Bus Idling and Emissions

Report

Prepared for

Passenger Transport Executive Group

by

Transport & Travel Research Ltd

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0. EXECUTIVE SUMMARY

Aims of the study

This study investigates whether air pollutant emissions from idling buses could be reduced by measures that address three causal factors: behavioural factors, network/infrastructure factors and technical factors. The basis for the study is three example routes in the Public Transport Executive (PTE) areas of Centro in the West Midlands, GMPTE for Greater Manchester and SYPTE for South Yorkshire.

Why and where do idling emissions occur

The study has estimated that significant proportions of total bus emissions on a given route are the result of stationary and idling vehicles. From the three bus routes it was found that buses were stationary yet idling between 30% and 44% of the time. Idling vehicles are using fuel for little benefit, and when this is combusted it releases varying quantities of air pollutants, for example Particular Matter (PM) and Oxides of Nitrogen (NO_x), and CO_2 which is a green-house gas (GHG). Buses that are stationary yet idling are estimated to produce emissions that account for between 5-25% of total PM emissions and 15-25% of total NO_x emissions for each route.

Emissions from idling vehicles occur at:

- Bus stops.
- Termini at either end of the routes.
- Junctions/traffic signals along the network.

These locations are spread along the routes and include densely populated city and district centres, where exposure to air pollutants is harmful to human health (see Section 4.3.2).

What causes idling emissions

Idling bus emissions are the result of a combination of behavioural, network and technical factors. No one factor causes idling emissions, or provides the sole route to their reduction. However, behavioural measures that invest in training and incentives for drivers to undertake safe and fuel efficient driving are an essential part of achieving reductions in idling emissions. In contrast, overall emission reduction can be achieved with solely technical approaches (e.g. more recent Euro standard vehicles), but require investment in new vehicles or retrofit equipment.

The largest emissions savings are realised by immediate switch off of engines when the bus comes to a halt. There is no hard evidence to prove that turning off the engine will either damage modern engines or cause reliability issues.

Current good practice and its potential contribution

Good practice approaches to reducing fuel consumption will lead directly to reduced emissions of air quality pollutants.

Idling emissions are a sub-set of overall emissions, and can be addressed using the following measures:

- Switch-off policy (e.g. training and monitoring) – reducing fuel use, air pollutants (NO_x/PM) and GHG.
- Anti-idling support technologies (e.g. in-cab alerts) – reducing fuel use, air pollutants (NO_x/PM) and GHG.
- Enforcement (e.g. fines, signs, wardens) - reducing fuel use, air pollutants (NO_x/PM) and GHG.

Overall route emissions can be tackled via eco-driving techniques and support programmes/technologies:

- Eco-driving training and incentive scheme - reducing fuel use, air pollutants (NO_x/PM) and GHG.
- Fuel-management systems and in-vehicle monitoring - reducing fuel use, air pollutants (NO_x/PM) and GHG.
- Vehicle replacement (e.g. Euro standard) – reducing air pollutants (NO_x/PM).
- Retrofit (e.g. Diesel Particulate Filters) – reducing air pollutants (PM).
- Retrofit (SCR/EGR) – reducing air pollutants (NO_x).

Some measures will overlap one another, for example retrofitting a bus with a DPF will remove some of PM emissions that could also be reduced from an anti-idling policy. Other measures would be additive to some extent, for example eco-driving techniques would bring benefits when the vehicle is in motion therefore complementary to anti-idling measures focussed on stationary bus at termini.

Recommended actions

The key measures recommended for deployment on the specific routes investigated, and across other routes in PTE areas are:

- At bus stops, implement a policy to achieve engine switch off after 10 seconds to reduce around 13-17% of total idling emissions (equivalent to about 3-4% of total emissions) OR if this is not feasible to aim for a 30 second cut-off, saving between 1% and 11% of idling emissions (up to 3% of total emissions);
- At termini implement a policy to achieve engine switch off, estimated at about 2% of PM and 6% of NO_x in total on average for a 40 minute route;
- Undertake traffic management or implement selective vehicle detection technologies to provide priority to buses at key junctions and target specific bus stops. Tackling the 3 top causes of delay identified along each route in this study would remove 33% of idling emissions (equivalent to 7% of total emissions) and removing the stationary phase of a bus travelling past each average junction is estimated to reduce total emissions by 0.5%.

To implement the above recommendations will require buy-in from drivers, which is best achieved through training and incentive schemes to encourage fuel-efficiency through anti-idling practices. Drivers and managers should be supported to achieve both anti-idling and eco-driving through the use of comprehensive fuel and performance monitoring systems. Drivers need to feel confident that problem vehicles that are at risk of not re-starting after switch-off have problems rectified or the vehicles are removed. PTEs should continue their monitoring and responding to reports of vehicle idling with communication and enforcement practices.

1. INTRODUCTION

This report has been produced by Transport & Travel Research Ltd (TTR) on behalf of the Passenger Transport Executive Group (***pteg***). The report reviews the factors affecting emissions from buses, particularly with respect to idling buses, both in general terms and specifically in three different areas participating in the study: Centro in the West Midlands, GMPTE for Greater Manchester and SYPTE for South Yorkshire.

The study involved both interviews with drivers and managers and detailed route analysis based on observations from on-bus surveys and GPS data.

1.1 Study Aims

The key aims for this study were to:

- Provide an overview of factors affecting bus emissions, organised under behavioural factors (e.g. driver training and behaviour), factors arising from the network (such as junctions, congestion, or improvements through bus lanes) and technical factors (such as barriers due to bus design and potential improvements, including through vehicle emission standards).

- Evaluate a designated bus route in each of the three participating areas in terms of emissions and their source. This assessment is to consist of two parts,
    - A set of interviews with managers and drivers
    - Analysis of GPS tracks and linked observations of each route.

- Assess the degree to which various factors affect emissions, quantify the potential improvements that might be made and provide recommendations on steps to reduce emissions from buses in the most effective and efficient way.

1.2 Content of this report

Following this introduction the report consists of a methodology section setting out the study approach. A section on background research reports on the findings from the literature review and provides a description of the study routes. The main analysis findings are set out in the results section, before we make recommendations in the final section.

2. METHODOLOGY

2.1 Overview

The study was completed through the three main tasks of:

- Literature Review;
- On-bus observations and GPS measurements; and
- Interviews with drivers and managers.

2.2 Data collected

The literature review was split into three sections to cover each of the categories of factors identified – behavioural factors, network factors and technical factors. This review was carried out before the on-bus and interview stages of the study were started as information identified in the review was fed into the other sections, particularly the questions for the interviews.

The on-bus observations were completed over three days, one day for each participating area. One route was selected by each PTE and this route was then surveyed in both directions by an observer from TTR using a GPS tracking device.

The observer made notes about the reasons for the bus being stationary, network features affecting bus speeds and whether the driver switched off the engine when the vehicle was idling stationary. Observations of buses at a terminus of the route were made, to observe whether stationary buses had their engines running.

Ten journeys were completed in Manchester, six were completed in Sheffield, where the route was longer, and ten were completed in Wolverhampton.

The GPS recorder recorded a GPS track of the route, which was formed of individual measurements of position and velocity, taken roughly once per second. The data gathered was used to generate analysis of emissions along the routes and provide evidence to support the suggestions for improvements in the study reporting.

The interviews were carried out both face to face and by telephone with a number of drivers and managers. They comprised questions on the behavioural, network and technical factors which either encouraged or discouraged idling. These interviews were carried out in anonymity and the managers and drivers were interviewed separately to ensure that both felt able to speak openly about positive and negative aspects of their experiences.

Drivers and managers from two different locations were interviewed. The information collected in these results comes from interviewees based in South Yorkshire and Greater Manchester. The main themes that emerged from the interviews were the same and so we have assumed that these themes could hold true in other areas as well.

2.3 Data cleaning and analysis

GPS data is generally of good quality, but this can vary with a number of factors, notably including the "urban canyon" effect, In built up areas buildings on either side can obscure some satellites and also reflect the signal from satellites so that it takes a different path to the device. As the number of satellites the GPS device can "see" goes down, it is harder for it to provide an accurate reading. This can lower the quality of the GPS data.

There are, therefore, some errors that need to be removed before the data can be usefully analysed. Two techniques were employed to correct two related sources of error.

1) Occasionally the GPS receiver will record a sudden movement which is due to GPS error rather than actual movement of the observer and bus. The location reported by the data can fluctuate for a couple of seconds around the point where the GPS device was physically located.

To eliminate errors caused by this effect the data was searched for cases where a sudden (physically unrealistic) acceleration occurred. These values and the subsequent values showing oscillation around a point were identified. This data was then replaced with an estimated speed using the previous speed of the bus. This approach removes some error caused by the nature of GPS readings.

2) The GPS system can mistakenly record data that records the measurement unit "wandering" around a given point. This is caused by the accuracy of the GPS recorder being around 1 to 10 metres, depending on the terrain (the device is more accurate in an open, non built up area). Within that error margin the same point can be reported in different places. This has two effects
    a. The length of a GPS track will be a slight overestimate of the actual distance travelled by a vehicle.
    b. When stationary, the vehicle will not always be recorded as having a speed of 0 kph.

The first effect is unavoidable, but does not fundamentally alter any of the analysis or conclusions of this report. The second effect could make it difficult to understand which readings came from a stationary vehicle, as much of the stationary time would be missed due to it being reported as the vehicle moving a small, but non-zero kph.

To reduce the error introduced by this aspect of the GPS data, our analysis will take any points where the vehicle is recorded as travelling under 5kph as stationary. Following some pre-analysis of the GPS data, this is thought to provide a reasonable cut off point. This is based on the fact that few occasions were observed where the bus was travelling at lower than 5kph except as it came to or pulled away from a halt, This value captures all of the occasions where the bus was actually stationary according to on bus observations, but was reported as moving at a low speed because of a GPS error.

Together, these two corrections make the data suitable for analysis. The data is imported into a custom designed spreadsheet, as each run is composed of 1000s of points and is therefore unsuitable for hand-analysis. This spreadsheet is used to apply the corrections discussed above, then to analyse the data, providing information about the time spent on the route, the estimated emissions caused and so forth.

In order to calculate the emissions data from the imported GPS data, factors must be used to convert vehicle speeds into emission rates. The most suitable factors to use are the latest DfT emissions factors, released in 2009[1]. These consist of equations for emissions of different Euro standard vehicles at different speeds. Although they do not include factors for idling vehicles the equations can be extrapolated back to zero to give idling emission factors for each Euro standard of vehicle, in the form of g/hr (grams per hour) numbers for both NOx and PM.

2.4 Route Descriptions

One route was selected by each of the participating PTEs, which was surveyed in both directions by an observer with a GPS tracking device.

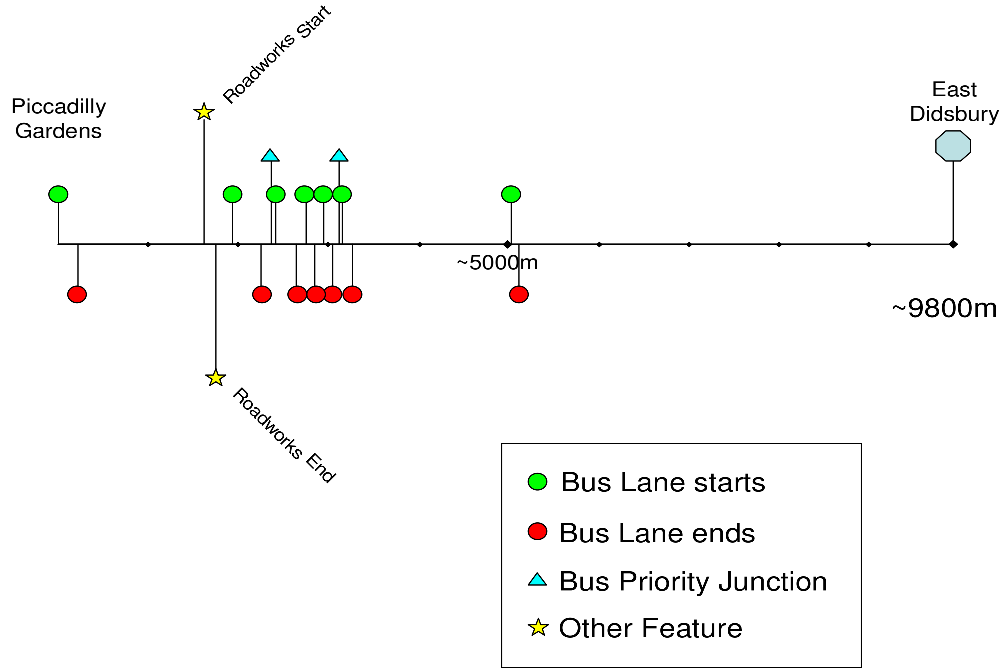
Descriptions and diagrams of each route follow.

2.4.1 Manchester

In Manchester, the route surveyed was Route 42, from Piccadilly Gardens to East Didsbury. The route starts in a busy central location in Piccadilly gardens in Manchester and heads southbound out of the city towards Stockport.

[1] P G Boulter, T J Barlow and I S McCrae, (June 2009). Emissions factors 2009: Report 3 – Exhaust emission factors for road vehicles in the United Kingdom, TRL Report 356.

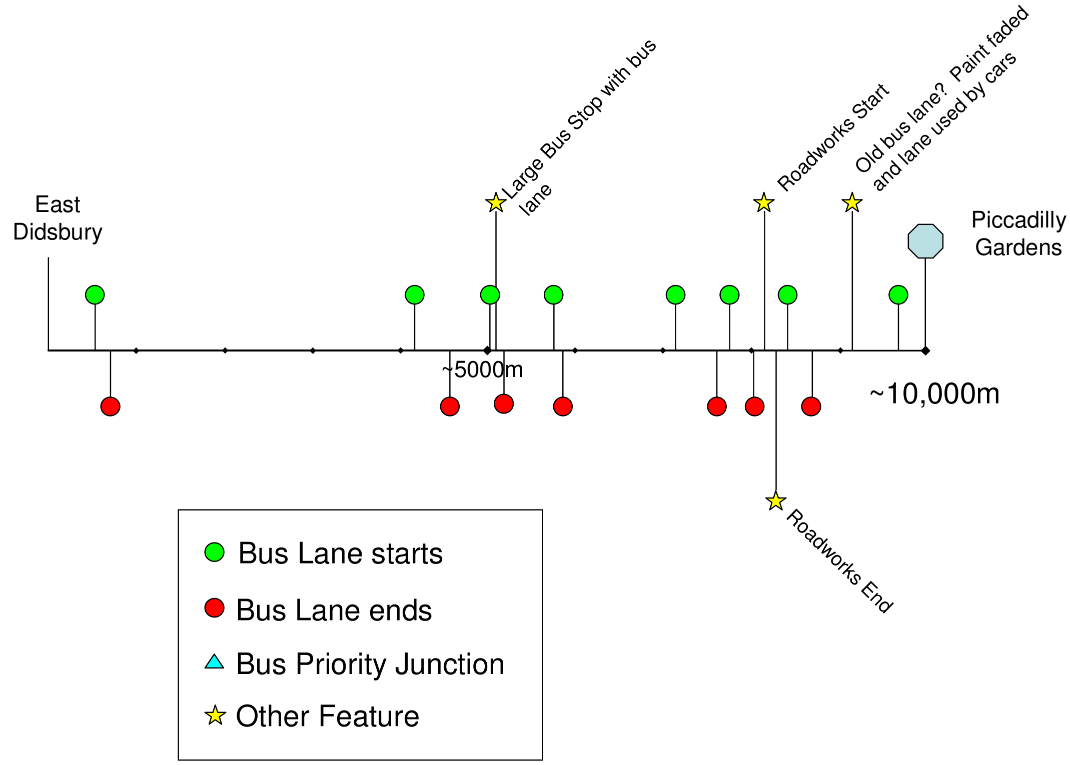
Figure 2.1 - Manchester Route 42 (South Bound)



The route southbound from Manchester centre has several sections of bus lane, along with bus priority junctions. These are concentrated nearer the centre of Manchester, after which there are relatively few bus priority measures. At the time of the survey there were roadworks in the initial section of the route, which may have affected journey times and the results of this study.

Estimates of route length are averages from all runs and are likely to be slight overestimates, due to GPS inaccuracies as discussed in section 2.3. The southbound route was recorded as being on average 9800m in distance. The average time to complete the route was just over 40 minutes. The times recorded varied between just over 30 minutes to just over 45 minutes.

Figure 2.2 - Manchester Route 42 (North Bound)



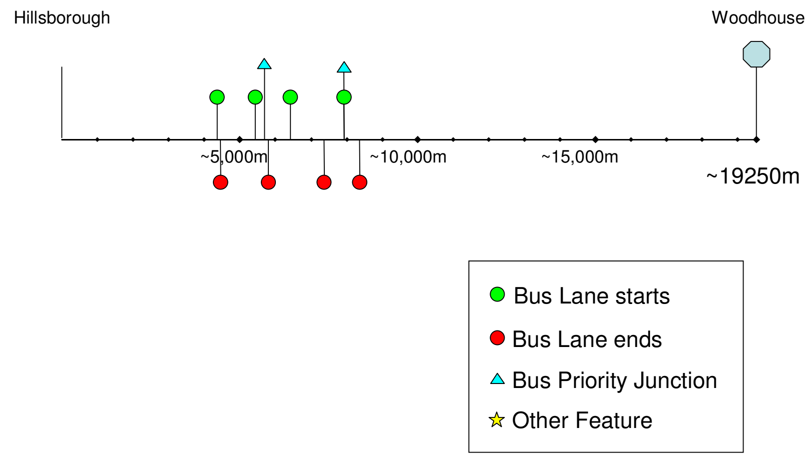
The reverse route, from East Didsbury heading north to Manchester city centre, also has several sections of bus lane. These are concentrated near the centre of Manchester, with fewer bus priority measures towards East Didsbury. At the time of the survey there was a section of roadworks near the Piccadilly Gardens terminus, which may have affected journey times and the results of this study. Other notable infrastructure included a large, manned bus stop just under halfway along the route and an old bus lane which was used by cars, perhaps indicating it was no longer in operation (although no visual confirmation of this was found by the observer)

The northbound route was recorded as being on average 10,000m in distance. The average time to complete the route was 39 minutes. The travel times recorded varied between just over 36 minutes to 45 minutes.

2.4.2 Sheffield

In Sheffield, the route chosen was route 52, which travels from one side of the city to the other, through the city centre, from Hillsborough in the West to Woodhouse in the East and vice versa.

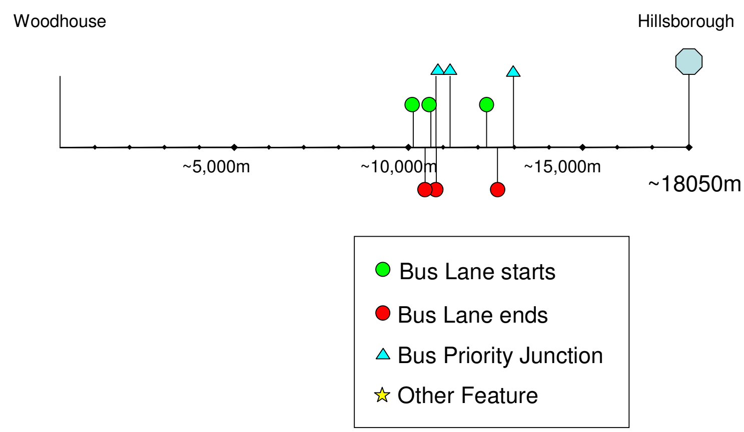
Figure 2.3 - Sheffield Route 52 (East Bound)



The eastbound route features several sections of bus lane and bus priority junctions concentrated around the city centre, with no bus priority measures outside this area.

The eastbound route was recorded as being on average 19,250m in distance. The average time to complete the route was just over 65 minutes. The times recorded varied between 61.5 minutes and 70 minutes.

Figure 2.4 - Sheffield Route 52 (West Bound)



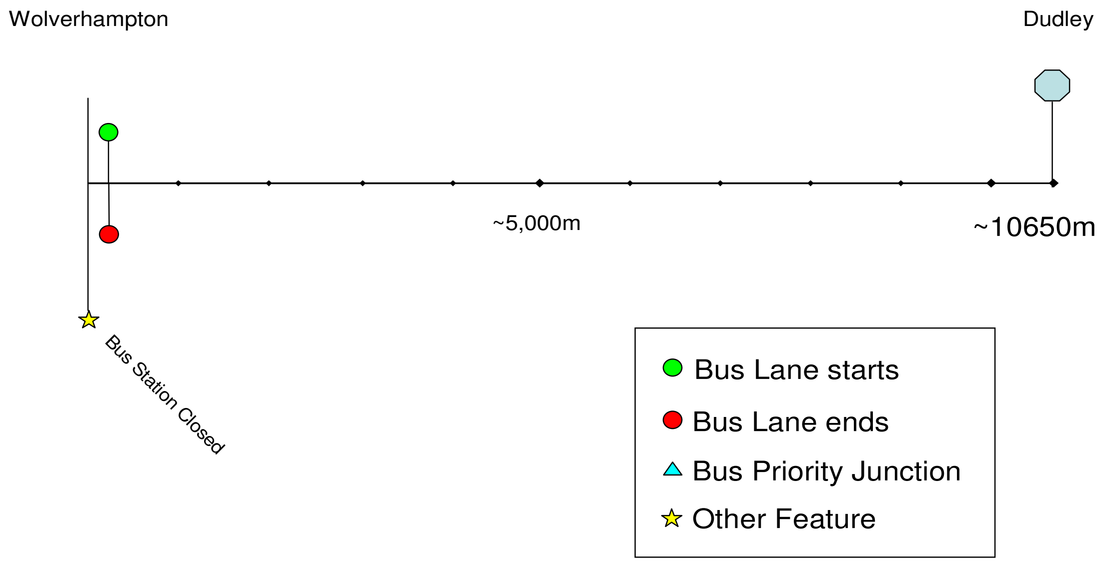
The westbound route also features several sections of bus lane and bus priority junctions, which are concentrated in the city centre. No bus priority features were observed in the sections either side of the city centre.

The westbound route was recorded as being on average 18,050m in distance. The average time to complete the route was just over 65 minutes. The travel times recorded varied between just over 61 minutes and 69 minutes.

2.4.3 <u>Wolverhampton</u>

The route selected in Wolverhampton was the 558, from Wolverhampton to Dudley via Sedgley. This route travels between these two settlements, normally between the two bus stations, but on the day of the observations the Wolverhampton bus station was closed for building works and buses stopped instead along a street nearby.

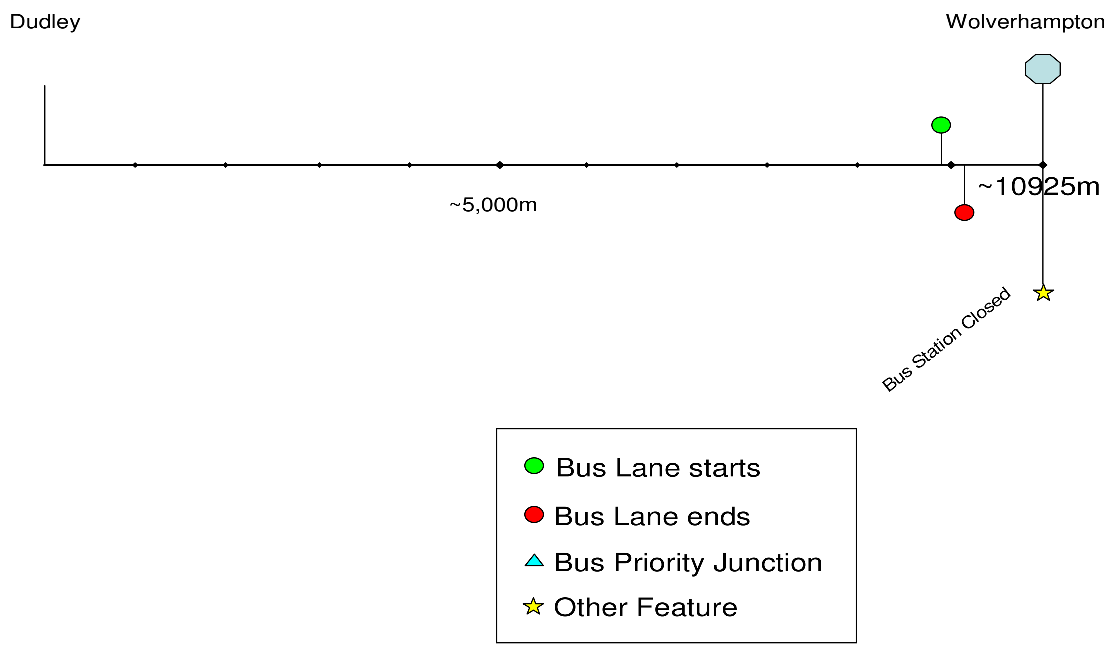
Figure 2.5 - Wolverhampton Route 588 (South Bound)



This southbound route from Wolverhampton to Dudley, passing through Sedgley features one section of bus lane, in Wolverhampton. The bus station at Wolverhampton was closed and buses instead stopped on Queen Street, which was used as the start point of this route.

The southbound route was recorded as on average as 10,650m in distance. The average time to complete the route was about 37 minutes. The times recorded varied between just over 30 minutes and just over 42 minutes.

Figure 2.6 - Wolverhampton Route 588 (North Bound)



The northbound route was in the opposite direction, from Dudley to Wolverhampton, passing through Sedgley. The northbound route also features one section of bus lane, in Wolverhampton.

The northbound route was recorded as being on average 10,925m in distance. The average time to complete the route was just under 38 minutes. The travel times recorded varied between just over 30.5 minutes and 41.5 minutes.

3. BACKGROUND RESEARCH

3.1 Introduction

There are a number of factors that have the potential to contribute towards emissions from stationary vehicles. A literature review was carried out in order to investigate these factors and understand better how they might impact on emissions.

The literature review was split into three sections to cover each of the categories of factors identified – behavioural factors, network factors and technical factors. A review of the regulatory powers has also been carried out, to provide context for steps that might be taken to address idling bus emissions.

The review includes studies done on cars and with HGV operators where it is felt that these findings are relevant to emissions from buses.

3.2 Behavioural Factors

3.2.1 Eco driving

Driver behaviour can have a significant effect on emissions. In the case of buses, a reduction in emissions of up to 30% has been noted[2] as a result of efficient driving techniques, such as avoiding sudden acceleration and excessive idling. The percentage reduction in fuel consumption seen in cars is lower[3], in the region of 1.7% to 7.3%, likely due to the different profiles of a typical car journey when compared to a typical bus route. Training in efficient driving can help to ensure that a consistent and economic approach to driving is taken across a fleet.

A recent project between Arriva and Merseytravel[4] has demonstrated the potential for eco driving interventions in reducing emissions. This project involves the installation of equipment in buses which displays coloured LEDs on the dashboard to indicate fuel consumption, and which records engine data to provide drivers with feedback on their driving. This feedback is supported by training which is available to drivers if they require it to allow them to improve their eco-driving performance. Results from this joint project have shown a reduction of up to 12% in fuel consumption.

Another view on potential indicators for good eco-driving behaviour in cars by the Department of Energy Technology in Belgium includes the following suggestions [3]

- gear shifting behaviour: An earlier shifting profile indicates more eco friendly driving
- acceleration-deceleration profile: With a profile that avoids incidents of acceleration or deceleration of over 2m/s being seen as more eco friendly. A derived value was also used, which was designed to compensate for the

[2] http://www.internationaltrucks.com/ICCorp/documents/White_Paper_on_Fuel_Economy.pdf
[3] B. Beusen & T. Denys, Department of Energy Technology, VITO, Belgium, Long-term effect of eco-driving education on fuel consumption using an on-board logging device.
[4] http://www.arrivabus.co.uk/eco-friendly-driving-gets-green-light-to-save-fuel-on-arriva-buses.aspx

reduced acceleration that vehicles are capable of when already travelling at high speeds, even if they use excessive power. This was called Relative Positive Acceleration (RPA). The RPA was calculated as speed x acceleration and $15m^2/s^3$ was used as a threshold for "bad" aggressive driving
- roll out in gear: Modern vehicles use very little fuel when coasting in gear. Drivers were encouraged to coast towards (e.g.) traffic lights, which avoided burning fuel only to brake hard for the lights and also meant there was more time for a light to change to green so the car did not come to a complete halt. The length of time drivers spent doing this was measured, with an increase pointing to a more eco-friendly driving style.

3.2.2 In-cab data logging and driver feedback

The Freight Best Practice programme is funded by the Department for Transport and offers a range of publications to help freight operators improve their efficiency. A publication from the programme[5] outlines a number of techniques which have been implemented to reduce the fuel consumption of HGVs, via the use of in-cab data logging and dashboard feedback, where a device is mounted onto the vehicle which measures and records several variables. Targets can be set for these variables, for example not to exceed a certain threshold. Data loggers can measure, for example:
- idling: the time when the vehicle is stationary with the engine running is recorded. After a set idling time, the data logger issues an audible warning to the driver and penalty points are deducted if idling continues
- over-revving: the optimum engine speed level is within the vehicle's green band. An audible warning is given when the driver approaches the top end of the green band and points are deducted when the green band is exceeded
- speeding: the parameter for vehicle speed is set and points deducted when this speed is exceeded
- harsh braking: penalty points are deducted if vehicle speed decreases faster than a given rate.

These targets can then be connected to a 'penalty points' or 'bonus/incentive' scheme. One example of such an incentive based scheme described in the DfT publication reported a 6.5% improvement in fuel efficiency across the fleet.

3.2.3 Anti-idling campaigns and practice

From the UK DfT Freight Best Practice programme, a guide is available specifically addressing truck idling[6] and advice on how to set up an anti-idling campaign within freight fleets. Several freight companies have introduced successful anti-idling campaigns and these are profiled in the guide as case studies. One company, Allied Bakeries in West Bromwich, has a fleet of 89 vehicles and implemented their anti-idling campaign in January 2007. As a result of simple anti-idling training given to drivers, the depot has achieved in the first year:

[5] Proactive Driver Performance Management Keeps Fuel Efficiency on Track, Freight Best Practice, Department for Transport, January 2007.
[6] Engine Idling - Costs You Money and Gets You Nowhere!, Freight Best Practice, Department for Transport, April 2009.

- engine idling reduced from 66.03 minutes per route per week to 11.45 minutes per route per week (an 83% reduction in engine idling)
- miles per gallon (MPG) increased from 11.34 to 11.97 (a 5% improvement).

Over one year, Allied Bakeries operations at West Bromwich could potentially save:

- 59,300 litres of diesel
- £50,405 and
- 156 tonnes of CO_2.

3.2.4 Overall driver reaction

An American study into the attitudes of truck drivers to this type of measure[7] indicated that in general drivers are likely to be broadly supportive of technology that monitors and provides feedback on their driving style, providing it is designed and implemented properly. It should be noted that this finding is not automatically transferable to bus drivers in the UK, however, early evidence from schemes such as the Arriva/Merseytravel project indicate there is a good potential for gaining driver buy-in and achieving fuel (and thereby emission) savings.

3.3 Network factors

There are a number of network factors that can have an impact on bus speeds and therefore emissions these include:

- congestion
- bus stops
- traffic signals
- traffic management
- bus priority
- on-street-parking
- gradients

3.3.1 Congestion

Vehicle speeds can decrease as the number of vehicles on a road network increases resulting in traffic congestion. As vehicle speed decreases, fuel economy per km travelled also decreases. Lower vehicle speeds are also generally associated with stop-start conditions. Emission testing for London buses has shown that higher levels of emissions are produced in these conditions[8].

3.3.2 Bus stops

The location and spacing of bus stops can have an impact on bus emissions[9]. Bus stop locations along a bus route will vary depending on:

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[7] Matthias Roetting, Yueng-Hsiang Huang, Jamie R. McDevitt and David Melton, Liberty Mutual Research Institute for Safety, 71 Frankland Road, Hopkinton, MA 01748, USA, When technology tells you how you drive—truck drivers' attitudes towards feedback by technology.

[8] London Transport Buses 1998. Buses: a cleaner future-bus emissions and air quality in London.

[9] Saka, A. A. 2003. Effect of Bus-Stop Spacing on Mobile Emissions in Urban Areas. Prepared for Presentation at the 82nd Transportation Research Board Annual Meeting Washington, DC

- land use intensity - bus stops are more closely spaced in high-density urban areas than in low-density rural areas
- service demand
- achieving the highest level of patronage possible
- providing highly accessible bus services.

Some bus operators may provide too many stops, particularly at high-density land use locations, but this can be counter-productive. Close bus-stop spacing results in disrupted traffic flow on a bus route, particularly during peak hours when buses make frequent stops to provide services to passengers. Frequent stops are also costly to bus operators because fuel costs and journey times are increased. Conversely when bus stops are distantly spaced, bus operators risk providing inaccessible services and this may lead to a loss in passenger numbers.

It is possible to reduce emissions by optimising the spacing of bus stops along a route. Saka[8] found that an ideal distance was between 700m and 800m, based on American experience.

3.3.3 Traffic Signals

Changes in junction control can impact on emissions. Studies have shown that adopting a mandatory stop on junction approaches can increase emissions[10] and similarly roundabouts can have an impact on emissions[11].

Urban Traffic Control (UTC) systems for traffic signalled networks are generally designed to optimise traffic flow rather than directly reduce vehicle emissions. However, UTC systems reduce congestion by reducing delays and therefore increase free flowing traffic, reducing the need to stop and start vehicles, which in turn can reduce emissions[12]

Figures quoted by McCrae et al[13] show that fully adaptive coordination of traffic signals (e.g. using SCOOT) can give emission reductions in the order of 7% for NO_x and 10% for particulates, when compared to uncontrolled traffic signals.

Emission reductions relate to the size of the road network covered by a UTC system. Many large UK towns already have some form of UTC system but future improvements may be possible with close attention to specific junctions where emissions are a significant problem.

[10] Henriksson P, (1992). Estimate of delays and emissions at four way junctions with different forms of regulation, principally four way mandatory stop. Swedish Road and Traffic Research Institute (VTI) s-581, 01. Linköping.
[11] Hoglund P, (1992). Alternative intersection design - a possible way of reducing air pollutant emissions road and street traffic? The Fourth International Symposium on Highway Pollution, 18-22 May 1992 in Madrid. Middlesex Polytechnic, UK
[12] Traffic Management and Emissions, Traffic Advisory Leaflet 4/96, Department for Transport. (1996).
[13] McCrae I S, Green J M, Hickman A J, Hitchcock G, Parker T and Ayland N, (2000),Traffic Management during high pollution episodes: a review, TRL Report 459.

3.3.4 Traffic Management

Traffic management schemes can affect vehicle emissions by altering the volume, speed and composition of a traffic stream and driving patterns including steady speed, stop/start, acceleration and deceleration.

A study on the impacts of traffic calming measures on vehicle exhaust emissions[14] concluded that traffic calming measures such as speed humps and chicanes can increase emissions (CO, HC and CO_2) from passenger cars by 20-60%. The more 'severe' traffic calming measures tend to result in greater speed reductions and this therefore results in a greater increase in emissions.

3.3.5 Bus priority

Bus priority measures can result in smoother driving patterns and therefore a decrease in emissions because of the increase in speed and fewer stop-starts. However, these benefits need to be balanced against a possible increase in congestion due to reduced road space for other traffic[8].

Studies have shown that bus priority will impact on overall emissions. Krawack[15] showed that bus lanes can reduce NO_x particulate emissions by 5–12% and that this can be increased to 15-30% if buses do not have to stop at traffic lights. The EC funded ENTRANCE project showed that a bus lane in Hampshire, UK reduced bus emissions by 15%, however in this case it was offset by a 5% increase in emissions associated with remaining car traffic. Generally, well designed bus priority schemes have tended to show an overall benefit to vehicle journey times by bus, with little or no affect on journey time by other modes.

Selective Vehicle Detection (SVD) can be used to give priority to buses at road intersections. This not only improves service reliability and decreases journey times but also eliminates stop-start conditions and therefore reduces emissions[16].

3.3.6 On-street parking

On street parking, particularly if it includes illegally parked vehicles, can impede general traffic flow and result in more stop-start conditions. Reducing on street parking can reduce congestion, journey times and promote smoother driving patterns for other vehicles using the highway. Reducing and properly managing on street parking can lower emissions by 1-17%[17].

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[14] Boulter P G, Hickman A J, Latham S, Layfield R, Davison P, Whiteman P. (2000) The impacts of traffic calming measures on vehicle exhaust emissions. TRL
[15] Krawack S. (1993) Traffic management and emissions. The Science of the Total Environment. Vol 134, Issues 1-3, Pgs 305-314.
[16] Abbott P G, Hartley S, Hickman A J, Layfield R E, McCrae I S, Nelson P M, Phillips S M, Wilson J L. (1995). The environmental assessment of traffic management schemes: a literature review. TRL Report 174.
[17] Wood K, Smith P. (1993). Assessment of the pilot priority (red) route in London. TRL Report PR 31

3.3.7 Gradients

Buses operated in areas with steep gradients, such as Sheffield, may return a lower mpg than similar vehicles operating similar routes in other flatter areas. There may be a case for re-routing buses onto alternative routes in some instances, if the emissions are lower overall, and the passenger demands can be met.

3.4 Technical Factors

Technical approaches to support reduced idling include installing a vehicle shutdown timer in a vehicle, over-revving alarms and use of gear-shift or rev counter indicators to signal when the driver should change gear for most fuel efficient driving.

There are a number of technical issues to consider, including:
- method of estimating emissions
- engine start-up and switch off
- in-cab heaters
- Euro (emissions) standards
- retrofit exhaust abatement equipment

3.4.1 Method of estimating emissions

The latest DfT emissions factors, released in 2009[18], do not include factors for idling vehicles. However, the emission in g/hr can be extrapolated back to zero to give idling emission factors[19]. This data source has been used as the basis for the emissions estimates in this study, as discussed in the methodology.

3.4.2 Engine start-up and switch off

Hot start / switch off

Hot start emissions are of particular interest to this study, as every time a bus switches off its engine at a stop, it must start it again, and this will be a hot start. Therefore any emissions from hot starts directly offset the benefits of switch off.

In fact, hot-start emissions should not in principal be any greater than those from an idling vehicle, as the engine is already warmed. During the study it was not possible to find any evidence to support the assertion (heard from various sources) that it makes sense to switch off 'after (X) seconds/minutes'. There was no study or evidence found to support a technical argument for not switching off sooner.

Personal communication during this study with a Millbrook test centre employee confirmed no evidence of increased emissions from a hot-start, thereby confirming the theory that switch off for even short periods would reduce emissions overall.

[18] P G Boulter, T J Barlow and I S McCrae, (June 2009). Emissions factors 2009: Report 3 – Exhaust emission factors for road vehicles in the United Kingdom, TRL Report 356.
[19] Communication from Dr Tim Barlow, TRL Limited, 2009.

In addition to whether a hot-start would increase emissions it was important to investigate whether there were any risks of engine damage to vehicles that were switched off as soon as they started to idle, and if this was repeatedly done.

An earlier GMPTE commissioned study contacted local bus operators and bus engine manufacturers to investigate claims that buses required a lengthy period of idling after operation because there is a chance that various mechanical items will fail when engines are switched off, due to oil starvation.[20]

On behalf of GMPTE, GreenUrban Technologies contacted four bus engine manufacturers and reports that the response of Cummins was typical of all engine manufacturers contacted. They recommend a period of idle before shut down, with time variations depending on how hard the engine has been worked. If the engine has undertaken a heavy work load, Cummins recommended the engine idle for a period of 5 minutes in order to equalise and reduce temperatures. However, if the engine has not been worked hard the recommended idle is 30 seconds to let the turbocharger slow down before the oil supply is cut off. GreenUrban's conclusions however were that in practice, bus operators do not adhere to these recommendations and buses tend to be moving slowly as they approach bus stations. No manufacturer could provide any data to GreenUrban to suggest that it is necessary for vehicles to idle before turning off the ignition. The report concludes that while all were seemingly aware of the 'urban myth' that turbochargers would fail if they did not run down prior to switch off, no manufacturer was capable of providing any such supporting evidence or recommendation. GreenUrban's opinion was that there is unlikely to be any mechanical failure if the engines are shut down after an idling period of 30 seconds.

TTR undertook personal communication with a representative of another bus engine manufacturer (Mercedes Benz) not covered by the GMPTE who had no concerns about switch off of engines and when pressed on the issue of oil starvation of turbo-chargers.

There was little evidence in the available literature to suggest that restarting a vehicle after switching the engine off should be problematic. However, this was further explored during driver interviews where some specific problems were perceived with individual (generally older) vehicles, which points to a maintenance issue.

In conclusion the largest emissions savings are realised by immediate switch off of engines when the bus comes to a halt. There is little evidence to suggest that turning off the engine will either damage modern engines or cause reliability issues to modern engines. Some engine manufacturers do recommend significant idle time after hard-working of engines in order to safeguard certain components (i.e. turbo-chargers), but do not provide further evidence to support this view which is also not unanimous among the manufacturers. No evidence has been found to suggest that additional emissions are caused by restarting a modern diesel engine.

[20] GreenUrban Technologies Ltd, (January 2007), Bus idling report, GMPTE 2007.

Cold start

Conversely to hot start emissions, there is a peak of emissions caused during engine start up from cold (so called cold-start emissions).

There is a UK focussed tool available[21] to estimate the excess cold-start emissions, however it is only designed for cars. The model and associated literature suggest that cold start emissions are more significant for petrol powered vehicles rather than diesel vehicles.

There has been little investigation of cold start emissions in heavy duty vehicles, as noted by Boulter and Latham[22]. This DfT commissioned report notes that although a previous report has shown that “excess cold start emissions per HDV were minimal” local contributions to air pollution could still be significant.

It is possible to avoid the need for a cold start by using some form of engine heater.

3.4.3 In-cab heaters

One issue raised by the literature review was the experience of HGV drivers that are required to leave the engine running in order to operate powered equipment in the cab, most notably the in-cab heater. This can lead to significant stretches of engine idle time when the vehicle is stationary and waiting to pick up or drop off goods.

In the case of buses it is important to determine whether the passenger cabin can be cooled or heated independently of the engine being turned on. This may vary by vehicle model, but from the driver interviews was not found to be a potential cause of significant idling.

3.4.4 Euro (emission) standards

Euro standards describe the emissions criteria that vehicle manufacturers must type-approve their vehicles to in order to supply for general sale in the EU.

Euro I vehicles began to be produced for an EC-specific type-approval standard that came into force in 1993, with pre-Euro vehicles generally being those registered before this date. The dates at which these standards came into force for the type-approval of Heavy Duty vehicle types are shown in Table 3.1. These apply to buses of the type used in PTE areas. The entry into service date is generally one year later, so all vehicles entering service after October 2009 should be of Euro V standard, although an amount of overlap is allowed to enable old stock to be sold.

[21] The EXEMPT Model, available at http://www.airquality.co.uk/laqm/tools.php?tool=emission
[22] P G Boulter and S Latham, (June 2009). Emissions factors 2009: Report 4 – A review of methodologies for modelling cold start emissions, TRL Report 357.

Table 3.1 - Introduction dates and mass emissions standards (g/kWh[1]) for HDV

Tier[2]	Type-approval date[3]	NO_x	PM	HC	CO
Euro I[4]	Oct. 1992[5]	8.0	0.36	1.1	4.5
Euro II[4]	Oct. 1996	7.0	0.25	1.1	4.0
	Oct. 1998	7.0	0.15	1.1	4.0
Euro III	Oct. 2000	5.0	0.16	0.78	5.45
Euro IV	Oct. 2005	3.5	0.03	0.55	4.0
Euro V	Oct. 2008	2.0	0.03	0.55	4.0
Euro VI[6]	Potentially Oct 2014	1.0-0.2	0.025-0.01	0.55-0.16	4.0
EEV[7]	Oct. 1999	2.0	0.02	0.4	3.0

Notes:

1 The rates have to be complied with during the approved test cycle. The emission rates in the table are in terms of mass per power rating rather than mass per distance travelled (e.g. g/km). Detailed established methods are used to convert between the two sets of units when necessary.

2 There is a roman numeral naming convention for heavy-duty vehicles.

3 The dates refer to new type approvals. A second date usually a year later applies for entry into service (i.e. all vehicles whose first registration was after October 2009 would need to be at least of Euro V standard).

4 The approval of Euro I and II was based on a different test cycle (ECE R-49) compared to the other values in this table (ETC test cycle). This explains the observed discontinuity among values in the table.

5 For vehicles with greater than 85kW power rating.

6 Euro VI standards are still being negotiated hence values are representative of the range of proposals under consideration.

7 Enhanced Environmentally-friendly Vehicle.

Each successive Euro standard has reduced the amount of toxic pollutants produced, as measured in bench-testing over given cycles

3.4.5 Retrofit exhaust abatement equipment

Exhaust gas abatement equipment can be retrofitted to buses to target specific pollutants, without having to upgrade the engine via a new vehicle.

The assumed abatement efficiency of the various exhaust abatement retrofit options are as follows:

- Diesel Particulate Filter (DPF) = 95% abatement efficiency for PM
- Selective Catalytic Reduction (SCR) = 65% abatement efficiency for NOx
- Exhaust Gas Recirculation (EGR) = 45% abatement efficiency for NOx

DPF and SCR can be retrofitted together.

Retrofit abatement equipment costs are in the following ranges:

- DPF capital cost = £3,000 (low), £4,000 (high), operating cost = £400 (low), £800 (high)
- SCR capital cost = £4,000 (low), £10,000 (high), operating cost = £1000 (low), £1000 (high)
- EGR capital cost = £6,500 (low), £20,000 (high), operating cost = £700-1000 (low), £800-1100 (high)

3.5 Regulatory powers

Based on the information found in the literature review, it can be concluded that some idling can be avoided by good highway network design and addressing technical issues associated with buses. However there still may be scenarios where idling takes place, largely due to behavioural factors. This is where regulations can help.

The regulations that are considered include:

- enforcement powers
- enforcement policies and campaigns
- signage.

3.5.1 Enforcement powers

The *Road Traffic (Vehicle Emission) (Fixed Penalty) (England) Regulations 2002* enable local authorities in England to issue Fixed Penalty Notices (FPN) to drivers who allow their vehicle engines to run unnecessarily while the vehicle is parked or stationary. The Regulations include provisions that specify the format and amount of the FPN, which is £20. An FPN should only be issued if the driver refuses to turn off the engine even though requested to do so.

There are a number of situations where an FPN would not be issued:

- Where a vehicle is stationary 'due to traffic conditions' e.g. where a vehicle is stationary at traffic lights
- Where an engine is being run so that a fault may be traced and rectified e.g. when defrosting a windscreen in winter
- Where machinery on a vehicle requires the engine to be running, e.g. where the engine powers a refrigeration unit.

These regulations came into force on 18th July 2002. The powers to issue FPN are automatically conferred by the Regulations therefore local authorities do not have to apply to use them. Councils such as North Lincolnshire Council, Havant Borough Council and Manchester City Council have adopted this policy[23,24,25].

Although buses are not specifically mentioned in the Regulations, it is stated that the Regulations apply to all vehicles including both private and public transport vehicles.

[23] Havant Borough Council-Pollution Control-Idling Vehicles http://www.havant.gov.uk/havant-9163;
[24] Pilditch D. 2010 Drivers to get £20 fine for leaving engine running. The Express.; http://www.express.co.uk/posts/view/161432/Drivers-to-get-20-fine-for-leaving-engine-running
[25] North Lincolnshire Council 2010 Enforcement Powers-Vehicle engine running unnecessarily http://www.northlincs.gov.uk/NorthLincs/CouncilandDemocracy/cabinet/CabinetMinutes/DeputyLeader/2March2010.htm

3.5.2 Enforcement policies and campaigns

Within the PTE areas a number of enforcement policies and campaigns are in place, with a selection described here.

South Yorkshire Passenger Transport Executive (SYPTE) has drafted a set of 'general conditions' that are enforced at all their interchanges and bus stations [26] within this is a statement that bus engines should not run whilst stationary. An 'Operators Unsafe Act' document is sent by Customer Service Managers at bus stations to bus operators when drivers leave their engines running. This can be either when buses are on stand and are not loading or unloading passengers; or when buses are using the layover/stacking bays. Buses are also monitored daily by CCTV and patrolling CSO's to ensure operators are compliant in accordance with the General Conditions of Use. The aim is to provide a safe operating environment for passengers and bus operators. Anti idling regulations are also enforced in the West Midlands and included as part of Bus Station User Agreements.

In February 2010, the management team at Sheffield Interchange (Sheffield's principle bus station) conducted an analysis on how many buses operated through the site within the month and how many buses were contravening the General Conditions in relation to engines running. The results showed that idling was not a significant issue. This was due in part to site management having open communications and good working relationships with operators to address these kinds of issues.

There is evidence to suggest that issuing FPN has a positive impact on reducing idling. For example, a "significant rise" in compliance with anti-idling policies has been seen since FPN were adopted, according to Manchester City Council[27]. From April 2007 to March 2009 the Council has issued 244 idling Notices. These have mainly been issued at taxi ranks and bus 'layovers'. Stagecoach in Manchester has made it clear that it is the driver's responsibility to deal with a FPN if they are issued with one and Manchester City Council specifically target areas where complaints have been made by GMPTE or the public about bus idling.

Merseytravel enforces a 'no engine-idling' policy in its bus stations that have layover areas[28]. If a bus is parked in a layover area, the engine must be turned off. Fines are issued for any offences. It was felt by Merseytravel that whilst issuing fines can help to reduce the incidents of bus idling, a more proactive programme of education would also be beneficial in highlighting the impacts of idling. Alongside a poster campaign there were talks and 'air quality surgeries' held in several depots providing information to drivers on the effect that idling has on air quality. Reported incidents are monitored via the Annual Progress reports of the Merseytravel Environmental

[26] Mumford S. (Senior Customer Service Manager at Sheffield Interchange) 2010. Email sent on 31 March 2010 to M. Holmes

[27] Parking Review, Manchester calls time on idling vehicles. 10.09.09 Issue 209. http://www.parkingreview.co.uk/news/?ID=2113&StartRow=51

[28] Merseytravel Environmental and Sustainability Strategy http://www.merseytravel.gov.uk/information_environment.asp

Sustainability Strategy. A 51% reduction in reported incidents was seen between the 2004/05 and 2005/06 reports and this increased to an 80% reduction from the 2006/07 to 2007/08 report. However the Report does acknowledge the decrease may be in some part due to non-reporting of idling incidents when inspectors are told the bus “cannot be turned off”. Anti-idling policies have not been restricted to just bus stations. A ‘code of conduct’ has been developed to reduce bus idling at city centre ‘layover’ areas. It would appear that these policies have reduced bus idling as figures quoted in the Progress Reports show.

3.5.3 Signage

Signage can prompt drivers to turn off their vehicle’s engines when parked or stationary. Examples of this include:

- Doncaster Frenchgate Interchange[29]: 'please switch your engine off' signs have been put up to remind bus drivers of the Regulations;
- Merseytravel has worked with Arriva, the largest bus operator in the region, to produce posters highlighting the environmental harm that bus idling causes
- Stagecoach in Manchester have displayed posters in their bus stations that carry the message ‘Don’t idle your bus’, to highlight their anti-idling policies.

Signage is likely to work more effectively as part of a more comprehensive policy with enforcement practices and other forms of communications.

[29] Holmes M (Planning Manager, SYPTE) 2010. Email sent on 16 April 2010 to R Handley.

4. RESULTS

4.1 Overall emissions estimates from each route

4.1.1 Introduction

For each of the three routes, a significant amount of time on the route was spent stationary and a significant amount of the bus emissions on the routes were caused by stationary vehicles. This occurred at bus-stops, termini and at key points on the network such as junctions/traffic-signals. This confirms that the potential exists to significantly improve the emissions of the routes by reducing vehicle idling time. This chapter identifies how much of the observed bus emissions are due to idling and what proportion of these might be reduced from applying good practice approaches to fuel efficiency and environmental care.

4.1.2 Detailed Results

Using the location and timing data gathered from the GPS device, it was possible to understand how the speed of the bus varied along the routes. Using DfT emission factors equation (relating to vehicle speed) an estimate of the total emissions for each route can be made. This can be broken down further into information on how much of the total emissions were emitted during periods when the bus was stationary, slow moving or freely moving.

Each representative route in the following sections is presented with a breakdown of the time spent in each speed band and the emissions of Particulate Matter (PM) and Oxides of Nitrogen (NO_x) by speed band.

The speed bands chosen to analyse this data were

- stationary (0-5kph), to account for the GPS factors discussed in the methodology section
- slow moving (5-10kph), in order to isolate emissions from non-stationary buses which were still not travelling at the most efficient speeds
- two "free-flowing" speed bands, from 10-30kph and 30kph+.

The emissions for each run (an entire bus route in one direction) are presented in these speed bands. It is important to understand that these emissions are not adjusted for the time spent in each speed band – if a bus travelled at more than 30kph 90% of the time then a preponderance of emissions will be in the ">30%" band.

In order to present the detailed analysis, one representative run for each direction in each of the three areas has been used, providing 6 runs to be presented in the reporting. The profiles of all of the runs along one route have been examined and are similar enough that the routes used for the detailed analysis are representative of a "typical" daytime journey along the route, from the sample taken at each site. The data for each of the observed runs is available within the estimation spreadsheet developed by TTR for the analysis.

In addition Appendix 1 shows similar graphs of the breakdown of emissions and time spent by speed band for the routes during peak hours to illustrate how the profile of the routes differ from a typical daytime run. In fact, the peak hour charts shown in Appendix 1 generally show a similar profile to the daytime routes. There are some reductions in the time spent travelling at over 30 kph and some increases in the idling time on the routes. These changes are not thought to be large enough to suggest a separate treatment of the off-peak and peak time runs. Therefore the routes will be treated together in the following analysis.

As an indicative estimate, we have calculated the approximate annual emissions from the routes in each area using a generic bus timetable. In making this estimate the assumption was made that buses run every 15 minutes on average, throughout the day from 5am until midnight, 364 days per year. This results in 27,664 bus trips, so the emissions estimates for a single route are multiplied by 27,664 to illustrate the total potential annual emissions.

Using these assumptions, the total annual emissions from each route are given in the appropriate section.

4.1.3 Manchester (GMPTE)

In Greater Manchester various buses were observed on the selected route, ranging from Euro II standard to Euro V standard. All of the buses observed on this route were double deck buses. A Euro III double deck bus was used for the emissions calculations.

Southbound

The total emissions from a representative southbound leg were estimated to be 2.4g of PM and 144g of NO_x. The total emissions at each speed band are shown in Figure 4.2. Large amounts of both PM and NO_x were emitted at free moving speeds over 10 kph. However, there were significant emissions at lower speeds, including almost 30g of NO_x emissions during idling time (shown as under 5 kph). The proportion of NO_x and PM emitted at a given speed remained similar, except for stationary vehicles where the NO_x emissions were markedly higher in comparison to PM emissions.

Overall, the representative bus on the southbound GMPTE route was recorded as spending 39% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 7.1% of the total PM and 20.5% of total NO_x produced by the vehicle for the entire route (see Table 4.1).

The total annual emissions estimate for this route is 67kg of PM and 3.99 tonnes of NO_x, based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.1 - Manchester Southbound Time Spent in Speed Bands

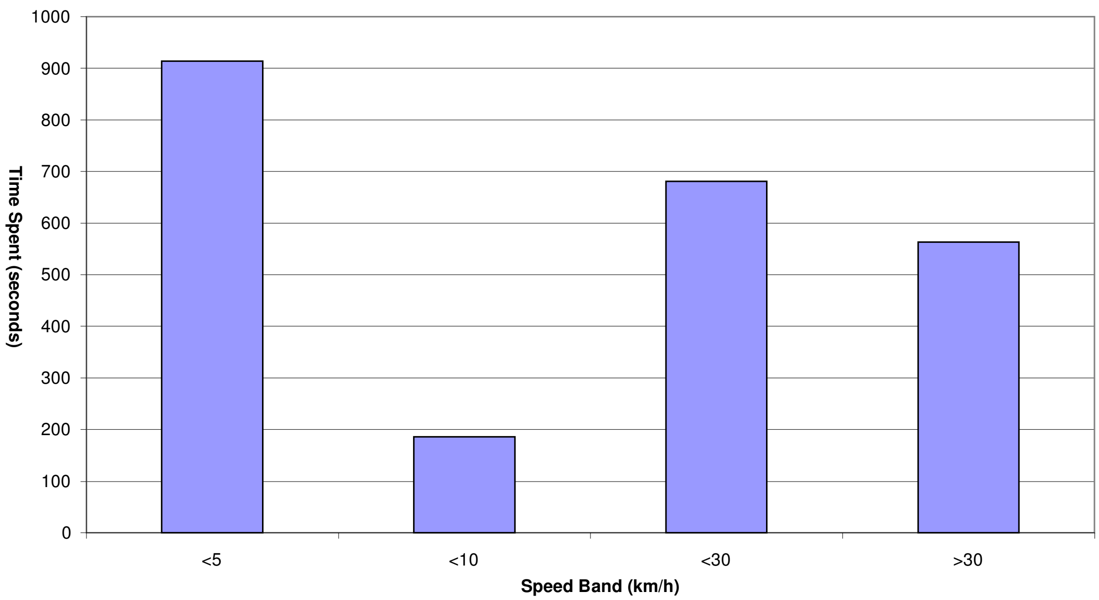


Figure 4.2 - Manchester Southbound emissions by Speed Band

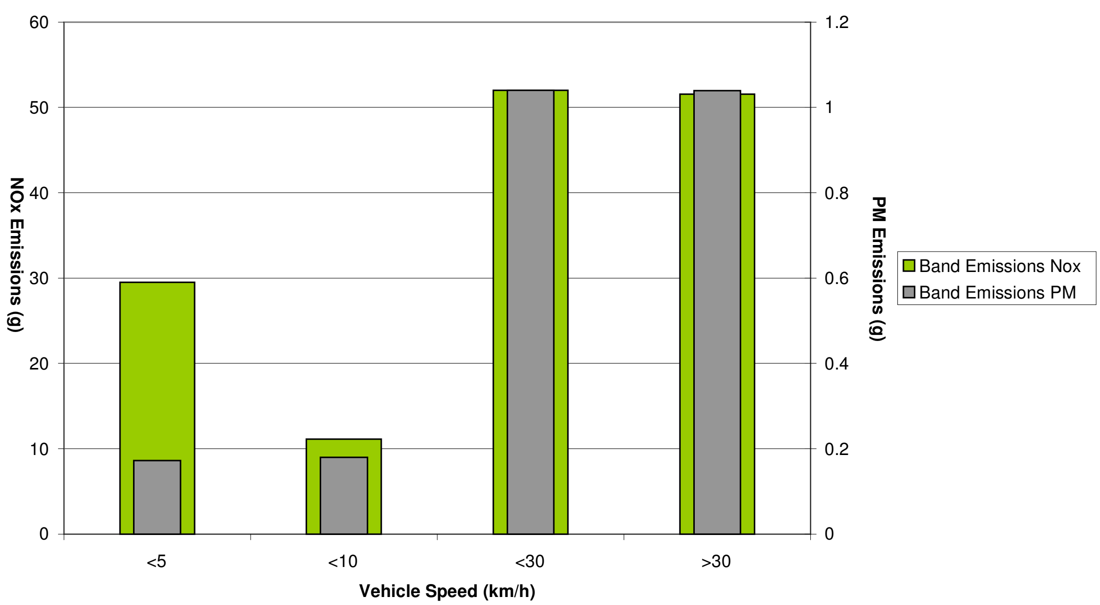


Table 4.1 - Manchester Southbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	914	39.0%	0.17	7.1%	29.5	20.5%
5 to 10 kph	186	7.9%	0.18	7.4%	11.1	7.7%
10 to 30 kph	681	29.1%	1.04	42.8%	52.0	36.1%
>30 kph	563	24.0%	1.04	42.7%	51.6	35.8%
All speeds	2344	100.0%	2.43	100.0%	144.2	100.0%

Northbound

The total emissions from a representative northbound leg were estimated to be 2.2g of PM and 136g of NO_x. The total emissions by speed band are shown in Figure 4.3 The Northbound leg is quite similar to the Southbound leg seen in Figure 4.2. Again the majority of emissions are produced at higher speeds, but there are significant emissions at lower speeds and again, the stationary emissions of NO_x are the most significant of these. The Northbound route does have slightly more emissions at over 30 kph than between 10 and 30, largely because it spent more time at this speed.

Overall, the representative bus on the northbound GMPTE route was recorded as spending 43.5% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 9.4% of the total PM and 23.9% of total NO_x produced by the vehicle for the entire route (see Table 4.2.)

The total annual emissions estimate for this route is 62kg of PM and 3.77 tonnes of NO_x based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.3 - Manchester Northbound Time Spent in Speed Bands

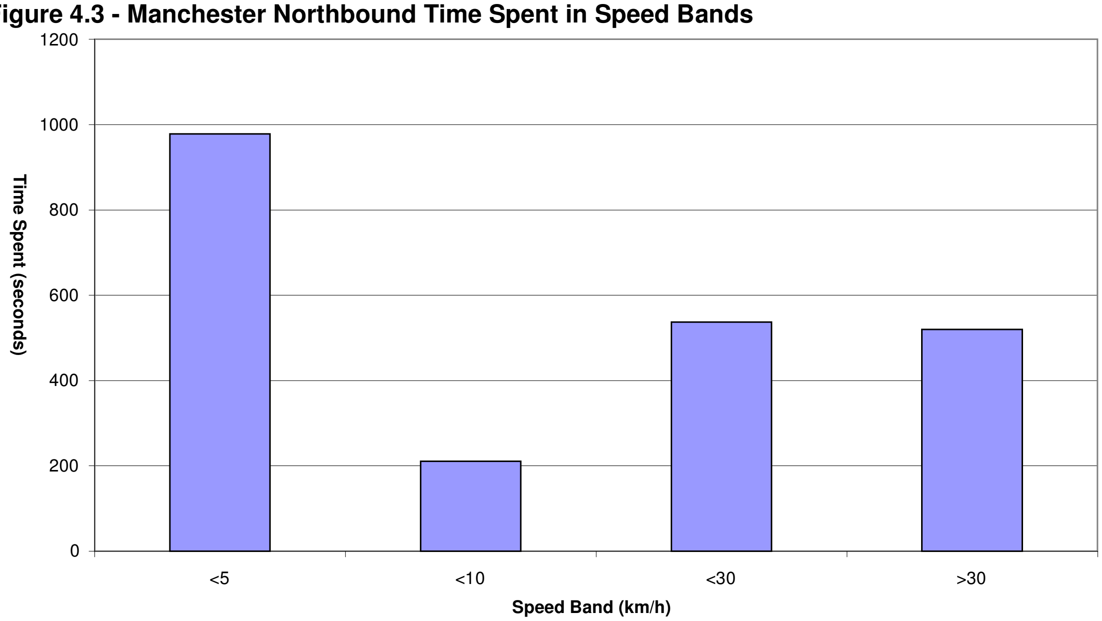


Figure 4.4 - Manchester Northbound Emissions by Speed Band

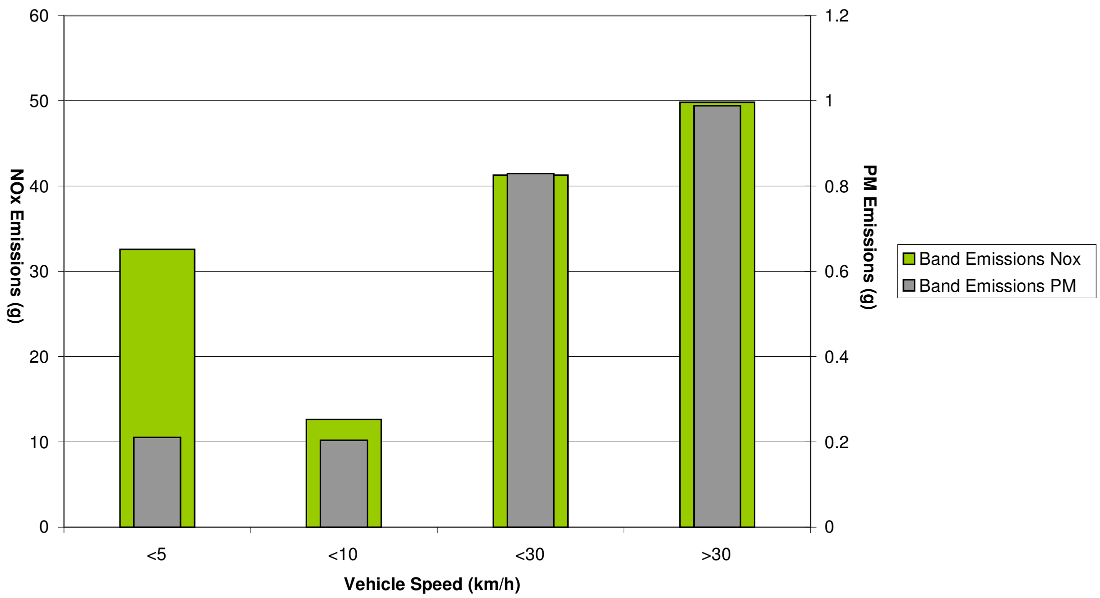


Table 4.2 - Manchester Northbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	978	43.5%	0.21	9.4%	32.6	23.9%
5 to 10 kph	211	9.4%	0.20	9.1%	12.6	9.3%
10 to 30 kph	537	23.9%	0.83	37.1%	41.3	30.3%
>30 kph	520	23.2%	0.99	44.3%	49.9	36.6%
All speeds	2246	100.0%	2.23	100.0%	136.3	100.0%

4.1.4 Sheffield (SYPTE)

In Sheffield the buses observed on the test route ranged from Euro II standard to Euro III standard. A Euro III single decker bus was chosen as representative and used for the emissions calculations.

Eastbound

The total emissions from a representative eastbound leg were estimated to be 4.7g of PM and 224g of NO_x. The total emissions within each speed band are shown in Figure 4.6. Again, the bulk of the emissions were emitted at speeds greater than 10 kph, but significant amounts of emissions occurred when the vehicle was slow moving or stationary. The NO_x and PM emissions occurred in similar proportions at any given speed.

Overall, the representative bus on the eastbound SYPTE route was recorded as spending 29.9% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 21.6% of the total PM and 21.4% of total NO_x produced by the vehicle for the entire route (see Table 4.3.)

The total annual emissions estimate for this route is 130kg of PM and 6.19 tonnes of NOx, based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.5 - Sheffield Eastbound Time Spent in Speed Bands

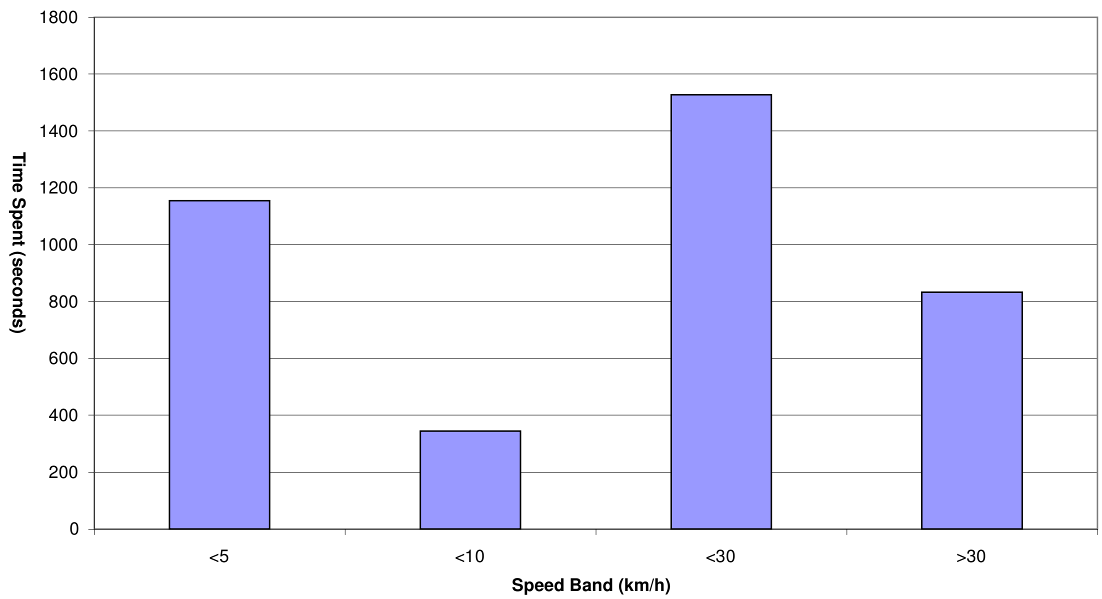


Figure 4.6 - Sheffield Eastbound Emissions by Speed Band

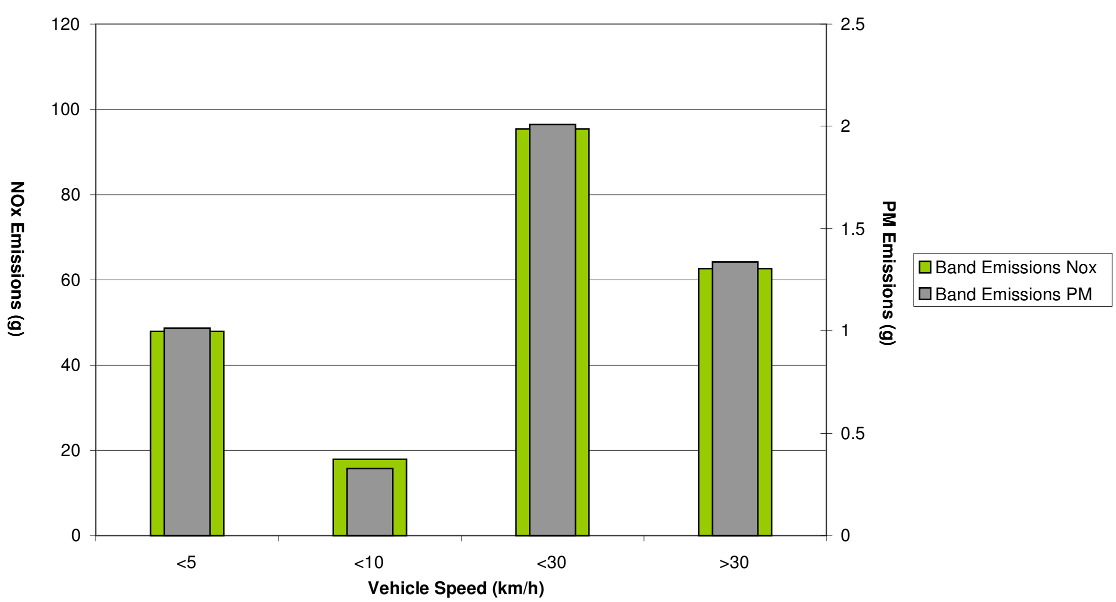


Table 4.3 - Sheffield Eastbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	1155	29.9%	1.01	21.6%	47.9	21.4%
5 to 10 kph	345	8.9%	0.33	7.0%	17.9	8.0%
10 to 30 kph	1527	39.6%	2.01	42.9%	95.4	42.6%
>30 kph	833	21.6%	1.34	28.5%	62.6	28.0%
All speeds	3860	100.0%	4.69	100.0%	223.8	100.0%

Westbound

The total emissions from a representative westbound leg were estimated to be 4.7g of PM and 223g of NO_x. The total emissions from each speed band are shown in Figure 4.8. There was a large contribution to total emissions from both stationary periods, periods of travelling between 10 and 30 kph and periods of travelling over 30kph.

Overall, the representative bus on the westbound SYPTE route was recorded as spending 34.2% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 25.2% of the total PM and 24.9% of total NO_x produced by the vehicle for the entire route (see Table 4.4.)

The total annual emissions estimate from this route is 131kg of PM and 6.18 tonnes of NO_x, based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.7 - Sheffield Westbound Time Spent in Speed Bands

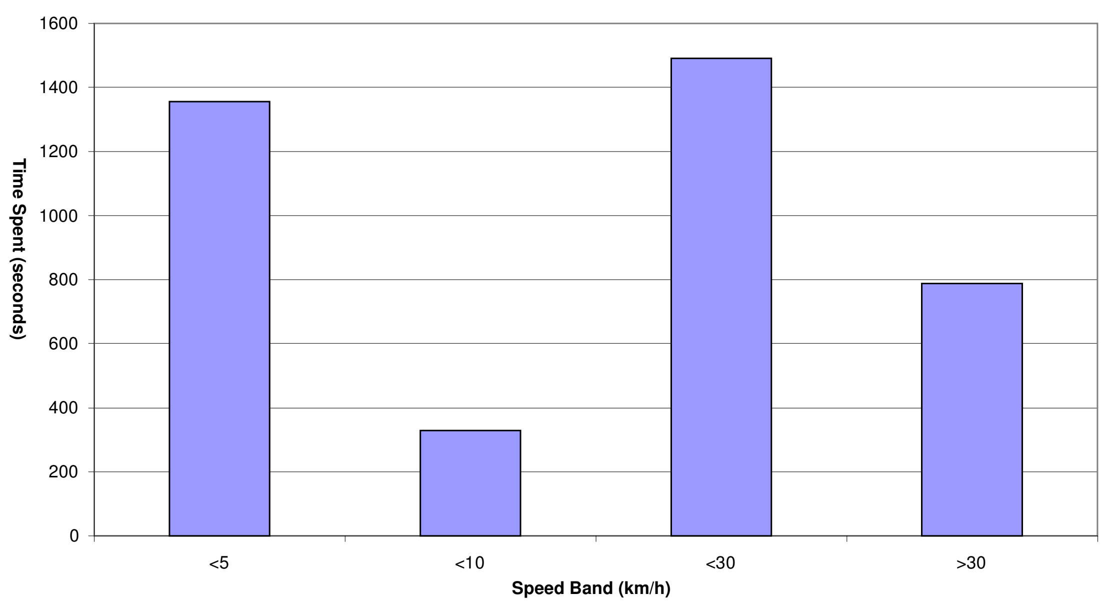


Figure 4.8 - Sheffield Westbound Emissions by Speed Band

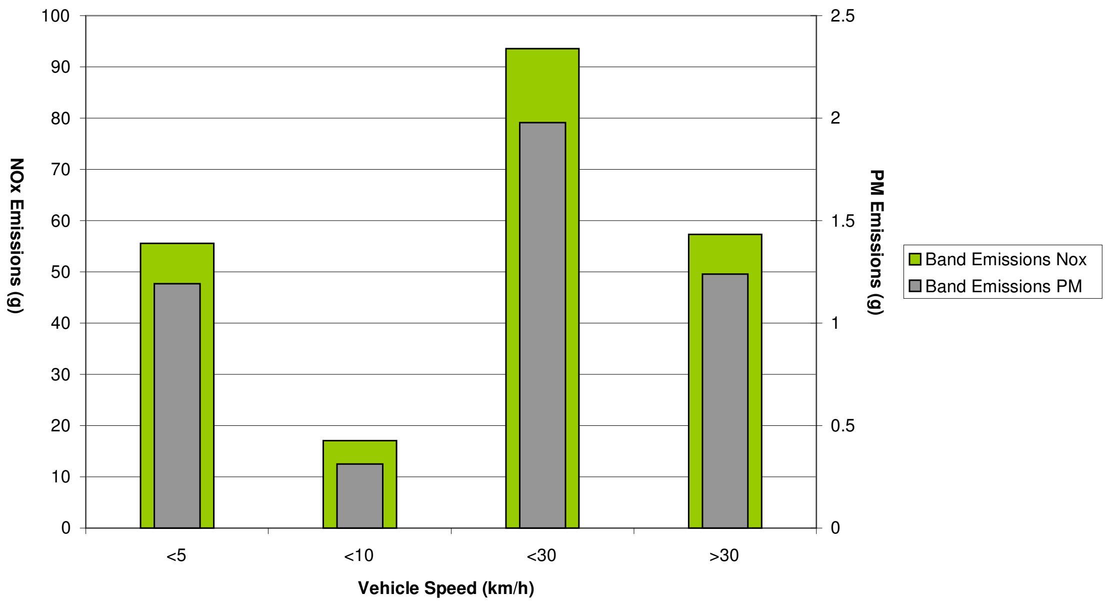


Table 4.4 - Sheffield Westbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	1356	34.2%	1.19	25.2%	55.6	24.9%
5 to 10 kph	328	8.3%	0.31	6.6%	17.0	7.6%
10 to 30 kph	1491	37.6%	1.98	41.9%	93.6	41.9%
>30 kph	787	19.9%	1.24	26.2%	57.3	25.6%
All speeds	3962	100.0%	4.72	100.0%	223.4	100.0%

4.1.5 Wolverhampton (Centro)

In Wolverhampton all of the buses observed on the test route were Euro III standard double decker buses. This is the bus type that has been used to generate the emissions estimates.

Southbound

The total emissions from a representative southbound leg were estimated to be 2.6g of PM and 150g of NO_x. The total emissions from each speed band are shown in Figure 4.10. Most emissions occur at speeds greater than 10kph, but there are significant contributions from stationary and slow moving vehicles, particularly for NO_x emissions.

Overall, the representative bus on the southbound Wolverhampton route was recorded as spending 32.9% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 5.4% of the total PM and 16.5% of total NO_x produced by the vehicle for the entire route (see Table 4.5.)

The total annual emissions estimate for this route is 72kg of PM and 4.16 tonnes of NO_x, based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.9 - Wolverhampton Southbound Time Spent in Speed Bands

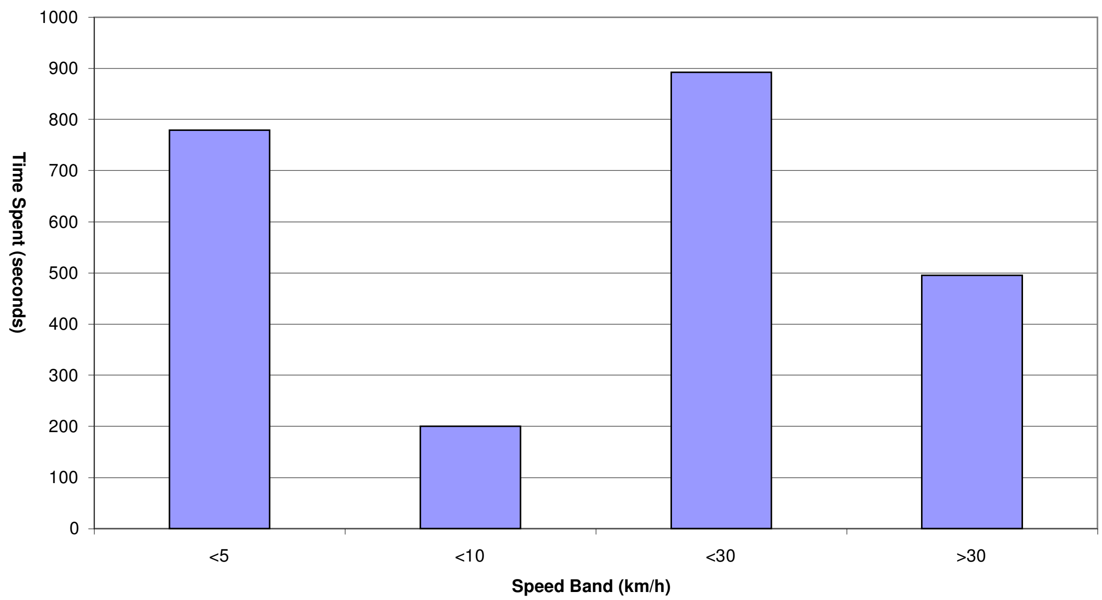


Figure 4.10 - Wolverhampton Southbound Emissions by Speed Band

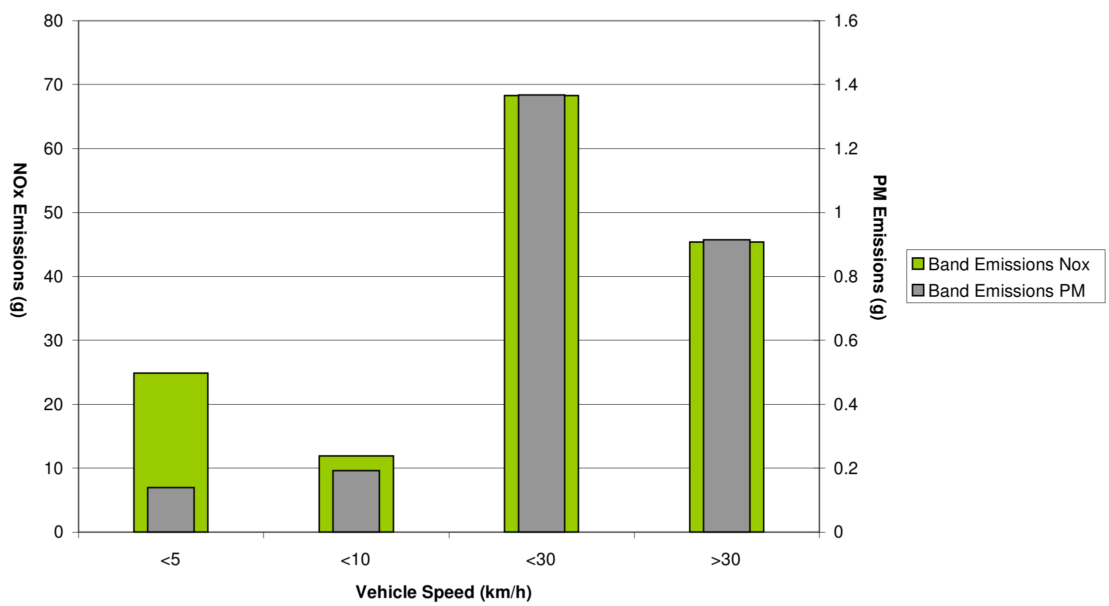


Table 4.5 - Wolverhampton Southbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	779	32.9%	0.14	5.4%	24.9	16.5%
5 to 10 kph	200	8.5%	0.19	7.4%	11.9	7.9%
10 to 30 kph	892	37.7%	1.37	52.3%	68.3	45.4%
>30 kph	495	20.9%	0.91	35.0%	45.4	30.1%
All speeds	2366	100.0%	2.61	100.0%	150.5	100.0%

Northbound

The total emissions from a representative northbound leg were estimated to be 2.6g of PM and 143g of NO_x. The total emissions from each speed band are shown in Figure 4.12. The emissions for this northbound route are very similar to those for the southbound route. Most emissions occur at speeds greater than 10kph, but there are significant contributions from stationary and slow moving vehicles, particularly for NO_x emissions.

Overall, the representative bus on the northbound Wolverhampton route was recorded as spending 29.5% of the time under 5 kph (i.e. stationary, and with the engine idling), which accounted for 5.8% of the total PM and 14.9% of total NO_x produced by the vehicle for the entire route (see Table 4.6.)

The total annual emissions estimate for this route is 71kg of PM and 3.97 tonnes of NO_x, based on the assumptions in section 4.1.2 to illustrate the total potential annual emissions.

Figure 4.11 - Wolverhampton Northbound Time Spent in Speed Bands

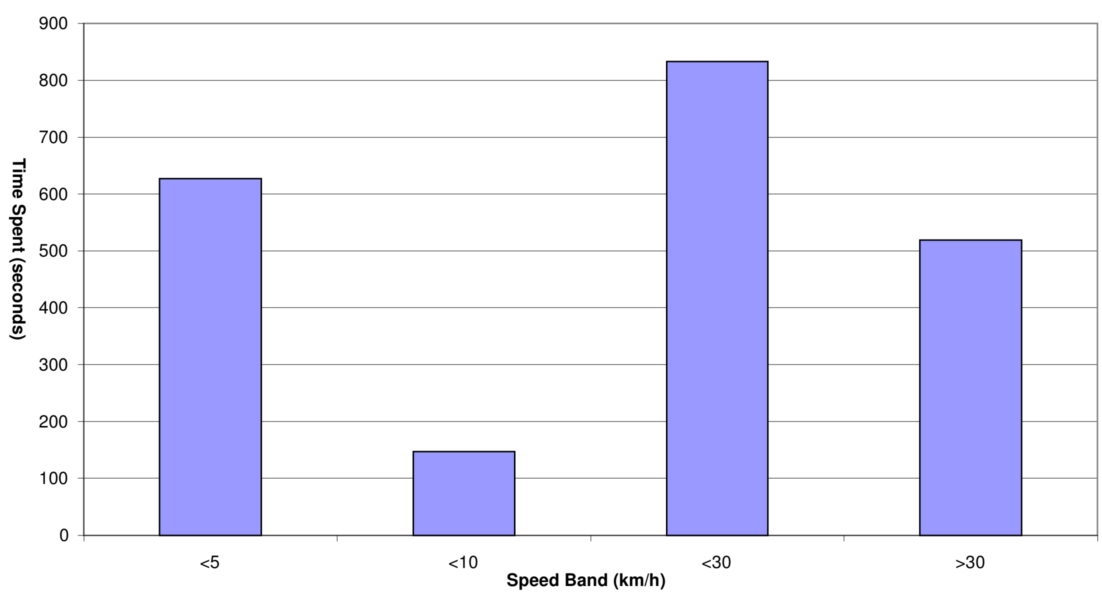


Figure 4.12 - Wolverhampton Northbound Emissions by Speed Band

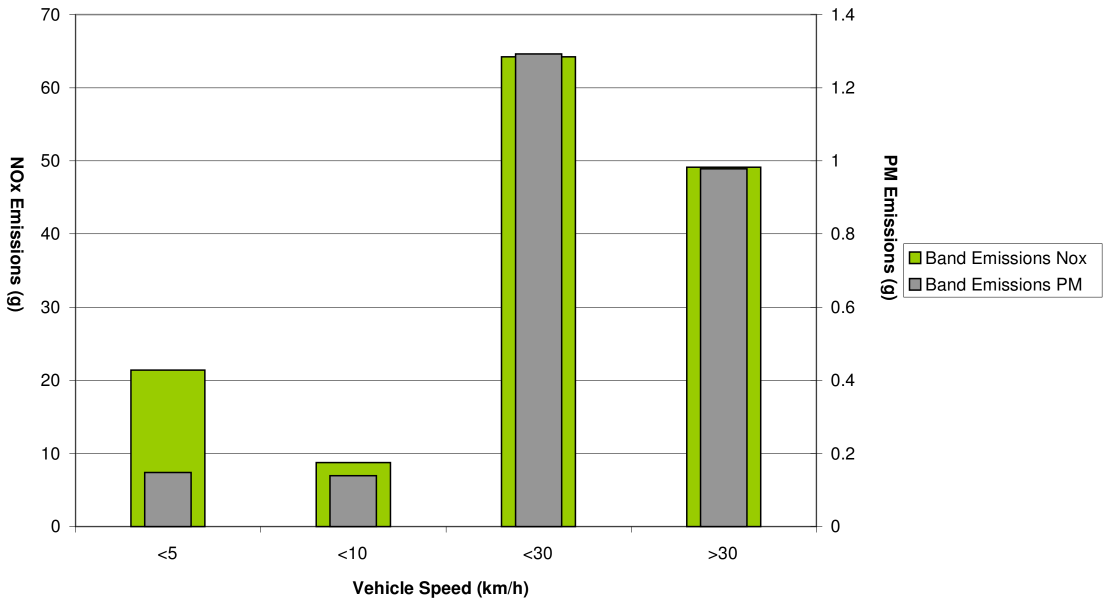


Table 4.6 - Wolverhampton Northbound Route Summary

Speed	Time in bands		PM		NO_x	
	seconds	%age	grams	%age	grams	%age
<5 kph	627	29.5%	0.15	5.8%	21.4	14.9%
5 to 10 kph	147	6.9%	0.14	5.4%	8.7	6.1%
10 to 30 kph	833	39.2%	1.29	50.5%	64.2	44.8%
>30 kph	519	24.4%	0.98	38.2%	49.1	34.3%
All speeds	2126	100.0%	2.56	100.0%	143.4	100.0%

4.2 Behavioural Factors

4.2.1 Summary of findings

- Drivers are worried about the potential for a vehicle to fail to restart if they switch the engine off

- Driver's stated awareness of eco-driving techniques and impacts, and their explanation of the basics of these techniques and impacts during interview is generally good, with a few exceptions. However, there is a strong feeling that there are insufficient incentives to encourage all drivers to follow-through on good practice as 'it's not my fuel'. Understanding of eco-driving does not currently extend to the practice of regularly switching-off when idling at bus stops and termini, unless these are also bus stations where enforcement is practiced.

- In practice, the majority of buses are kept idling at bus stops and termini (where these are not bus stations). A significant proportion of bus stops needed dwell times of over 10 seconds (up to half of observed stops on a route), and a 10 second policy for switch off would capture significant proportions of emissions from these stops.

- There are few bus stops where dwell times were observed as being greater than 30 seconds and buses were observed idling at these stops. This significant length of time means that even with only a few such stops emissions savings are still possible. For most routes a cut off time of 30 seconds (after which the engine is switched off) offers emissions savings of between 0.7% and 9.1% of idling emissions at bus stops. In two observed runs, however, this potential saving was over 25%, or about 11% of all idling emissions (3% of total emissions).

- Bus drivers were observed to generally not switch off their bus engines at termini. This results in additional emissions to each route, estimated at about 2% of PM and 6% of NO_x for a 40 minute route. Note, the contribution would be less for a longer route, and more for a shorter route.

4.2.2 Average Time at bus stops (distribution)

Idling time at bus stops across the three sample routes varied quite widely from as little as four seconds (for a single passenger leaving the bus) to several minutes if a lot of people were buying tickets. The time spent stationary at each bus stop on a route was assessed and is shown in the following charts.

Each of the following charts is the summary of bus dwell time at stops for the representative journeys used in section 4.1. The stops were identified from on-bus observation data and matched to the GPS recorded vehicle speed in order to calculate and display these dwell times.

These dwell times are used as the basis for estimates of potential emissions reduction from a policy mandating engine switch off if a vehicle is stationary for longer than a certain length of time, to be applied at bus stops. The background research has indicated that there is no penalty, in emissions terms, for re-starting a bus when the engine is warm. The lengths of time initially considered for engine switch off were 5 seconds, 10 seconds and 30 seconds.

Some of these stops may be timing points, where drivers wait if they are ahead of schedule. This does not affect the analysis of potential emission reductions, but does suggest that these points are more likely to be consistent contributors to idling emissions. The data gathered during the study does not identify timing points, so analysis is not possible, but it is felt that compulsory switch off at these timing points may be a good way to reduce idling emissions.

Each of the graphs in the following section display each bus stop as a point, spread along the X axis – so the first graph, Manchester Southbound, represents all 23 times the bus halted at a bus stop during the Manchester Southbound representative run.

4.2.2.1 Manchester

Figures 4.13 and Figure 4.14 show the dwell time at bus stops on runs in and out of Manchester sorted to show them in order of increasing dwell time. All but one stop was timed at over 5 seconds in duration, with about half between 5 and 10 seconds.. A few stops had dwell time of over 30 seconds.

Figure 4.13 - Manchester Southbound Dwell Time at Stops

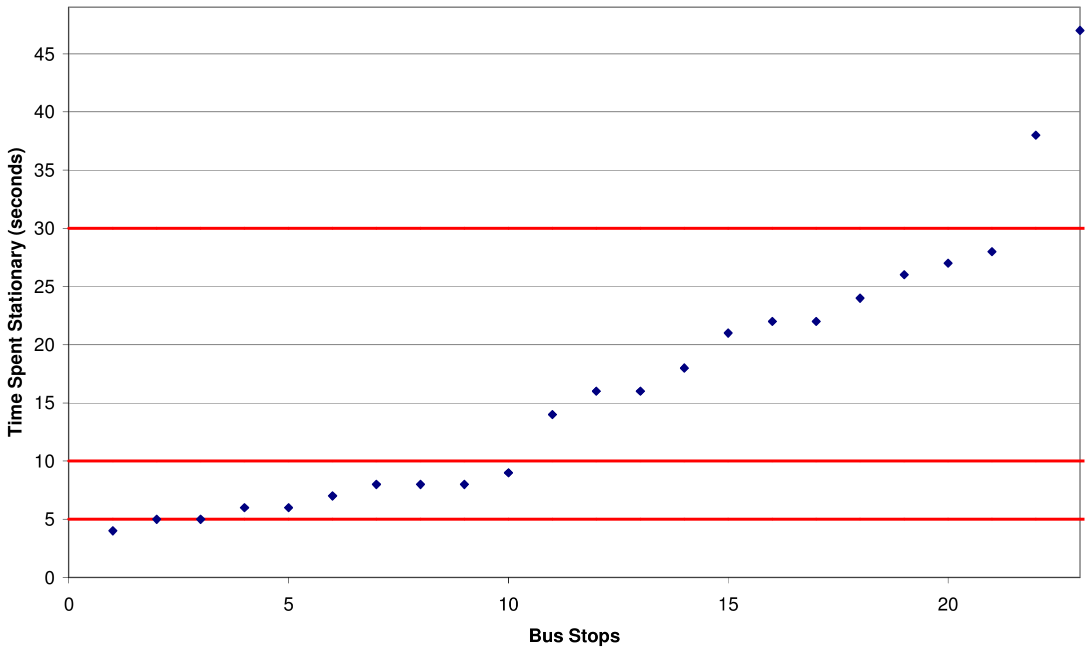
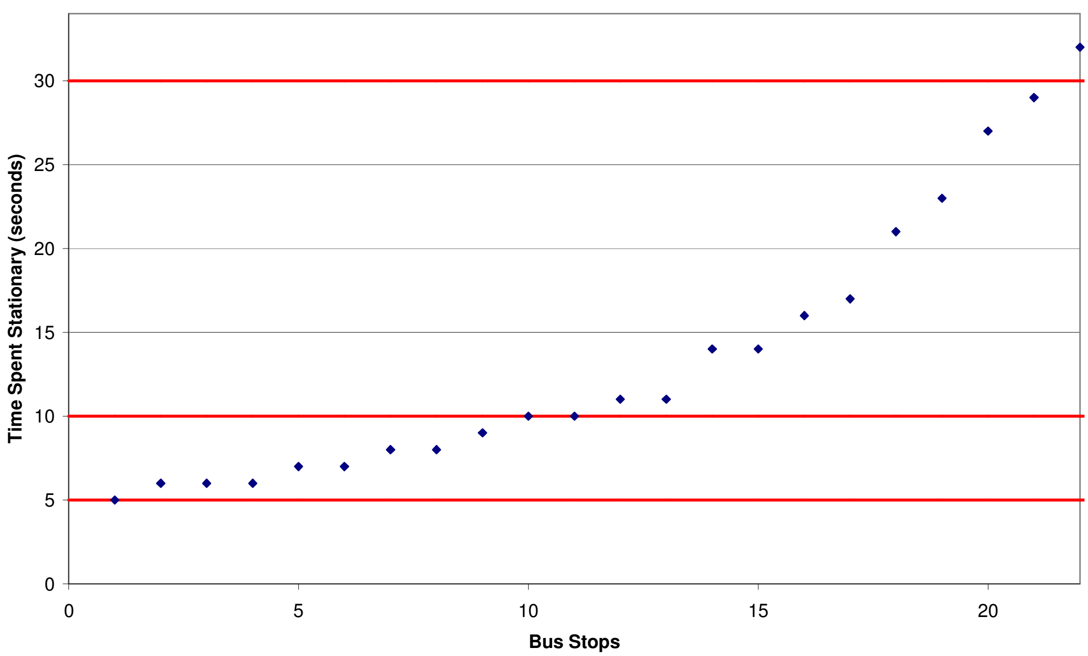


Figure 4.14 - Manchester Northbound Dwell Time at Stops



For the Southbound route, the maximum stop time was 47 seconds, the minimum stop time was 4 seconds and the average stop time was 16.7 seconds.

For the Northbound route stop times were slightly lower, with a maximum of 32 seconds, a minimum of 5 seconds and an average of 13.5 seconds.

4.2.2.2 Sheffield

Figure 4.15 and Figure 4.16 show the dwell time at stops on the eastbound and westbound legs of the route in Sheffield. They are sorted in order of increasing dwell time. There are a few stops where dwell time was under 5 seconds in duration and, similarly to the Manchester results, roughly half the stops are up to 10 seconds in duration and half over 10 seconds.

Figure 4.15 - Sheffield Eastbound Dwell Times at Stops

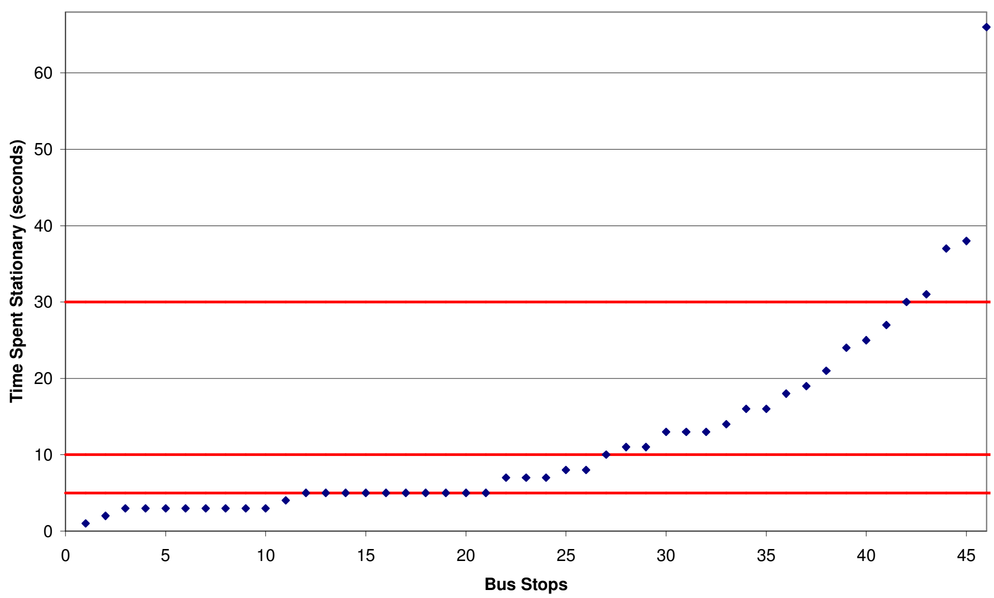
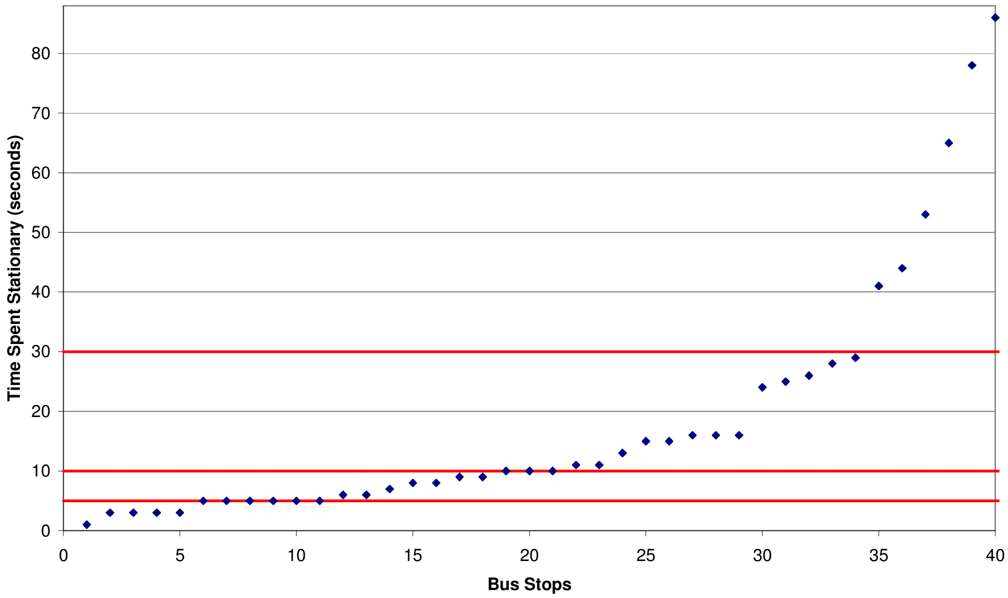


Figure 4.16 - Sheffield Westbound Dwell Times at Stops



For the Eastbound route the maximum stop time was 66 seconds. The minimum stop time was 1 second, where the passenger was waiting by the door as the bus came to a halt and the driver moved off again immediately. The average stop time was 12.4 seconds.

For the Westbound route the maximum stop time was 86 seconds, the minimum stop time was 3 seconds and the average was 18.6 seconds.

4.2.2.3 Wolverhampton

Figure 4.17 and Figure 4.18 show the dwell times for buses on the Southbound and Northbound routes in Wolverhampton, sorted to display them in order of stop length. There are a few stops that lasted less than 5 seconds and about a third of the stops were of 10 seconds or less.

Figure 4.17 – Wolverhampton Southbound Dwell Time at Stops

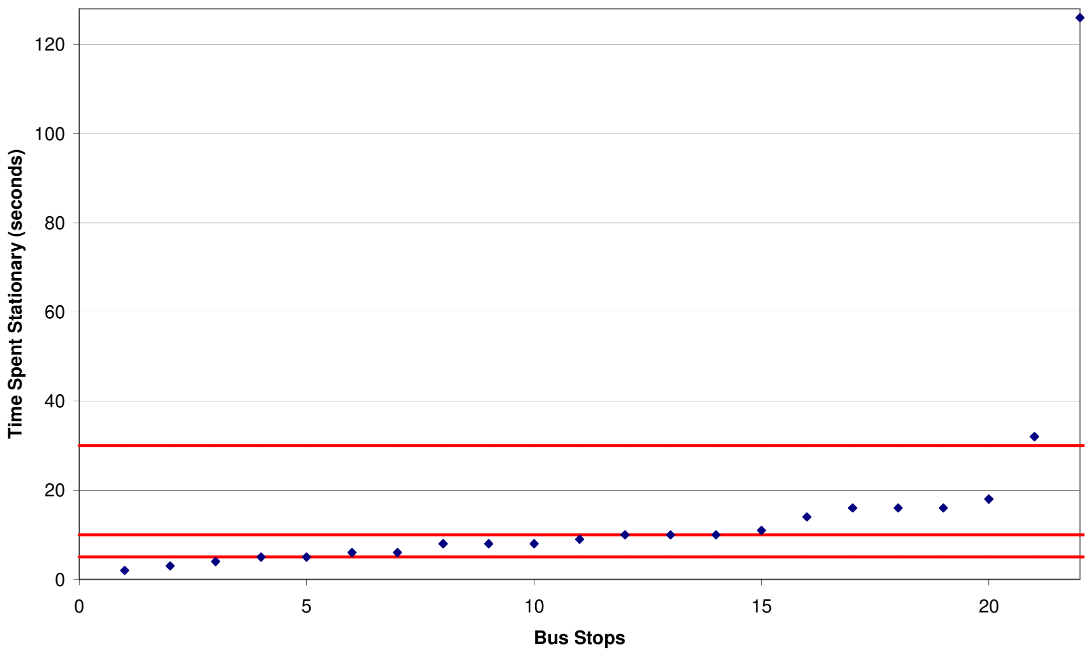
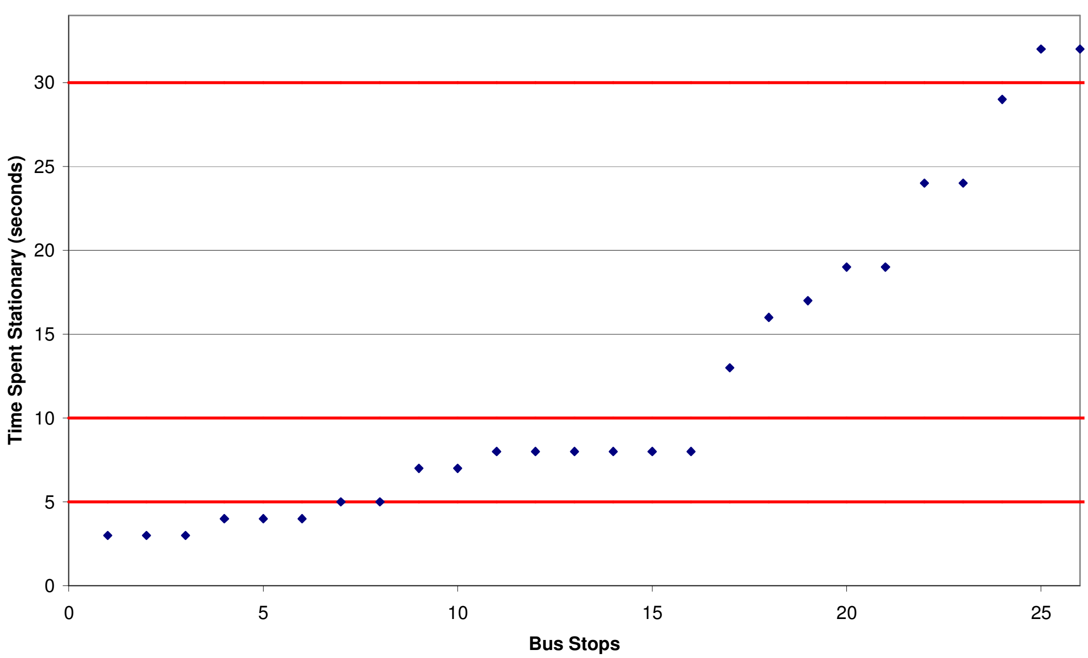


Figure 4.18 - Wolverhampton Northbound Dwell Time at Stops



The Northbound and Southbound Wolverhampton routes were quite similar in terms of stop times. The one exception to this is a single very long stop during the Southbound route.

The very long stop was the maximum length stop for the Southbound route, of 126 seconds. The minimum stop time of the Southbound route was 2 seconds and the average was 15.6 seconds. Excluding the very long stop, the longest stop was 32 seconds and the average was 10.3 seconds.

For the Northbound route the maximum stop length was 32 seconds, the minimum stop time was 3 seconds and the average stop time was 12.2 seconds.

4.2.3 Potential reductions resulting from switch off policy

By examining the stop times recorded during the route trials it is possible to make an estimation of the emissions savings that might be expected if it were possible to ensure that all drivers switched off the engine after they had been idling at a bus stop for a prescribed length of time.

The study has taken a selection of potential switch off times, ranging from 5 seconds to 5 minutes and considered what the effect of implementing these switch off times would be. Examining the graphs above (Figure 4.13 to Figure 4.18), it is noticeable that:

- very few stops are of less than 5 seconds;
- stops with dwell time under 10 seconds made up around half the stops across all routes;
- around half of stops had dwell times of between 10 and 30 sections; and
- there were a small number of stops over 30 seconds on any of the routes.

Therefore the times selected to assess as potential cut off times were:

- 5 seconds, to represent a minimum cut off time, as any time lower than this would offer relatively little benefit and cause significant inconvenience and effort from the driver
- 10 seconds, which would offer a benefit during about half of stops and represents a point after which stop times increase quickly
- 30 seconds, which is the longest cut off time that would offer a useful saving.

In addition a cut off time of 5 minutes was assessed to match an automatic engine switch off which both drivers and managers reported in interviews was present in some buses. It is likely this cut off time is aimed at buses in depots rather than at stops.

The reduction in idling time at bus stops predicted for cut off times of 5 seconds, 10 seconds, 30 seconds and 5 minutes is shown in Table 4.7, below. This is based on the number of seconds the buses remain idling after the selected cut-off time has been passed, i.e. the dwell time, normally spent idling, that could be avoided by switching off at 5, 10, or 30 seconds.

Table 4.7 - Reduction in Idling time at stops predicted for various cut off times

	Idling time reduction (s)				Total Time at stops (s)	Percentage Reduction			
	Cut off time (s)					Cut off time (s)			
	5	10	30	300		5	10	30	300
Manchester Sbound	271	189	25	0	385	70.4%	49.1%	6.5%	0.0%
Manchester Nbound	187	105	2	0	297	63.0%	35.4%	0.7%	0.0%
Sheffield Ebound	365	253	52	0	571	63.9%	44.3%	9.1%	0.0%
Sheffield Wbound	550	422	187	0	745	73.8%	56.6%	25.1%	0.0%
Wolverhampton Sbound	239	169	98	0	343	69.7%	49.3%	28.6%	0.0%
Wolverhampton Nbound	197	125	4	0	318	61.9%	39.3%	1.3%	0.0%
					Avg Saving	67.1%	45.7%	11.9%	0.0%

Reductions of around 30 to 40% of idling time at bus stops could be achieved (or 13-17% of total idling time on the run), depending on route, if the cut off time is set to 10 seconds.

There are few bus stops with dwell times greater than 30 seconds, however the length of time spent at these stops means that savings are still possible for a cut off time set as this. For most routes a cut of time of 30 seconds offers emissions savings of between 0.7% and 9.1% of idling emissions at bus stops. In two examples routes, however, this potential saving was over 25%, or about 11% of all idling emissions (3% of total emissions).

Using a cut off time of 5 minutes on the test routes yielded absolutely no benefit because bus stop idling time never extended this long.

The greatest potential for improvements in emissions through reducing idling time at stops can be reached by setting a low switch off threshold, which we suggest is 10 seconds given the data above, and the tolerance of drivers for being asked to switch off their engines frequently and for relatively short periods of time.

A more conservative and precautionary approach, if there is concern about engine damage, would be a 30 second cut off time to capture a proportion of the emission reduction benefits with lower risk and greater potential for driver buy-in.

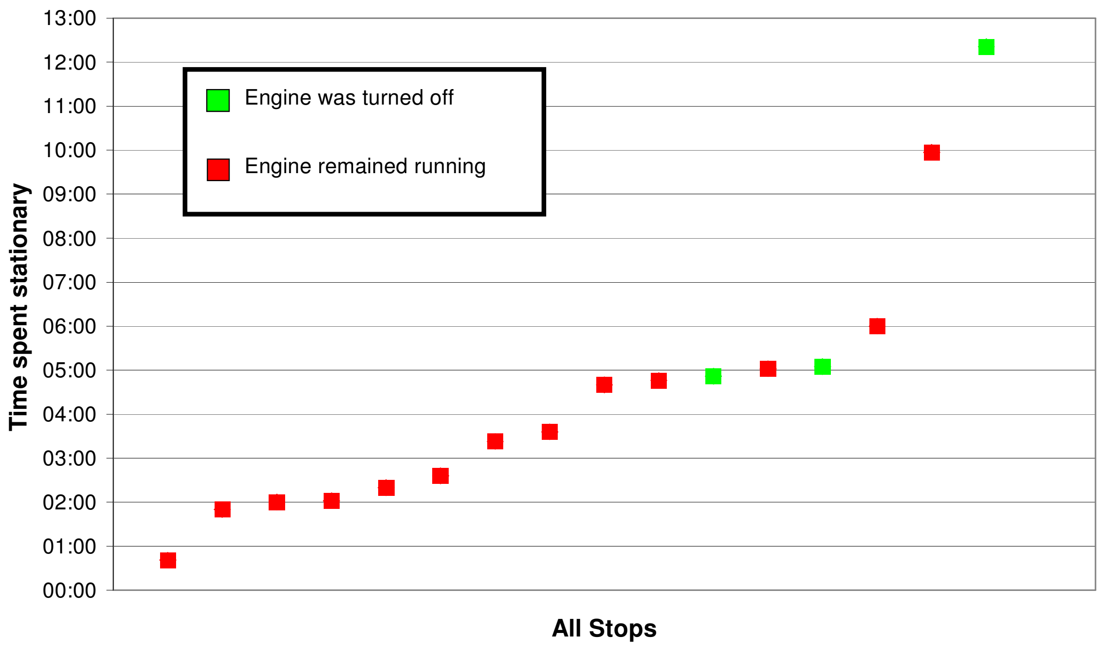
4.2.4 Idling activity at route terminus/depot

During the course of the survey days, observations were made at one terminus of the given routes to help understand the idling time of buses at these points.

Observations were made at Manchester Piccadilly Gardens, Sheffield Woodhouse Terminus and Dudley Bus Station. These results have been aggregated and the distribution of stop time (in minutes) at termini is shown in Figure 4.19. Incidents where the bus engine was switched off are shown in green.

It should be noted that this assessment has been done separately and in addition to the idling time on the representative runs, so any emissions from this terminus activity is additional to that reported in the sections above.

Figure 4.19 - Stationary Buses at Termini



Most buses observed at these termini do not switch off their engines when stationary and therefore continued to operate at idle. There were three exceptions among the buses which had their stationary time measured and recorded: two buses which stopped for around 5 minutes and one bus that stopped for over 12 minutes, where the driver switched off the engine.

The two buses that switched off while waiting for around 5 minutes were observed on the Wolverhampton route, in Dudley bus station. The bus that switched off while stationary for over 12 minutes was observed in Sheffield at the Woodhouse layover. This bus was notable because it was switched off and then failed to restart. Bus staff at the terminus were overheard saying that they had seen this previously that morning on the same route. The bus eventually restarted without intervention.

In addition, other buses were seen switching off engines at all three termini while not being timed, but this was thought to be the exception rather than the norm.

From these observations it is felt that there is good potential for emissions reductions by reducing the time spent idling at termini, through enforced/encouraged switch off policies.

The mean waiting time at terminus of the observed buses was found to be 4 minutes 26 seconds (266 seconds). Comparing this to the total idling time on the representative runs shows this is over 33% of the idling time on the route for the buses in Wolverhampton and around 20% of the idling time on the longer Sheffield routes. If these observations are typical, idling time at terminus of a route is adding significant amounts to the emissions from the route itself.

Enforcing a “switch off when stationary at terminus” policy could have noticeable benefits on emissions – estimated at 2% of PM and 6% of total NO_x, depending on the length of the route in question.

4.2.5 Interview data on behavioural factors

There were two main behavioural/perception issues found during the interviews. These were driver perception of vehicle reliability after switch off (and the resulting behaviour of drivers) and the potential of training, monitoring and incentivising drivers to improve fuel efficient behaviour.

Reliability after switch off

The main behavioural factor emerging from the interviews was a difference in perception between managers and drivers about the reliability of buses after they have been switched off. This is discussed in more detail in section 4.4.3, although in essence drivers see buses that fail to start as a persistent problem which has an impact on their willingness to switch off bus engines, whereas managers tend to see it as less of a problem, or something that occurs so rarely as to be a non-issue.

Drivers explained that they are the customer facing part of the business, who get initial complaints from customers if a bus fails to start. This compounded their perception that the buses would sometimes fail to restart and made them feel less inclined to switch off engines.

Training, Monitoring and Incentives

The second most prominent factor emerging from the interviews was that both monitoring and incentivisation have potential to improve how drivers react to company guidance.

Signs at termini are mentioned frequently by drivers as a motivation and reminder to switch off their engines and certain depots have a reputation as having particularly stringent managers – “you’d better turn off when you visit Depot X, or the manager will be tapping on your window within 30 seconds”

Additionally, some drivers stated that if rewards were offered for improved driver performance, there would be significant progress. This was reflected by comments by managers that some drivers would never care about eco-driving because “it’s not their fuel”. This supports the findings from the background research that driver incentive schemes can impact on fuel consumption.

There are some training measures in place to educate drivers about eco-driving in the bus fleets covered by the study and among the sample of drivers interviewed, understanding of the benefits and the techniques associated with eco-driving was mostly very good. One driver did ask “are we supposed to turn off at terminus?”, but this was notable as being unusual.

The techniques needed for eco-driving are generally similar to customer friendly driving – gentle braking, gentle acceleration, avoiding excess speed. These driving characteristics are encouraged among drivers and monitored by the bus company managers interviewed using both overt and covert assessors.

It was mentioned by both drivers and managers that there were a few drivers who would refuse to follow guidelines, but the consensus among both groups was that these drivers were the exception and the majority of drivers will comply well with sensible instruction.

The interview findings are encouraging and point towards considerable potential if clear policies can be agreed and communicated about the locations and protocols for engine switch off.

4.3 Network Factors

4.3.1 Summary of findings

- The most significant three network features for delays and adding idling time contributed significantly to emissions on all routes. Just three network features contributed up to 33% of idling emissions in the worst case, or 7% of total emissions. Savings could be made by addressing network features (if they are junctions that can be re-designed) or by making drivers aware of them and encouraging switch off at these locations (particularly suitable for bus stop features).

- Analysis undertaken that focussed specifically on delays at junctions and traffic signals suggests that the average period of idling accounts for about 0.5% of the emissions from a given route, depending on the route length. Eliminating just 4 average halts due to junctions or traffic signals would save over 2% of emissions from the route.

4.3.2 Network delay analysis

In order to assess the impact of the network in delaying the buses and increasing emissions caused by stationary or slow moving buses, each route has been analysed to determine which features of the network caused the longest single delays.

To determine which features had the most impact on bus idling, the routes have been broken down into 1000 sections of equal length – each corresponding to 0.1% of the entire route. By splitting the routes into percentage based sections rather than length based sections the data is normalised to account for error in the GPS signal recording different runs on the same route as having different lengths. The time taken for the bus to cross one of these sections directly corresponds to how quickly the bus was travelling through the section. A peak in the time taken corresponds to a delay suffered by the bus. All the data available from the observed and recorded runs were used in this analysis, which confirms the pattern of delay from multiple data sets.

To determine the worst features of the network a graph of time taken per 0.1% distance travelled along the route was produced. On this graph areas where a peak occurred in more than one of the multiple runs were taken to indicate a consistently bad feature in terms of bus idling times.

On the following graphs, the x axis shows how far along the route the vehicle had come, in terms of a percentage of the total length measured by the GPS for that route. The y axis shows the time taken to cover the last 0.1% of the route.

The three features which caused the highest peaks in the graph – the “worst” network features for inducing idling emissions – were identified and correlated to a map of the route. These are shown on the following graphs for the 3 routes in each direction, Figures 4.20 to 4.25.

Figure 4.20 - Manchester Southbound Delay Analysis

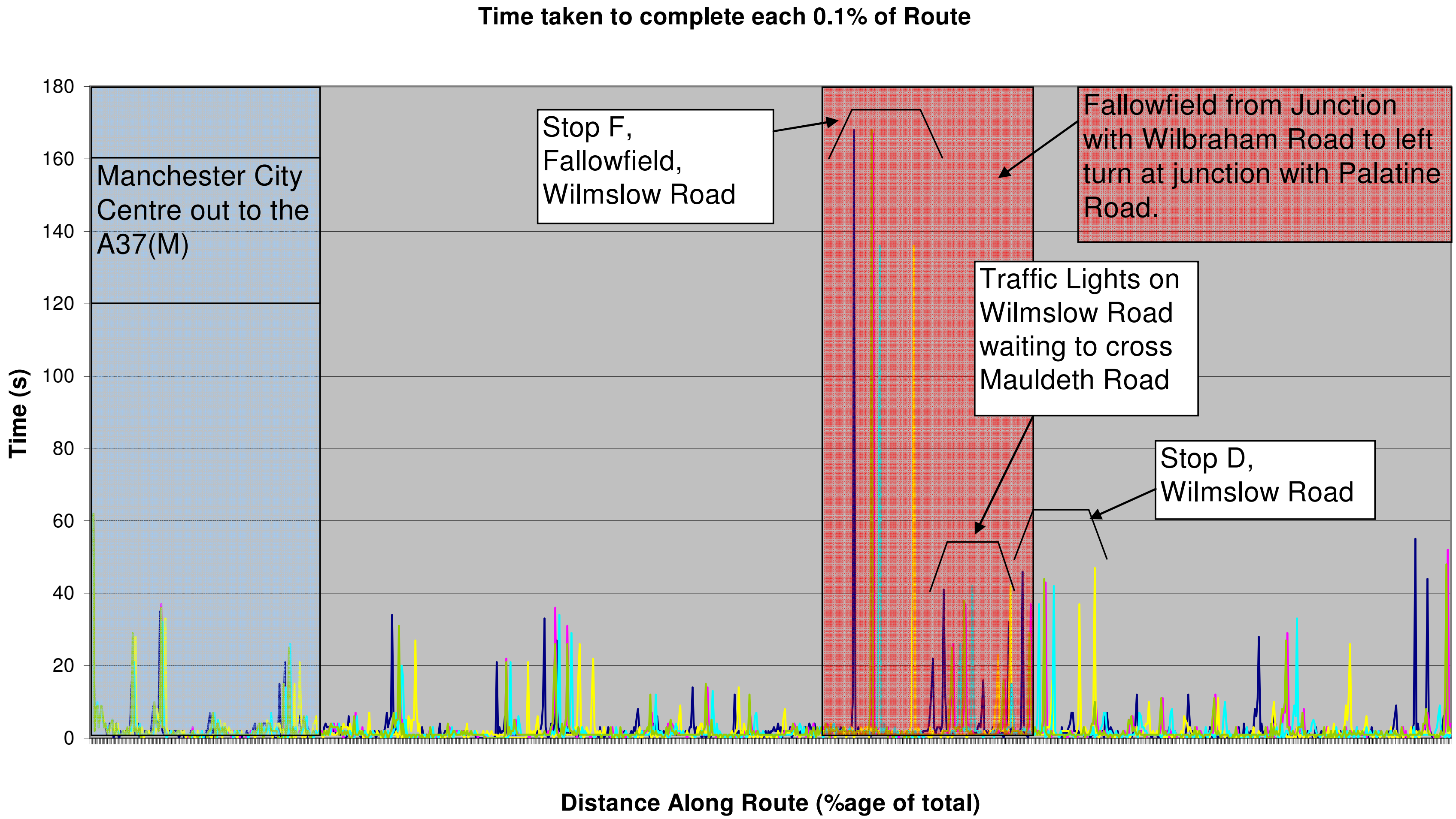


Figure 4.21 - Manchester Northbound Delay Analysis

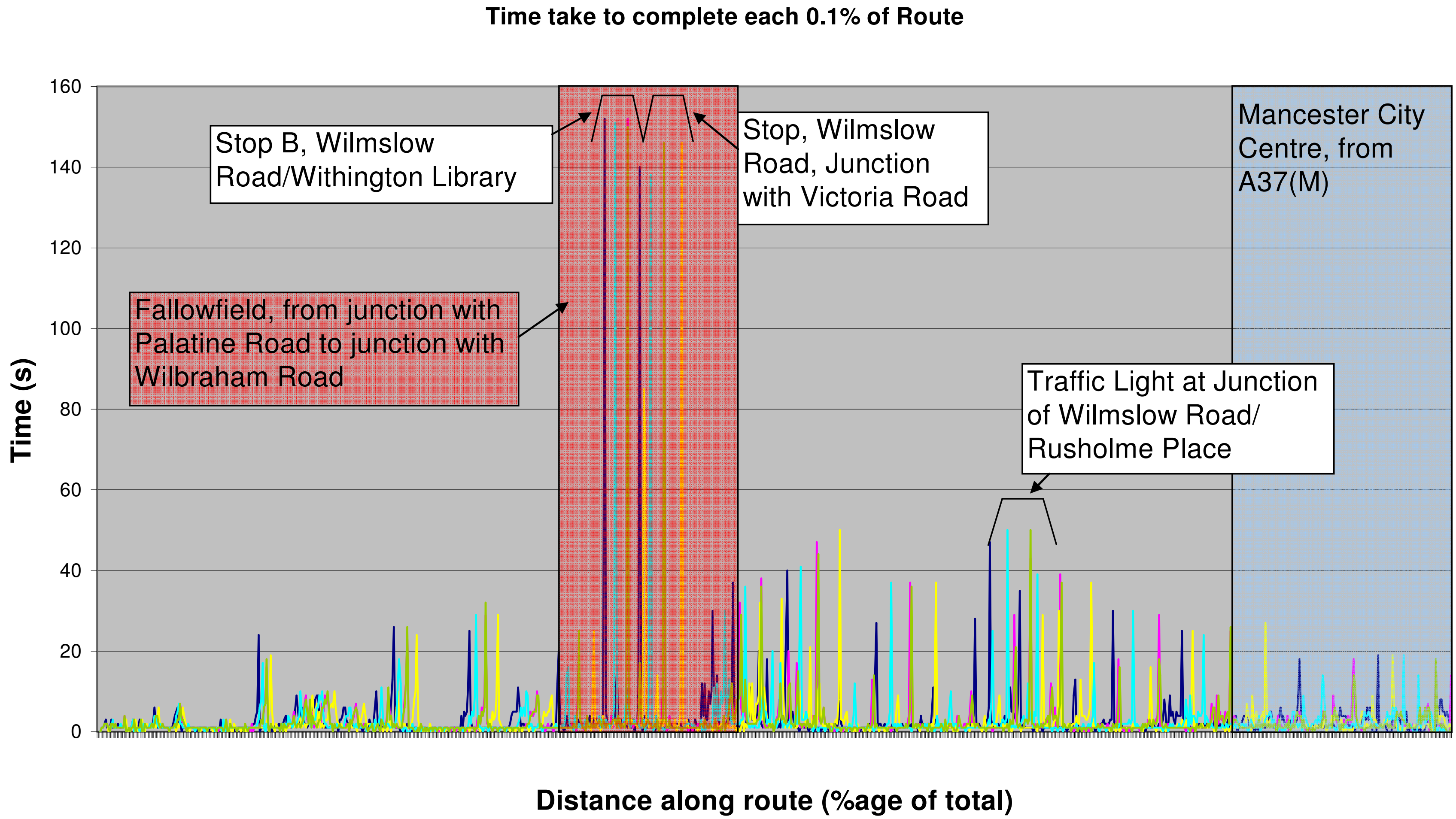


Figure 4.22 - Sheffield Eastbound Delay Analysis

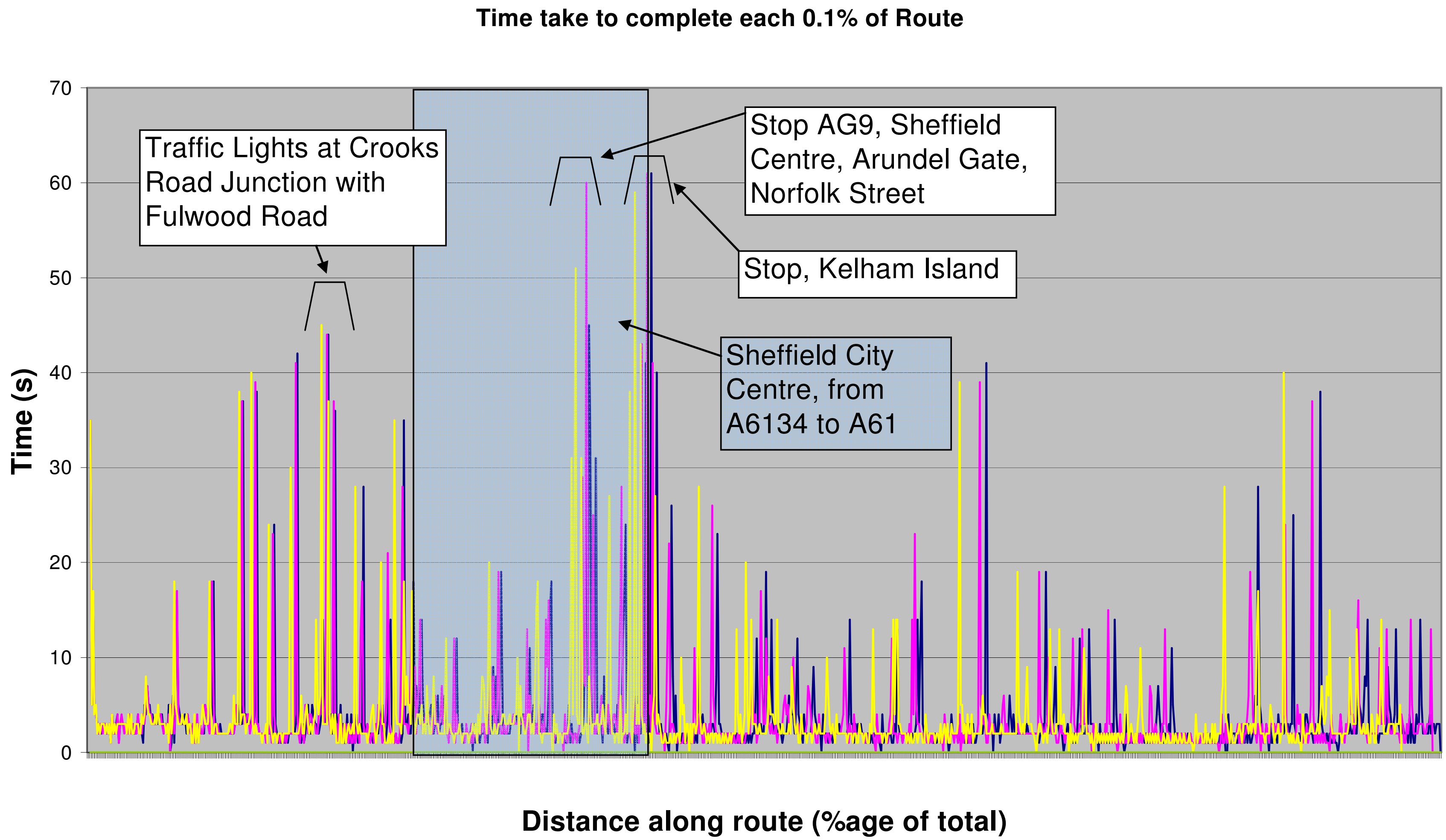


Figure 4.23 - Sheffield Westbound Delay Analysis

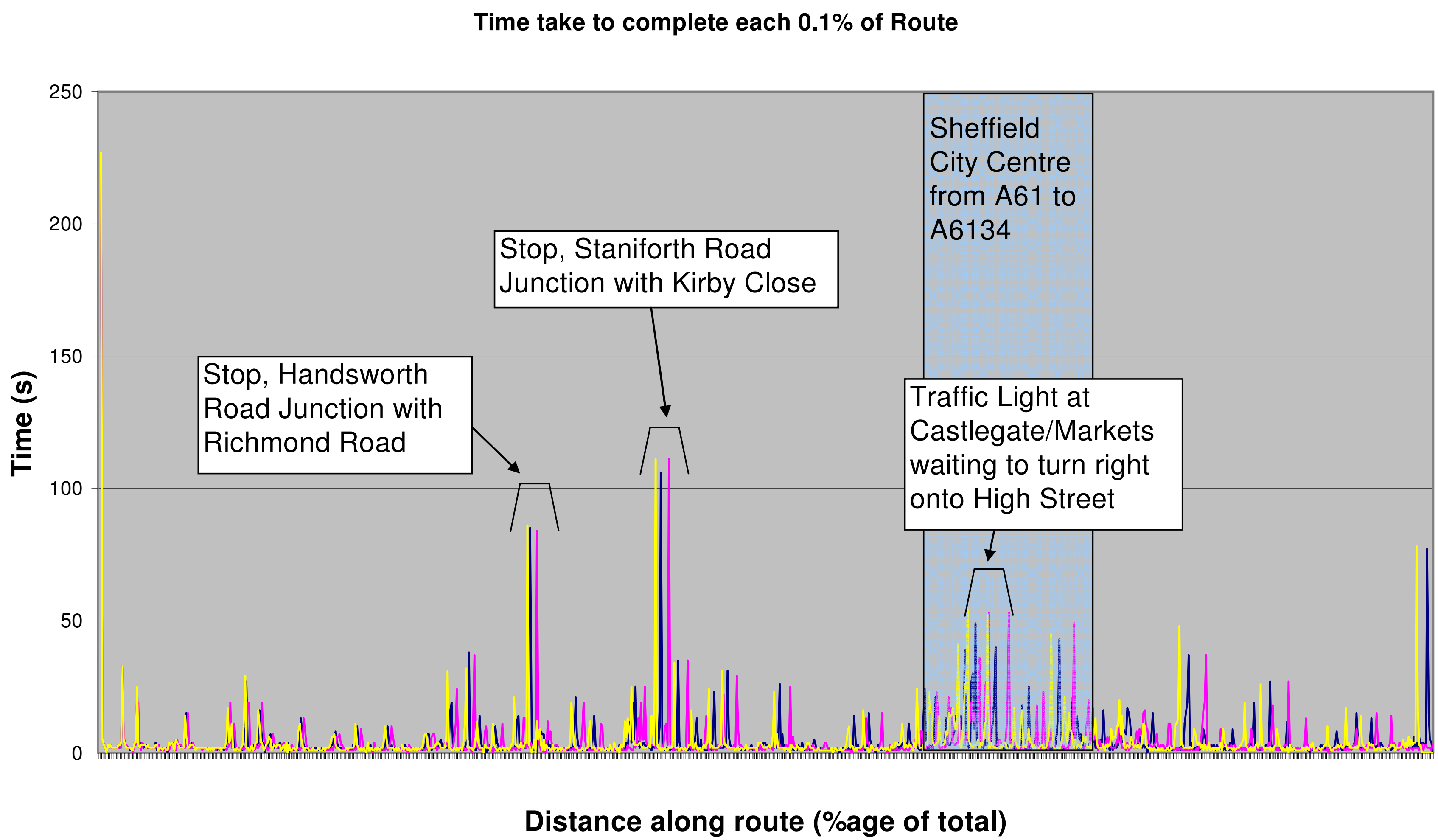


Figure 4.24 - Wolverhampton Southbound Delay Analysis

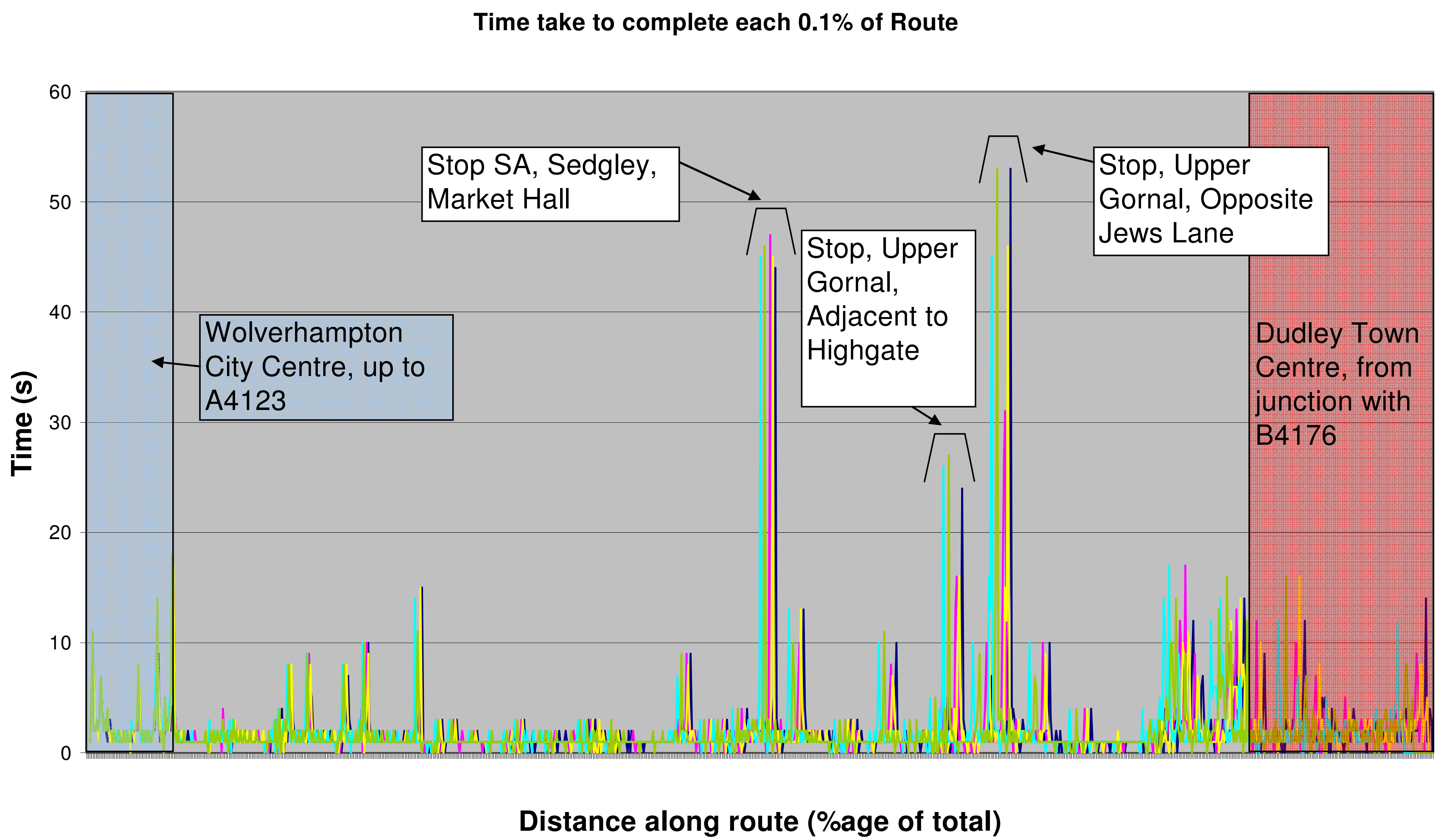
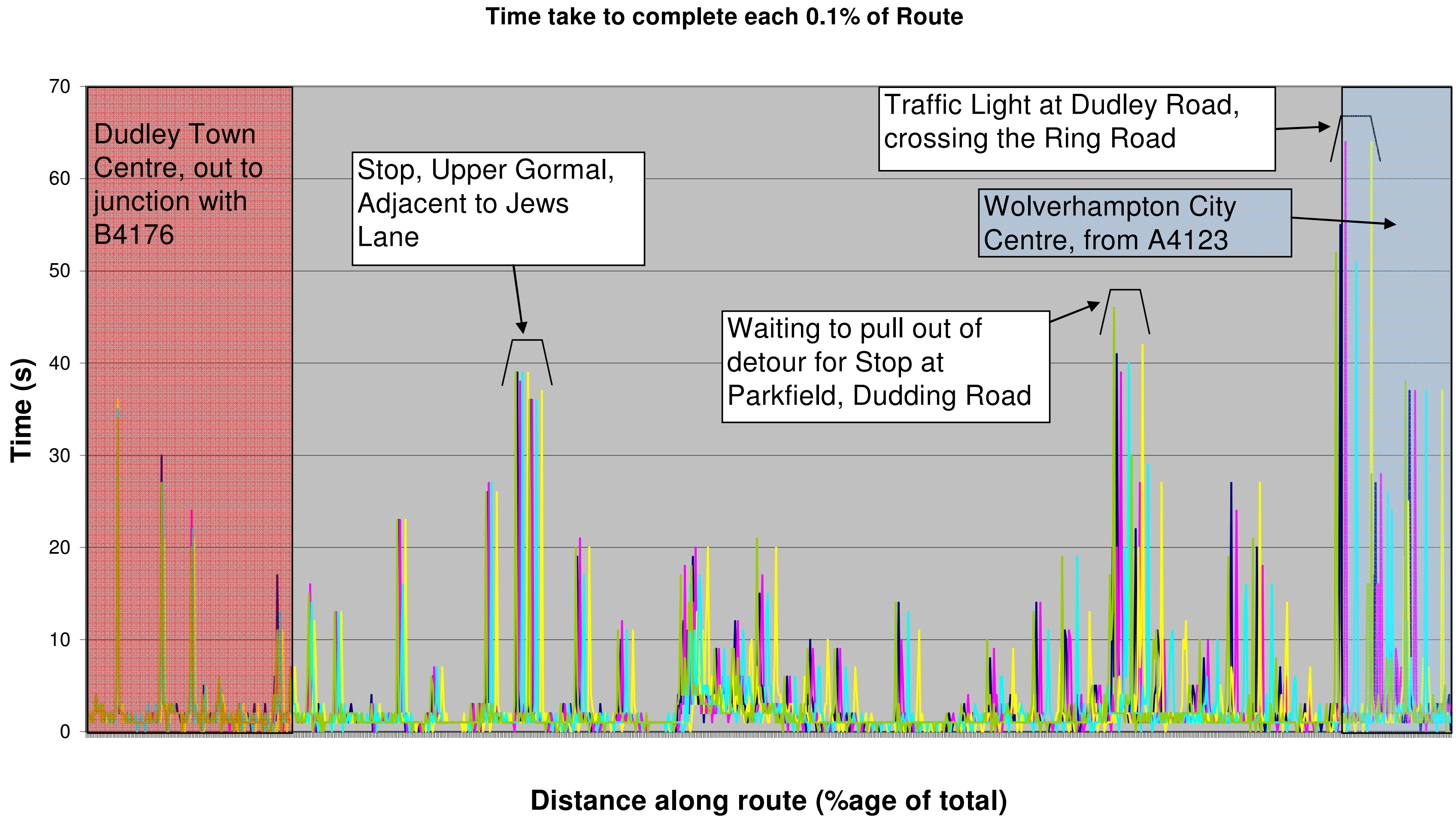


Figure 4.25 - Wolverhampton Northbound Delay Analysis



In almost every example route (six in total), the three features that caused the most consistent long delays were a mixture of bus stops and traffic lights.

In the Wolverhampton Southbound route all three features were bus stops. In the Wolverhampton Northbound route significant delays were caused at the stop at Parkfield, Dudding Road. This is because at this point the bus pulls off the main road and into a stop in a siding. When the bus attempts to join the main road there is a delay caused by the traffic on the main road making it difficult to pull out.

In all routes at least three key features are consistently delaying buses and contributing a noticeable portion of idling time to the route. Removing the effect that the features have on the route would have a positive impact on emissions.

The total delay caused by these features varied across the routes. In the worst case (the northbound route into Manchester) the total delay involved was about 340 seconds on average. This was approximately 33% of the total idling time during the route and so would contribute roughly 33% of the idling emissions. Given that idling emissions contribute up to 25% of total emissions along the routes (see section 4.1.3 to 4.1.5, and summary in 4.5), these three worst features are contributing up to about 7% of total emissions on the route.

As these features seem to consistently cause delays to the bus, it may be sensible to make drivers aware of these features – particularly the most prominent ones – and to suggest that given the consistent long delays, some of these places are prime candidates for engine switch off. This might be particularly useful for delays caused at bus stops where the driver can to some extent anticipate when he will be able to leave the stop.

4.3.3 Length of Idling at Junctions/Signals

The data has been manipulated in order to determine the amount of idling time at . junctions or traffic signals. This is distinct from idling time at bus stops which must be made to provide the service, or delays caused by congestion which was not attributable to a particular network feature.

To do this, the data gathered by the observer on the bus routes has been stripped of idling incidents where the idling time was noted as being due to a bus stop, or due to congestion. This left the idling incidents which were directly attributable to network features – overwhelmingly junctions and traffic lights.

Table 4.8 shows the break down of these results. Each route had some very short halts where the bus barely came to a rest at a junction because traffic was mostly free moving. Each route also had some long halts, in all but one cases the longest halt observed on a route exceeded a minute in length.

Table 4.8 - Idling directly due to network factors (junctions, traffic signals, crossings)

	Average Total Idle Time at Halt (per route) (min:sec)	Average Halt time (seconds)	Minimum Halt time (seconds)	Maximum Halt time (min:sec)	Total route length (mins)
Manchester (South Bound)	07:39	25	2	01:14	40
Manchester (North Bound)	07:56	23	2	01:05	39
Sheffield (West Bound)	07:07	18	1	00:53	65
Sheffield (East Bound)	06:07	18	1	01:12	65
Wolverhampton (South Bound)	03:31	21	2	01:28	37
Wolverhampton (North Bound)	03:43	25	3	01:09	38

This means that for each average halt caused by junctions or traffic signals that it was possible to eliminate, a saving of somewhere around 0.5% of total emissions could be realised. Eliminating just 4 of these incidents would improve emissions by more than 2%.

In nearly all cases, eliminating the worst junction-related idling period would result in more than twice the emissions reductions of an average stop – over 1% of total emissions. (The exception to this is the case of the Sheffield analysis, where a longer route means that the single worst idling period makes up a smaller percentage of the emissions for the route).

4.3.4 Interview Data on network factors

Drivers and managers were generally happy with the level of bus priority infrastructure. There was a feeling that it would always be the case that providing more bus priority measures would be helpful in terms of journey times and emissions, but it was also believed that what exists is sufficient. Additionally, what exists is largely thought to be helpful although there are few examples of bus priority measures that do not have a positive effect.

It was, however, mentioned that some routes are better supplied with priority infrastructure than others and that on some routes compliance of other vehicles with the bus priority measures was not good. A particular problem mentioned by one driver was vehicles planning to turn left ahead, using the bus lane as a filter lane.

In addition to a general feeling of satisfaction with existing priority measures, scheduling was an important issue for drivers, who felt that a number of routes did not always have 'recovery time' in the right place, which leads newer drivers to drive aggressively in order to recover time. They also believe that scheduling is not sensitive to events such as Market day, busy Fridays, or quiet Thursdays. Managers reported monthly scheduling meetings discussing issues about routes – this may therefore reflect a difficult problem, rather than the driver's perception that nothing is done about it.

The problems managers had with scheduling appears to be the nature of the network and how vulnerable it is to rapid and unanticipated change. Roadworks will sometimes appear on a route and throw scheduling out overnight and any system where advance warning could be assured would assist with scheduling and reduce this problem.

4.4 Technical Factors

4.4.1 Summary of findings

- There is a strong perception among drivers that older buses are likely not to restart when switched off, which is presenting a major barrier to them switching off.
- Drivers suggested that buses manufactured in Germany have the cab location swapped, but air intakes are still on the left, meaning these pick up roadside debris and impede cooling performance.
- There may be an issue with vehicles overheating when switched off on very hot days (observed by TTR). Some drivers said that had been told not to switch the engine off when the weather was very hot.
- Improving the Euro standards of buses to a more recent standard has a large benefit in emissions terms.

4.4.2 Potential Emission Reductions From Fleet Replacement

As technology improves it becomes possible to build more efficient, cleaner buses. A good way to look at this improvement as it applies to fleet vehicles is by measuring their compliance with Euro emission standards, which set a minimum standard that every new vehicle sold in the EU must comply with based on a standard test cycle.

Basing emissions estimates on Euro standards is not the same as measuring emissions from individual vehicles at the tailpipe. As vehicles age they tend to perform less well with regard to emissions and there can be a significant difference between the test cycle and actual use. On the other side of the scale, older vehicles may have post purchase technology fitted to improve their performance, for instance diesel particulate filters ('traps'), which is not reflected in calculations based on their Euro standard.

However, despite these complicating factors, the Euro standard that a vehicle was built to is a good way to estimate the emissions it puts out and the potential improvement available by upgrading the vehicle to a newer vehicle with a higher Euro standard. Emission speed curves (in the form of a set of factors) have been produced to help estimate the emissions produced by different Euro standard vehicles in different driving conditions (i.e. speed).

Emissions factors are available for all Euro standards from I to VI, for both single and double deck buses. In most of the emissions calculations in this study an “average” vehicle of the fleet observed during the on-bus route survey has been used, which is a Euro III vehicle. In order to show the potential emissions gains from upgrading vehicles to a higher standard, the potential emissions from each route have been calculated for each Euro standard.

Table 4.9 - Euro Standards by Year of Introduction

Euro Standard	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
Year	1992	1996	2000	2005	2008	2013

It is important to note that for this study the emissions have been estimated, using the DfT emissions factors. These are polynomial equations designed to model emissions at a given speed when the Euro standard of a vehicle is known. Based on these factors the Euro I and II data suggests that such vehicles are better in terms of NO_x and PM emissions at very low speeds (about 8kph for PM and about 15kph for NO_x). As a result, some of the graphs show lower emissions for Euro II buses than for Euro III.

The study team are unaware of any technical factor that would lead to earlier engines producing lower emissions specifically at low speeds and, this being the case, believe it is an artefact of the equations used to estimate emissions. The fact that the data in the following graphs that show Euro II buses to have lower NO_x emissions than Euro III buses should be treated with some caution.

An illustration of the emissions from each representative run using each Euro standard vehicle are shown in the graphs below.

4.4.2.1 Manchester

Figure 4.26 - Manchester Southbound Emissions by Euro Standard

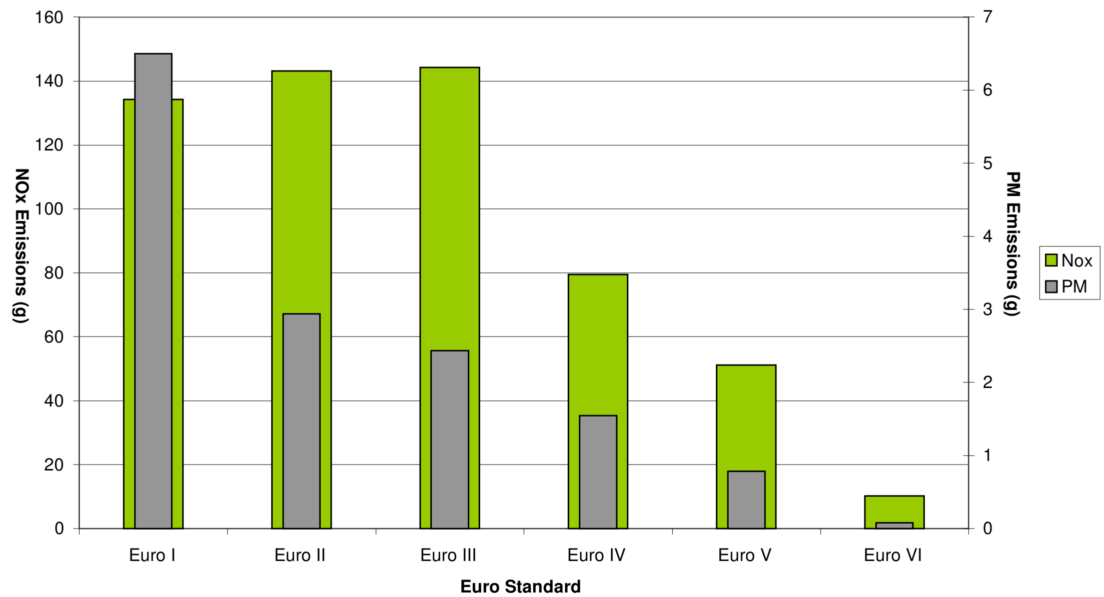
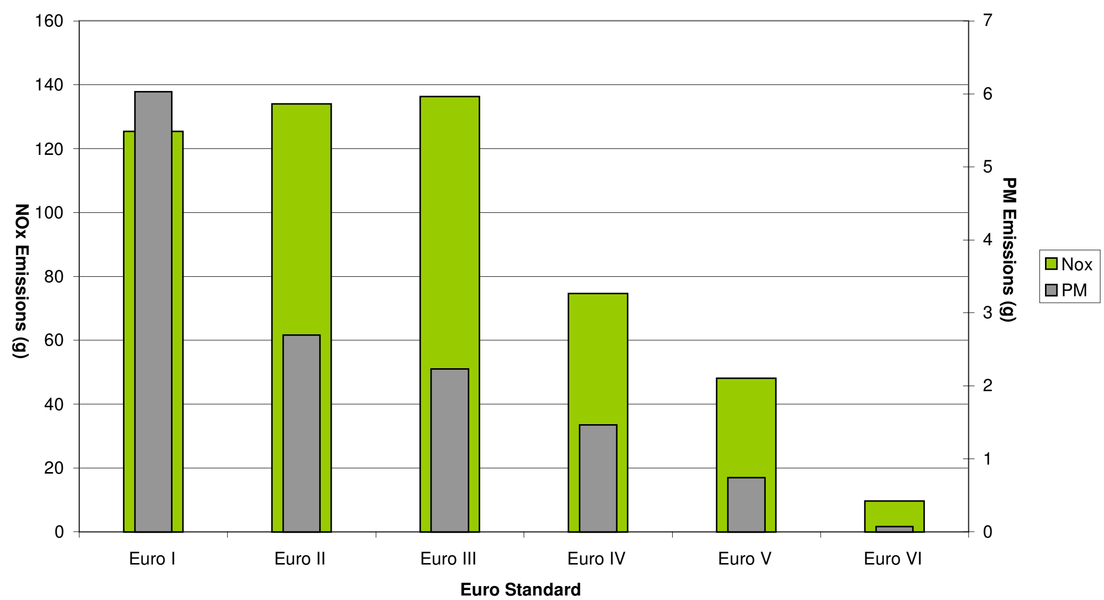


Figure 4.27 - Manchester Northbound Emissions by Euro Standard



4.4.2.2 Sheffield

Figure 4.28 - Sheffield Eastbound Emissions by Euro Standard

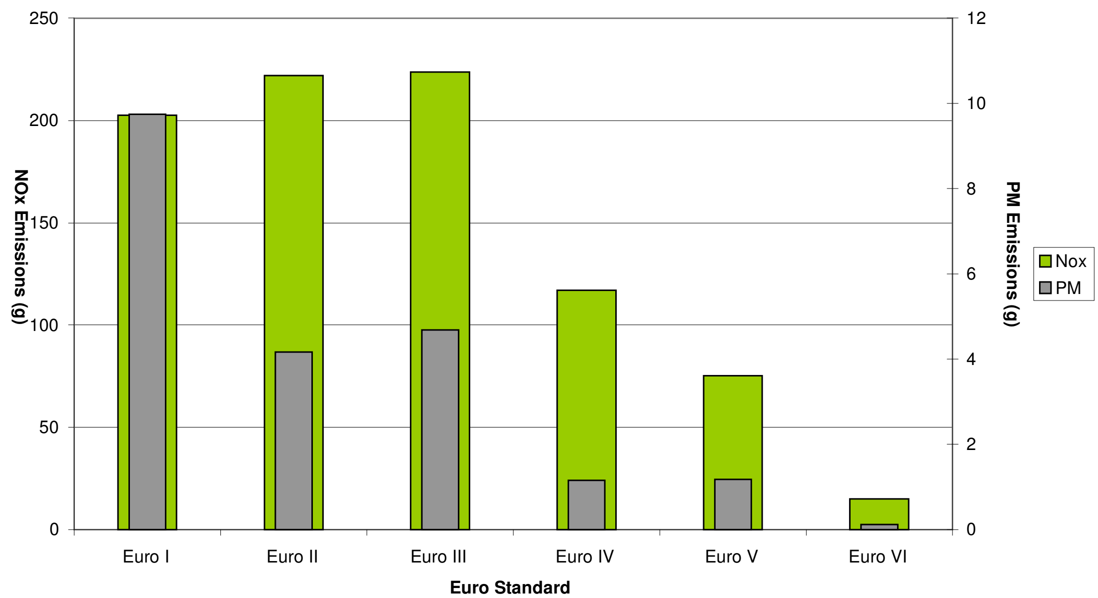
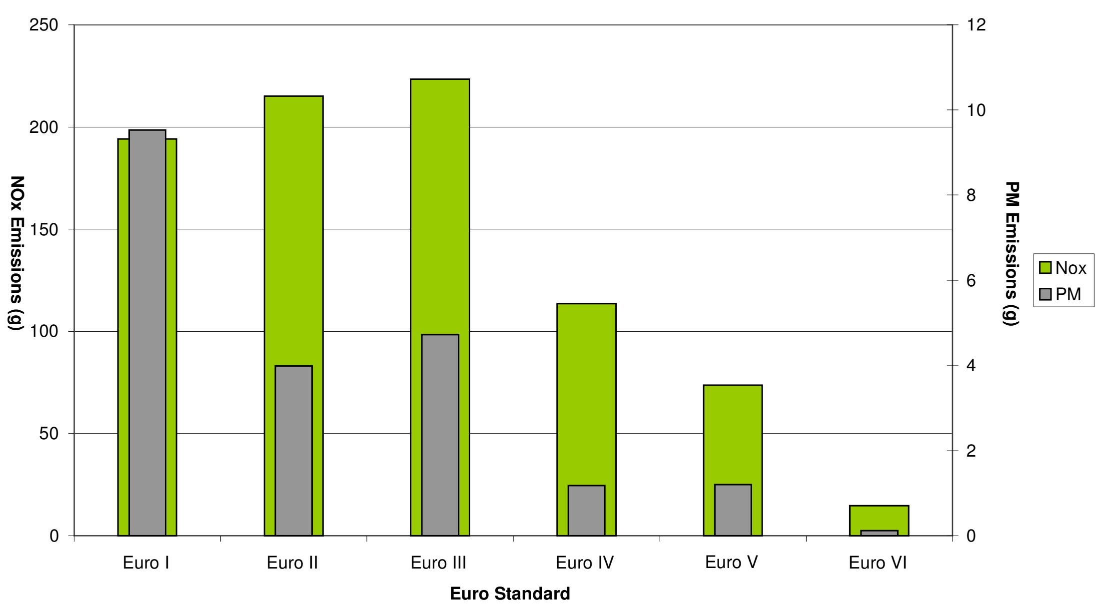


Figure 4.29 - Sheffield Westbound Emissions by Euro Standard



4.4.2.3 Wolverhampton

Figure 4.30 - Wolverhampton Southbound Emissions by Euro Standard

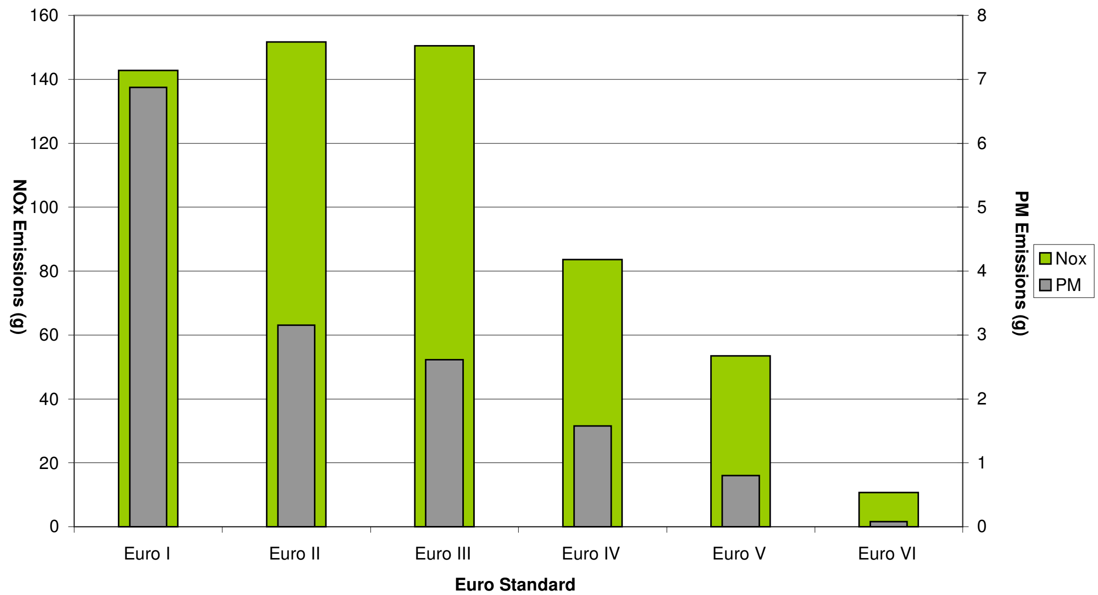
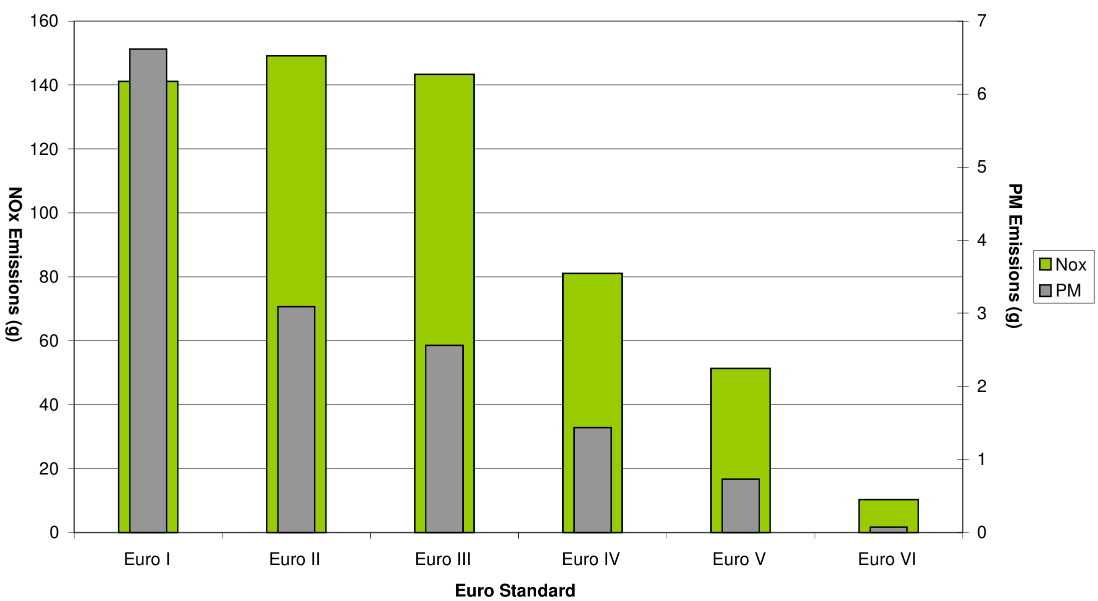


Figure 4.31 - Wolverhampton Northbound Emissions by Euro Standard



4.4.2.4 Potential Savings

This section provides estimates of emissions savings for replacing buses of Euro standards II, III and IV with higher standard buses. The potential reductions in emissions achieved on one route by replacing a bus with an equivalent bus of higher Euro standard are shown in Table 4.10 below, for three Euro standards, starting with Euro II and ending with Euro IV. The average vehicle on the observed routes was a Euro III bus.

The current Euro standard is Euro V. The Euro VI standard is not yet in force and will be applied to manufacturers beginning 2013. Euro VI compliant vehicles will be available shortly after this point.

Table 4.10 - Potential Savings from Upgrading Buses to Higher Euro Standard

	Manchester Southbound		Manchester Northbound		Sheffield Eastbound		Sheffield Westbound		Wolverhampton Southbound		Wolverhampton Northbound	
Euro II to	PM	NO_x	PM	NO_x	PM	NO_x	PM	NO_x	PM	NO_x	PM	NO_x
Euro III	17.2%	-0.7%	17.3%	-1.8%	-12.5%	-0.8%	-18.4%	-3.9%	17.1%	0.8%	17.3%	3.8%
Euro IV	47.5%	44.5%	45.8%	44.3%	72.2%	47.3%	70.5%	47.2%	50.0%	44.9%	53.6%	45.7%
Euro V	73.4%	64.3%	72.5%	64.1%	71.7%	66.1%	69.9%	65.7%	74.6%	64.7%	76.4%	65.6%
Euro VI	97.3%	92.9%	97.2%	92.8%	97.2%	93.2%	97.0%	93.1%	97.5%	92.9%	97.6%	93.1%
Euro III to												
Euro IV	36.6%	45.0%	34.4%	45.3%	75.3%	47.7%	75.1%	49.2%	39.7%	44.5%	43.9%	43.5%
Euro V	67.8%	64.6%	66.7%	64.7%	74.9%	66.4%	74.6%	67.0%	69.4%	64.4%	71.5%	64.2%
Euro VI	96.8%	92.9%	96.7%	92.9%	97.5%	93.3%	97.5%	93.4%	96.9%	92.9%	97.2%	92.8%
Euro IV to												
Euro V	49.2%	35.6%	49.2%	35.4%	-1.8%	35.6%	-1.9%	35.1%	49.3%	36.0%	49.3%	36.7%
Euro VI	94.9%	87.1%	94.9%	87.1%	89.8%	87.1%	89.8%	87.0%	94.9%	87.2%	94.9%	87.3%

The maximum potential gain seen in the chart above is found from upgrading to Euro VI standards, especially from Euro II and Euro III buses, as might be expected. This emissions reduction is sometimes as much as 97% for PM reduction and 93% for NO_x reduction. Euro VI standard vehicles are not currently available, but upgrading buses to the current Euro V standard can offer reductions in emissions of 64-76%, depending on the route and pollutant under discussion. Even the difference between Euro III and Euro IV buses is significant here, where an upgrade to the latter shows an emissions reduction of around 45% in NO_x and around 35-40% in PM, except for the single decker buses in Sheffield, where a 75% reduction in PM is seen.

In some places in the chart a negative value is reported, signalling an increase in emissions. This is thought to be caused by the cross over in emission rates from the DfT emissions factor equations at low speeds for Euro I and Euro II buses, as discussed above, or, in the case of the buses in Sheffield, a similar cross over between the equations for Euro IV and Euro V PM emission standards in single decker buses.

4.4.3 Interview data on technical factors

By far the most frequent complaint about the vehicles among the drivers interviewed was the universal perception that there were certain vehicles which were prone to not starting once they were switched off. Drivers believed this was overwhelmingly the older vehicles and this was stated multiple times in the driver interview as the biggest reason not to switch the engine off.

This issue will need to be addressed before a desirable level of compliance with switch off guidelines is reached. At the moment drivers are genuinely worried that after shutting down the engine a vehicle will not start up again and they will have to face angry customers and a long wait for an engineer. In contrast, Managers have relayed that actual breakdowns are very rare and this suggests that education/information designed to convince drivers that engines will re-start, or the offending buses are removed from service (or fixed) would be the appropriate solution.

Another technical issue raised is a tendency for some bus engines to overheat if the engine is switched off. The reason given is that the cooling fans switch off and the water used to cool the engine overheats. Drivers reported having been told by managers to keep the engines on in “scorching hot” weather.

A related technical issue was that some buses are sourced from Germany. Although the cab is swapped for right hand drive, the radiator is still on the left. It therefore picks up debris from the kerb, which makes overheating more likely.

Other technical problems that used to exist as a barrier to switch-off have been addressed which means there are fewer reasons not to turn off idling engines. For example, one operator’s buses had destination boards that turned off with the engine, which meant if a driver switched off the engine in the depot passengers would not know which bus to board.

4.5 Summary of Key Results

4.5.1 Route overview

- Significant amounts of time and related emissions from each route surveyed in the study are caused when buses are stationary. This suggests that there exists the potential to significantly reduce emissions by addressing idling vehicles.

- An illustration of the potential annual emissions from each of the routes is given below, in Table 4.11.

Table 4.11 - Summary of annual emissions estimates

PTE Area	Direction	PM (kg)	NO_x (tonnes)
Manchester (GMPTE)	South	67	3.99
	North	62	3.77
Sheffield (SYPTE)	East	130	6.19
	West	131	6.18
Wolverhampton (Centro)	South	72	4.16
	North	71	3.97

- The proportion of emissions from a route that can be attributed to periods when the bus was idling is given in Table 4.12.

Table 4.12 - Summary of percentage time idling and emissions resulting

PTE Area	Route	Time	PM	NO_x
Manchester (GMPTE)	South	39.0%	7.1%	20.5%
	North	43.5%	9.4%	23.9%
Sheffield (SYPTE)	East	29.9%	21.6%	21.4%
	West	34.2%	25.2%	24.9%
Wolverhampton (Centro)	South	32.9%	5.4%	16.5%
	North	29.5%	5.8%	14.9%

4.5.2 Behavioural factors and findings

- Drivers are worried about the potential for a vehicle to fail to restart if they switch the engine off, whereas managers consider this to be a minor issue and addressed through routine maintenance.

- Driver's stated awareness of eco-driving techniques and impacts, and their explanation of the basics of these techniques and impacts during interview is generally good, with a few exceptions. However, there is a strong feeling that there are insufficient incentives to encourage all drivers to follow-through on good practice as 'it's not my fuel'. Finally, understanding of eco-driving does not currently extend to the practice of regularly switching-off when idling at bus stops and termini, unless these are also bus stations where enforcement is practiced.

- In practice, the majority of buses are kept idling at bus stops and termini (where these are not bus stations). A significant proportion bus stops needed dwell times of over 10 seconds (up to half of observed stops on a route), and a 10 second policy for switch off would capture significant proportions of emissions from these stops.

- There are few bus stops where dwell times were observed as being greater than 30 seconds and buses were observed idling at these stops. This significant length of time means that even with only a few such stops emissions savings are still possible. For most routes a cut of time of 30 seconds (after which the engine is switched off) offers emissions savings of between 0.7% and 9.1% of idling emissions at bus stops. In two observed runs, however, this potential saving was over 25%, or about 11% of all idling emissions (3% of total emissions).

- Bus drivers were observed to generally not switch off their bus engines at termini. This results in additional emissions to each route, estimated at about 2% of PM and 6% of NOx for a 40 minute route. Note, the contribution would be less for a longer route, and more for a shorter route

4.5.3 Network factors and findings

- The most significant three network features for delays and adding idling time contributed significantly to emissions on all routes. Just three network features contributed up to 33% of idling emissions in the worst case, or 7% of total emissions. Savings could be made by addressing network features (if they are junctions that can be re-designed) or by making drivers aware of them and encouraging switch off at these locations, something that is particularly suitable for bus stop features.

- Analysis undertaken that focussed specifically on delays at junctions and traffic signals suggests that the average period of idling accounts for about 0.5% of the emissions from a given route, depending on the route length. Eliminating just 4 average halts due to junctions or traffic signals would save over 2% of total emissions from the route.

4.5.4 Technical factors and findings

- There is a strong perception among drivers that older buses are likely not to restart when switched off, which is presenting a major barrier to them switching off.

- Some vehicles are overheating when switched off on very hot days and some drivers related being told to keep the engine running in these conditions to prolong the operation of the cooling equipment. Drivers suggested that some buses manufactured in Germany have the cab swapped, but air intakes still on the left, meaning they pick up roadside debris and also impede cooling performance.

- Improving the Euro standards of buses to the most recent standards would have a large benefit in terms of air pollutants, as would Diesel Particulate Filters on PM emissions.

5. RECOMMENDATIONS

A series of recommendations are made with behavioural, network and technical actions identified. The recommendations are grouped as actions for firstly addressing idling emissions at stops, termini and network features (such as junctions) and then overall emissions from along the entire route.

5.1 Reducing Idling Emissions

There are significant time periods when buses are stationary and idling on each of the routes investigated in the study (between 30% and 44% of total journey time). This is estimated to produce emissions that account for between 5-25% of total PM emissions and 15-25% of total NOx emissions, based on the vehicle speeds for the remainder of the route and the Euro standard of vehicle. Several potential measures have been identified that could address avoidable proportions of these idling emissions.

5.1.1 Behavioural actions

In order to achieve good results with emission reduction policies, the buy-in and cooperation of drivers is vital. Technical solutions such as improving the Euro standards of fleet vehicles may operate independently of drivers, but the success factor for other policy measures will be the willingness of drivers to react positively to fuel efficiency policy and technical aids, emission reduction protocols and practice.

Drivers' stated that understanding of eco-driving techniques and impacts is generally good. Drivers also report that pro-active enforcement of anti-idling at bus stations and reminder signs are helpful in encouraging good behaviour. The foundations for bus managers to encourage and reward good practice in overall eco-driving and specific anti-idling seem very robust.

The perception that drivers have, concerning vehicles refusing to restart, needs to be addressed if any policy of engine switch off is to be successful as this is a major factor in discouraging drivers from switching off their engines:

- Managers should combat driver perceptions about unreliable vehicles by demonstrating that problem vehicles have their faults quickly and permanently rectified or are removed from service.

A policy on stationary vehicle cut off times is recommended, where drivers are required and encouraged to switch off the engine after they have been stationary at a stop for a determined length of time. Although there is no minimum time that a vehicle must be stationary before engine switch off provides overall emissions savings, operators may find it difficult to accept and implement a "turn off immediately when stationary" when some engine manufacturers recommend a more cautious approach. Therefore:

- A switch off time of 10 seconds offers significant environmental benefit, reducing around 13-17% of total idling emissions (about 3-4% of total emissions) and should be considered if PTE/operators want to achieve a maximum emission reduction; OR
- For most routes a cut of time of 30 seconds offers emissions savings of between 0.7% and 9.1% of idling emissions at bus stops and should be implemented as the minimum to achieve emissions reductions.

Buses were found to spend a significant amount of time idling at the end of each route (at termini), which, if avoided, could save up to 6% of total emissions for NOx and approximately 2% for PM. Therefore:

- It is recommended that measures are put in place to encourage drivers to switch off immediately upon reaching a terminus, either through increased signage, in-cab indicators, training or enforcement (or some combination of these).

5.1.2 Network actions

It is clear from the study that on each route there are several network features which are the cause of a significant proportion of idling time for that route. These include specific bus stops in busy locations as well as junctions/signals. If these features could be eliminated, noticeable emissions savings (up to 33% of idling emissions, or 7% of total emissions) could be realised:

- The key network delay points should be highlighted to bus drivers and managers as part of any fuel efficiency scheme or anti-idling policy, training or campaign together with the information regarding the impact that keeping bus engines idling has on emissions (and fuel use).

Junctions were also observed to regularly contribute to delays through stationary traffic, where buses were idling. As each junction/signal that caused delay led to 0.5% of total emissions on average we estimate that eliminating just 4 average halts caused by junctions or traffic signals could reduce emissions on the route by over 2%. Therefore:

- Serious consideration should be given to future extension of bus priority at junctions and implementing selective vehicle detection at traffic signals in order to address the most cost effective opportunities this would give to reduce emissions from stationary buses (waiting at junctions).

5.1.3 Technical actions

The largest emissions savings are realised by immediate switch off of engines when the bus comes to a halt. There is little evidence to prove that turning off the engine will either damage modern engines or cause reliability issues to modern engines. Some engine manufacturers do recommend significant idle time after hard-working of engines in order to safeguard certain components (i.e. turbo-chargers), but do not provide further evidence to support this view which is also not unanimous among the manufacturers. No evidence has been found to suggest that additional emissions are caused by restarting a modern diesel engine.

The main recommendations are that:

- Managers should combat driver perceptions about unreliable vehicles by demonstrating that problem vehicles have their faults quickly and permanently rectified or removed from service.
- A low-cost solution to avoid buses overheating when switched off in very hot weather is required so the engine is not kept running to operate the cooling fans.
- In-cab alerts to remind drivers to switch off when idling should be considered as part of any driver training and incentive scheme to address idling emissions at bus stop and termini points.

5.2 Addressing Overall Emissions

In addition to idling emissions when buses are stationary it is possible to realise emissions reduction across the entire route by improving the emissions performance of the drivers and vehicles on that route. This can be achieved by bus drivers applying more fuel efficient driving methods, by implementing emission reduction technology (e.g. diesel particulate filters), by replacing older vehicles with later Euro standard technology or a combination of any of these options.

5.2.1 Behavioural actions

Both driver and manager groups were of the opinion that it was sometimes difficult to get past the fact drivers felt it was that “it isn’t my fuel”, and this could limit the practice of eco-driving techniques they understood in theory. Success in addressing this specific barrier to fuel use and emission reduction has been proven in schemes that offer drivers encouragement and incentives to improve their fuel efficiency through their driving style (e.g. best practice SAFED programmes). Implementing such measures would contribute to reduced fuel consumption and emissions across all parts of a drivers’ duty and bus route, not simply to times the bus is idling. It is noted that fuel efficiency programmes are currently being rolled out by some of the operators in PTE areas. Therefore:

- Fuel efficiency programmes with driver incentives should be implemented in all PTE area bus fleets, based on good practice and experience of leading operators;
- PTEs should work with bus operators to introduce a minimum standard of scheme in each depot/operating unit, which should be benchmarked and monitored on the basis of sharing (anonymous) data between operators and the PTEs in order to promote good practice and raise standards.

5.2.2 Network actions

Interviews with bus company managers and drivers found that their schedules are sometimes disrupted by unexpected road-works, potentially resulting in increased fuel use and emissions as some drivers drive aggressively to try to make up time lost from stationary and slow-moving traffic earlier on the route. The experience of managers and drivers expressed in the interviews suggest that if possible:

- A communication process should be set up with the highway authority so that bus operators are regularly updated and made aware in advance of road-works, so they are able to adjust their scheduling to reduce associated problems.

5.2.3 Technical actions

A number of technical approaches could be taken to further reduce air quality pollutants:

- Large reductions in emissions of NO_x and PM would be realised by replacing the oldest vehicles with vehicles meeting the latest Euro standards;

- Retrofitting older vehicles with diesel particulate filters would reduce PM emissions significantly (by more than 95%).

However, such technical approaches only address air quality pollutants by reducing the pollution caused by the combustion of diesel fuel.

In contrast, anti-idling and eco-driving measures directly reduce emissions by reducing the amount of fuel used. In this way they should be more cost-effective as there is a direct payback to the operator from implementing them, and an additional benefit on a global basis as carbon emissions are reduced. Therefore:

- PTEs should look for opportunities to encourage uptake of technical and technology options that support fuel-efficient 'eco' driving among bus drivers (such as rev-warning, in-cab telematics and automated fuel management systems).

Annex A

A1 PEAK HOUR DATA FOR COMPARISON

Figure A.1 - Manchester Southbound Emissions by Speed Band (Peak)

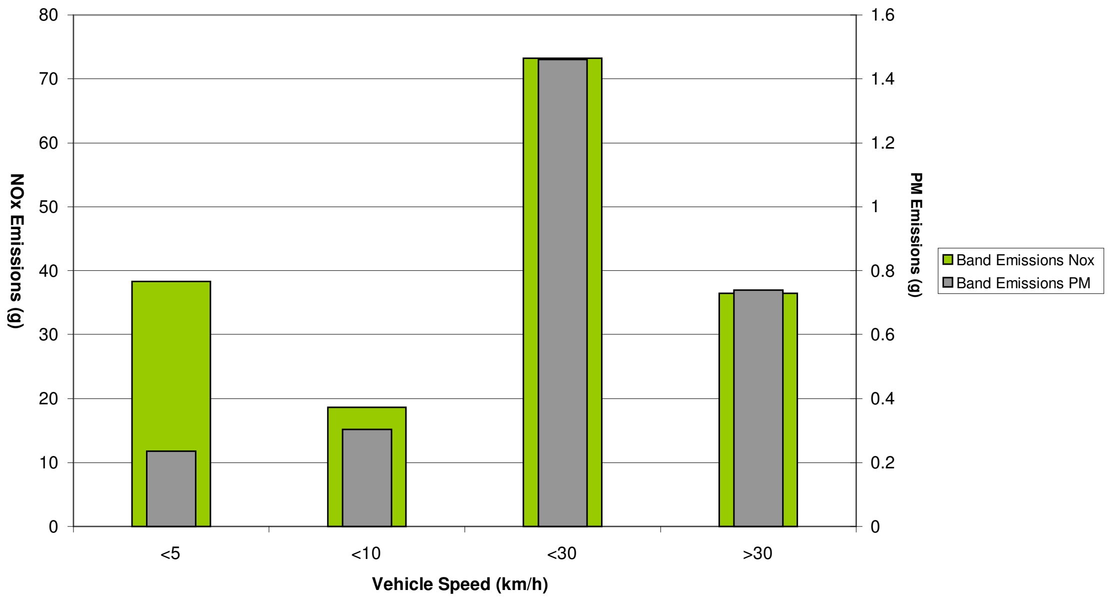


Figure A.2 - Manchester Southbound Time Spent in Speed Bands (Peak)

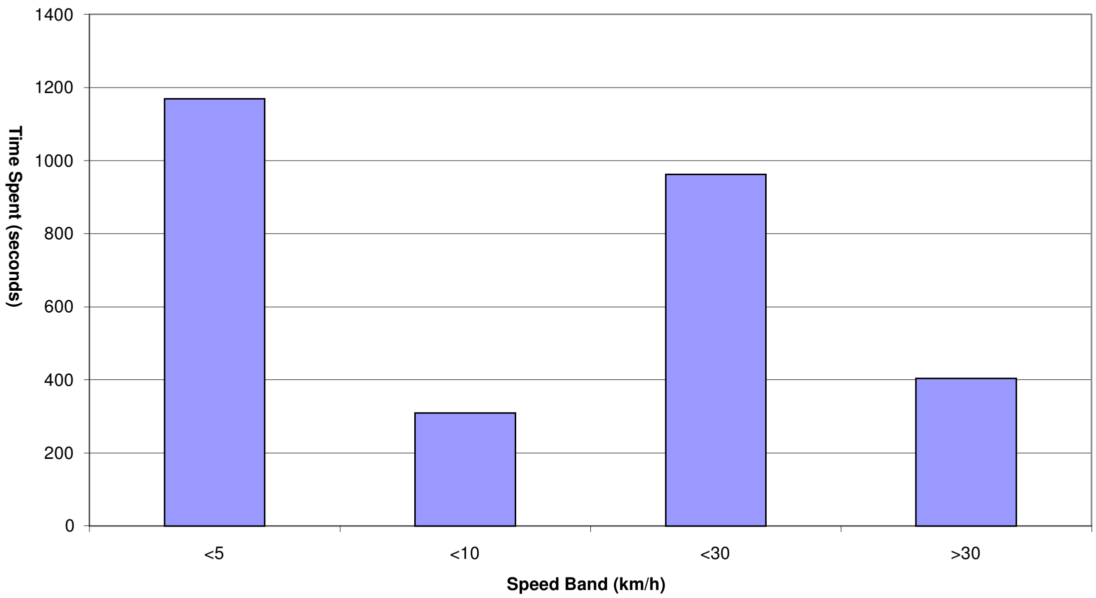


Figure A.3 - Manchester Northbound Emissions by Speed Band (Peak)

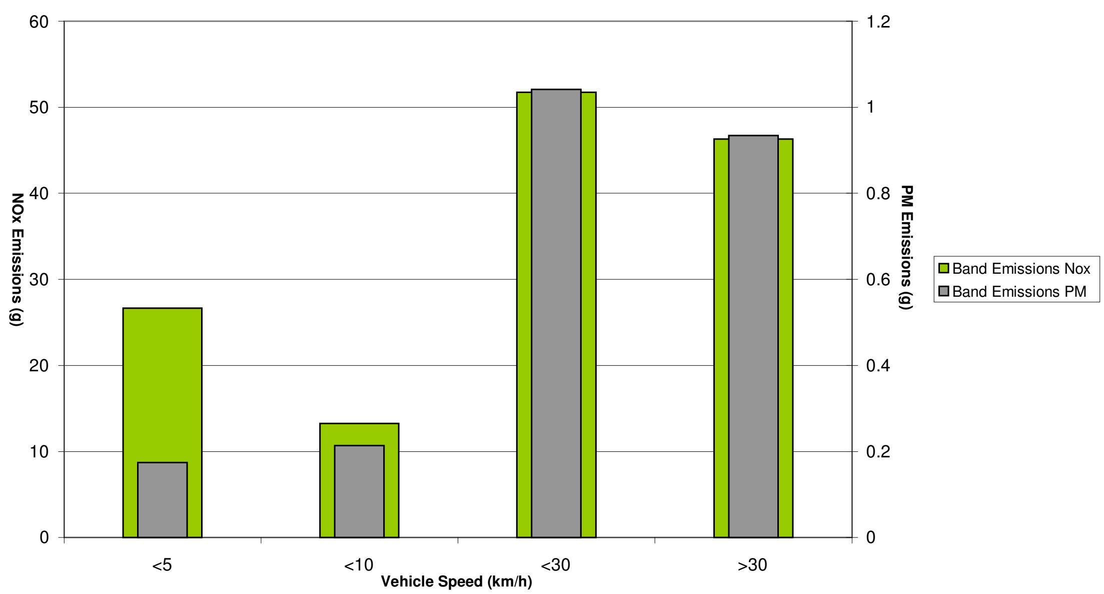


Figure A.4 - Manchester Northbound Time Spent in Speed Bands (Peak)

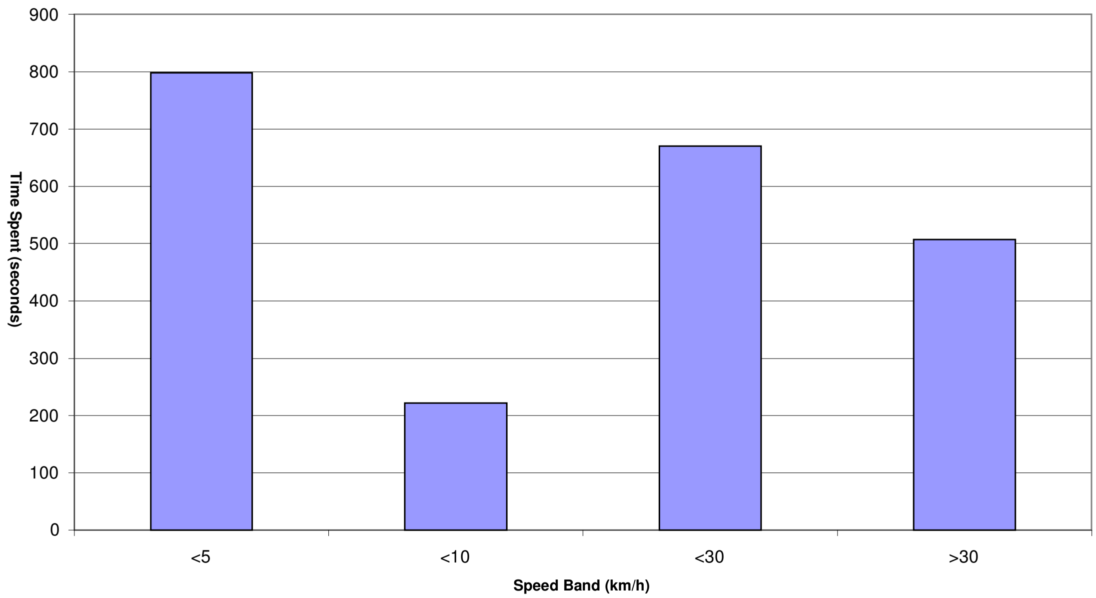


Figure A.5 - Sheffield Eastbound Emissions by Speed Band (Peak)

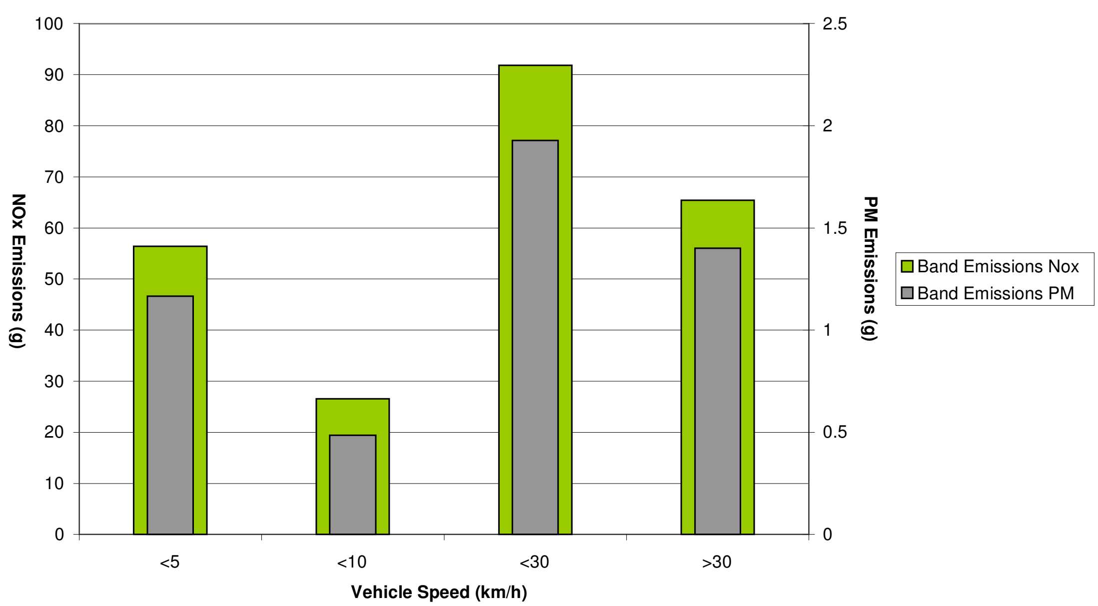


Figure A.6 - Sheffield Eastbound Time Spent in Speed Bands (Peak)

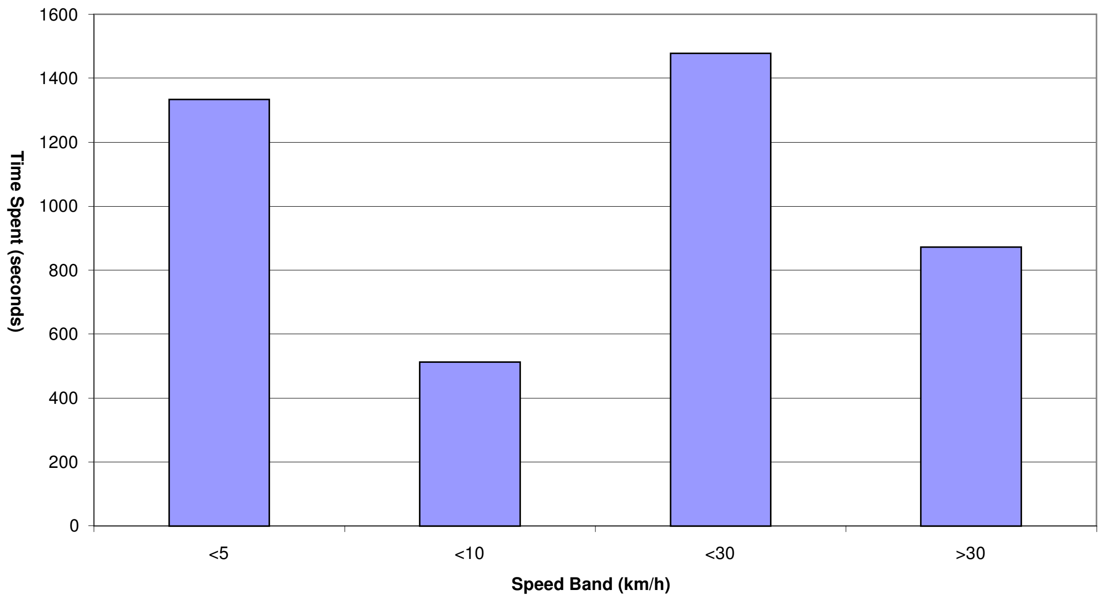


Figure A.7 - Sheffield Westbound Emissions by Speed Band (Peak)

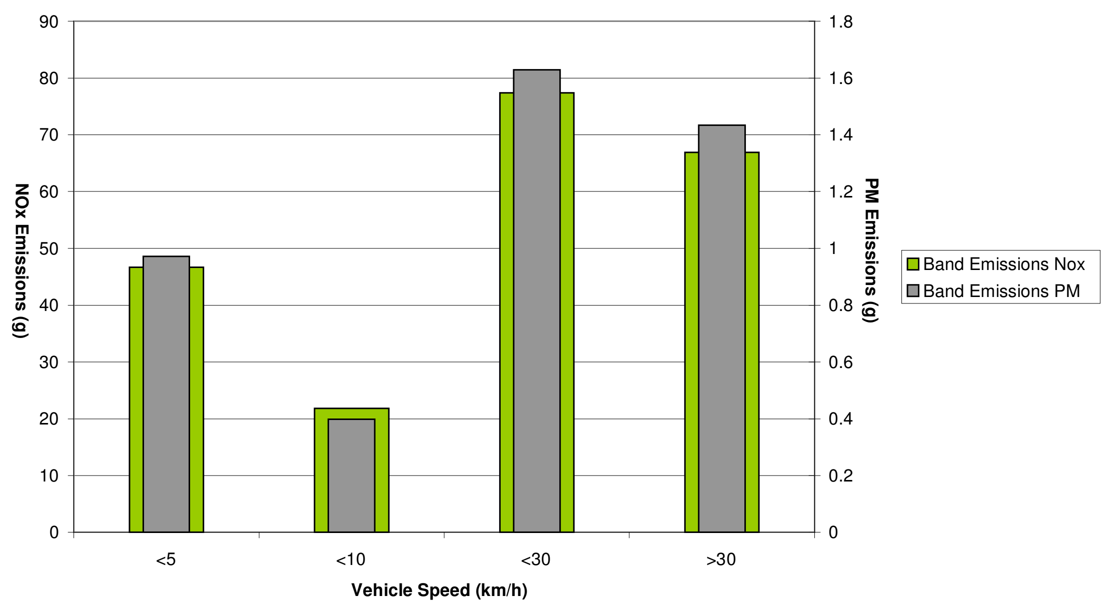


Figure A.8 - Sheffield Westbound Time Spent in Speed Bands (Peak)

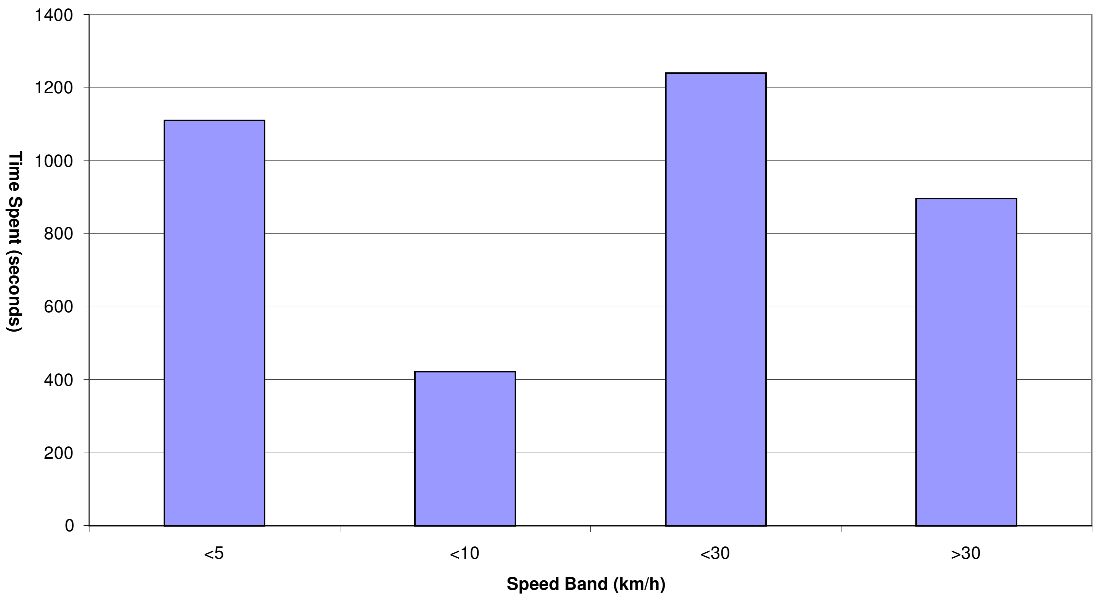


Figure A.9 - Wolverhampton Southbound Emissions by Speed Band (Peak)

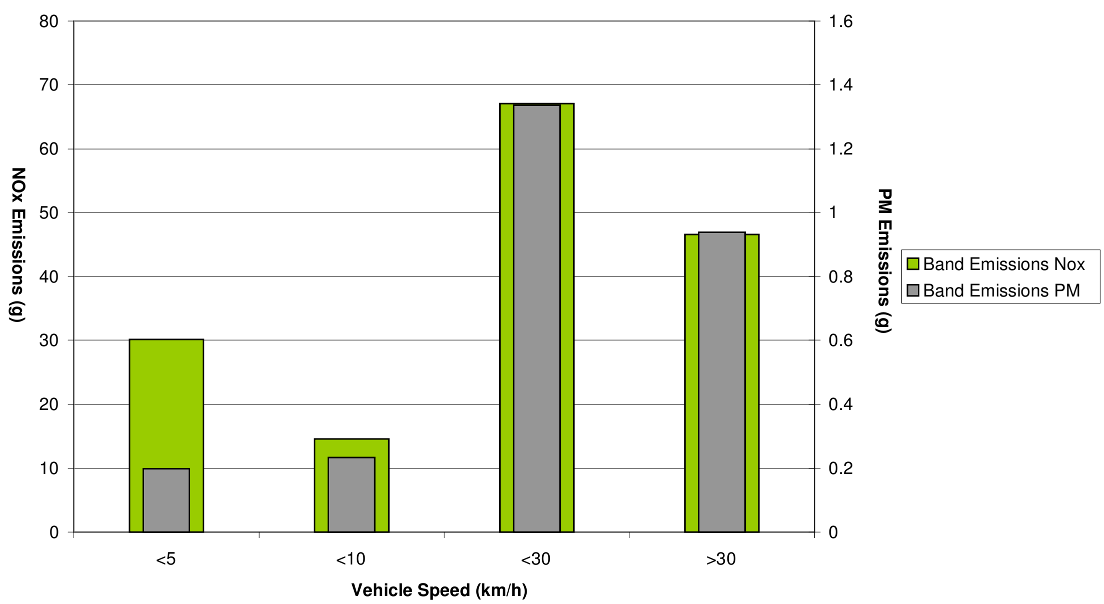


Figure A.10 - Wolverhampton Southbound Time Spent in Speed Bands (Peak)

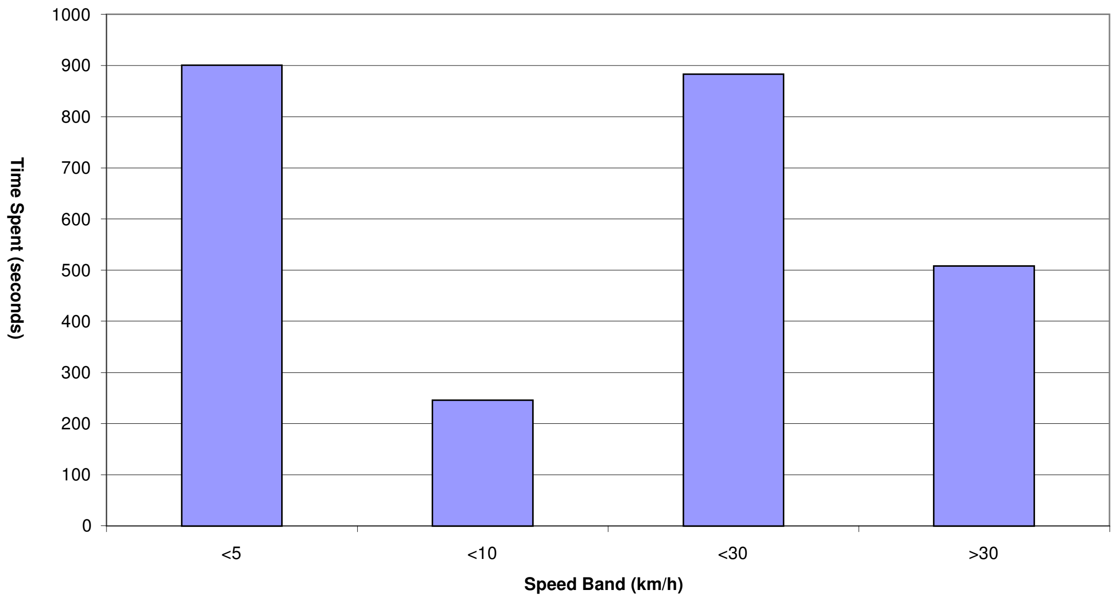


Figure A.11 - Wolverhampton Northbound Emissions by Speed Band (Peak)

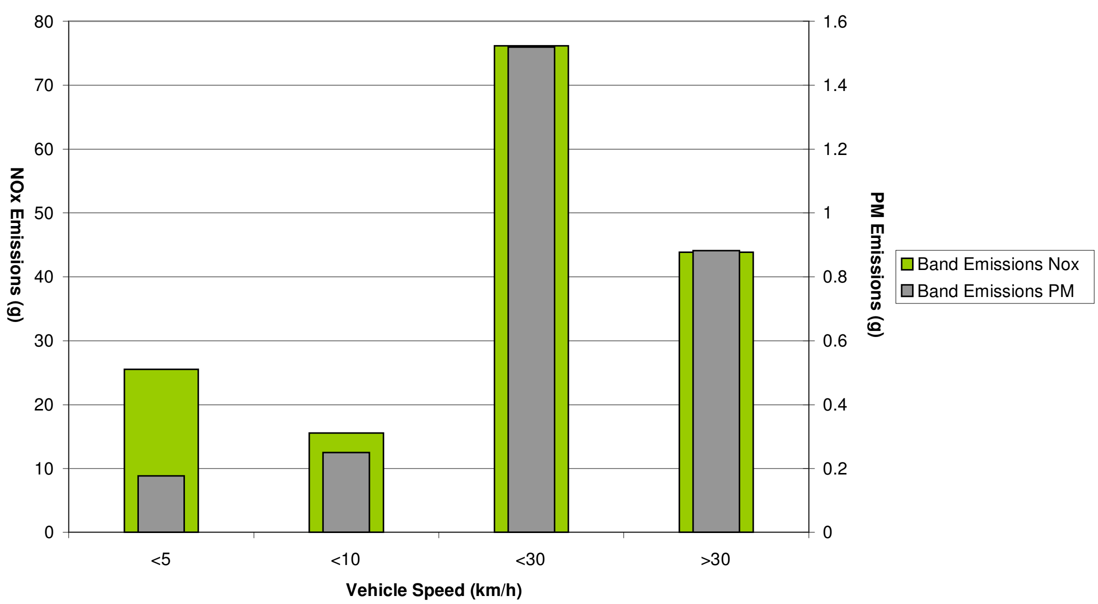


Figure A.12 - Wolverhampton Northbound Time Spent in Speed Bands (Peak)