 2%. Emissions of CO and HC per HDV increased by 6%, and emissions of NO_x and CO_2 per HDV increased by 3%. It could be argued that the effects on emissions of each pollutant per vehicle of the anti-skid surfacing, gateways, speed cameras, and pedestrian refuges installed during this period were similar to the effects on links with no measures, and that therefore the effect of there measures were negligible.

During the 1997-98 period the driving pattern effects on links with no measures were negligible, although the only links where any substantial impact could be observed were those on Cheltenham Road.

5 Summary and discussion

5.1 The Safer City Project

In December 1995 Gloucestershire County Council was awarded £5m by the Department of the Environment, Transport and the Regions to reduce the number of road casualties in Gloucester by implementing a coherent range of traffic management and traffic safety measures according to a well-defined strategy. The strategy became known as the Safer City Project.

TRL is monitoring the environmental impacts of the Safer City Project, and the main objective of the work in the air pollution area is to achieve an understanding of the effects on road traffic emissions of the different safety and traffic management schemes. Detailed surveys of passenger car driving cycles, traffic flow, and traffic composition are being made to assess the changes in emissions along a sample of roads in Gloucester which are likely to be affected. These surveys are being repeated at annual intervals and this Report presents the results of the first three. These were conducted in November of 1996, 1997, and 1998. The 1999 survey has also been completed but the results are not yet available. Further surveys are planned for 2000, 2001, and 2002.

During the period between the 1996 and 1997 surveys a range of measures were introduced in various parts of the city. The measures were generally small in scale and typified by localised effects on traffic. The main exception was an area-wide traffic calming scheme in Elmbridge. However, because the measures in Elmbridge were installed on residential and local distributor roads they were not covered during the TRL surveys. During the 1997-98 period, work on the Safer City Project mainly concentrated on two schemes: an area-wide traffic calming scheme in the Longlevens area, and the pedestrianisation of Northgate and Southgate in the town centre.

5.2 Methodology

A link-based approach was used to estimate the evolution of vehicle speeds, traffic flows, and exhaust emissions from vehicles and traffic in the city. Representative driving cycles and traffic flows were used in conjunction with a state-of-the-art emissions model.

5.2.1 Driving cycle and traffic flow measurements

The main experimental work in Gloucester involved the determination of a range of driving cycles that were representative of driver behaviour on 76 selected links. These links covered most of the main roads in the city area. In each year of the study, the speed data were collected during two-week surveys in which an instrumented car was driven in the traffic.

Automatic traffic flow measurements and 12-hour (07:00-19:00) manual classified counts were made by TRL and Gloucester City Council (on behalf of TRL) at a number of locations in the area. In total, traffic flow measurements were available for 44 of the links covered by the 1996 and 1997 driving cycle surveys, and 42 of the links covered by the 1998 survey. The traffic counts were mostly conducted during a two week period in November of each year which coincided with the timing of the driving cycle surveys. Average 24-hour weekday flows were determined, and the manual classified counts were used to determine the heavy-duty vehicle proportion of the traffic flow.

The mean speed of each driving cycle on a link was calculated from the length of the link and the time taken to travel along it. The resulting values were again averaged to give an overall mean speed for the link. The links studied were arranged into the following groups according to the main (or only) type of traffic management measure that was implemented between the 1996 and 1997 surveys:

- Links with anti-skid surfacing alone.
- Links with a gateway.
- Links with a roundabout.
- Links with a speed camera.
- Links with pedestrian refuges.
- Links with carriageway narrowing combined with a cycle lane.

On two links, **BN** and **NB** on Cheltenham Road, measures were introduced during both the 1996-97 and 1997-98 periods. Particularly during the latter period, a broad range of traffic calming and traffic management measures appeared. Consequently, the results for these links have been reported in a separate ‘Cheltenham Road’ category. A sample of links on which no traffic management measures had been introduced was also considered.

Changes in overall mean speed were determined for each link type. The ‘stop time’ (*i.e*. the length of time that a vehicle is stationary as a result of waiting at traffic lights, waiting for pedestrians, or involved in conflicts with other vehicles) was also calculated for each link and link type. As further aids to understanding the changes in speed on different links, the date sheets compiled by the navigators and graphs depicting the driving cycles were examined to assess the significance of the effects of congestion and road works.

In addition, the annual changes in city-wide speeds and traffic flows have also been documented. The overall mean speed of traffic in the city during each survey year was calculated using a speed index which accounted for both the average speed and average flow of the traffic on each link.

5.2.2 Emission modelling

In order to determine the overall effects on emissions of the changes in the traffic conditions encountered on each link studied in Gloucester, it was necessary to account for changes in traffic flow and the vehicle fleet, as well as changes in the emissions performance of vehicle types resulting from changes in driving pattern. However, the limited availability of emissions data for some vehicle categories (*e.g*. buses and light-duty goods vehicles) imposed restrictions on the estimation of emissions from traffic. Vehicles were therefore simply separated into two generic groups: light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs).

The calculation of emissions on each link was either a one-step or two-step process, depending upon the level of information available. For all 76 links where driving cycles had been recorded, emissions from LDVs in each year were estimated using the driving cycles measured in those years as an input to the MODEM emission model. Emissions from HDVs were calculated using empirical emission functions for heavy goods vehicles relating to average link speed. For the sub-sample of around 40 links where traffic flow and composition had been recorded, daily emissions from traffic during each year of the study were estimated by weighting the emissions from LDVs and HDVs by the traffic flow and composition.

As the MODEM model provides results for twelve different vehicle categories, large amounts of emission data can rapidly be generated. In order to simplify the presentation of the emission rates of LDVs in these different emission categories, a ‘composite’ vehicle was defined. This composite vehicle reflected the composition of the LDV fleet in terms of the categories of emission control, fuel type, and engine size used in MODEM. The emission rate of the composite vehicle on each link was determined by weighting the predicted emission rate for each MODEM category by the proportion of the national LDV fleet in the same category.

For 1996 and 1997 the composition of the LDV fleet was determined from national registration statistics. The proportion of LDVs in each category during 1998 was estimated by extrapolating the trend in the registration statistics between 1996 and 1997. The gradual phasing-in of catalyst-equipped petrol vehicles was an important factor in the analysis. In 1996 these vehicles formed 24% of the LDV fleet, and by 1997 the proportion had risen to 30%. By extrapolating the 1996-97 data it was estimated that by 1998 around 36% of LDVs were equipped with a catalyst. These increases in the proportion of vehicles equipped with a catalyst were mirrored by decreases in the proportion of non-catalyst petrol vehicles. The proportion of diesel vehicles increased from 9% to 11% between 1991 and 1998.

The emission calculation covered four pollutants: carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), and carbon dioxide (CO_2). Consideration was only given to 'hot' exhaust emissions (*i.e*. those emissions produced when an engine is at its normal operational temperature); the study did not account for exhaust emissions due to cold starts or evaporative emissions - both of which are likely to be significant in an urban area such as Gloucester.

For each type of link, an assessment was made of the relative importance of different factors contributing to the changes in traffic emissions. In order to examine the evolution of emissions from traffic on a city-wide basis, the daily emissions of each pollutant were summated over the links where flow was measured.

5.3 Vehicle speed and traffic flow

In general, the changes in mean speed along most individual links were quite small; on only one link did the 1997 mean speed differ from the 1996 mean speed by more than 10.0 km/h (6.2 mph), and for around three quarters of the links the change in mean speed during the 1996-97 period was less than 5.0 km/h (3.1 mph). For three quarters of all links there was a reduction in speed, and an increase in speed was recorded on the remainder. The 1998 speed differed from the 1997 speed by more than 10.0 km/h on just 3 links, and the speed change was less than 5.0 km/h for over 80% of the links. There was a decrease in speed during this period on half of all links, and an increase in speed on the other half.

Following the introduction of any type of traffic management or traffic safety measure, there was a decrease in the mean speed recorded along the affected links. On links where either anti-skid surfacing, a gateway, a roundabout, pedestrian refuges, or carriageway narrowing combined with a cycle lane had been introduced during 1996-97, the resulting speed reduction was maintained during 1997-98.

The extent of the speed reduction effected by the introduction of measures was dependent upon the type of measure. Link speeds were reduced by around 2 km/h (1 mph) where the measures were least severe (*i.e.* the anti-skid surfacing, the gateways, and the pedestrian refuges), and by around 6-8 km/h (4-5 mph) where the measures were either more severe or occupied long sections of road (*i.e.* the roundabout, the carriageway narrowing combined with a cycle lane, and the measures introduced on Cheltenham Road).

However, during 1996-97 it was found that there was also a decrease in mean link speed of 1.8 km/h (1.1 mph) on unaffected links, and during the 1997-98 period the mean speed on unaffected links increased by 0.8 km/h. The reduction in speed on unaffected links during 1996-97 may have been due, in part, to the initial publicity campaign to raise awareness of the Safer City Project. If these general changes in speed on unaffected links were to be taken into account when considering the net effects of the traffic safety or traffic management measures on other links, it could be argued that speeds were only reduced substantially on the links where the measures were either relatively severe or occupied long sections of road. For example, during 1996-97 the reductions in speed would only have been substantial on links with a roundabout and links where carriageway narrowing was combined with a cycle lane. During 1997-98 a substantial reduction in speed was only observed on the Cheltenham Road links .

Along the links affected by the introduction of speed cameras the reduction in mean speed during 1996-97 was only slight, and was actually followed by an increase in speed during 1997-98. However, in this study the links on which the cameras were installed were several kilometres long. A more localised speed-reduction effect may have occurred, but this would have had little impact on the mean speed over an entire link. In addition, some congestion and reasonably large changes in stop time were observed on some of the affected links. Consequently, the actual effect of the cameras on vehicle speed was unclear.

Changes in stop time were not a particularly important determinant of changes in the overall mean speed for the types of link studied and the periods covered except, perhaps, for the two Cheltenham Road links during 1997-98, where changes were made to the phasing of the traffic lights at the junction with Old Cheltenham Road. On the westbound link, changes in the road layout at the same junction, which included the introduction of a bus lane, may also have contributed to the increase in stop time of 41 seconds.

On the whole, few links were seriously affected by road works or congestion.

On around two thirds of the links where traffic flow had been recorded in the 1996 and 1997 surveys, the change in flow was less than 10%. A reduction in traffic flow was observed on 60% of the link. Similar statistics describe the changes in flow between 1997 and 1998. Again, for around two thirds of the links where traffic flow had been recorded the change in flow was less than 10%. A reduction in traffic flow was observed on half of the links.

For the various link types, changes in traffic flow of more than 10% were only observed in a few cases; on links with pedestrian refuges there was a 15% decrease in flow between 1997 and 1998, and on the Cheltenham Road links there was an 11% decrease in flow between 1997 and 1998. It is likely that the changes in flow were related to the introduction of traffic safety or traffic management measures only for the Cheltenham Road links. Overall traffic flow on links with no measures hardly changed.

The overall speed in the city calculated using the speed index decreased from 35.4 km/h (22.0 mph) in 1996 to 34.1 km/h (21.2 mph) in 1997, and then decreased slightly again in 1998 to 33.9 km/h (21.0 mph). There was found to be little overall change in the total traffic flow recorded.

5.4 Emissions

The changes in driving pattern effected by the introduction of traffic management or traffic safety measures on a link tended to result in increases in emissions of CO, HC, and CO_2 *per LDV*, with NO_x emissions changing only slightly. There was also a tendency for emissions of all four pollutants *per HDV* to increase after the introduction of measures. The largest increases in emissions per vehicle (particularly for CO and HC) were observed for the links where the largest reductions in link speed had occurred. Consequently, in this study the largest increases in emissions per vehicle were observed for the links where a roundabout was introduced during 1996-97, the links where carriageway narrowing combined with a cycle lane was introduced during 1996-97, and for the Cheltenham Road links where various traffic safety and traffic management measures where introduced during 1997-98.

For the links with a roundabout and the links with carriageway narrowing combined with a cycle lane during the 1996-97 period, emissions of CO per LDV increased by 9% and emissions of HC per LDV increased by 11-13%. NO_x emissions per LDV decreased by 1-3%, and CO_2 emissions per LDV increased by 4% On links with a roundabout CO emissions per HDV increased by 27%, and on links with carriageway narrowing combined with a cycle lane CO emissions per HDV increased by 19% On the two types of link, emissions of HC per HDV increased by around 20%, and emissions of NO_x and CO_2 per HDV increased by around 10%.

As with vehicle speed, these changes can be compared with the changes in emissions per vehicle on unaffected links during the same period. The changes in driving pattern alone on links with no measures resulted in increases in CO and HC emissions per LDV of 4% and 5% respectively, a decrease in NO_x emissions per LDV of 1%, and an increase in CO_2 emissions per LDV of 2%. On the unaffected links, emissions of CO and HC per HDV increased by 6%, and emissions of NO_x and CO_2 per HDV increased by 3%. Again, it could be argued that the net effects on emissions per vehicle of the anti-skid surfacing, gateways, speed cameras, and pedestrian refuges installed during this period were similar to the effects on links with no measures, and therefore effectively negligible. Similar reasoning would also suggest that the effects of the roundabout and carriageway narrowing with a cycle lane on emissions per LDV were small for CO and HC, and negligible for NO_x and CO_2. The net effects of the roundabout and the carriageway narrowing combined with a cycle lane on emissions of CO and HC per HDV were larger than those for LDVs, but the net effects on emissions of NO_x and CO_2 per HDV were similar to those for LDVs.

For the Cheltenham Road links during the 1997-98 period, emissions of CO and HC per LDV increased by 10%, and emissions of CO_2 per LDV increased by 6%. Emissions of NO_x per LDV decreased by 2%, and emissions of CO_2 per LDV increased by 6%. For HDVs, emissions of CO and HC per vehicle increased by 18% and 22% respectively, NO_x emissions per vehicle increased by 11%, and CO_2 emissions per vehicle increased by 13%. During the same period the driving pattern effects on links with no measures were negligible.

The mean change in the total emissions of a given pollutant from traffic was calculated for around 40 of the links where flow and composition were recorded. In addition, the relative contributions of changes in driving pattern, changes in traffic flow, and changes in vehicle fleet composition to the overall changes in emissions from LDVs and HDVs were estimated for each type of link, each pollutant, and each period. Driving cycles were also recorded on a further 32 links, but because no traffic counts were conducted on these links no estimate of emissions from traffic could be made. In terms of the overall effects of changes in driving pattern and fleet composition on emissions for each link type, there were no major differences between the results for these links and the results for the links where flow was recorded.

In spite of the increases in emissions per vehicle on the links where traffic management measures had been installed and, in some cases, increases in traffic flow, total emissions of CO, HC, and NO_x from traffic on the different types of link decreased by between 1% and 13% during the 1996-1997 period, and by between 4% and 20% during the 1997- 1998 period. The general reductions in total emissions of CO, HC, and NO_x were mainly due to the changes that occurred in the composition of the LDV fleet, although the decreases in emissions were amplified on the types of link where large reductions in traffic flow had occurred. The emission characteristics of the LDV fleet are changing rather dramatically at present. Emissions from catalyst-equipped LDVs are typically an order of magnitude lower than those from non-catalyst LDVs, and during the course of a year a significant proportion of older vehicles are replaced by newer ones. This alone results in a general reduction in the absolute emissions of CO, HC, and NO_x, and a slight increase in CO_2 emissions, from traffic on all roads. For example, during 1996-97 total city-wide weekday emissions of CO from traffic decreased by 4% during 1996-97, and decreased by a further 8% during 1997-98. City-wide emissions of both HC and NO_x decreased by 6% during each period. Total emissions of CO_2 increased by 2.3% during 1996-97, though during the 1997-98 period emissions actually decreased by 1%. Currently, the outcome is that unless traffic flow on any given road increases markedly, or driving patterns are changed so radically that a large increase in emissions per vehicle occurs, there will usually be a reduction in emissions of CO, HC, and NO_x from traffic over the course of the year. However, driving pattern and traffic flow effects may become more important in the future, when catalyst-equipped vehicles will dominate the fleet.

There may have been a few exceptions concerning the impact of changes in driving patterns. For example, changes in driving pattern may have had a significant effect on traffic emissions on the links with a roundabout during 1996-97. However, this cannot be confirmed in the absence of traffic flow data for the links. On links where carriageway narrowing was combined with a cycle lane, changes in driving pattern during 1996 and 1997 may have been responsible for slightly moderating the reductions in CO and HC, and increasing the reduction in NO_x, during the period. Also, the effects of changes in the driving pattern on Cheltenham Road would have moderated the overall reduction in emissions of each pollutant had traffic flow not decreased.

It should be noted that wherever impacts on emissions have been assessed in this study, the impacts have related only to particular links. Some traffic may have been diverted onto links that were not covered in the surveys. However, the impacts of this diverted traffic are diffuse and difficult to quantify.

6 Conclusions

The following conclusions have been drawn from this study:

Effects of traffic safety and traffic management measures on link speed

1 The links covered in the study of the Gloucester Safer City Project were grouped according to the main (or only) type of traffic management or traffic safety measure that had been implemented. The measures investigated were anti-skid surfacing, gateways, a roundabout, speed cameras, pedestrian refuges, and carriageway narrowing combined with a cycle lane. These measures were all introduced during the 1996-97 period. On Cheltenham Road, measures were introduced during both the 1996-97 and 1997-98 periods, with a broad range of traffic calming and traffic management measures appearing during the latter period. Consequently, the results for the two affected links were treated as a separate ‘Cheltenham Road’ category. A sample of links on which no traffic management measures had been introduced was also considered. Following the introduction of any type of measure, there was a decrease in the overall mean speed recorded on the affected links. On links where either anti-skid surfacing, a gateway, a roundabout, pedestrian refuges, or carriageway narrowing with a cycle lane had been introduced during 1996-97, the resulting speed reduction was maintained during 1997-98. The extent of the speed reduction effected by the introduction of measures was dependent upon the type of measure. Link speeds were reduced by around 2 km/h (1 mph) where the measures were least severe (*i.e.* anti-skid surfacing, gateways, and pedestrian refuges), and by around 6-8 km/h (4-5 mph) where the measures were either more severe or occupied long sections of road (*i.e.* roundabout, carriageway narrowing with a cycle lane, and Cheltenham Road).

2 During 1996-97 it was found that there was also a decrease in mean speed of 1.8 km/h (1.1 mph) along unaffected links, and during the 1997-98 period the mean speed on unaffected links increased by 0.8 km/h. If these general changes in speed on unaffected links were to be taken into account when considering the net effects of the measures introduced on other links, it could be argued that during 1996-97 the reductions in speed would only have been substantial on links with a roundabout and links where carriageway narrowing was combined with a cycle lane. During 1997-98 a substantial reduction in speed was only observed on the Cheltenham Road links .

3 Along the links affected by the introduction of speed cameras the reduction in mean speed during 1996-97 was only slight, and was actually followed by an increase in speed during 1997-98. However, in this study the links on which the cameras were installed were several kilometres long. A more localised speed-reduction effect may have occurred, but this would have had little impact on the mean speed over an entire link.

4 It appears that for each type of link, changes in stop time were not a particularly important determinant of changes in mean link speed. The Cheltenham Road links, where alterations had also been made to the phasing of the traffic lights, were possibly an exception.

Effects of traffic safety and traffic management measures on traffic flow

5 During both the 1996-97 and 1997-98 periods the change in flow was less than 10% on around two thirds of the links where it had been recorded. For the various link types, changes in traffic flow of more than 10% were only observed in a few cases; on links with pedestrian refuges there was a 15% decrease in flow between 1997 and 1998, and on the Cheltenham Road links there was an 11% decrease in flow between 1997 and 1998. Overall traffic flow on links with no measures hardly changed during the study.

Effects of traffic safety and traffic management measures on emissions per vehicle

6 The changes in driving pattern effected by the introduction of traffic management and traffic safety measures on a link tended to result in increases in emissions of CO, HC, and CO_2 *per LDV*, with NO_x emissions being affected only slightly. There was also a tendency for emissions of all four pollutants *per HDV* to increase after the introduction of measures. The

largest increases in emissions per vehicle coincided with the largest speed reductions. Consequently, the largest increases in emissions per vehicle were observed for the links with a roundabout and links where carriageway narrowing was combined with a cycle lane during 1996-97, and the Cheltenham Road links during 1997-98.

7 For the links with a roundabout and the links where carriageway narrowing was combined with a cycle lane, emissions of CO per LDV increased by 9% and emissions of HC per LDV increased by 11-13% during the 1996-97 period. NO_x emissions per LDV decreased by 1-3%, and CO_2 emissions per LDV increased by 4% On the links with a roundabout CO emissions per HDV increased by 27%, and on links with carriageway narrowing and a cycle lane CO emissions per HDV increased by 19% On the two types of link, emissions of HC per HDV increased by around 20%, and emissions of NO_x and CO_2 per HDV increased by around 10%.

8 During the 1996-97 period the changes in driving pattern on links with no measures resulted in increases in CO and HC emissions per LDV of 4% and 5% respectively, a decrease in NO_x emissions per LDV of 1%, and an increase in CO_2 emissions per LDV of 2%. On the unaffected links, emissions of CO and HC per HDV increased by 6%, and emissions of NO_x and CO_2 per HDV increased by 3%. As with vehicle speed, it could be argued that the net effects on emissions per vehicle of the anti-skid surfacing, gateways, speed cameras, and pedestrian refuges installed during this period were similar to the effects on links with no measures, and therefore effectively negligible. Similar reasoning would also suggest that the net effects of the roundabout and the carriageway narrowing with a cycle lane on emissions per LDV were small for CO and HC, and negligible for NO_x and CO_2. The net effects of these two measures on emissions of CO and HC per HDV were larger than those for LDVs, but net effects on emissions of NO_x and CO_2 per HDV that were similar to those for LDVs.

9 For the Cheltenham Road links during the 1997-98 period, emissions of CO and HC per LDV increased by 10%. Emissions of NO_x per LDV decreased by 2%, and emissions of CO_2 per LDV increased by 6%. For HDVs, emissions of CO and HC per vehicle increased by 18% and 22% respectively, NO_x emissions per vehicle increased by 11%, and CO_2 emissions per vehicle increased by 13%. During the same period the driving pattern effects on links with no measures were negligible.

Effects of traffic safety and traffic management measures on total emissions from traffic

10 In spite of the increases in emissions per vehicle on the links where traffic management measures had been installed and, in some cases, increases in traffic flow, total emissions of CO, HC, and NO_x from traffic on the different types of link decreased by between 1% and 13% during 1996-1997, and decreased by between 4% and 20% during 1997-1998. The general reductions in total emissions of CO, HC, and NO_x were mainly due to the changes that occurred in the composition of the LDV fleet, although the decreases in emissions were amplified on the types of link where large reductions in traffic flow had occurred. The emission characteristics of the LDV fleet are changing rather dramatically at present. Emissions from catalyst-equipped LDVs are typically an order of magnitude lower than those from non-catalyst LDVs, and during the course of a year a significant proportion of older vehicles are replaced by newer ones. This alone results in a general reduction in the absolute emissions of CO, HC, and NO_x, and a slight increase in CO_2 emissions, from traffic on all roads. For example, during 1996-97 total city-wide weekday emissions of CO from traffic decreased by 4% during 1996-97, and decreased by a further 8% during 1997-98. City-wide emissions of both HC and NO_x decreased by 6% during each period. Total emissions of CO_2 increased by 2.3% during 1996-97, though during the 1997-98 period emissions actually decreased by 1%. Currently, the outcome is that unless traffic flow on any given road increases substantially, or driving patterns are changed so radically that a large increase in emissions per vehicle occurs, there will usually be a reduction in emissions from traffic over the course of the year. However, driving pattern and traffic flow effects may become more important in the future, when catalyst-equipped vehicles will dominate the fleet.

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Notes

[1] PM_{10} is the fraction of particulate matter with an aerodynamic diameter of less than 10µm.

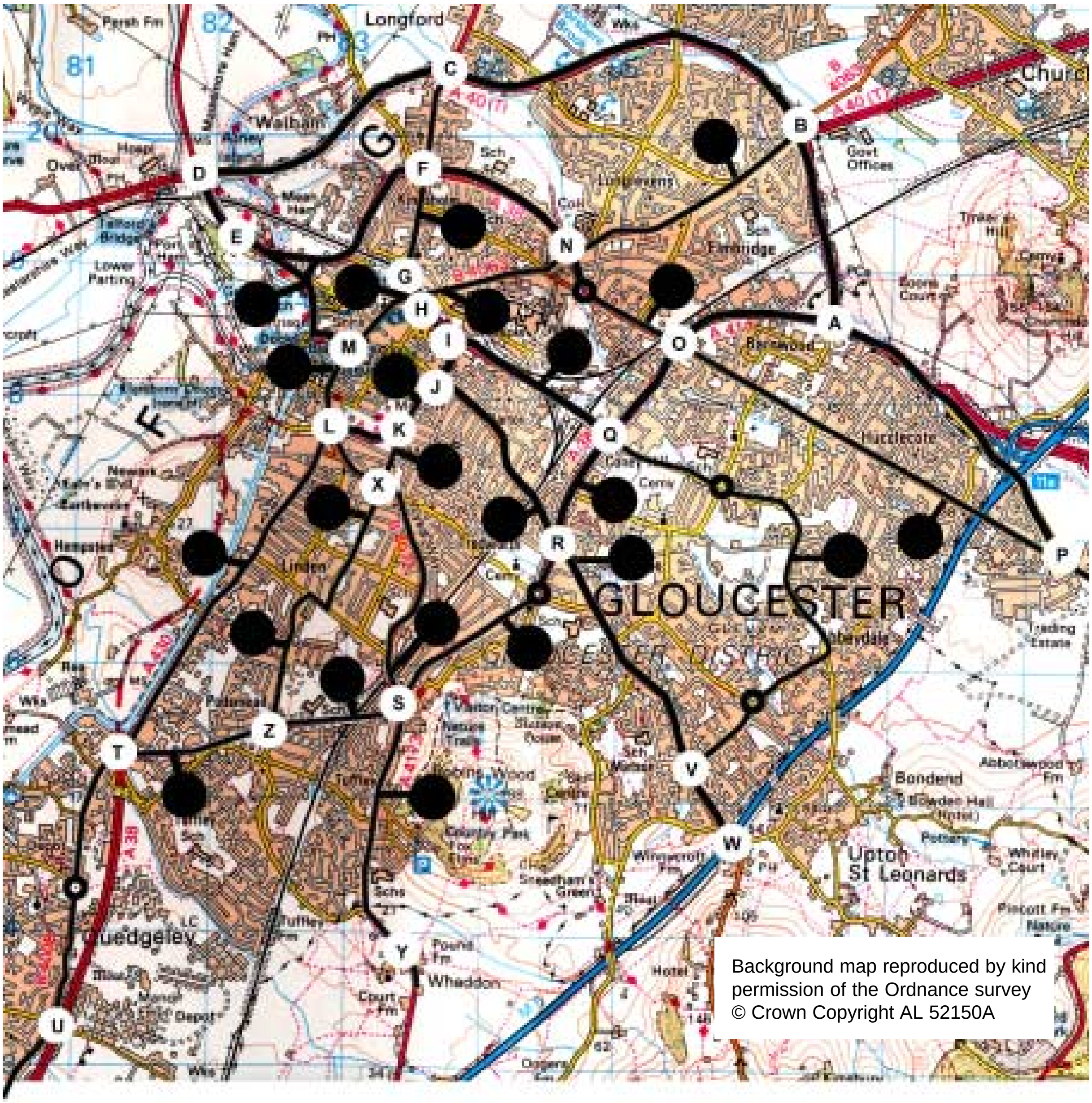
[2] In the context of this report, 'road traffic' excludes motorcycles and pedal cycles.

[3] 'Dragons' teeth' are a series of white triangles that are painted on the road surface to give the impression of a narrowing carriageway.

[4] Clearly, the LDV fleet composition *did* change between successive years. The reported effect on emissions is therefore an average of the changes calculated firstly using the 1997 composition, then the 1998 composition.

[5] The driving cycles also changed between successive surveys. The reported effect on emissions is again an average of the changes calculated firstly using the 1997 cycles then the 1998 cycles.

Appendix A: Traffic count locations



Approximate location of traffic count

Figure A1 Traffic count locations

Appendix B: Mean link speeds

The mean speed of each driving cycle on a link was calculated from the length of the link and the time taken to travel along it. The resulting values were again averaged to give an overall mean speed for the link. The mean speed recorded on each link in the three survey years, and the changes in mean between successive years are given for each of the link types considered in Tables B1 to B8.

T-tests were conducted to assess the significance of the difference between the mean speeds along each link in successive years. The 0.05 criterion of significance was applied (*i.e.* the difference between the two means was accepted as significant for probability values lower than 0.05).

The results of the *t*-tests are also given in Tables B1 to B8. An asterisk inserted alongside the change in link speed for a given period indicates that the change was statistically significant. It should be noted, however, that the statistical significance of the change in mean speed on each link is not particularly useful in the context of the effect of the change on emissions. It is the magnitude of the change that is more important in this respect.

Table B1 Links with anti-skid surfacing

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
IQ	38.0	38.0	34.7	0.0	-3.3
JK	25.8	32.8	32.9	+7.0*	+0.1
JR	34.3	29.7	27.6	-4.6	-2.1
QR	43.7	41.7	39.6	-2.0	-2.1
QV	46.4	44.5	43.6	-1.9	-0.9
RJ	20.2	22.7	21.0	+2.5	-1.7
RV	44.9	36.9	41.0	-8.0*	+4.1
VQ	39.8	37.9	41.6	-1.9	+3.7
VR	40.9	35.3	37.8	-5.6	+2.5
Overall mean	37.1	35.5	35.5	-1.6	0.0

Table B2 Links with a gateway

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
CF	40.6	39.8	38.3	-0.8	-1.5
FC	41.4	39.0	36.6	-2.4	-2.4
OP	36.8	37.9	34.9	+1.1	-3.0
PO	31.7	28.1	31.4	-3.6	+3.3
SY	52.3	51.3	53.5	-1.0	+2.2
VW	55.4	51.9	50.4	-3.5	-1.5
WV	48.6	46.3	45.9	-2.3	-0.4
YS	46.6	41.6	45.4	-5.0	+3.8
Overall mean	44.2	42.0	42.0	-2.2	0.0

Table B3 Links with a roundabout

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
DF	60.5	52.5	50.8	-8.0 *	-1.7
FD	56.1	47.9	51.5	-8.2 *	+3.6
Overall mean	58.3	50.2	51.2	-8.1	+1.0

Table B4 Links with a speed camera

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
LT	33.1	31.5	30.0	-1.6	-1.5
OQ	27.1	34.2	36.4	+7.1	+2.2
QO	37.4	32.5	37.0	-4.9	+4.5
RQ	34.1	29.0	33.3	-5.1	+4.3
TL	30.7	32.5	34.1	+1.8	+1.6
Overall mean	32.4	31.9	34.1	-0.5	+2.2

Table B5 Links with pedestrian refuges

	Mean link speed (km/h)			*Change (km/h)*	
Link	1996	1997	1998	1996-97	1997-98
HN	38.3	35.5	33.5	-2.8	-2.0
NH	34.9	33.2	34.5	-1.7	+1.3
Overall mean	36.6	34.3	34.0	-2.3	-0.3

Table B6 Links with carriageway narrowing combined with a cycle lane

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*[1]	*1996-97*	*1997-98*
RS	45.5	39.5	37.8	-6.0	-1.7[2]
SR	43.2	37.4	40.4	-5.8*	+3.0[2]
Overall mean	44.4	38.4	39.1	-6.0	+0.7

[1] *Mean speed for each link is the average of two shorter links.*
[2] *Statistical significance not calculated.*

Table B7 Links on Cheltenham Road

	Mean link speed (km/h)			*Change (km/h)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
BN	41.4	38.4	31.0	-3.0	-7.4 *
NB	33.8	32.4	28.0	-1.4	-4.4
Overall mean	37.6	35.4	29.5	-2.2	-5.9

Table B8 Links with no measures

Link	Mean link speed (km/h)			Change (km/h)	
	1996	*1997*	*1998*	*1996-97*	*1997-98*
AB	52.5	52.6	58.4	+0.1	+5.8
AO	57.6	49.3	50.6	-8.3	+1.3
AP	64.5	60.0	66.4	-4.5*	+6.4*
BA	59.7	56.1	53.0	-3.6	-3.0
BC	83.5	78.1	82.7	-5.4	+4.6
CB	70.0	65.5	87.1	-4.5	+20.6*
CD	54.4	43.8	40.4	-10.6	-3.4
DC	67.9	58.5	60.8	-9.4*	+2.3
EM	29.6	29.6	31.5	0.0	+1.9
FG	34.3	34.1	30.9	-0.2	-3.2
FN	56.7	55.7	55.8	-1.0	+0.1
GF	33.4	31.3	22.2	-2.1	-2.1
GH	20.2	11.1	9.6	-9.1*	-1.5
GM	19.8	15.3	22.9	-4.5	+7.6 [1]
HG	26.7	25.2	16.9	-1.5	-8.3*
HI	25.1	25.2	21.0	+0.1	-4.2*
IH	19.1	19.9	23.1	+0.8	+3.2
IJ	33.0	25.8	25.4	-7.2	-0.4
JI	35.4	37.4	29.6	+2.0	-7.8*
KJ	20.1	21.8	17.4	+1.7	-4.4*
KL	23.4	29.7	29.8	+ 6.3	+0.1
KX	33.2	33.0	26.4	-0.2	-6.6
LK	32.7	33.7	39.6	+1.0	+5.9*
LM	26.4	28.8	26.2	+2.4	-2.6
LX	13.6	26.0	21.9	+2.4	-4.1
MD	47.3	48.7	44.8	+1.4	-3.9
MG	21.2	21.0	33.9	-0.2	+12.9 [1]
ML	20.8	23.6	24.3	+2.8	+0.7
NF	53.0	45.3	50.0	-7.7	+4.7
NO	30.9	29.1	32.6	-1.8	+3.5
OA	49.4	43.4	54.0	-6.0	+10.6
ON	34.4	33.6	36.4	-0.8	+2.8
PA	54.4	59.7	52.7	+5.3	-7.0
QI	52.5	48.7	42.7	-3.8	-6.0
SX	39.7	38.6	36.8	-1.1	-1.8
SZ	49.7	49.3	46.9	-0.4	-2.4
TU	43.7	45.5	46.9	+1.8	+1.4
TZ	38.5	32.9	38.8	-5.6	+5.9
UT	39.4	39.9	39.6	+0.5	-0.3
XK	31.0	31.9	30.0	+0.9	-1.9
XL	13.7	16.5	17.4	+2.8	+0.9
XS	43.0	36.0	35.4	-7.0*	-0.6
XZ	30.9	26.9	27.9	-4.0	+1.0
ZS	40.0	36.5	39.5	-3.5	+3.0
ZT	31.8	32.2	34.2	+0.4	+2.0
ZX	27.3	24.8	26.8	-2.5	+2.0
Overall mean	39.0	37.2	38.0	-1.8	+0.8

[1] *Alternative route taken during 1998 survey because of town-centre pedestrianisation. Statistical significance of 1997-98 change not calculated.*

Appendix C: Mean stop time

The mean 'stop time' (*i.e.* the length of time that a vehicle is stationary as a result of waiting at traffic lights, waiting for pedestrians, or involved in conflicts with other vehicles) was calculated for each link in each year of the study. The stop time values obtained for a link tend to be quite variable, and this is probably a result of varying degrees of congestion.

The mean stop time on each link in the three survey years, and the changes in stop time between successive years are given for each of the link types considered in Tables C1 to C8. Again, *t*-tests were conducted to assess the significance of the difference between the mean stop times along each link in successive years. As before, an asterisk inserted alongside the change in stop time for a given period indicates that the change was statistically significant.

Table C1 Links with anti-skid surfacing

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
IQ	41	46	51	+5	+5
JK	24	13	13	-11*	0
JR	11	25	36	+14	+11
QR	6	7	6	-1	-1
QV	9	13	10	+4	-3
RJ	108	66	91	-42	+25
RV	7	14	20	+7	+6
VQ	39	28	36	-11	+8
VR	38	38	24	0	-14
Overall mean	29	28	32	-1	+4

Table C2 Links with a gateway

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
CF	3	3	3	0	0
FC	3	7	7	+4	0
OP	24	22	29	-2	-7
PO	42	66	48	+24	-18
SY	8	2	3	-6	+1
VW	1	0	1	-1	+1
WV	5	4	4	-1	0
YS	17	22	14	+5	-8
Overall mean	13	16	14	+3	-2

Table C3 Links with a roundabout

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
DF	0	0	1	0	+1
FD	1	4	3	+3	-1
Overall mean	1	2	2	+1	0

Table C4 Links with a speed camera

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
LT	37	41	64	+4	+23
OQ	43	31	26	-12	-5
QO	5	18	7	+13*	-9
RQ	27	37	35	+10	-2
TL	38	34	22	-4	-12
Overall mean	30	32	31	+2	-1

Table C5 Links with pedestrian refuges

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
HN	2	5	7	+3	+2
NH	4	6	11	+2	+5
Overall mean	3	5	9	+2	+4

Table C6 Links with carriageway narrowing combined with a cycle lane

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*[1]	*1996-97*	*1997-98*[2]
RS	7	7	3	0	-4
SR	1	4	1	+3	-3
Overall mean	4	6	2	+2	-4

[1] *Mean stop time for each link is the average of two shorter links.*
[2] *Statistical significance not calculated.*

Table C7 Links on Cheltenham Road

	Mean link stop time (s)			*Change (s)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
BN	6	6	47	0	+41*
NB	35	43	55	+8	+12
Overall mean	20	25	51	+5	+26

Table C8 Links with no measures

Link	*Mean link stop time (s)*			*Change (s)*	
	1996	*1997*	*1998*	*1996-97*	*1997-98*
AB	23	19	11	-4	-8*
AO	3	13	4	+10	-9
AP	0	0	0	0	0
BA	10	12	29	+2	+17
BC	2	13	6	+11	-7
CB	18	20	7	+2	-13*
CD	9	23	27	+14	+4
DC	1	2	4	+3	+2
EM	22	11	15	-11	+4
FG	3	13	26	+10	+13
FN	8	3	1	-5	-2
GF	25	9	24	-16	+15
GH	25	51	59	+26*	+8
GM	32	81	85	+49*	+4[1]
HG	11	9	34	-2	+25*
HI	16	18	41	+2	+23*
IH	27	35	32	+8	-3
IJ	7	37	28	+30*	-9
JI	4	9	14	+5	+5
KJ	42	33	48	-9	+15*
KL	63	45	39	-18	-6
KX	14	10	19	-4	+9
LK	23	17	11	-6	-6
LM	16	10	18	-6	+8
LX	38	22	33	-16	+11
MD	6	5	8	-1	+3
MG	55	50	13	-5	-37[1]
ML	26	25	19	-1	-6
NF	6	10	5	+4	-5
NO	28	33	18	+5	-15
OA	12	29	8	+17	-21*
ON	20	9	13	-11	+4
PA	20	13	30	-7	+17
QI	2	10	23	+8	+13
SX	18	13	22	-5	+9
SZ	14	17	11	+3	-6
TU	17	15	6	-2	-9
TZ	28	25	19	-3	-6
UT	35	32	30	-3	-2
XK	11	7	10	-4	+3
XL	128	82	83	-46	+1
XS	4	8	12	+4	+4
XZ	43	65	63	+23	-2
ZS	18	6	7	-12	+1
ZT	50	46	34	-4	-12
ZX	89	107	81	+18	-26
Overall mean	23	24	25	+1	+1

[1] *Alternative route taken during 1998 survey because of town-centre pedestrianisation. Statistical significance of 1997-98 change not calculated.*

Appendix D: Congestion effects

For some links, the observed changes in mean speed may have been due in part to the effects of congestion. Congestion effects were assessed semi-quantitatively. During each survey the navigators made a note of the links affected by congestion. During the analysis, a subjective judgement on the presence of congestion on a trip was made from the driving cycles. Where the instrumented car had driven more than around 250m in a stop-start fashion and without exceeding 20 km/h, it was assumed that congestion had occurred. The percentage of the trips driven on a link that were affected by congestion is presented for each link and link type in Tables D1 to D8. A '-' sign indicates that no congestion was observed.

Table D1 Links with anti-skid surfacing

	% of trips affected		
Link	*1996*	*1997*	*1998*
IQ	–	–	–
JK	–	2	–
JR	–	–	17
QR	–	–	–
QV	–	–	–
RJ	25	6	43
RV	–	–	–
VQ	–	10	5
VR	–	13	–

Table D2 Links with a gateway

	% of trips affected		
Link	*1996*	*1997*	*1998*
CF	5	–	10
FC	–	3	8
OP	–	5	6
PO	–	45	28
SY	–	–	–
VW	–	–	–
WV	–	–	–
YS	11	19	9

Table D3 Links with a roundabout

	% of trips affected		
Link	*1996*	*1997*	*1998*
DF	–	–	–
FD	–	–	–

Table D4 Links with a speed camera

	% of trips affected		
Link	*1996*	*1997*	*1998*
LT	–	–	12
OQ	–	–	–
QO	–	10	17
RQ	–	–	–
TL	–	–	–

Table D5 Links with pedestrian refuges

	% of trips affected		
Link	*1996*	*1997*	*1998*
HN	–	–	7
NH	0	10	6

Table D6 Links with carriageway narrowing combined with a cycle lane

	% of trips affected		
Link	*1996*	*1997*	*1998*[1]
RS	–	10	19
SR	–	–	–

[1] *% for each link is the average of two shorter links.*

Table D7 Links on Cheltenham Road

	% of trips affected		
Link	*1996*	*1997*	*1998*
BN	–	–	6
NB	0	13	7

Table D8 Links with no measures

	% of trips affected		
Link	*1996*	*1997*	*1998*
AB	11	4	–
AO	–	15	19
AP	–	10	–
BA	–	7	10
BC	–	–	–
CB	–	–	–
CD	17	28	20
DC	–	–	–
EM	25	9	17
FG	–	2	2
FN	–	–	6
GF	3	2	13
GH	4	3	3
GM	–	20	6[1]
HG	–	–	3
HI	3	2	2
IH	–	3	4
IJ	–	3	–
JI	–	4	–
KJ	2	–	–
KL	–	–	–
KX	–	–	–
LK	–	–	–
LM	–	3	–
LX	–	–	7
MD	–	–	–
MG	–	15	–[1]
ML	4	10	11
NF	20	–	6
NO	–	–	–
OA	–	10	6
ON	–	–	–
PA	–	–	13
QI	–	–	–
SX	–	–	6
SZ	–	5	–
TU	–	–	–
TZ	–	20	6
UT	–	–	–
XK	–	–	–
XL	–	–	–
XS	–	6	7
XZ	–	–	–
ZS	7	10	–
ZT	–	–	31
ZX	–	6	–

[1] *Alternative route taken during 1998 survey because of town-centre pedestrianisation.*

Appendix E: Traffic flows

Automatic, average week-day, 24-hour traffic flow measurements and 12-hour (07:00-19:00) manual classified counts were made by Gloucester City Council and TRL at a number of locations in the area. In total, traffic flow data was available for 44 of the links covered by the 1996 and 1997 driving cycle surveys, and 42 of the links covered by the 1998 survey (since no counts were made on the pedestrianised links). The traffic counts were mostly conducted during a two week period in November of each survey year which coincided with the timing of the instrumented car surveys.

The mean weekday traffic flows recorded in the three survey years, and the percentage changes in flow between successive years are given for each of the link types considered in Tables E1 to E7. Blank spaces in the traffic flow columns indicate links for which no flow data were collected. No flow data were collected for the links with roundabouts.

Knowledge concerning the accuracy of traffic counts appears to be relatively poor. There are two types of error: those associated with the measurement technique and those associated with the choice of measurement period. According to OECD (1979), automatic loop detectors installed in each lane (the type primarily used in this study) can overestimate flows by up to 5% as some vehicles are counted in both lanes. Regarding day-to-day traffic changes, when counting over five successive weekdays the average margin of error will be 13% if the daily traffic flow is 2,500 vehicles, and 9% if it is 10,000. A '–' sign indicates where no traffic flow was recorded.

Table E1 Links with anti-skid surfacing

	Mean weekday flow (vpd)			*Change (%)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
IQ	9312	10842	11342	+16	+5
JK	15967	15102	15796	-5	+5
JR	7659	7698	7716	+1	+0
QR	16454	15873	16334	-4	+3
QV	8132	8371	8428	+3	+1
RJ	7375	7561	7390	+3	-2
RV	6854[1]	6753	6550	-1	-3
VQ	7879	8136	8175	+3	0
VR	6854[1]	6601	6846	-4	+4
Overall mean	9610	9660	9842	+1	+1

[1] *Derived from combined traffic flow.*

Table E2 Links with a gateway

	Mean weekday flow (vpd)			*Change (%)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
CF	–	–	–	–	–
FC	–	–	–	–	–
OP	7004	7550	7542	+8	0
PO	7435	7949	8027	+7	+1
SY	8155[1]	7635	7570	-6	-1
VW	–	–	–	–	–
WV	–	–	–	–	–
YS	8155[1]	7959	787–2	-2	-1
Overall mean	7687	7773	7753	+1	0

[1] *Derived from combined traffic flow.*

Table E3 Links with a speed camera

	Mean weekday flow (vpd)			*Change (%)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
LT	11800	12459	12175	+6	-2
OQ	–	–	–	–	–
QO	–	–	–	–	–
RQ	18900	18532	18907	-2	+2
TL	10849	11456	11195	+6	-2
Overall mean	13850	14149	14092	+3	-1

Table E4 Links with pedestrian refuges

	Mean weekday flow (vpd)			*Change (%)*	
Link	*1996*	*1997*	*1998*	*1996-97*	*1997-98*
HN	10074	9824	9293	-2	-5
NH	13187	11538	8751	-13	-24
Overall mean	11631	10681	9022	-7	-15

Table E5 Links with carriageway narrowing combined with a cycle lane

	Mean weekday flow (vpd)			*Change (%)*	
Link	*1996*	*1997*	*1998[1]*	*1996-97*	*1997-98[2]*
RS	14271	13697	13310	-4	-3
SR	15376	14804	14760	-4	0
Overall mean	14824	14251	14035	-4	-2

[1] *Mean speed for each link is the average of two shorter links*
[2] *Statistical significance not calculated*

Table E6 Links on Cheltenham Road

Link	Mean weekday flow (vpd)			Change (%)	
	1996	1997	1998	1996-97	1997-98
BN	8263	8273	7375	0	-11
NB	7004	7052	6309	1	-11
Overall mean	7634	7663	6842	0	-11

Table E7 Links with no measures

Link	Mean weekday flow (vpd)			Change (%)	
	1996	1997	1998	1996-97	1997-98
AB	–	–	–	–	–
AO	–	–	–	–	–
AP	–	–	–	–	–
BA	–	–	–	–	–
BC	–	–	–	–	–
CB	–	–	–	–	–
CD	–	–	–	–	–
DC	–	–	–	–	–
EM	11947	11288	12854	-6	+14
FG	6687[1]	7908	6909	+18	-13
FN	–	–	–	–	–
GF	6687[1]	8064	7136	+21	-12
GH	–	–	–	–	–
GM[2]	5067	4705	–	-7	–
HG	–	–	–	–	–
HI	–	–	–	–	–
IH	–	–	–	–	–
IJ	–	–	–	–	–
JI	–	–	–	–	–
KJ	14111	13495	13928	-4	+8
KL	–	–	–	–	–
KX	9534[1]	8580	8481	-10	-1
LK	–	–	–	–	–
LM	12205[1]	13003	11861	+7	-9
LX	–	–	–	–	–
MD	15822	15050	16697	-5	+11
MG[2]	4773	4065	–	-15	–
ML	12205[1]	10995	9741	-10	-11
NF	–	–	–	–	–
NO	14404	15192	13518	+5	-11
OA	–	–	–	–	–
ON	13944	11000	15792	-21	+44
PA	–	–	–	–	–
QI	9736	11106	10824	+9	+2
SX	8783[1]	7554	7196	-14	-5
SZ	11051[1]	10897	11386	-1	–
TU	–	–	–	–	–
TZ	11077[1]	12077	12415	+9	+4
UT	–	–	–	–	–
XK	9534[1]	8446	8455	-11	0
XL	–	–	–	–	–
XS	8783[1]	7554	7196	-14	-5
XZ	4029[1]	3925	4137	-3	+5
ZS	11051[1]	11496	12019	+4	+5
ZT	11077[1]	11661	11627	+5	0
ZX	4029[1]	4215	4253	+6	0
Overall mean[3]	10145	10134	10033	+1	-1

[1] *Derived from combined traffic flow.*
[2] *Alternative route taken during 1998 survey because of town-centre pedestrianisation.Traffic flow on new route not recorded.*
[3] *Excluding links **ON**, **GM**, and **MG.***

Appendix F: Emissions from traffic

Table F1 Links with anti-skid surfacing

	CO					*HC*					*NO_x*					*CO_2*				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
IQ	160	184	183	+15	-1	21	23	23	+14	-2	32	34	34	+5	0	2622	3080	3297	+17	+7
JK	117	92	785	-21	-8	16	12	11	-23	-9	17	15	16	-12	+3	1703	1497	1588	-12	+6
JR	158	159	156	+1	-2	21	21	21	-1	-4	31	34	32	+8	-4	2636	3037	3170	+15	+4
QR	181	161	157	-11	-3	24	21	20	-12	-3	36	32	31	-11	-2	2936	2808	2953	-4	+5
QV	362	349	326	-4	-6	48	46	42	-4	-8	75	72	67	-3	-7	5668	6194	6244	+4	+1
RJ	201	178	164	-11	-8	27	24	21	-12	-10	35	34	31	-4	-8	3373	3309	3270	-2	-1
RV	149	150	127	+1	-15	20	20	17	+1	-17	30	28	26	-7	-8	2464	2588	2424	+5	-6
VQ	362	347	319	-2	-8	47	46	41	-2	-11	72	68	66	-5	-3	5826	6086	6132	+4	+1
VR	155	155	139	0	-10	21	21	18	-2	-11	31	29	28	-7	-4	2507	2625	2593	+5	-1
Overall mean	204	197	184	-4	-7	27	26	24	-5	-8	40	38	37	-4	-4	3337	3469	3519	+4	+2

Table F2 Links with a gateway

	CO					*HC*					*NO_x*					*CO_2*				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
OP	285	276	265	-3	-4	39	37	35	-5	-6	53	53	50	0	-5	4510	4758	4909	+6	+3
PO	306	291	266	-5	-9	41	39	35	-6	-10	55	53	50	-5	-5	4839	4994	4979	+3	0
SY	158	146	130	-8	-11	21	19	17	-9	-13	36	33	30	-9	-7	2711	2648	2589	-2	-2
YS	182	179	153	-2	-15	24	23	19	-2	-16	37	35	32	-6	-7	2971	3081	2933	+4	-5
Overall mean	233	223	203	-4	-10	31	30	26	-5	-11	45	43	41	-5	-6	3758	3870	3852	+3	-1

Table F3 Links with a speed camera

	CO					HC					NO_x					CO_2				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
LT	457	449	396	-2	-12	62	60	52	-3	-14	102	105	91	+2	-13	8410	9042	8405	+8	-7
RQ	228	231	200	+1	-13	31	30	26	-1	-15	41	39	37	-4	-5	3551	3852	3698	+8	-4
TL	412	395	349	-4	-12	56	53	46	-5	-13	92	92	86	0	-7	7619	7933	7641	+4	-4
Overall mean	366	358	315	-2	-12	49	48	41	-3	-14	78	78	71	-1	-8	6527	6942	6581	+7	-5

Table F4 Links with pedestrian refuges

	CO					HC					NO_x					CO_2				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
HN	156	149	136	-4	-9	21	0	18	-7	-10	29	27	24	-7	-10	2465	2524	2467	+2	-2
NH	207	171	120	-17	-30	28	23	16	-19	-31	36	30	21	-17	-28	3179	2857	2178	-10	-24
Overall mean	181	160	128	-11	-19	25	21	17	-13	-20	32	28	23	-12	-19	2822	2690	2323	-4	-13

Table F5 Links with carriageway narrowing combined with a cycle lane

	CO					*HC*					*NO_x*					*CO_2*				
	*Emissions from traffic (kg/day) **			*Change (%)*		*Emissions from traffic (kg/day) **			*Change (%)*		*Emissions from raffic (kg/day) **			*Change (%)*		*Emissions from raffic (kg/day) **			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
RS	281	277	275	-1	-1	36	36	35	0	-2	67	57	54	-15	-6	5207	5042	5243	-3	+4
SR	295	290	246	-2	-15	39	38	32	-2	-16	71	64	56	-11	-12	5564	5507	5064	-1	-8
Overall mean	288	283	260	-2	-8	38	37	34	-1	-9	69	60	55	-13	-9	5385	5275	5154	-2	-2

** The 1998 values represent the average value for two shorter links.*

Table F6 Links on Cheltenham Road

	CO					*HC*					*NO_x*					*CO_2*				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
BN	189	183	167	-3	-9	26	25	22	-4	-11	35	33	31	-5	-8	2941	3048	3110	+4	+2
NB	199	185	167	-7	-10	27	25	22	-8	-11	37	33	29	-9	-14	3178	3153	3006	-1	-5
Overall mean	194	184	167	-5	-9	26	25	22	-6	-11	36	33	30	-7	-11	3059	3100	3058	+1	-1

Table F7 Links with no measures

	CO					*HC*					*NO_x*					*CO_2*				
	Emissions from traffic (kg/day)			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*		*Emissions from traffic (kg/day)*			*Change (%)*	
Link	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*	*1996*	*1997*	*1998*	*96-97*	*97-98*
EM	243	203	210	-16	+3	33	27	27	-17	0	38	33	36	-12	+8	3589	3339	3730	-7	+12
FG	74	81	68	+10	-16	10	11	9	+9	-17	13	14	12	+10	-14	1128	1341	1231	+19	-8
GF	79	89	80	+13	-9	11	12	10	+11	-12	13	15	13	+16	-14	1179	1463	1413	+24	-3
GM	69	74	–	+8	–	9	10	–	+6	–	12	12	–	-5	–	1204	1321	–	+10	–
KJ	129	103	110	-20	+7	17	14	14	-21	+5	15	13	15	-14	+14	1723	1530	1868	-11	+22
KX	63	53	53	-17	0	9	7	7	-18	-1	11	9	9	-19	0	947	848	925	-10	+9
LM	102	95	99	-9	+5	14	13	13	-8	+3	15	15	14	-3	-4	1496	1520	1653	+2	+9
MD	351	309	326	-12	+5	45	39	41	-13	+5	72	64	67	-11	+5	5865	5581	6277	-5	+12
MG	84	65	–	-23	–	11	9	–	-25	–	14	12	–	-11	–	1367	1226	–	-10	–
ML	119	98	92	-18	-6	16	13	12	-19	-7	15	13	12	-14	-1	1649	1467	1516	-11	+3
NO	254	257	191	+1	-26	34	34	25	+1	-27	42	42	34	-1	-17	3891	4208	3505	+8	-17
ON	222	162	208	-27	+28	30	21	27	-28	+26	38	28	38	-26	+35	3407	2722	3809	-20	+40
QI	139	155	149	+12	-4	18	20	19	+10	-6	30	30	30	+1	-1	2289	2598	2769	+13	+7
SX	183	149	136	-19	-8	25	20	18	-20	-10	36	29	26	-18	-9	2930	2577	2533	-12	-2
SZ	124	116	104	-6	-10	16	14	13	-8	-10	24	22	22	-8	-1	2006	2015	2037	0	+1
TZ	161	195	161	+21	-18	21	26	21	+21	-20	30	31	29	+3	-5	2556	3107	2930	+22	-6
XK	66	54	51	-18	-6	9	7	7	-20	-7	11	9	9	-16	-4	996	887	909	-11	+2
XS	179	167	146	-7	-12	24	22	19	-9	-13	36	30	27	-18	-8	2909	2805	2686	-4	-4
XZ	129	125	122	-3	-2	18	17	16	-4	-5	22	20	21	-8	+3	1986	2049	2202	+3	+7
ZS	147	140	132	-5	-5	19	18	17	-5	-8	26	26	25	-1	-3	2256	2367	2429	+5	+3
ZT	168	157	142	-7	-9	22	21	18	-7	-12	30	29	28	-2	-6	2593	2659	2654	+3	0
ZX	138	135	126	-2	-7	19	18	17	-4	-8	23	22	22	-4	-2	2097	2216	2263	+6	+2
Overall mean[1]	143	134	132	-5	-6	19	18	17	-7	-8	25	23	24	-6	-3	2222	2244	2396	+2	+3

[1] *Excluding links **ON**, **GM**, and **MG**.*

Abstract

In December 1995 Gloucestershire County Council was awarded £5m by the Department of the Environment, Transport and the Regions to reduce the number of road casualties in Gloucester by implementing a coherent range of traffic management and traffic safety measures according to a well-defined strategy. The strategy became known as the Safer City Project. TRL is monitoring the effects of the different measures on accidents, traffic distribution and speed, vehicle emissions and air quality, vehicle and traffic noise, vibration, and public perception of the environment. This Report deals with the effects on vehicle emissions. Detailed surveys of passenger car driving cycles, traffic flow, and traffic composition have been made to assess the changes in emissions along a sample of links in Gloucester which are likely to be affected. These surveys are being repeated at annual intervals, and the Report presents the results of the first three. These were conducted in November of 1996, 1997, and 1998.

The links were arranged into groups according to the main (or only) type of traffic management or traffic safety measure that was implemented during 1996-97. The measures investigated were anti-skid surfacing, gateways, a roundabout, speed cameras, pedestrian refuges, and carriageway narrowing combined with a cycle lane. On two links where measures had been introduced during the 1996-97 period, a broad range of measures were also introduced during 1997-98. Consequently, these links were treated separately. A sample of links on which no traffic management measures had been introduced was also considered.

The calculation of emissions on each link was either a one-step or two-step process, depending upon the level of information available. For all 76 links where driving cycles had been recorded, emissions from LDVs in each year were estimated using the driving cycles as an input to the MODEM emission model. Emissions from HDVs were calculated using empirical emission functions for heavy goods vehicles relating to average link speed. For the sub-sample of links where traffic flow and composition had been recorded, weekday emissions from traffic were estimated by weighting the emissions from LDVs and HDVs by the traffic flow and composition. For each type of link, an assessment was made of the relative importance of the different factors contributing to the changes in traffic emissions.

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