Renfrewshire Council

DRAFT AIR QUALITY ACTION PLAN 2008

SHONA I. C. MacDOUGALL
DIRECTOR OF ENVIRONMENTAL SERVICES

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Executive Summary

Renfrewshire Council is required to undertake regular reviews and assessments of air quality within the area in accordance with Scottish Executive Guidance and Objectives as set out in the Air Quality (Scotland) Regulations 2000. The council's regular assessments of the seven main air pollutants indicate that objectives are met for six pollutants. However, concentrations of NO_2 were assessed as being above the acceptable levels in one location. Following a detailed assessment of the area, the council was required to declare an Air Quality Management Area (AQMA) for Central Road, Paisley.

In accordance with our statutory requirements, this Action Plan has been prepared to outline a series of actions aimed at reducing emissions of NO_2 within the designated AQMA to below the objective level. It is estimated that a reduction of up to 45% is required to meet the current NO_2 objective at the AQMA.

The Action Plan assesses a wide range of initiatives and developments in terms of their feasibility, timescale, costs, predicted air quality impact and other advantages/disadvantages. These assessments indicate that there are likely to be feasible actions capable of significantly influencing NO_2 levels within Renfrewshire Council's AQMA. These actions include public transport initiatives, change of fuel used in public transport, enforcing idling periods and Low Emission Zones. It is expected that a reduction of 20-25% will be realistically achieved because of the unique aspects of the AQMA. Therefore, although a significant improvement in air quality within the AQMA will be expected, Renfrewshire Council is unlikely to achieve the current Air Quality Objective for NO_2 hourly mean at Central Road, Paisley. This is line with the situation in many urban areas elsewhere in Scotland and throughout the UK.

Renfrewshire Council also wishes to give more detailed and wider consideration to Air Quality in Paisley town centre and will concentrate on the following issues in its future Master Action Plan to address the areas which have been identified as potential AQMAs:

- Encouraging greater use of public transport;
- Lobbying to include NO_x in the MOT test;
- Petitioning for tighter regulation of buses;
- Lobbying for tighter regulation of taxis and their emissions
- Engagement with the Department of Planning and Transport that will have a positive impact on air quality without harming investment and regeneration in Paisley Town Centre;
- Encouraging clean technology and a reduction of emissions from heavy goods vehicles;

- Encouraging the UK Government to provide a clearer message on the use of alternative fuels, e.g – long term tax incentives;
- Encouraging investment in public transport infrastructure in the west of Scotland to encourage a modal shift from cars to public transport;
- National action to change from older, more polluting vehicles to newer, cleaner vehicles within the private fleet.

1.0 Introduction

Renfrewshire Council declared an Air Quality Management Area (AQMA) covering Central Road, Paisley in September 2005. This was due to both measured and predicted exceedences of the air quality objectives for nitrogen dioxide (NO_2).

Under section 84 of the Environment Act 1995, Renfrewshire Council is required to prepare an Air Quality Action Plan following the declaration of the AQMA. The Action Plan outlines the actions it is already taking or intends to take with the intention of meeting the national objectives for NO_2. This document represents Renfrewshire Council's contribution to its fulfillment of the statutory requirements.

The production of a successful Action Plan requires both the understanding of the pollutant involved and the local sources of the pollutant, in order to ensure that all methods of reducing emissions are investigated.

Further to the results of the Detailed Assessment, 2007 indicating further exceedences within the Paisley Town Centre area, this Action Plan is considered as an interim measure to address air quality within the boundary of the current AQMA. It is recognised that the exceedences at the Central Road AQMA are as a result of unique conditions in that area and as such, requires a specialist approach. However, any measures to reduce emissions in the AQMA are likely to have a negative effect on the surrounding area – which is currently being considered as a potential AQMA. Consequently, it is considered necessary to adopt a simultaneous approach at a later stage to achieve an overall reduction in emissions and a satisfactory strategic approach to air quality in the area as a whole.

At this stage, The Action Plan will address the current AQMA only and at a later stage this interim Action Plan will be fully integrated into a masterplan document which addresses all AQMAs within the Renfrewshire area.

2.0 Background

Central Road, Paisley is described in the Detailed Assessment, 2004 as the main bus interchange in the centre of Paisley, being a convenient transfer point for shops, the railway station and a taxi rank. The road runs in an east-west direction, and is directly below a multi-storey car park. The Piazza shopping centre is located to the south of Central Road, and Gilmour Street railway station to the north (see Figure 1 and Figure 2). The railway station and a ramp leading up to the multi-storey car park can be seen on the left-hand site of the photograph in Figure 2. On the right-hand side of the photograph is the service road, and in the foreground is the taxi rank.

Although the site is often described as a ‘tunnel’, it is only partially enclosed. In terms of ventilation, the northern boundary is open, with air flow being partially restricted by the structural supports of the multi-storey car park, the ramp to the car park, the arches of a railway bridge, and the station building (Figure 3). The southern side of the tunnel is completely enclosed by the shopping centre. There is a service road (for deliveries) between Central Road and the shopping centre. Delivery doors extend the full length of the service road. Central Road is separated from the service road by pedestrian barriers and roof support pillars.

There are four bus stops on Central Road, two on either side of the road, with each bus stop being used by a number of different companies. There are few reasons for members of the public to remain in the area other than to wait for a bus, and there are often considerable numbers of people doing so for relatively long periods. The Council has therefore recently provided benches in the area.

Figure 1: Central road bus terminus, viewed from the west.

Figure 2: Central road bus terminus, viewed from the west, showing railway station, car park and service road.

Figure 3: Central road bus terminus, viewed from the east.

3.0 Declaration of AQMA

The Local Air Quality Management (LAQM) framework, which was introduced under the Environment Act 1995, is designed to help local authorities review and assess current and future air quality in their areas. The LAQM framework requires local authorities to assess concentrations of various air pollutants against standards and objectives set out in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland. For local authorities within Scotland further regulations are set out in the Air Quality (Scotland) Regulations 2000 and Air Quality (Scotland) Amendment Regulations 2002. The LAQM process and its associated objectives are subject to periodic review. The latest consultation was undertaken in April 2006, and led to the release of the revised AQS in July 2007 (Defra *et al.*, 2007). The pollutants contained within these regulations, and their relevant objectives are presented Table 1.

Table 1: Air pollutants and objectives in the UK Air Quality Strategy.

Pollutant	Objective	Compliance date
NO_2	**Hourly mean concentration should not exceed 200 µg m^{-3} more than 18 times a year.** Annual mean concentration should not exceed 40 µg m^{-3}.	**31 December 2005**
Particulate matter, expressed as PM_{10}	24-hour mean concentration should not exceed 50 µg m^{-3} more than 35 times a year. Annual mean concentration should not exceed 40 µg m^{-3}.	31 December 2004
	Scotland: 24-hour mean concentration should not exceed 50 µg m^{-3} more than 7 times a year. Annual mean concentration should not exceed 18 µg m^{-3}.	31 December 2010
Particulate matter, expressed as $PM_{2.5}$	*UK urban areas* Target of 15% reduction in concentrations at urban background.	Between 2010 and 2020
	Annual mean concentration should not exceed 25 µg m^{-3}.	31 December 2004
	Scotland: Annual mean concentration should not exceed 12 µg m^{-3}.	
Benzene	Running annual mean concentration should not exceed 16.25 µg m^{-3}.	31 December 2003
	Scotland & Northern Ireland: Running annual mean concentration should not exceed 3.25 µg m^{-3}.	31 December 2010
	England & Wales: Annual mean concentration should not exceed 5 µg m^{-3}.	31 December 2010
1,3-butadiene	Running annual mean concentration should not exceed 2.25 µg m^{-3}.	31 December 2003
CO	Maximum daily running 8-hour mean concentration should not exceed 10 mg m^{-3}. In Scotland it is expressed as a running 8-hr mean.	31 December 2003
PAHs	Annual mean concentration of B(a)P should not exceed 0.25 ng m^{-3}	31 December 2010
Lead (Pb)	Annual mean concentration should not exceed 0.5 µg m^{-3}. Annual mean concentration should not exceed 0.25 µg m^{-3}.	31 December 2004 31 December 2008
SO_2	Hourly mean of 350 µg m^{-3} not to be exceeded more than 24 times a year. 24-hour mean of 125 µg m^{-3} not to be exceeded more than 3 times a year. 15-min mean of 266 µg m^{-3} not to be exceeded more than 35 times a year.	31 December 2004 31 December 2005
Ozone (O_3)	Running 8-hour concentration of 100 µg m^{-3} not to be exceeded more than 10 times a year	31 December 2005

LAQM comprises two phases. The first phase is an Updating and Screening Assessment (USA), which is a checklist designed to review new monitoring data, new objectives, new pollution sources or any significant changes to existing pollution sources which may affect air quality. This is required every three years. The second phase is a Detailed Assessment which is required where the Screening Assessment has shown that there is a risk of an air quality objective being exceeded. If the Detailed Assessment confirms an exceedence of an objective, it is then necessary to designate an Air Quality Management Area (AQMA). A Progress Report is required in the years following the Screening Assessment and/or the Detailed Assessment.

Central Road was identified as a potential pollution ‘hot spot’ in the initial Updating and Screening Assessment. The location had, in the past, been the subject of complaints by members of the public about the concentrations of bus ‘fumes’. There has been a NO_2 diffusion tube site on a bus stop stand at the kerbside on the north side of Central Road since 1994. The results from the diffusion tubes indicated that air quality levels at Central Road were likely to exceed the annual mean objective for NO_2, although the site was not considered to be an area of relevant public exposure for this objective. The 2003 Screening Assessment concluded, however, that there was a need for a Detailed Assessment at Central Road to determine whether exceedences of the one-hour NO_2 objective were likely. The results from diffusion tube monitoring on the north side of Central Road in the USA showed the need for a Detailed Assessment, based on Scottish Executive advice that an annual mean of 60 $\mu g/m^3$ should be taken as a threshold for further assessment in terms of the one-hour objective.

A Detailed Assessment was conducted in 2004 and an automatic, continuous oxides of nitrogen (NO_x) analyser was operational in Central Road from mid-January 2004. Diffusion tubes were placed near the inlet of the continuous analyser from the beginning of February 2004. Two other diffusion sites were also started at the end of June 2004, one in Central Road to the west of the continuous analyser location, and the other in Smithhills Street close to the junction with Central Road and to the east of the continuous analyser. The continuous analyser recorded 343 exceedences of the one-hour mean objective concentration for NO_2 of 200 $\mu g/m^3$ over a six-month period. The concentrations of other pollutants were not monitored.

A subsequent Progress Report provided updated monitoring results for 2004. The Report also highlighted further exceedences of the NO_2 one hour mean objective at Central Road. The continuous analyser recorded 606 exceedences of the one-hour mean objective concentration for NO_2 of 200 $\mu g/m^3$ between the beginning of February and the end of December 2004 (based on a data capture rate of 88.7%). The highest one-hour mean concentration was 833 $\mu g/m^3$ on 7 December 2004.

The Government-sponsored Monitoring Helpdesk was consulted on the Central Road results, as the concentrations were extremely high and as there were many exceedences of the one-hour mean objective for NO_2 when compared with national network sites such as Glasgow Kerbside and London Marylebone Road. The Helpdesk was provided with the Central Road data and with photographs showing the location of the monitoring site. The Helpdesk agreed that the concentrations were very high but thought that this was a reflection of the location, which was considered to be extreme from the perspective of ambient NO_2 environments in the UK.

It was therefore concluded that Central Road would, in all likelihood, fail to meet the one-hour objective for NO_2 in 2005 (the relevant deadline for this objective) unless action was taken to reduce concentrations in the area. This prompted the declaration of an Air Quality Management Area in the Central Road area. The USA and Detailed Assessment were subject to a statutory consultation process. Responses were received from, among others, the then Scottish Executive and the Scottish Environment Protection Agency, the main statutory consultees. Both these consultees agreed that Central Road should be declared an AQMA.

The Council approved an Air Quality Management Area Order in September 2005, and produced literature explaining the AQMA, an example of which is shown in

Figure **4**. The location of the Central Road AQMA in Paisley is shown in Figure 5 (some other roads where air pollution has been measured are also indicated), and an aerial view of the Central Road area is given in Figure 6. A more detailed plan of the site is given in Figure 7.

The USA, 2006 indicated that the 2005 NO_2 annual mean and one-hour mean objectives were still being exceeded at Central Road, and therefore the decision to declare an AQMA remained valid (BMT Cordah, 2007). The Council was also expected to produce an Air Quality Action Plan, and to show what measures it intended to introduce to improve air quality in the AQMA.

Figure 4: Renfrewshire Council leaflet explaining the AQMA

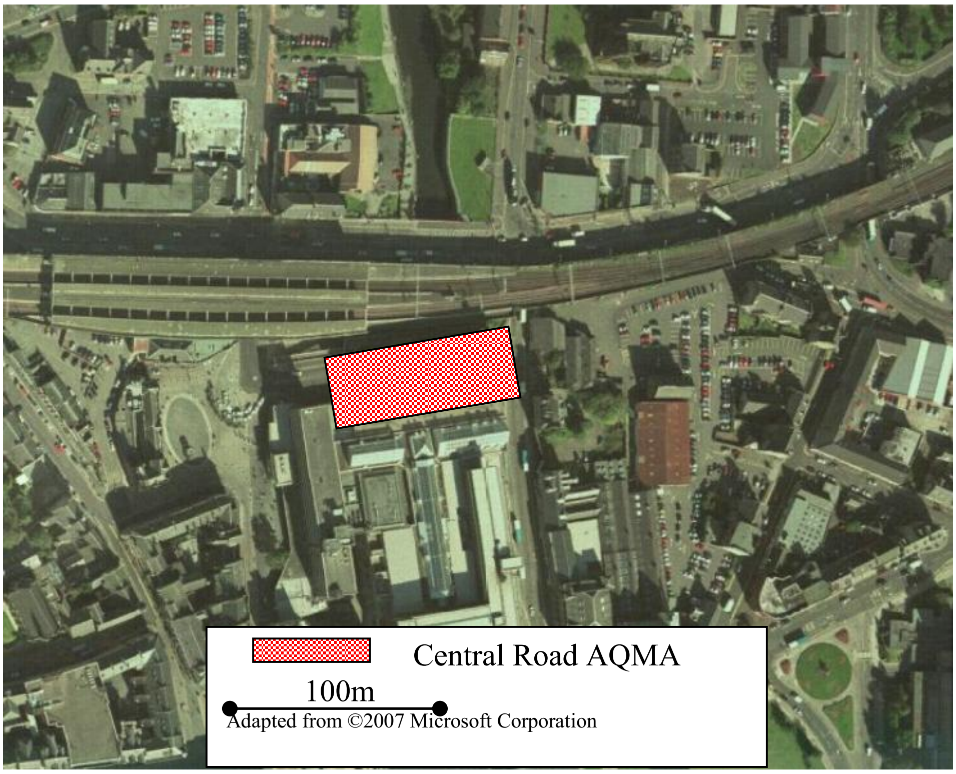


Figure 5: Location of the Central Road AQMA in Paisley

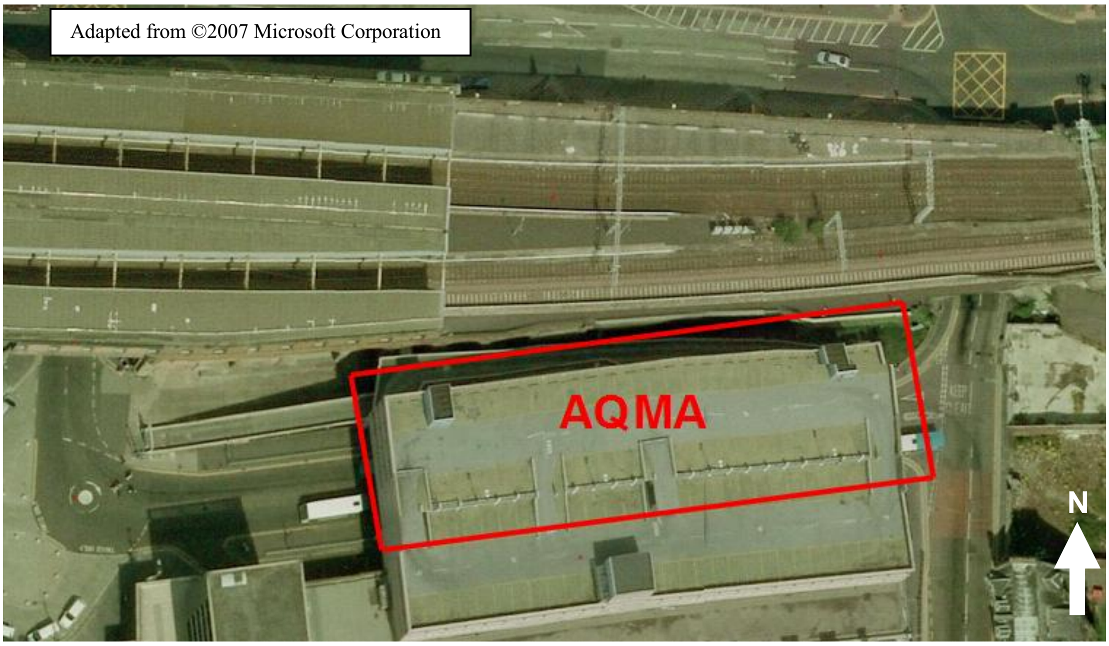


Figure 6:. Aerial view of the Central Road area.

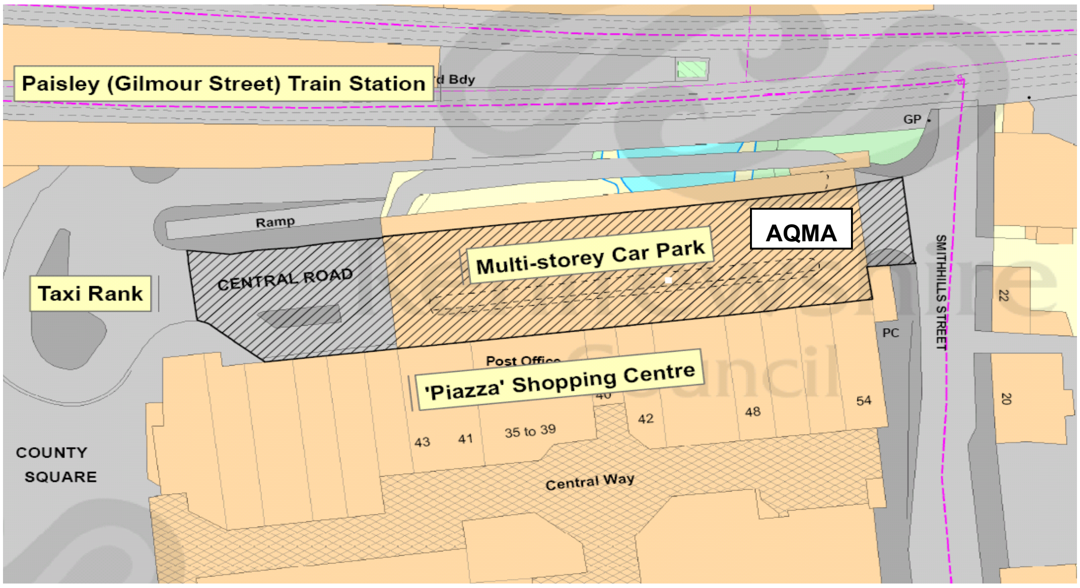


Figure 7: Detailed plan of Central Road area showing the extent of the AQMA

4.0 Aims and Objectives

It is considered important to list the aims and objectives of Renfrewshire Council's Action Plan in order of importance. These are:

1. To achieve the National Air Quality Strategy Objective for NO2. However, this may be difficult due to the unique aspect of the AQMA.

2. To collaborate with other council services, public bodies and external agencies to develop a long–term acceptable and efficient multi-component strategy to solve Renfrewshire's air quality problem.

3. To improve Renfrewshire's general air quality

4. To support national strategies to improve air quality

The Action Plan is intended to outline the actions and long-term strategies that the council and other agencies have investigated as methods of reducing emissions of NO_x within Renfrewshire. It includes all management measures that have been considered in Renfrewshire since the declaration of the AQMA in 2005.

In the guidance, 'Action Plan Appraisal Checklist' (Casella Stanger), five general sources of air pollutants were identified:

- Road transport
- Other transport
- Industry
- Domestic
- Aviation

Of these five source types, only Road Transport is considered to represent a significant source of NOx in the AQMA, and as such, only strategies influencing NOx emissions from Road Transport will be considered in this Action Plan.

5.0 Sources of air pollution in the Central Road area

5.1 Road vehicles

In most urban areas road vehicles are an important source of NO_2. Road vehicle exhaust contains both NO_2 and nitric oxide (NO). Collectively, these two gases are termed oxides of nitrogen (NO_x). Most of the NO_x in vehicle exhaust is usually present as NO, whereas most of the NO_2 in the atmosphere is formed by the reaction of NO with ozone (O_3), and in ambient roadside air NO_2 levels are generally limited by the local concentration of O_3 rather than the emission of NO from vehicles. The NO_2 which is emitted directly from vehicle exhaust is commonly referred to as 'primary NO_2'.

It has already been noted that a major contributor to the elevated NO_2 concentrations in the Central Road area is likely to be buses remaining stationary at bus stops for prolonged periods in the enclosed section. Idling of buses within this tunnel not only results in unnecessary emissions, but also adds to congestion within the area. Several hundred buses pass along Central Road each day, some of which remain stationary with the engine left running for more than 20 minutes. Taxis also use the road to access a taxi rank at the junction of Central Road and Gilmour Street to the west of the bus station. Vehicles delivering goods to the shops in the Piazza Centre can also remain stationary in the service road with engines left running. Buses, taxis and commercial delivery vehicles predominantly use diesel engines. Diesel-engined vehicles tend to emit considerably more NO_x than petrol-engined vehicles. Furthermore, the Local Transport Plan (Dept. of Planning and Transport 2007) cites the main problem as old, badly maintained buses.

Another contributing factor to NO_2 levels inside the tunnel could be the car park above Central Road. For example, the emission levels of vehicles entering the car park are likely to be elevated because of the gradient of the entry ramp. Secondly, the emissions of vehicles leaving the car park are likely to be elevated on account of cold-start effects. However, these factors are probably of secondary importance compared with the emissions from the vehicles which are actually in the tunnel. The opening hours of the car park are 08:00 to 19:00, Monday to Saturday.

5.2 Trains

The Central Road area is adjacent to Gilmour Street railway station. The station is on the Inverclyde and Ayrshire Coast lines and is managed by First ScotRail. It is the busiest of four stations serving the town. Indeed, it is the fourth busiest railway station in Scotland[1]. It is an important interchange, not only for the bus link to Glasgow Airport which is approximately 2 km away, but also for many local

[1] http://www.rail-reg.gov.uk/

buses which depart from the area surrounding the town centre and run to destinations throughout Paisley and Renfrewshire, and to the out of town shopping centre, Braehead.

The LAQM Technical Guidance (TG03, Defra) indicates that assessment of railway locomotives is required where diesel locomotives are regularly stationary for 15 minutes or more and where there is public exposure within 15 metres of the track. The 2003 USA highlighted a section of railway where railway locomotives were stationery for periods of 15 minutes or more. A local resident had complained about the stationary locomotives, and agreement had been reached with the train operator to switch off engines at this location after 15 minutes. The complainant has since moved house, and Renfrewshire Council have confirmed that no further complaints regarding the locomotives had been received. Further assessment was therefore not required (BMT Cordah, 2007).

Again, in the context of air pollution in the Central Road area, the movements of any diesel trains in and out of Gilmour Street station are probably of secondary importance. Nevertheless, they would contribute to background pollution levels (see below). However, the lines running through the station are electrified, and the actual numbers of diesel trains are not known.

5.3 Background pollution

An important element of any attempt at mitigation must take into account the prevailing background pollution levels. The background pollution level defines a limit to the extent to which pollution may be reduced by action in the vicinity of the AQMA. The background concentration of a given pollutant has both a natural and an anthropogenic component, with the latter generally being more significant in built-up areas. Clearly, the magnitude of the anthropogenic component will vary as the level of polluting human activity varies.

In the case of the Central Road area of Paisley, the anthropogenic background component will include contribution from transport (other roads, rail transport, Glasgow airport), as well as local industrial, commercial and domestic activity.

6.0 Cost-Benefit Analyses/Time Scales

According to the guidance, the Scottish Government does not expect local authorities to undertake detailed cost-benefit analyses, or to attempt to calculate, for example, the monetary value of lives lost or extended due to actions proposed in Action Plans. However, local authorities are required to assess the benefits, costs (financial, socio-economical and environmental) and thus feasibility of different actions proposed within the Action Plan. In addition, time-scales for the implementation of feasible actions should be included. However, many of the scenarios proposed will be difficult to assess in terms of cost and time due to requirement of funding and/or co-operation with other agencies/bodies. Where available, timescales for implementing measures are included.

7.0 Data Analysis

Renfrewshire Council appointed a consultant (Transport Research Laboratory Ltd) to carry out a detailed study of the Central Road AQMA. TRL presented the council with a source apportionment study and potential mitigation measures to improve air quality in the area. The results of this study form the main basis for the Action Plan options presented in this document.

Tunnel dimensions

The dimensions of the Central Road ‘tunnel’ are important in relation to the dispersion and ambient concentration of traffic-derived pollutants. The tunnel is approximately 80 m long, 21 m wide (including the service road), and 6 m high.

7.1 Air pollution data - Continuous roadside measurements

A chemiluminescence NO_x analyser (Monitor Europe ML9841B) was operational in Central Road (grid reference 248450,664195) from mid-January 2004 onwards. The monitor is housed in a metal security enclosure on the pavement area between Central Road and the service road, as shown in

Figure **8**. The results from this monitor have been calibrated and ratified in accordance with Defra Guidance LAQM.TG(03) and in accordance the manufacturer’s recommendations.

Figure 8: Central road bus terminus, viewed from the east and showing the location of the NO_x analyser.

Data Available

2005 (only January to September valid)

- 24-hour mean concentrations for NO_x, NO and NO_2
- 1-hour mean concentrations for NO_x, NO and NO_2
- 15-minute mean concentrations for NO_x, NO and NO_2

2007 (September only)

- 15-minute mean concentrations for NO_x, NO and NO_2 (unratified)

The unratified data for September 2007 were used to assess trends as opposed to analyse absolute concentrations against the Air Quality Objectives.

The NO_2 values for 2005, given in the 2006 Screening Assessment Report, are shown in
Table 2. The results indicate that 420 exceedences of the one-hour mean objective for NO_2 were recorded at Central Road. However, the data after 11 September were invalid, resulting in a low data capture rate. It is therefore likely that the annual number of exceedences could have been much higher. Not surprisingly, the recorded annual mean NO_2 concentration at Central Road was also above the objective. NO_2 and NO_x concentrations calculated by TRL from the hourly data for September 2005 and September 2007 are shown in Table 3 to give a broad indication of relative concentrations over the two years.

Table 2: Reported NO_2 concentrations and exceedences for 2005 at Central Road (BMT Cordah, 2007).

Data capture rate (over 12 months)	Annual mean concentration ($\mu g/m^3$)	Maximum 1-hour mean concentration ($\mu g/m^3$)	Number of exceedences of 1-hour objective
61%	76.5	795.7	420

Table 3: Mean concentrations and exceedences in September 2005 and September 2007 at Central Road.

Period	Mean concentration ($\mu g/m^3$)		Number of exceedences of 1-hour NO_2 objective
	NO_2	NO_x (as NO_2)	
1-11 Sept[a]	43.4	221.1	
1-11 Sept[b]	46.7	268.5	1
1-30 Sept[b]	59.4	339.2	3

a Based on period 1-11 September only, as data after 11 September were invalid. *b Data unratified – for guidance only*

To illustrate the scale of the air quality problem on Central Road, the pollution data and traffic data from the site were compared with the data from another roadside site in Paisley town centre – Gordon Street. For the Gordon Street site, the concentrations for NO_x, NO and NO_2 were supplied as 24-hour mean values for 2005 and 15-minute mean values for September 2007 (unratified data). In addition, 24-hour mean PM_{10} concentrations were provided for 2005.

Hourly NO_x concentrations, NO_2 concentrations and traffic flows at Central Road and Gordon Street in September 2007 are shown in Figure 9. Traffic flow data were only available for a one week period at each site. Clearly, the NO_x and NO_2 concentrations at Central Road are much higher than those at Gordon Street, even though the traffic flows are considerably lower.

Aside from the fact that Central Road is enclosed, and therefore the effectiveness of dispersion is reduced, the location of the NO_x analyser clearly influences the measured NO and NO_2 concentrations. In particular, the proximity of the air inlet of the analyser with respect to vehicle exhaust is of crucial importance. It can be seen from Figure 10 that the distance between the air inlet of the analyser and the bus stop is such that the exhaust pipe of any bus will be very close to the inlet, as also suggested by Figure 11.

The data in Figure 9 also indicate that the NO_x and NO_2 concentrations inside the tunnel at Central Road are particularly high on certain Tuesdays (*i.e.* 4 September, 11 September, 18 September), but apparently not on others (*i.e.* 25 September). This required further investigation.

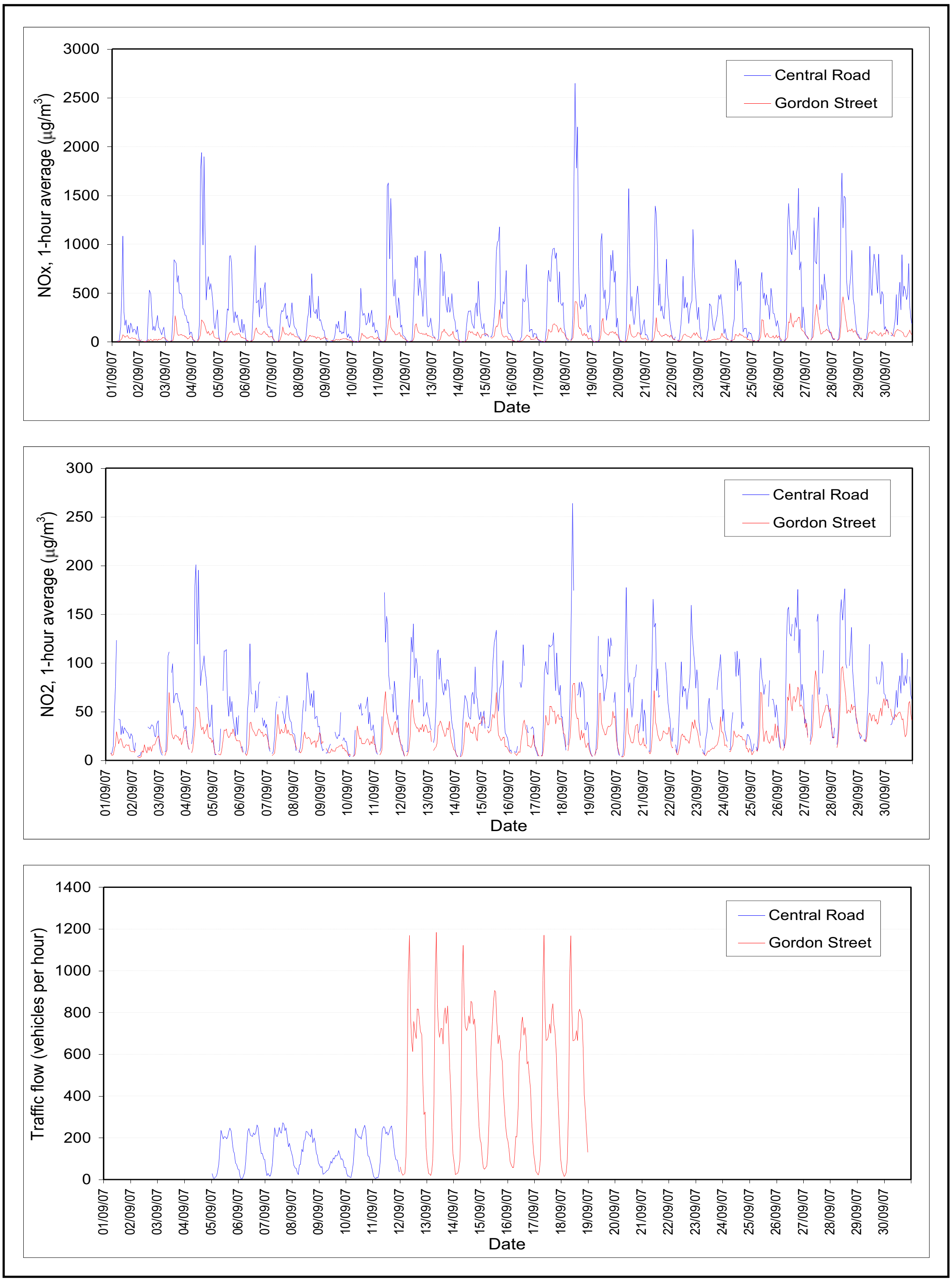


Figure 9: Hourly NO_x concentrations, NO_2 concentrations and traffic flows at Central Road and Gordon Street in September 2007.

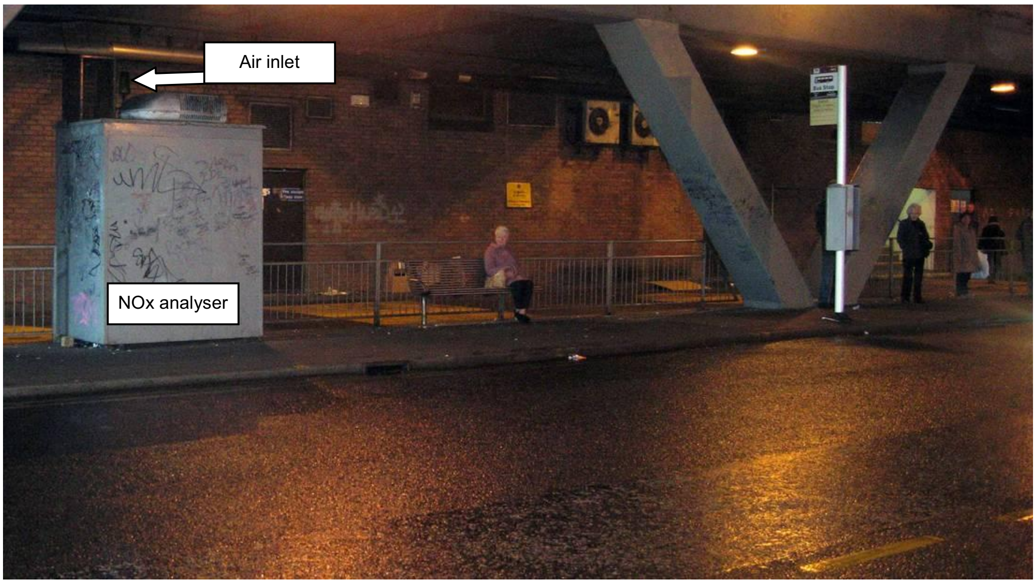


Figure 10: Location of the NO_x analyser, viewed from inside tunnel.

Figure 11: Location of the NO_x analyser in relation to bus exhaust pipe, viewed from inside tunnel.

7.2 Diffusion tube monitoring

The diffusion tubes in Paisley are prepared and analysed by Glasgow Scientific Services using 20% triethanolamine in water. The Technical Guidance recommends that diffusion tubes are co-located with a continuous chemiluminescence monitor in order to determine any laboratory bias within the results (Defra, 2003). The reported bias adjustment factor for Glasgow Scientific Services for 2005 (0.75) has been applied to all diffusion tube results throughout Renfrewshire (BMT Cordah, 2007).

Some selected results for 2005 are shown in Table 4. The roads which are included here were indicated in Figure 5. Those sites which exceed the annual objective concentration of 40 μg/m^3 are highlighted in bold. The data capture rate for Central Road (North) was less than 90%, therefore the results from this site should be treated with caution.

The diffusion tube at Gordon Street was located at a kerbside location, and was subsequently re-located to a nearby building façade to be representative of a location of public exposure for the annual mean objective. The results indicate that the NO_2 objectives are unlikely to be exceeded outside the tunnel area of Central Road (BMT Cordah, 2007). The results for the three diffusion tubes co-located with the automatic analyser on Central Road all demonstrate exceedences of the annual mean objective (Table 5)

Table 4: Results of NO_2 diffusion tube monitoring in Paisley for 2005 with exceedences highlights in bold (adapted from BMT Cordah, 2007).

Monitoring site	Annual mean concentration (μg/m^3)[a]	Data capture rate (%)
Gilmour Street	22	92
Central Road (W)	33	100
Central Road (N)	**50**	67
Gordon Street	**40**	92
Smithhills Street (W)	**47**	92
Smithhills Street (E)	33	100
Old Sneddon Street	37	100

a corrected for bias (0.75)

Table 5: Results from NO_2 diffusion tubes co-located with continuous analyser on Central Road in 2005 with exceedences highlighted in bold (adapted from BMT Cordah 2007).

Monitoring site	Annual mean concentration (µg/m^3)^a	Data capture rate (%)
Central Road (1)	**57**	100
Central Road (2)	**56**	100
Central Road (3)	**58**	100

a corrected for bias (0.75)

7.3 Background pollution

In order to work out the contribution of the traffic to the NO_2 concentration at Central Road, it was necessary to know the urban background concentration, and how this varied as a function of time of day. There are no continuous urban background monitoring sites in Paisley. Annual mean background NO_2 concentrations for Renfrewshire, obtained from the LAQM website, were presented in the 2006 Screening Assessment Report (BMT Cordah, 2007). The NO_2 concentrations for 2005 and 2010 were 25.5 µg/m^3 and 22.7 µg/m^3 respectively. It was also noted that the highest background concentrations are experienced in the east of Renfrewshire at the border with Glasgow City Council.

There are six urban background diffusion tube sites in Paisley: Oakshaw Street, Lochfield Road, Regent Street, Greenock Road, St Andrew Crescent and Montgomery Drive. The bias-adjusted annual mean NO_2 concentrations for these sites were 14, 11, 16, 21, 22 and 30 µg/m^3 (BMT Cordah, 2007). However, Renfrewshire Council considers that the three sites with the highest concentrations do not reflect the true urban background as there is a strong road traffic influence.

7.4 Traffic data

Traffic data from 2007 was used for Central Road (and the adjacent service road) and covered the period 5-11 September 2007, and included the following:

- 15-minute total traffic volume by direction.
- 15-minute traffic by vehicle class and by direction.
- 15-minute speed distribution, according to eight bands.
- 15-minute mean and 85th percentile speed.

The ATC systems used records the wheelbase of each individual vehicle passing a counter. Then, using this information, the software (MetroCount) allocates each vehicle to one of twelve classes, according to the 'ARX' classification (Table 7.

Table 6). The ARX classification is based on the Australian AustRoads94 system, hence the presence of 'road train' classes. The ATC data aggregated the ATC into five classes. These five classes, and the corresponding ARX classes, are given in Table 7.

Table 6: ARX traffic classification.

Vehicle class	Description	Axles
1	Bicycle or motorcycle	2
2	Car, light van	2
3	Car towing caravan	3, 4 or
4	Two-axle truck or bus	2
5	Three-axle truck or bus	3
6	Four axle truck	> 3
7	Three-axle articulated vehicle or rigid truck	3
8	Four-axle articulated vehicle or rigid truck and	4
9	Four-axle articulated vehicle or rigid truck and	5
10	Four-axle articulated vehicle or rigid truck and	>= 6
11	Double articulated truck or heavy truck and	> 6
12	Double or triple road train	>6

Table 7: Renfrewshire Council traffic classification.

Vehicle class	Description	ARX classes
1	Motorcycle or pedal	1
2	Car	2, 3
3	LGV[a]	4
4	OGV1[b] or PSV[c]	5, 6
5	OGV2[d]	7, 8, 9, 10,

*a*LGV = light goods vehicle *c*PSV = public service vehicle (bus)
*b*OGV1 = other goods vehicle (type 1) *d* OGV2 = other goods vehicle (type 2)

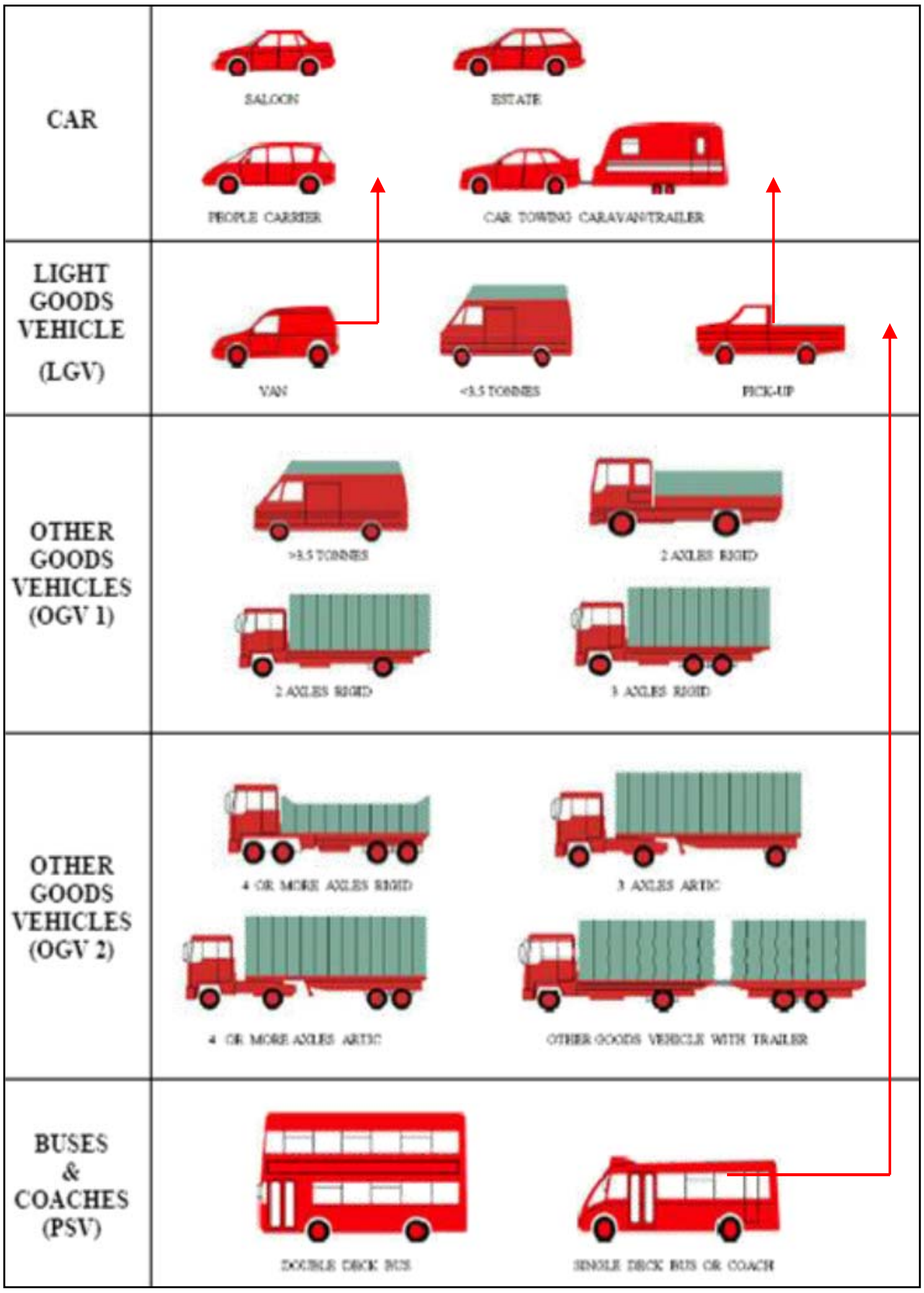
In the original data supplied to TRL (the consultant), the buses in Paisley were assumed to be mainly of the 'Sprinter' type (an example of which can be seen on the right-hand side of Figure 1). The wheelbase of such vehicles falls short of the length which the classifier unit would normally require to identify a bus. These specific vehicles were therefore classified as LGVs by Renfrewshire Council. In addition, larger buses were classified as PSVs, and were combined with OGV1s. However, in a survey of the site conducted by TRL (see Chapter 5) most of the buses at central road were identified as being of the conventional single-deck variety (as shown on the left-hand side of Figure 1). Furthermore, video surveys commissioned by the Council to validate the traffic counts also indicated that most of the buses in the Central Road area were of the conventional type. Consequently, the original traffic data for Central Road were revised to provide a better representation of the actual conditions. Based on the validation survey results (total values), 94% of all LGVs in the original data were re-classified as conventional buses. In addition, 99% of the vehicles in the 'OGV1 or PSV' category were re-classified as conventional buses, although few vehicles were actually in this class.

The vehicle classes used in the revised traffic counts broadly agree with those used in the Highways Agency's Design Manual for Roads and Bridges (DMRB). Differences between the DMRB classification and the classification of vehicles in Paisley are indicated. The types of 'van' and 'pick-up' shown in Figure1were classified as cars in Paisley. The image shown for a 'single deck bus or coach' in Figure 12 is very much like the Sprinter buses used in Paisley. These types of vehicle were classified as LGVs. On the other hand, conventional single-deck buses are not depicted in Figure 12.

The hourly traffic composition on Central Road before and after the revision is shown in Figure 12 and Figure 15. It can be seen that before the revision most of the traffic was composed of cars and LGVs. After the revision, most of the traffic was composed of cars and conventional buses.

The traffic flows on the service road were very low and, in spite of the road being one-way (westbound), the data show that vehicles were travelling in both the eastbound and westbound directions (albeit predominantly the latter).

Figure 12: Vehicle classes used in DMRB. Motorcycles not shown. (Highways Agency *et al.*, 2004)



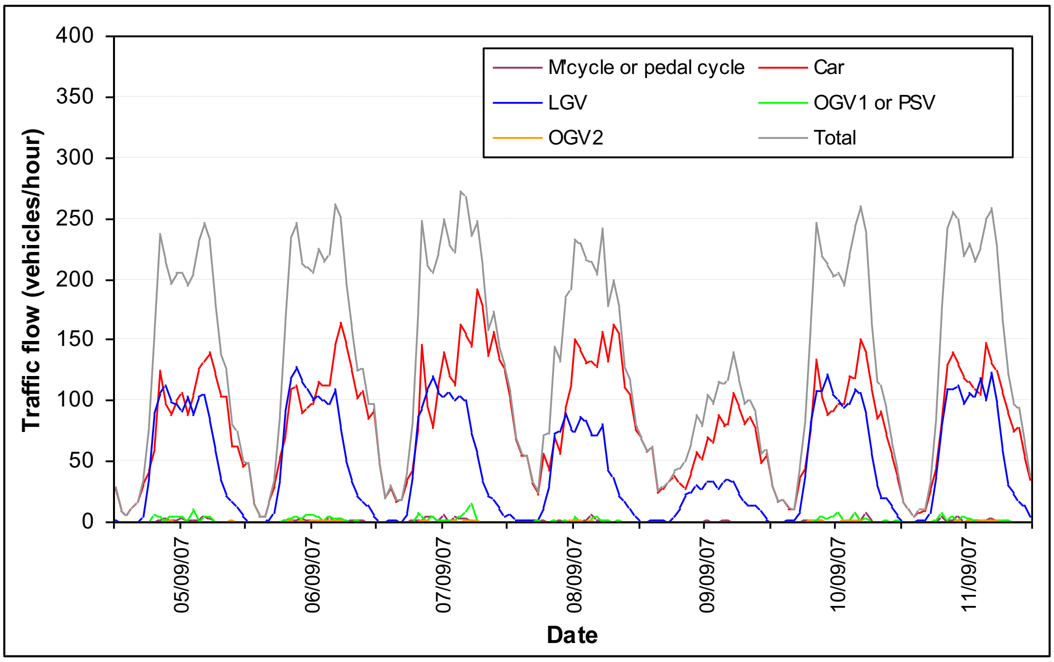


Figure 12: Traffic composition on Central Road during the period 5-11 September 2007 (original data).

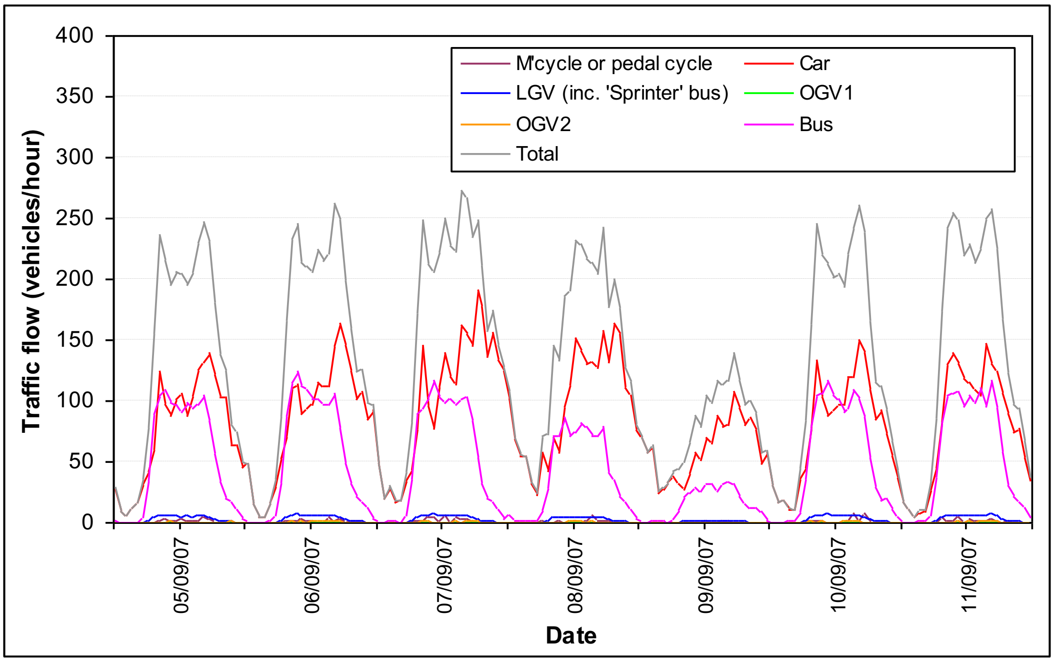


Figure 13: Traffic composition on Central Road during the period 5-11 September 2007 (revised data).

8.0 Site survey

8.1 Background

The traffic data from the ATC systems in the Central Road area provided useful data for the assessment, but there remained a number of uncertainties regarding the different traffic and travel patterns in and around the site. These included specific details concerning vehicle flows, vehicle types, vehicle age distributions and operational characteristics such as speed, idling duration, *etc*. It was therefore considered that an *ad hoc* survey of the pedestrian and traffic activity in the Central Road area would be beneficial.

8.2 Method

The survey was conducted by TRL consultants on Tuesday 13 November 2007. A Tuesday was selected because the monitoring data clearly indicate that NO_x and NO_2 levels in the tunnel are particularly high on certain Tuesdays. The survey was used to gather qualitative and quantitative evidence to support the assessment of pollution levels in the AQMA.

Two consultants observed traffic and pedestrian movements between 07:00 and 12:00. A number of specific tasks were undertaken, including the following:

- Bus operators with services in the area were noted.
- Every 30 minutes, the number of pedestrians waiting for buses, and the number of taxis waiting at the taxi rank, were noted.
- The composition of the traffic was assessed via manual counts, using the classification system shown in
-
- (DMRB version rather than ATC version).
- The idling times of buses were recorded.
- The registration numbers of buses were noted to determine vehicle ages.
- Vehicles using the service road were noted.

The results from the survey are summarised below. Other information from the surveys has been used in research for this Action Plan.

8.3 Results

8.3.1 Bus operators

Vehicles owned by the following bus operators were identified in the area:

- Arriva
- Firstbus (Firststop)
- Gibson
- Riverside

It is recognised that this list is not exhaustive.

8.3.2 Pedestrian movements

TRL reported that no pedestrians were observed to use Central Road as a thoroughfare. It is assumed that pedestrians in Central Road are there solely for the purpose of making bus journeys. The majority of pedestrian movements were to and from bus stops via the narrow crossing point which links Central Road to the rear access of the shopping mall. This crossing point is between the bus stops, and has coloured asphalt but no other road markings or signs. A few pedestrians were observed to cross Central Road at a point closer to the taxi rank. The numbers of pedestrians waiting for buses at given times are shown in Table 8.

Table 8: Pedestrian and taxi survey.

Time	Number of passengers waiting at all bus stops	Number of taxis waiting at taxi rank
07:25	25	0
07:55	30	5
08:25	23	6
08:55	25	6
09:25	20	5
09:55	22	8
10:25	12	9
10:55	30	8
11:25	30	3
11:55	58	11
Observation: On average, passengers at bus stops in the direction of the taxi rank outnumbered passengers on the opposite side by about 2:1 at every count (possibly reversed in the afternoon).		

8.3.3 Traffic movements in Central Road

TRL reported that very few private cars were observed to use Central Road. Most of the cars present were taxicabs (Hackney Carriages) heading to, or coming from, the taxi rank, or private hire taxis heading to, or coming from, the railway station or shopping centre. The traffic composition is shown in Table 9. Most of the vehicles present in Central Road were cars and PSVs. Contrary to the ATC traffic count data, few short-wheelbase 'Sprinter' buses (which could be classified as LGVs) were observed. Photographs taken at the time of the survey appear to be confirm that most buses were of the regular single-deck variety (*e.g.* Figure **8**, Figure 11).

Table 9: Results of manual traffic count.

Start time	End time	Number by vehicle class					Direction
		Car	LGV	OGV1	OGV2	PSV	
07:00	07:20	4	1	1		23	Westbound
07:30	07:50	8	1			34	Eastbound
08:00	08:20	23	1	1		18	Westbound
08:30	08:50	16	2			22	Eastbound
09:00	09:20	22	3			20	Westbound
09:30	09:50	16	3			21	Eastbound
10:00	10:20	11	2			21	Westbound
10:00	10:20	15	1			19	Eastbound
10:30	10:50	10				23	Westbound
10:30	10:50	8				18	Eastbound
11:00	11:20	14				18	Westbound
11:30	11:50	11	2			29	Eastbound
Observation: Only 1 double-deck bus was observed, but it did not stop. All other buses were single-deck.							

Bus idling times are given in Table 10. It is interesting to report that at bus stop number 1, immediately next to the continuous analyser, buses were reported to be stationary with the engine running for significant periods (17 minutes, 10 minutes, 20 minutes, 9 minutes and 17 minutes). The overall average idling period was around 6 minutes.

Table 10: Bus idle times.

Start time	End time	Bus stop[a]	Idle time (mins)		Start time	End time	Bus stop[a]	Idle time (mins)
07:00	07:20	1	17		10:00	10:20	3	6
		2	3				4	3
07:30	07:50	3	12		10:30	10:50	1	9
		4	0				2	3
08:00	08:20	1	10		10:30	10:50	3	2
		2	0				4	7
08:30	08:50	4	1		11:00	11:20	1	17
09:00	09:20	1	4				2	8
		2	3		11:30	11:50	3	5
09:30	09:50	3	6				4	2
		4	1					
10:00	10:20	1	20		Overall mean			6
		2	10					

a Numbered clockwise from AQ monitoring station (1-4). The related services are:

Stop 1: 25,18,101, 21A
Stop 2: 169, 300, 66, 22, 21, 60
Stop 3: 18, 19, 60, 902
Stop 4: 1, 4, 24, 26

8.3.4 Age distribution of buses

The age distribution of the buses observed by TRL in the Central Road area is shown in Table 11. Clearly, most of the buses in service are rather old. For example, more than 70% of the observed buses were more than 10 years old (P registration and earlier).

Table 11: Age distribution of buses.

Model year	Registration index	Number observed		Model year	Registration index	Number observed
1990/91	H	1		1999/2000	V	4
1991/1992	J	4		2000	W	12
1992/1993	K			2000/2001	X	
1993/1994	L	12		2001	Y	14
1994/1995	M	46		2001/2002	01/51	1
1995/1996	N	29		2002/2003	02/52	
1996/1997	P	54		2003/2004	03/53	2
1997/1998	R	7		2004/2005	04/54	5
1998/1999	S	4		2005/2006	05/55	8
1999	T					

8.3.5 Delivery vehicles in the service road

The service road is a one-way road in the direction of the taxi rank, although TRL observed some drivers direct their vehicles up Central Road towards the taxi rank and then reverse to their delivery destination on the Service Road. This explains why two-way flows are present in the traffic data collected by the ATC traffic counts.

Few delivery vehicles used the service road during the survey period. During a total observation period of 200 minutes, only 14 vehicles were observed to use the service road (2 cars which passed straight through without stopping, 5 LGVs, 6 OGV1s and a road sweeper). Five of the vehicles parked in the service road, and all drivers switched off the engines of their vehicles for the duration of their stay.

8.3.6 Taxi rank

Some taxis were observed by TRL to idle their engines while in the queue for passengers but they were not stationary for more than a few minutes. The numbers taxis waiting at given times were shown in Table 8.

9.0 Potential mitigation measures

9.1 Background

The Council is required to produce an Air Quality Action Plan to improve air quality on Central Road. This, in turn, requires that the merits of various potential mitigation measures are examined so that decisions relating to the formulation of the AQAP can be informed.

The problem of developing an Action Plan for Central Road is complicated by a number of issues. The Local Transport Plan (LTP) recognises that the Central Road area is generally in very poor condition and requires upgrading. The LTP also recognises that the railway station (adjacent to the AQMA) requires upgrading. However, the car park and shopping centre are privately owned. There is a Central Road Improvement Committee, although this appears to be for cosmetic improvement rather than to address any environmental issues. Private stakeholders appear to have shown little interest in improving air quality due to perceived costs and other aesthetic issues taking priority.

9.2 Reduction of road traffic flow and modification of traffic composition

An obvious approach to reducing NO_2 concentrations at Central Road would be to reduce the total amount of road traffic (including movements on the service road), either permanently or temporarily. Buses, delivery vehicles and taxis may be targeted separately or in combination, although Figure 13 suggests that the focus ought to be placed on cars and buses. The possibility of re-routing of taxis to avoid Central Road may be an option, and automatic barriers might be installed on Central Road to permit the access of specific vehicles at certain times.

9.3 Modification of vehicle operation

The Vehicle and Operator Services Agency (VOSA) has, in the past, undertaken campaigns to enforce a maximum two-minute idling period for buses in the Central Road area. This measure conforms to best practice and is reliant on voluntary agreements. However, the two-minute period is usually exceeded due to congestion. It is understood that all bus operators who run services through Central Road have a Traffic Regulation Condition applied to their licenses by the Traffic Commissioner, allowing their buses to stop only for the minimum period necessary for the safe boarding and alighting of passengers. Where a vehicle remains in the tunnel for a period longer than two minutes, the driver is required to switch off the engine.

9.4 Modernisation of vehicle fleet

European Union legislation has resulted in incremental reductions in emissions of NO_x (and other pollutants) from individual road vehicles. However, the site survey indicated that many of the buses passing through the Central Road tunnel are more than 10 years old. Emissions may therefore be reduced through more rapid fleet replacement. The LTP also suggested a Quality Bus Partnership with stakeholders to improve the quality of buses, through enhanced fleet turnover. A Quality Bus Partnership has recently been formed with Renfrewshire Council and Strathclyde Passenger Transport. In addition to encouraging enhanced renewal of bus fleets there are also personnel regularly enforcing the Traffic Regulation Condition and moving buses on once passengers are safely seated.

9.5 Adaptation of vehicles

Specific exhaust after-treatment devices could be fitted to some vehicles to limit emissions of NO_x NO_2 and PM from the existing fleet. Heavy-duty vehicles could be re-engined, and alternative fuels (*e.g.* compressed natural gas – CNG) could be introduced. These types of adaptation require an understanding of the costs and benefits in relation to general age and condition of buses.

9.6 Local infrastructure improvement/modification

The LTP also mentions reviewing a historical proposal to create a bus interchange at Old Sneddon Street (immediately behind the railway station), and a simpler proposal of converting the Central Road 'tunnel' into a dedicated bus and taxi lane and revising the surrounding road layout to accommodate this. This would almost certainly have (beneficial) implications for the AQMA and possibly displace traffic from the area, depending on the resulting road layout. Modifications to the local infrastructure and road layout could be used to influence the characteristics of the traffic and hence the emissions. However, the actual effects of specific infrastructure measures are beyond the scope of this Action Plan and will be discussed in the Master Action Plan.

9.7 Installation of mechanical ventilation

There have already been discussions between the Council and Piazza shopping centre management to install mechanical ventilation systems, but initial investigations identified relatively high costs associated with this option. In addition, these discussions also highlighted uncertainties over the responsibilities for managing air quality and remediation works within the tunnel area. It is worth noting that ventilation is achieved by introducing 'clean' air into a space. This air is either mixed with the air already present ('mixing' ventilation), or is used to displace the polluted air ('displacement' ventilation). Displacement ventilation methods are generally more effective than mixing methods. In a conventional road tunnels pollutant concentrations are reduced by the displacement of polluted air. On the other hand, in the Central Road tunnel, which is less confined than a normal tunnel, a mechanical ventilation system would probably lead to the mixing of air and the effectiveness of displacement would be reduced. Overall, it appears that mechanical ventilation is unlikely to be a realistic option.

9.8 Adaptation to conditions

A further option would be to reduce exposure to pollution by adaptation to the existing conditions. For example, the provision of a screened and air-conditioned waiting area could be introduced for bus passengers. Exposure to air pollution could be further minimised by the introduction of a more developed passenger information system. Again, the effects of such measures are beyond the scope of this Action Plan, and would require a separate study, possibly including the monitoring of individual exposure.

10.0 Assessment methodology

10.1 Overview

Various approaches have been developed to determine the effects of different air pollution mitigation measures. Typically, these approaches are based on the use of models that can estimate the emissions and air quality associated with a given traffic activity. The approach used must be practical and appropriate for the actual situation, and it should be possible to validate it in some way. It was decided that, in order to accurately consider the likely effects of possible mitigation measures that a source apportionment study should be carried out. In addition, a number of the considered mitigation measures were also modelled to determine which would be most effective at reducing emissions at Central Road, Paisley. This course of action was taken due to the unique nature of the AQMA. In addition, if certain mitigation measures were suggested that may have a high cost impact or high public interest then the Council would have a research based criteria for reaching that decision. In the case of the Central Road area, in order to be able to model the likely effects of different types of mitigation measure on air pollution levels it was important that the predicted NO_x and NO_2 concentrations from the model were comparable to those recorded by the continuous analyser in the tunnel.

However, the Central Road AQMA is a complex environment which is difficult to represent in any simple or sophisticated air pollution model. For example, there are large, short-term (but frequent) peaks in pollutant concentrations. In addition, the geometry is unconventional compared with existing AQMAs and modelled situations. The AQMA is not ‘open’, but is in a confined space which cannot be assessed using conventional models. Neither can the enclosed space be considered to be a true tunnel on account of its structure - the absence of a solid side wall on the northern side of the tunnel means that the external air can mix with the ‘tunnel’ air along the entire length. Consequently, the pollutant concentrations in the AQMA are likely to be higher than those alongside an equivalent open road, but lower than those in an equivalent tunnel environment. Furthermore, different types of individual are exposed to air pollution (*e.g.* members of the public, bus company staff).

Given the physical characteristics of the Central Road area, the initial objective of the assessment was to develop an *ad hoc* modelling approach which could be used to predict NO_x and NO_2 concentrations which were similar to those recorded by the continuous analyser. If this could be achieved, it would then be possible to examine effects on NO_x and NO_2 of changes made to the original traffic data, thus assisting the development of possible solutions for improving air quality in the AQMA.

10.2 Model development

10.2.1 Estimation of emissions from vehicles in motion

Given the budgetary constraints of the project, the assessment was restricted to road transport and the use of an off-the-shelf emission model. The model used was the DMRB spreadsheet (version 1.03d - unreleased)[2]. Although the air pollution prediction routine in the DMRB spreadsheet is rather simplistic (and is not used here), the emission factors (which are used here) are the same as those used in more sophisticated models.

For a defined road link, the DMRB spreadsheet can be used to calculate emissions of the following pollutants from road traffic:

- carbon monoxide (CO)
- total hydrocarbons (THC)
- nitrogen oxides (NO_x)
- particles with a diameter of less than 10 μm (PM_{10})
- carbon

In order to use the DMRB to produce an emissions estimate for the link, the user must provide the following information:

- The year (1996-2025).
- The length of the link.
- The annual average daily traffic flow (AADT).
- The annual average speed.
- The road type (A, B, C or D), where:
  - A = all motorways and A roads.
  - B = urban roads which are neither motorways nor A roads.
  - C = any other roads.
  - Type D is explained below.
- The proportions of different generic vehicle categories in the traffic.

Here, emissions were calculated for hourly periods. This required that the actual hourly traffic flow was multiplied by a factor of 24 to obtain the AADT.

The ‘road type’ parameter acts as a proxy for differences in the coarse composition of the traffic under different conditions. When selecting either of road types A, B and C, only the proportions of light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) need to be specified. The selection of road type D allows a slightly more detailed classification to be specified by the user (*i.e.* passenger cars, LGVs, buses and coaches, rigid HGVs and articulated HGVs). Road type D was therefore used for this work. The more detailed breakdown of the traffic *within* the generic vehicle categories is internal to the model, and cannot normally be specified by the user. However, as the DMRB spreadsheet was developed by

[2] http://www.highways.gov.uk/business/238.aspx

TRL the internal parameters could be changed. In the case of buses, the main parameter of importance is the emission standard (and the associated definition of the fleet composition).

In the European Union, emission standards for heavy-duty applications (including HGVs and buses) apply to all engines used in motor vehicles with a 'technically permissible maximum laden mass' of more than 3,500 kg, equipped with compression ignition, positive ignition natural gas or liquefied petroleum gas (LPG) engines. The regulations for heavy-duty engines were originally introduced by the Directive 88/77/EEC, followed by a number of amendments. Some of the most recent emission standards, implementation dates and limit values are summarised in Table 12.

Table 12: European Union emission standards for heavy-duty diesel engines.

Emission standard	Date[a]	Test	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	Smoke (m^{-1})
Euro I	1992, <85 kW	ECE49	4.5	1.1	8.0	0.612	
	1992, >85 kW	ECE49	4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	1999.10, EEVs	ESC/ELR	1.5	0.25	2.0	0.02	0.15
	2000.10	ESC/ELR	2.1	0.66	5.0	0.10	0.8
Euro IV	2005.10	ESC/ELR	1.5	0.46	3.5	0.02	0.5
Euro V	2008.10	ESC/ELR	1.5	0.46	2.0	0.02	0.5

a Dates in the tables refer to new type approvals; the dates for all type approvals are in most cases one year later (EU type approvals are valid longer than one year).

10.2.2 Description of vehicle fleet

The age distributions of vehicles in the DMRB model are based upon average values for the UK. However, the results of the site survey indicated that the buses in the Central Road area are generally older than the UK figures would suggest. Consequently an alternative age distribution was used for these vehicles.

Assumed emission standards for buses, based on vehicle registration index, are shown Table 13. The age distribution of buses in the Central Road area was derived using this system of classification. The age distributions given in the DMRB model for 2007, and those assumed for the Central Road area, are given in Table 14.

The DMRB model also requires the sub-division of cars by engine size, and the relative proportions of petrol and diesel cars and LGVs. The engine size proportions used are given in Table 15. National petrol/diesel splits for cars and LGVs are given in WebTAG[3] Unit 3.5.6. However, in the case of cars the vehicles in the Central Road are likely to be predominantly diesel. Consequently, the national proportions were ignored, and it was assumed that 90% of cars had diesel engines, as shown in Table 16. The petrol/diesel split for LGVs was retained from WebTAG.

[3] http://www.webtag.org.uk/. The web-TAG site provides detailed guidance on the appraisal of transport projects, and wider advice on scoping and carrying out transport studies.

Table 13: Assumed emission standards for buses, based on vehicle registration number.

Registration index	Period	Assumed cut-	Emission standard
K-	Jul 93 and	01/12/1992	pre-Euro I
L-	Aug 93 to Jul 97	01/12/1993	Euro I
M-	Aug 94 to Jul 95	01/12/1994	
N-	Aug 95 to Jul 96	01/12/1995	
P-	Aug 96 to Jul 97	01/12/1996	Euro II
R-	Aug 97 to Jul 98	01/12/1997	
S-	Aug 98 to Feb	01/12/1998	
T-	Mar 99 to Aug	01/06/1999	
V-	Sep 99 to Feb	01/12/1999	
W-	Mar 00 to Aug	01/06/2000	
X-	Sep 00 to Feb	01/12/2000	
Y-	Mar 01 to Aug	01/06/2001	
-51-	Sep 01 to Feb	01/12/2001	Euro III
-02-	Mar 02 to Aug	01/06/2002	
-52-	Sep 02 to Feb	01/12/2002	
-03-	Mar 03 to Aug	01/06/2003	
-53-	Sep 03 to Feb	01/12/2003	
-04-	Mar 04 to Aug	01/06/2004	
-54-	Sep 04 to Feb	01/12/2004	
-05-	Mar 05 to Aug	01/06/2005	
-55-	Sep 05 to Feb	01/12/2005	
-06-	Mar 06 to Aug	01/06/2006	
-56-	Sep 06 to Feb	01/12/2006	Euro IV

Table 14: Vehicle fleet characteristics at Central Road.

Vehicle class	Emission standard	Proportion of vehicles by class (total by class =1)	
		DMRB	Central Road
Petrol cars	Pre-Euro I	0.0666	As DMRB
	Euro I	0.0762	
	Euro II	0.2119	
	Euro III	0.1665	
	Euro IV	0.4788	
Diesel cars	Pre-Euro I	0.0046	As DMRB
	Euro I	0.0840	
	Euro II	0.1710	
	Euro III	0.4585	
	Euro IV	0.2819	
Petrol LGV	Pre-Euro I	0.0464	As DMRB
	Euro I	0.0597	
	Euro II	0.1873	
	Euro III	0.4510	
	Euro IV	0.2556	
Diesel LGV	Pre-Euro I	0.0161	As DMRB
	Euro I	0.0616	
	Euro II	0.2645	
	Euro III	0.3940	
	Euro IV	0.2638	
Rigid HGVs	Pre-Euro I	0.0041	As DMRB
	Euro I	0.0491	
	Euro II	0.2659	
	Euro III	0.5329	
	Euro IV	0.1480	
Artic HGVs	Pre-Euro I	0.0017	As DMRB
	Euro I	0.0253	
	Euro II	0.1973	
	Euro III	0.5978	
	Euro IV	0.1778	
Bus	Pre-Euro I	0.0617	0.0246
	Euro I	0.0658	0.4286
	Euro II	0.2872	0.4680
	Euro III	0.4605	0.0788
	Euro IV	0.1249	0.0000

Table 15: Engine size proportions in DMRB (assumed for all years).

Vehicle class	Engine size band	Proportion
Petrol cars	< 1.4 l	0.473
	1.4 - 2.0 l	0.460
	> 2.0 l	0.067
Diesel cars	< 2.0 l	0.843
	> 2.0 l	0.157

Table 16: Fuel proportions used for 2007.

Vehicle class	Fuel	Proportion
Cars	Petrol	0.10
	Diesel	0.90
LGVs	Petrol	0.15
	Diesel	0.85

10.2.3 Estimation of idle emissions

Some studies have shown that idle emissions of NO_x, CO, and THC are significant in comparison with driving emissions (*e.g.* McCormick *et al*., 2000). It was suggested earlier that the peaks in ambient NO_x and NO_2 concentrations in the tunnel are probably related to the presence of buses with engines running at idle. Although the emission factors used in the DMRB model are based on real-world driving with periods at zero speed, idle emissions are not treated explicitly. The operational conditions in the tunnel appear to be somewhat exceptional, with vehicles remaining at idle for long periods of time. Therefore, an effort was made to include the additional emissions associated with these idling periods. This introduced a number of problems. For example, there are no widely-available emission factors for engine idle conditions. Secondly, it is not known exactly when, where and for how long buses are actually idling in the tunnel, or indeed which types of bus are present. A number of assumptions were therefore required, and the results from this part of the work must be treated with some caution.

Few emission rates are available for European vehicles operating under idle conditions. For diesel cars, Boulter *et al.* (2005) reported NO_x emission factors at idle between 3.3 and 18.5 g/h. The emission standard did not have a systematic effect on the emission level. Two Euro III LPG-fuelled cars were also tested, and the NO_x emissions at idle were found to be very low (0.001 and 0.104 g/h). A number of studies and models in the US have provided substantially higher idle emission factors for HDVs. Huaia *et al*. (2006) gave a NO_x emission factor of 72 g/h for heavy-duty trucks. McCormick *et al*. (2000) measured, at high altitude, idle emissions from 12 diesel trucks, 12 diesel buses and 4 heavy-duty CNG vehicles. The diesel trucks averaged 85 g/h NO_x, and the diesel buses 121 g/h NO_x. The measured NO_x emissions were significantly higher than the predictions of the MOBILE5 and PART5 inventory models. NO_x emissions at idle from the CNG vehicles were much lower, averaging 16 g/h.

For this project, idle emission rates for buses were derived using the average-speed emission functions presented in the ARTEMIS Project (Boulter and Barlow, 2005). These were based upon predictions from the PHEM model (Rexeis *et al.*, 2005). The approach used is illustrated in Figure 14. In ARTEMIS, emission factor equations (emissions in g/km as a function of speed) are given for three types of diesel bus: 'Midi' (<15 t GVW), 'Standard' (15-18 t GVW) and 'Articulated' (>18 t GVW). The emission factors also vary with the emission standard (pre-Euro I to Euro V), the gradient, and the vehicle load. For Central Road the emission factors for 'Standard' buses were used, together with 0% gradient and a load factor of 0.5 (*i.e.* each vehicle was assumed to be loaded to half the maximum capacity). The typical form of the emission factor equation for NO_x is shown in graph (a). For each emission standard, the function was re-plotted to give the emission rate as a function of speed. In other words, the emission factor (in g/km) for each speed was multiplied by the speed (in km/h) to give the emission rate (in g/h). The values for all speeds were then plotted, and a liner regression curve was fitted to the data. The intercept of the regression curve on the y-axis represented the emission factor at zero speed (*i.e.* assumed engine idle). It should be noted that the emission factors at low speeds are rather variable, and it is possible that there could be a significant deviation from linearity. Consequently, there is a large degree of uncertainty associated with the idle emission rates derived in this way. In an attempt to address this uncertainty, specific emission factors for engine idle conditions were determined for conventional buses using the PHEM model (Boulter *et al,* 2007).

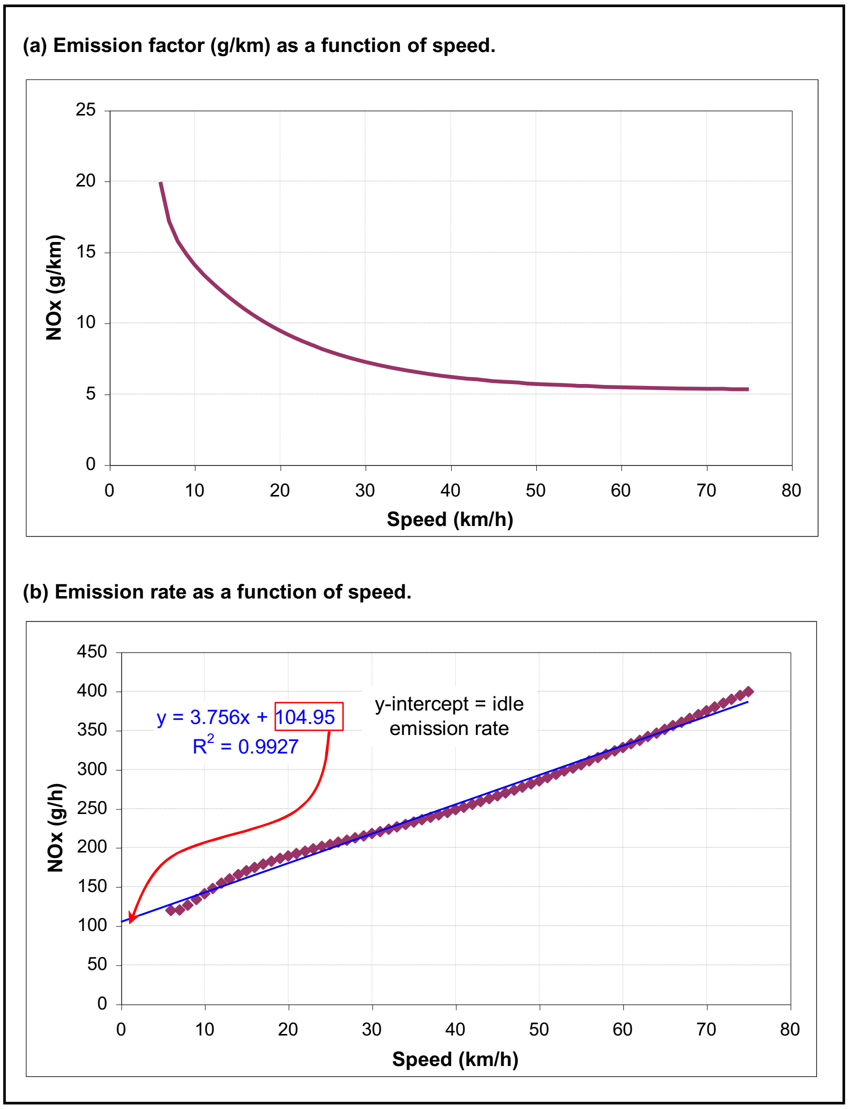


Figure 14: Approach used to determine NO_x idle emission rates for buses.

NO_x emissions are generally lower from CNG vehicles than from diesel vehicles. For CNG-fuelled HDVs, and HDVs fuelled on biodiesel, emission-reduction factors were also presented in the ARTEMIS project (Rexeis *et al*., 2005). It was assumed that a CNG-fuelled Euro III HDV would produce 15% less NO_x than an equivalent diesel-fuelled vehicle. However, it was noted that change in emissions for a given CNG-fuelled HDV could differ significantly from the value given, depending on the manufacturer, the mileage and the operational conditions. It was also noted that compared with Euro IV and Euro V diesel engines the advantages of CNG would diminish, since the Euro IV and Euro V limits require clear reductions in NO_x (Rexeis *et al*., 2005). Using exhaust gas recirculation and other advanced engine technologies, diesel NO_x emissions can be reduced, thus reducing the (apparent) advantage of CNG. However, further emission reductions could also be achieved for CNG vehicles. In the case of biodiesel, the measurements indicated an increase in NO_x emissions of 10-20%, and so the extended use of biodiesel has been ruled out as a mitigation option for Central Road.

The assumed idle emission rates used for conventional buses in this work are summarised in Table 17. 'Sprinter'-type buses were ignored on account of their much lower numbers. The values from CNG have been calculated from the values for diesel using reductions of 25% for pre-Euro I to Euro II, 15% for Euro III, and 5% for Euro IV. The values obtained directly from PHEM are much lower than the ones calculated from the average-speed functions, and one could argue that they are also lower than the values reported in the literature. At this stage it cannot be stated definitively which values are the most representative. Consequently, both sets of values were used in the calculations.

Table 17: Assumed idle emission rates for conventional buses.

Emission standard	Emission rate at idle (g/h)			
	Derived from g/km		Direct from PHEM	
	Diesel	CNG	Diesel	CNG
Pre-Euro I	194	146	65.8	49.4
Euro I	132	99	65.3	49.0
Euro II	143	107	68.3	51.2
Euro III	171	145	53.4	45.4
Euro IV	90	86	55.6	52.8

10.2.4 Calculation of NO_x emissions

The total NO_x emission from the traffic in the tunnel during each one-hour period was calculated as follows:

$$E_{NOx,\ total} = E_{NOx,\ moving} + E_{NOx,\ idle} \quad \text{(in g)} \qquad \text{(Equation 1)}$$

Where:

$E_{NOx,\ total}$ = Total NO_x emission from the traffic
$E_{NOx,\ moving}$ = NO_x emission from all moving vehicles, calculated using DMRB
$E_{NOx,\ idle}$ = Additional NO_x emission from buses at idle

11.0 Estimation of ambient concentrations

11.1 Traffic component of NO_x concentration

The hourly average ambient traffic-derived concentration of NO_x inside the tunnel was estimated using a two-step approach. Firstly, the maximum possible traffic-derived concentration was calculated based on the emissions from the traffic and the assumption that the tunnel represented a closed box, with no outlet for air and with a homogeneous distribution of pollutants. Secondly, the emissions from the traffic were reduced by a dilution factor (***D***) which resulted in the model predictions for NO_x matching, as closely as possible, the measured concentrations. The two steps combined in the following equation:

$$[NO_x] = (E_{NOx,\,total} \cdot 10^6) / (V \cdot D) \qquad \text{(Equation 2)}$$

Where:

[NOx]	=	Total NO_x concentration from the traffic (in µg/m^3)
V	=	Tunnel volume (10,080 m^3)
D	=	Dilution factor (derived by trial and error)

11.2 Background NO_x concentration

Background NO_x concentrations for the year 2005 were derived using the method described below. Although in principle the values could be reduced using scaling factors to represent the year 2007, the changes would have been rather small and were judged not to be important.
The urban background NO_2 concentration applicable to Central Road in 2005 was taken to be the average of the values obtained at the Oakshaw Street, Lochfield Road and Regent Street diffusion tube sites. This value was 14 µg/m^3.

In order to estimate the diurnal variation in the urban background NO_2 and NO_x concentrations at Central Road, data from the automatic urban background monitoring site at Glasgow City Chambers were used. The annual average NO_2 and NO_x values at the Glasgow site for 2005 were 46.0 µg/m^3 and 97.7 µg/m^3 respectively. The ratio between these NO_x and NO_2 values (97.7/46.0) was applied to the diffusion tube value for Central Road of 14 µg/m^3 to derive an annual mean background NO_x value of 29.8 µg/m^3. Similarly, average daily NO_x concentrations at Central Road were estimated for weekdays, Saturdays and Sundays. Diurnal background concentration profiles for the Glasgow site on weekdays, Saturdays and Sundays, normalised to daily mean, were then derived, and these scaled profiles were applied to the average daily background concentrations for the Central Road area.

11.3 Calculation of NO_2 concentration

The total NO_x concentration in the tunnel was calculated as the sum of the traffic-derived component and the background. The NO_2 concentration was then inferred from the estimated NO_x concentration using a relationship between NO_x and NO_2 derived from the continuous measurements in the tunnel. This relationship is shown in Figure 15.

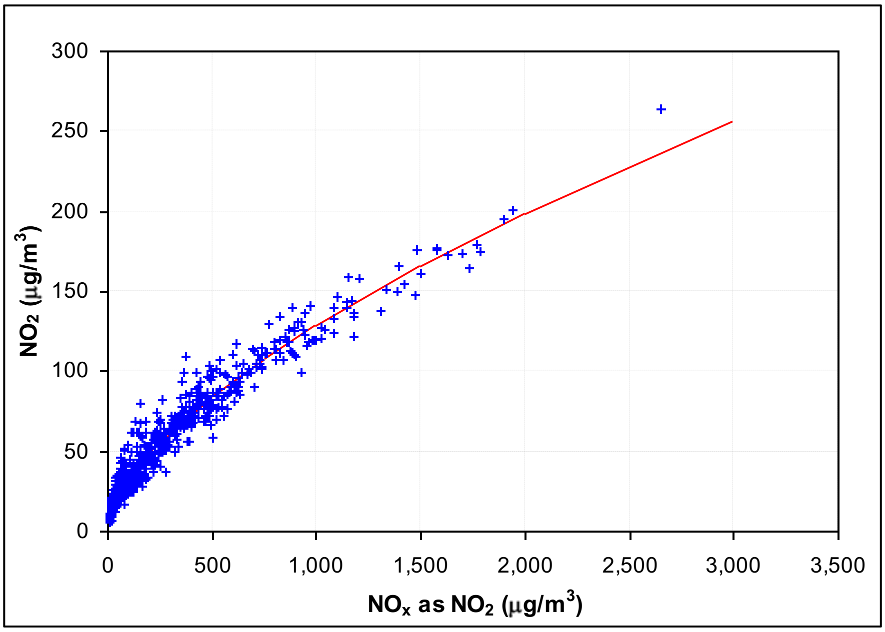


Figure 15: Relationship between hourly mean NO_x and NO_2 at the Central Road monitoring site in September 2007. The red line is a power function which has been fitted to the data.

The form of the relationship is given by:

$$[NO_2] = 7.0346 + 1.3605 \cdot [NO_x]^{0.6504} \qquad \text{(Equation 3)}$$

Where:

[NO₂] = concentration of NO_2 in µg/m^3.
[NOₓ] = concentration of NO_x in µg/m^3.

11.4 Scaling of predicted concentrations

The effects of the Central Road tunnel on ambient NO_2 concentrations could not be predicted in a deterministic manner as a result of the complexity of the environment and the air flows. However, a model was required to allow the effects of different mitigation measures on local air quality to be assessed. Consequently, the approach used was to adjust the predicted NO_x concentration - by varying the value of the dilution factor (***D***) in Equation 2 – until an approximate match (judged arbitrarily) was obtained with the underlying measured concentration (*i.e*. the peaks were not considered).

When using the idle emission rates based on average speed functions, a value of ***D*** of 500 gave the predicted NO_x and NO_2 concentrations (*i.e.* for baseline conditions) shown in Figure 16 and Figure 17. The implication of this is that the air in the tunnel is replaced 500 times per hour.

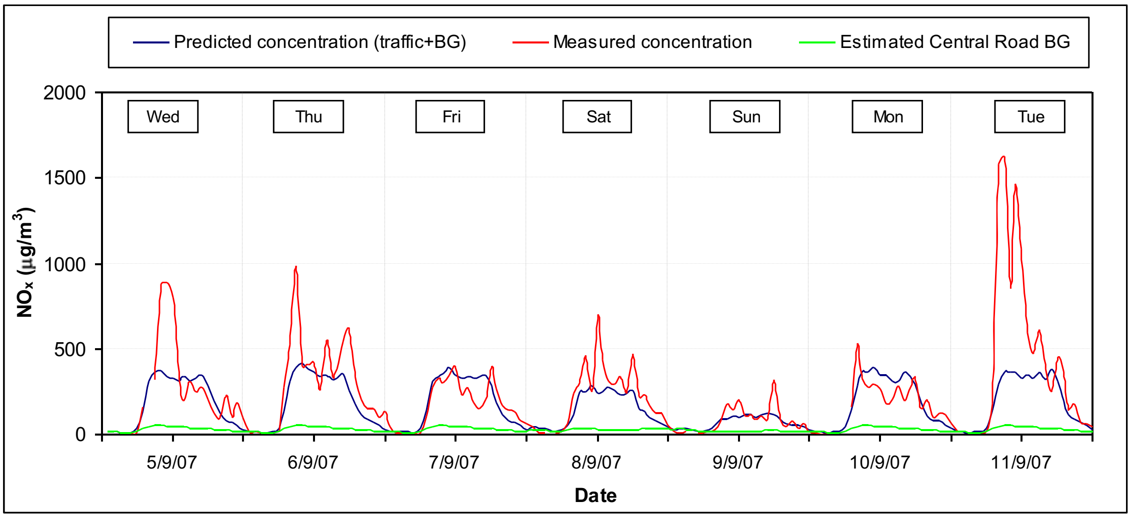


Figure 16: Measured and predicted hourly mean NO_x concentrations in the Central Road tunnel area.

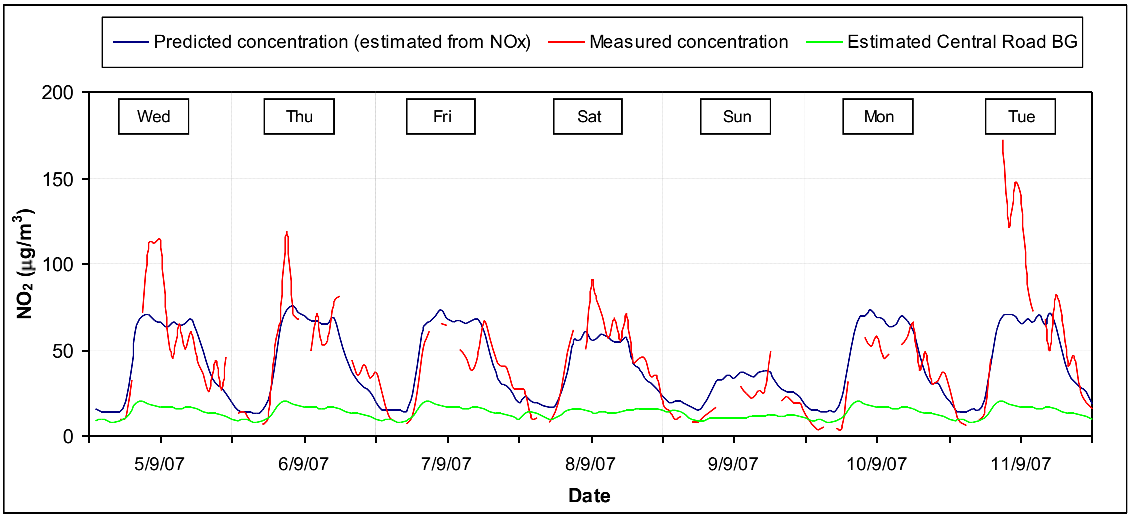


Figure 17: Measured and predicted hourly mean NO_2 concentrations in the Central Road tunnel area.

A ***D*** value of 500 appears to be rather high. However, in a conventional road tunnel the air flow speed is typically 3 m/s. For a tunnel length 80 m, as in the case of Central Road, this equates to 135 exchanges of air per hour. Given that the Central Road area is open to the atmosphere along one side, one can imagine that a dilution factor of 500 for is not unrealistic. When using the idle emission rates taken directly from PHEM, the value of ***D*** required to give the same baseline NO_2 concentration as before was 245. Clearly, both sets of idle emission rates and dilution factors cannot be correct.

It is also evident that the peak NO_x and NO_2 concentrations cannot be predicted by the model. This would require far more detailed data on traffic activity than are currently available. However, a metric was required upon which to base the assessment of different mitigation measures. The main metric which was chosen was the mean hourly NO_2 concentration on weekdays between 06:00 and 19:00 (***$[NO_2]_{06:00-19:00}$***). Although this metric is not in common use, it was considered to provide a good indication of the underlying NO_2 concentration in the tunnel during the working day. Weekly average NO_2 concentrations (***$[NO_2]_{week}$***) were also calculated. One could use this to give a broad indication on the annual mean, although the values in Table 3 indicate that the actual result obtained is rather dependent upon the time period used, and therefore it would not be wise to do so.

11.5 Definition of baseline and mitigation measures

The assessment was conducted for the week 5-11 September 2007. The baseline conditions for the assessment were taken to be the existing traffic conditions in Central Road during this week. The effectiveness of individual measures or polices on air pollution could not be assessed, because their actual effects on the traffic in Central Road would depend very much on the precise nature of their implementation. The assessment therefore focussed on the sensitivity of the values of $[NO_2]_{06:00-19:00}$ and $[NO_2]_{week}$ to changes in the traffic conditions and vehicle fleet which might result from the introduction of such measures. A total of 12 different measures (or effects) were tested, as listed in Table 18. In addition to these fixed scenarios, values of $[NO_2]_{06:00-19:00}$ were estimated for a range of reductions in bus traffic and bus idle periods.

Table 18: Mitigation measures tested.

Measure type	Measure number	Measure or effect
Measures which reduce traffic flow with no change in age distributions	M01	Reduction of traffic flow by 50%, with all types of vehicle affected proportionally.
	M02	Reduction of bus traffic by 75%.
	M03	Removal of all cars.
Measures which change age distribution with no change in traffic flow	M04	Replacement of pre-Euro II buses with Euro IV buses.
	M05	Replacement of pre-Euro III buses with Euro IV buses
	M06	Replacement of pre-Euro IV buses with Euro IV buses
	M07	Replacement of pre-Euro II taxis with Euro IV taxis.
	M08	Replacement of pre-Euro III taxis with Euro IV taxis.
	M09	Replacement of pre-Euro IV taxis with Euro IV taxis.
Measures which affect idling emissions	M10	Enforcement of maximum idling period of 2 minutes, or requirement for drivers to switch off engines after 2 minutes.
	M11	Requirement for bus drivers to switch off engines as soon as buses stop.
Use of alternative fuels	M12	All buses running on CNG (assuming existing age distribution).

12.0 Results

The results of the tests are given Table 19 and Table 20. The NO_2 value in the 'measurements' row includes the peak concentrations recorded in the tunnel. All other rows in the Table are based on the predictions of the model, and do not include the peak concentrations.

The modelling work suggests that any measures which only affected the numbers or types of cars in the traffic at Central Road had very little effect on the values of $[NO_2]_{06:00-19:00}$ and $[NO_2]_{week}$. NO_2 concentrations in the Central Road tunnel are dominated by emissions from buses, and in particular buses at idle. The most effective measures for reducing NO_2 concentrations in the tunnel air would therefore be a reduction in the number of buses and/or a reduction in the average period for which buses are stationary with the engine at idle. Eliminating idle emissions altogether could potentially bring the NO_2 concentration down considerably.

If it assumed that the total numbers of vehicles in the traffic and the average idling period remain unchanged, the overall modernisation of the bus fleet in terms of emission standards would be required, although this would be less effective overall. If reductions in bus numbers and/or idling periods could be achieved, there would probably be little additional benefit from introducing alternative fuels.

Although slightly different absolute NO_2 concentrations were obtained using the idle emission rates derived from the average speed functions and those taken directly from PHEM, the importance of buses running at idle was apparent using both approaches.

Table 19: Value of *$[NO_2]_{06:00-19:00}$* associated with different mitigation measures.

Condition/ measure number	Effect of measure on traffic	*$[NO_2]_{06:00-19:00}$* (µg/m^3)	
		Idle emission rate derived from g/km function	Idle emission rate taken directly from PHEM
Measurements		*67.59*	67.59
Baseline		63.63	63.56
Measure M01	Reduction of traffic flow by 50%, with all types of vehicle affected proportionally.	46.21	46.17
Measure M02	Reduction of bus traffic by 75%.	35.88	36.00
Measure M03	Removal of all cars.	63.52	63.33
Measure M04	Replacement of pre-Euro II buses with Euro IV buses.	58.74	60.83
Measure M05	Replacement of pre-Euro III buses with Euro IV buses.	52.65	57.46
Measure M06	Replacement of pre-Euro IV buses with Euro IV buses.	51.08	57.50
Measure M07	Replacement of pre-Euro II taxis with Euro IV taxis.	63.62	63.55
Measure M08	Replacement of pre-Euro III taxis with Euro IV taxis.	63.61	63.52
Measure M09	Replacement of pre-Euro IV taxis with Euro IV taxis.	63.58	63.47
Measure M10	Enforcement of maximum idling period of 2 minutes, or requirement for drivers to switch off engines after 2 minutes.	40.74	42.05
Measure M11	Requirement for bus drivers to switch off engines as soon as buses stop.	25.30	28.03
Measure M12	All buses running on CNG (assuming existing age distribution).	55.70	55.58

Table 20: Value of $[NO_2]_{week}$ associated with different mitigation measures.

Condition/ measure number	Effect of measure on traffic	$[NO_2]_{week}$ (µg/m^3)	
		Idle emission rate derived from g/km function	Idle emission rate taken directly from PHEM
Measurements		42.94	42.94
Baseline		41.23	41.23
Measure M01	Reduction of traffic flow by 50%, with all types of vehicle affected proportionally.	31.74	31.74
Measure M02	Reduction of bus traffic by 75%.	26.20	26.32
Measure M03	Removal of all cars.	41.12	41.01
Measure M04	Replacement of pre-Euro II buses with Euro IV buses.	38.57	39.74
Measure M05	Replacement of pre-Euro III buses with Euro IV buses.	35.26	37.92
Measure M06	Replacement of pre-Euro IV buses with Euro IV buses.	34.41	37.94
Measure M07	Replacement of pre-Euro II taxis with Euro IV taxis.	41.23	41.22
Measure M08	Replacement of pre-Euro III taxis with Euro IV taxis.	41.22	41.20
Measure M09	Replacement of pre-Euro IV taxis with Euro IV taxis.	41.19	41.14
Measure M10	Enforcement of maximum idling period of 2 minutes, or requirement for drivers to switch off engines after 2 minutes.	28.81	29.55
Measure M11	Requirement for bus drivers to switch off engines as soon as buses stop.	20.57	22.05
Measure M12	All buses running on CNG.	36.92	36.89

The values for $[NO_2]_{week}$ in Table 20 show that the mean concentration in the tunnel for the week 5-11 September was only slightly above the annual mean limit value of 40 µg/m^3, and therefore it is possible that major changes to the traffic would not be necessary for compliance with the annual mean objective. However, as stated earlier, it is not advisable to compare and make such inferences from the weekly mean values, as the two could differ significantly depending on the week selected. It should be noted that the annual mean NO_2 concentration in 2005 was more than 70 µg/m^3 (

Table 2).

The effects of reducing the number of buses in the traffic and reducing the idling period are shown for ranges of values in Figure 19 and 20. In both cases the value of ***$[NO_2]_{06:00\text{-}19:00}$*** is normalised to the baseline condition, and the calculations are based upon the idle emission rates derived from the average-speed functions. Reducing the average bus idling period to two minutes has a similar effect to removing 63% of the buses at Central Road.

It is worth reiterating that the modelling approach used cannot predict peak NO_2 concentrations, and even if stringent measures were taken to reduce the NO_x emissions from the traffic in the tunnel there would be no guarantee that the one-hour NO_2 objective would not be exceeded.

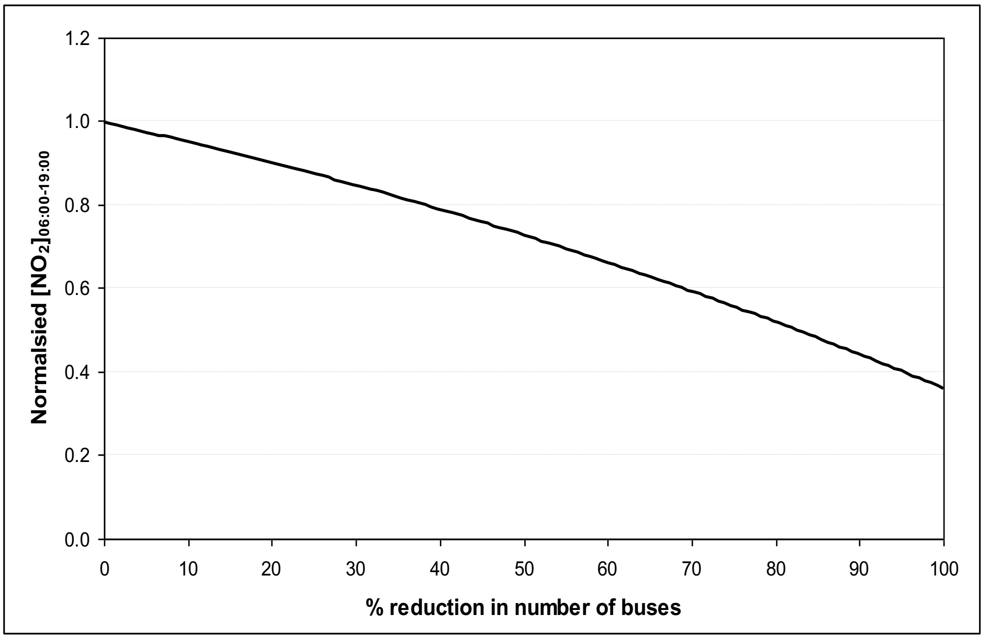


Figure 18: Normalised value of *$[NO_2]_{06:00\text{-}19:00}$* as a function of the reduction in the proportion of buses.

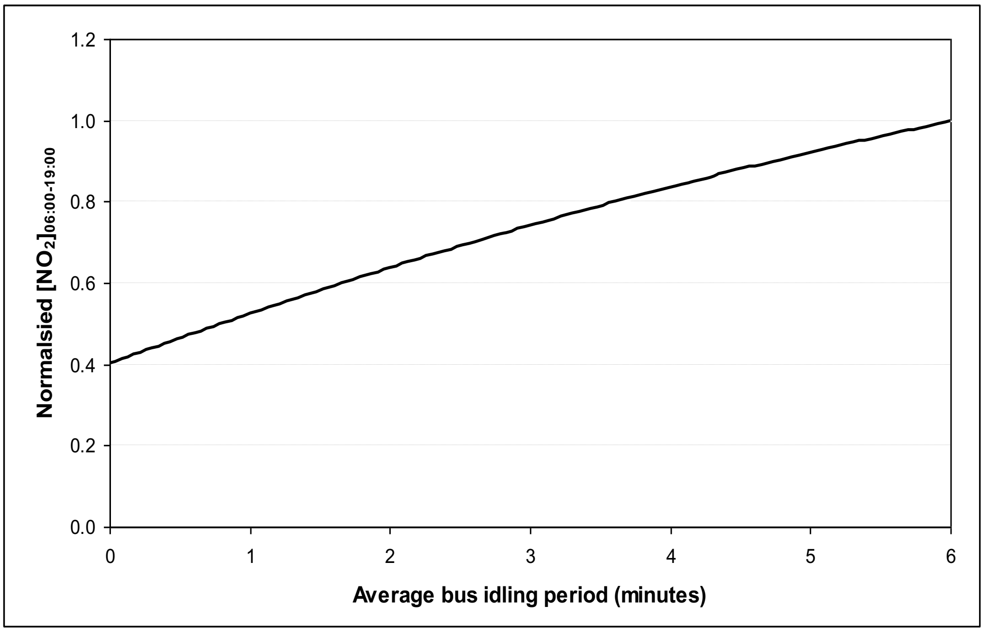


Figure 19: Normalised value of *$[NO_2]_{06:00-19:00}$* as a function of average bus idling period.

13.0 Conclusions of Emissions Study

As a result of exceedences of air quality standards for NO_2, Renfrewshire Council has declared an Air Quality Management Area (AQMA) for the Central Road area in Paisley. Within this Report the potential effects of a number of mitigation measures have been examined.

The Central Road AQMA is a complex environment which is difficult to represent in any simple or sophisticated air pollution model. In order to be able to model the likely effects of different types of mitigation measure on air pollution levels, a *ad hoc* modelling approach was therefore developed. As far as possible, the actual area layout and traffic conditions at Central Road were taken into account. However, the model had three major shortcomings:

(i) The complexity of the environment and the resulting air flows in the tunnel meant that an arbitrary dilution factor had to be used to ensure agreement with the underlying measured NO_2 concentration under the baseline (*i.e.* existing) conditions in the tunnel.

(ii) Because of the lack of data, the emission factors for engine idle conditions were based on a number of assumptions, and are therefore rather uncertain.

(iii) The peak NO_x and NO_2 concentrations cannot be predicted by the model. This would require far more detailed data on traffic activity than are currently available. Consequently, it could not be stated for certain that any given measure would lead to a reduction in the number of exceedences of the one-hour NO_2 objective at Central Road.

Nevertheless, the model could be used to predict NO_x and NO_2 concentrations which were similar to those recorded by the continuous analyser in the tunnel, and it was considered that it gave a reasonable first approximation of the likely effectiveness of different mitigation measures.

The conclusions of the work can be summarised as follows:

(i) NO_2 concentrations in the Central Road tunnel are dominated by emissions from buses, and in particular buses operating at idle.

(ii) The most effective measures for reducing NO_2 concentrations in the tunnel air would be a reduction in the overall number of buses and/or a reduction in the average period for which buses are stationary with the engine at idle.

(iii) The overall modernisation of the bus fleet in terms of emission standards, whilst having a noticeable effect, would probably not be sufficiently effective without a reduction in idling periods or bus numbers.

(iv) There would be little additional benefit from introducing buses fuelled on CNG.

14.0 Recommendations

It is recognised that the Central Road area is in need of overall development and improvement, and it is clear that, as part of any area-wide improvement, the risk of exposure of pedestrians to high levels of NO_2 could be removed if the bus stops in the tunnel could be moved to a location which is more adequately ventilated. An alternative would be to reduce exposure to pollution by adaptation to the existing conditions. For example, the provision of a screened and air-conditioned waiting area could be introduced for bus passengers. Exposure to air pollution could be further minimised by the introduction of a more developed passenger information system. However, such introductions would require further research in the area of individual exposure.

The focus of the study was therefore on traffic-related measures. It has highlighted the importance of NO_x emissions from buses in the Central Road tunnel in relation to exceedences of air quality standards and objectives for NO_2. However, there are a number of assumptions and uncertainties in the modelling work.

14.1 Further research

(i) From a research point of view, a more sophisticated modelling approach should be developed for complex environments such as Central Road. Further studies to improve the modelling work would be beneficial. The relationship between bus operation and NO_2 concentrations in the tunnel should be further examined. This should include the use of shorter averaging periods (*i.e.* one minute) for NO_2.

(ii) This work has highlighted the need for more research to be undertaken on emissions under engine idle conditions. In addition and with respect to Central Road AQMA a greater understanding is required to define exactly why buses tend to operate engines at idle for relatively long periods. This could be associated with a number of reasons, such as;

a. Drivers arriving early, and using this location to adapt to their timetables.
b. Buses unable to manoeuvre promptly away from Central Road due to traffic congestion.
c. Delays in passenger boarding and alighting.

14.2 Potential measures

(iii) In practical terms, restrictions on the period for which buses are stationary with the engine running at idle should be enforced for a trial period in Central Road. Drivers could be required to switch off the engines of their vehicles whilst stationary. During this trial period any changes in the NO_2 concentration in the tunnel should be quantified in order to identify possible benefits. Some form of enforcement would clearly be required, aided by a publicity campaign. For example, this might involve placing notice boards adjacent to all bus stops stating that buses are only permitted to idle their engines for a given maximum period. A free phone number could be provided to allow people to report any observed infringements to the Council.

(iv) A reduction in the overall number of buses actually stopping in the tunnel should be considered. For example, the possibility of moving some of the bus stops to a location outside the tunnel, reducing the number of routes, or restricting vehicle access should be investigated.

(v) The Council should encourage the modernisation of the bus fleet.

Whilst various mitigation measures have been broadly described, the task of fully investigating the resulting impacts is beyond the scope of this Action Plan. However when considering the evidence formed in this study it is possible to consider a number of preliminary options. For example in point (iv) 'restricting vehicle access' this could involve restricting the westbound carriageway to buses only (via automatic barriers) and allowing all traffic in the eastbound direction. Obviously, this would result in periodic queuing of buses away from Central Road. The measure could also involve re-siting bus stops in the eastbound direction (possible away from Central Road or utilising the westbound direction). The westbound carriageway must be free from other traffic during peak periods to allow buses clear access to manoeuvre. The eastbound direction would not require traffic restrictions based on the assumption that removing bus stops would alleviate any potential pinch points. It is assumed that the eastbound direction may at times get congested. However it is thought that pedestrians would tend to stay on the westbound side and so may not be directly exposed to the resulting traffic emissions. This specific measure would require further investigation.

There are direct and indirect costs associated with these measures and options should be considered in light of the associated cost benefits. A bus renewal programme (point v) is one example where direct costs are often disproportionate to the gains that may be achieved. However a combination of targeted fleet renewal, changes in the operational characteristics (potentially through the use of eco-driving training), may well provide a cost effective solution. A full cost benefit analysis will be included in the future Master Action Plan.

15.0 Abbreviations

AADT – Annual Average Daily Traffic Count

AQMA – Air Quality Management Area

AQS – Air Quality Strategy

ATC – Automatic Traffic Count

DMRB – Design Manual for Roads and Bridges

HGV – Heavy Goods Vehicles

LAQM – Local Air Quality Management

LGV – Light Goods Vehicle

LTP – Local Transport Plan

NO2 – Nitrogen Dioxide

OGV – Other Goods Vehicle

PHEM - Passenger car and Heavy-duty Emission Model

PSV – Public Service Vehicle

TRL – Transport Research Laboratory

USA – Updating and Screening Assessment

VOSA – Vehicle and Operator Services Agency

WEBTAG – site which provides detailed guidance of the appraisal of transport projects