Investigations of impacts of junction design on emissions: are our junctions sustainable?

Wafaa Saleh
*Transport Research Institute,
Edinburgh Napier University, Edinburgh, UK, and*
Alistair Lawson
School of Computing, Edinburgh Napier University, Edinburgh, UK

Abstract

Purpose – The purpose of this paper is an investigation of driving behaviour and impacts on emissions at two traffic junctions.

Design/methodology/approach – A signalised junction and a roundabout in Edinburgh have been selected. An instrumented car has been used and a GPS to monitor driving activities as well as a gas analyser to monitor the vehicle's emissions during the evening peak hour.

Findings – Vehicles' emissions are affected by a large number of factors including characteristics of the engine and the vehicle, characteristics of the road, the fuel used and driving behaviour.

Originality/value – Different methods and approaches have been used to investigate the behaviour of vehicles at various traffic junctions. The main aim, however, has mostly been to reduce travel times as well as traffic delays and queues at the junction. Consideration of environmental impacts has also been made, but often as a by-product of congestion reduction and not as a main aim.

Keywords Modelling of emissions at junctions, Traffic modelling and sustainability, GPS and emissions modelling, Driving cycles at traffic junctions, Emission, Traffic, Traffic control

Paper type Research paper

Introduction

In order to tackle air pollution and air quality issues, it is important to attempt to reduce the amount of travel (i.e. number of trips, their duration, and distance travelled), and also to attempt to reduce emissions from individual vehicles. This paper focuses on how emissions can be reduced by investigating different driving conditions at different parts of the transport system, such as signalised junctions and roundabouts.

Since the 1950s, a large number of research projects, frameworks and studies have been devoted to develop policies and standards to influence travel behaviour, reduce congestion and improve public transport in the first instance, whilst also improving air quality (see e.g. Saleh and Sammer, 2009; Muñoz and Ortúzar, 2008; Jara-Díaz and Gschwender, 2005; Bonsall *et al.*, 2007; Stewart, 2009; de Palma *et al.*, 2007).

Junctions are a crucial element in the road network as they are the "hot spots" where emissions, delays and accidents seemingly occur most often. "Problems posed by the environmental impact of traffic are growing and are a challenge for traffic engineers. Vehicular emissions are dependent on the total amount of traffic, intersection control type, driving patterns and vehicular characteristics", the amount of acceleration and deceleration and idling times (Mandavilli *et al.*, 2008).

The aim of this paper is to investigate impacts of traffic junction controls on emissions. This will be achieved through a survey of two junction control methods. Two junctions have been selected for the study, a signalised junction and a roundabout,

World Journal of Science, Technology and Sustainable Development
Vol. 10 No. 2, 2013
pp. 143-151

2042-5945
DOI 10.1108/20425941311323145

in Edinburgh (UK). Driving cycle investigations using the car chase technique at these two junctions were carried out using a performance box (PB) to collect the data. A survey of the two junctions was carried out to investigate further details about emissions and air quality, for the different control methods and their connection to vehicle speed. A driving cycle for a vehicle is a representative tool for a speed-time sequenced profile for a specific area, city or junction. It is commonly used to estimate transport air pollutant emissions and to build databases for emission inventories (Saleh *et al.*, 2009). In this paper, real-world driving cycles for passenger cars are investigated using trips performed through a signalised junction and a roundabout. Comparisons will be made to find out which driving cycle produced the least amount of air pollution and what recommendations can be made in regard to the most efficient junction control in terms of emissions under the considered case study.

Literature review

Roundabout junctions operate as one-way circulatory systems where entering traffic (in the UK) has to give way to traffic coming from the right, i.e., the circulating traffic. The construction costs for roundabouts are possibly higher and more land is required than with other junction designs, but maintenance costs are likely to be lower in the long run. Roundabouts have the ability to cope with U-turn manoeuvres that could be disruptive or awkward elsewhere. Accident severity and rates can be substantially lower than at signalised junctions. The biggest issue affecting safety is extreme speed, mainly on entering the roundabout. Generally, fewer delays occur at roundabouts than at signalised junctions during uncongested (off-peak) periods. Nevertheless, they are not compatible with urban traffic control (UTC) systems since they cannot respond to control commands. They can also be inadequate when there are a high number of pedestrians or cyclists. Special requirements for these road users may be necessary, which can also be rather expensive. A roundabout's operating efficiency depends mainly on the drivers' ability to accept gaps safely to join the circulating traffic stream.

The study by Mandavilli *et al.* (2008) investigated roundabouts and their possible impact on reducing vehicular emissions and fuel consumption, which would thus create a positive impact on the environment. Signalised junctions oblige road traffic to slow down or can even stop normal traffic flow. The longer the stationary period, the more emissions are produced and the more fuel is consumed. In the US, roundabouts are becoming increasingly popular for more than just safety motives. Roundabouts are there seen as the most efficient and safe form of junction control, improving the traffic flow as fuel consumption and emissions are cut, because idling time is reduced (Mandavilli *et al.*, 2008).

Mandavilli *et al.* (2008) showed the emissions produced for various junction control methods (i.e. a roundabout or any other form of junction control) where a vehicle has come to a stop in a "before" and "after" comparison. They showed that junction control with a roundabout produced statistically significantly less emissions (about 16-65 per cent less) than that from signalised junctions.

As for signalised junctions, there is no set rule or threshold level governing when to install traffic lights at a junction. Most decisions are based on one or more factors, such as expected level of vehicular and pedestrian flows, traffic speeds (and whether or not traffic lights are the only reasonable control instrument), accident records, or the feasibility of an alternative layout (i.e. roundabout, grade-separated or priority).

Traffic signals are utilised at numerous at-grade junctions, especially in urban areas, to maximise road capacity and safety by separating incompatible traffic movements in time (Salter and Hounsell, 1996, p. 273). This means, for instance, that the major road vehicles, which previously could cross the junction unaffected, now experience a delay as they are required to stop and wait. In contrast to this, the minor road vehicles see an improvement in delays (Salter and Hounsell, 1996, p. 276). Traffic signal have been designed to cope with a wide range of tasks, junction layouts and difficult traffic demands, plus cyclists and pedestrian crossings and public transport vehicles' special needs. Generally, traffic signals have many advantages: costs and land use are frequently lower when compared to other forms of junction control with the same capacity, they offers flexibility, e.g., due to specific strategies; a certain approach or arm could be favoured, and the linking of junctions with UTC offers further benefits to smooth the traffic flow and improve air quality. The main disadvantages are the lack of provision for U-turning manoeuvres (when compared to a roundabout), maintenance costs of the equipment, the increased accident risk for certain types of traffic accidents, and higher delays during low flow conditions (Salter and Hounsell, 1996, p. 278).

Traffic signal control measures can be most effective in small areas, such as individual junctions or a small network of linked junctions. UTC involves timing the sequence of traffic lights to influence the traffic flow.

In most British towns, UTC systems such as TRANSYT or SCOOT, can be found. The TRANSYT technique is a fixed-time system. It models traffic behaviour and determines the best signal setting to minimise congestion. A number of different settings can be used throughout the day to adapt to a regular pattern, e.g., re-occurring patterns: during rush-hour there is a higher traffic volume than during off-peak times, therefore the needs to ease traffic flow for both times are different. The SCOOT system is an adaptive-time system. It monitors the real-time traffic flow with loop detectors in the road and through these, it is able to constantly adapt the sequence timings to the traffic flow and volume.

The Environmental Forecasting for the Effective Control of Traffic (EFFECT) project was one of the pioneering projects that investigated the connection between UTCs and reductions in air pollution. In Maidstone, UTCs were used to create a priority strategy and gating strategy. For the hot spots and main roads this meant a reduction in carbon dioxide (CO_2) levels, but for the side roads it always meant an increase, which was quite often more than the reduction of the hot spots and main roads.

Methodology

A driving cycle for a vehicle is a representative tool for a speed-time sequenced profile for a specific area, city or junction. It is commonly used to estimate transport emissions and to build databases for emission inventories (Saleh *et al.*, 2009). A key drawback of much previous work has been that emission factors for passenger cars are founded on average-speed patterns, which are inadequate in numerous real-world driving conditions as they are based on uniform speed and acceleration patterns. They do not embrace actual driving behaviour and are not suitable for usage by the responsible agencies to control air quality (Saleh *et al.*, 2009).

To collect the data for the driving cycles, the data acquisition system PB was installed in a 2000 BMW 3-Series car that runs on regular unleaded fuel. The test vehicle was driven by its owner through the selected junctions on urban roads. The PB measured acceleration, deceleration, idling and cruising at these two junctions. Data were collected at intervals of 1/10th of seconds. From this, a very accurate speed reading ($\pm$0.1 km/h), acceleration, deceleration, and distance and GPS measurement ($\pm$10 cm in 400 m) were provided (Performance Box (PB), 2012). The readings from the GPS and the PB have been synchronised.

Site selection

The sites were selected based on traffic flows and traffic control measurements on the junction. The selection criteria also included junction location (busy urban junction). The selected sites are located on major commuter routes into the city centre for buses, private vehicles, taxis and delivery vans.

The signalised junction is located at Holy Corner at the junction of Colinton Road, Bruntsfield Place (A702), and Chamberlain Road (see Plate 1).

This junction is busy and most of the time experiences queues of vehicles. When vehicle stops are longer, fuel consumption increases and thus more vehicular pollution is produced. Colinton Road is a single carriageway, with the exception of the approach to the junction. The test vehicle has been driven through the junction approach ten times to collect the data for this analysis without any specific instructions to the driver other than just drive normally according to traffic conditions and regulations.

The Roundabout (Picardy Place Roundabout) is located at the junction of Leith Street (A900), Leith Walk (Picardy Place), and Broughton Street (Plate 2).

A pilot drive was carried out in order to test the procedures and methodology. The time of data collection was decided on taking into consideration traffic flows on the road. Data were collected during periods when the heaviest traffic occurs, namely, normal weekdays (Monday-Thursday) during the evening peak hour (4.00-6.00 p.m.).

These data were then edited and analysed. Graphical representation of the data as well as numerical analyses have been carried out in order to assess emissions at different driving cycles as well as impacts of speed and traffic volume at the traffic junctions. The emissions produced can differ hugely over the duration of a journey and this depends upon the road geometry, the road network and the nature of driving traffic

Plate 1.
Aerial view
of signalised junction

Source: Google Map © Googlemaps 2012

Source: Google Map © Googlemaps 2012

Plate 2.
Street view and aerial view of the roundabout

conditions. Most of the roads were urban single carriageways, with the exception of duelling when approaching the junction. Driving characteristics such as distance, acceleration, times and speed were observed in June 2010 during the school term.

Ideally, data should be collected over a longer period of time to facilitate for daily and seasonal discrepancies. The test vehicle navigated through the traffic without affecting other road users in their behaviour and decision making. It was part of the traffic flow like any other road user, i.e., the car chase technique was used. The car chase technique is representative of real-world driving.

The selected sites, the signalised junction and the roundabout have a few aspects in common. The similarities between the two include the fact that both contain within their vicinity schools, residential areas and supermarkets. Both are also located on major commuter routes into the city centre for buses, taxis, private vehicles and delivery vans.

Defining the four driving modes

The data collected by the PB provided the following information: timeline, velocity and acceleration and deceleration, respectively. This was transferred into an excel spreadsheet. The data were then sorted by acceleration. The negative values represented deceleration. Zero represented no change at all and the positive values represented acceleration. The complication in this was to find a workable definition for idling and cruising.

Technically, idling is at a standstill, so there is no speed reading (no acceleration and no deceleration), but the engine is still running, i.e., emissions are still produced. Idling happens mostly at junctions, when the driver has to wait for his or her turn to negotiate the junction. However, sometimes a driver approaches a junction at a very low speed and then speeds up when it is his or her turn to cross the junction, so there is no standstill of the vehicle because the vehicle is moving very slowly. Cruising is when the car is moving at a relatively constant speed above 5 km/h. For this analysis, there was almost no cruising, since most of the driving activities comprised acceleration, deceleration or idling.

In this work, idling is defined as when the car has a speed between 0 and 3.99 km/h. Cruising is defined as when the car either has no speed change (i.e. acceleration and deceleration equal zero) or when in an interval of one second, the speed change is < 1.6 km/h. The definition for idling was found to be viable.

Survey results

Pollution and emissions can be influenced by many different factors, including driver behaviour, fleet composition, traffic conditions, road geometry, roadside buildings and wind. They reach a maximum at a location where traffic accelerates, such as at junctions. This and further aspects can influence the results. For example, the test driver was aware that he was being monitored and therefore might have changed his natural driving style. Boulter *et al.* (1999) also mentioned that the test vehicle might be untypical of the vehicles in the area and the test driver may be unfamiliar with the area, and these might constitute possible influential factors on the results. However, these two points are not the case for this research as both junctions are close to the former and present home of the test driver, so the areas were known well.

The rationale for choosing the two junctions with different junction control methods is to show the difference in emission rates for each. For this purpose, the two junctions (a signalised junction and a roundabout) during evening peak hour were selected and compared.

The data collected by the PB were divided into three driving modes: idling, accelerating and decelerating. The PB measured speed and acceleration and according to this, the three driving modes were categorised, respectively. It should be noted here that for the purpose of this study, cruising was not very significant since most of the driving in the junction was in the idling, acceleration and deceleration modes. The calculated emission factors for CO_2, and oxides of nitrogen (NO_X), all show the same trend: the faster the vehicle is driven, the fewer emissions are discharged, and vice versa. Figures 1 and 2 show a summary of the level of emission achieved for each junction during the different phases of the driving cycle under examination (acceleration, deceleration and idling).

From the above data we can see that the levels of CO_2 emitted while the vehicle traverses the two junctions is very similar in the idling and acceleration phases. However, there is a slight increase in the amount generated in the deceleration phase of the roundabout driving cycle. This may be due to the fact that there was more time spent in this phase as the driver slows at a steady pace on approach to the junction, hoping to maintain a certain level of speed throughout. It may also be down to the use of different driving methods, whereby the driver uses the engine to slow the vehicle in this scenario, but relies fully on the breaks when approaching the traffic lights, thus reducing significantly the work being carried out by the engine.

Confidence intervals give a representation of the deviations in readings which were achieved throughout the study (the 95 per cent confidence levels are represented by the vertical bars in Figures 1 and 2). There is a relatively wide confidence interval on the deceleration phase, which would lead us to conclude that there were certain situations with much greater or less journey times spent within the deceleration phase than the

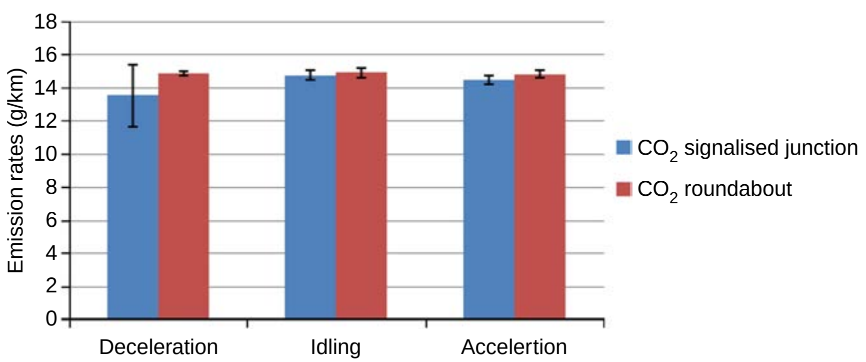

Figure 1.
CO_2 emissions for junctions

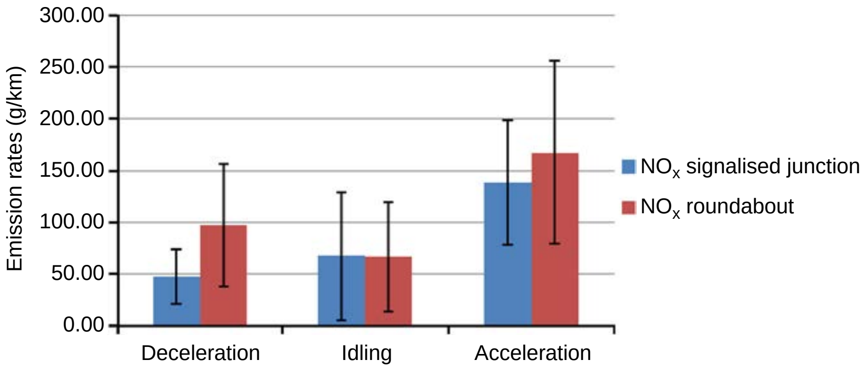

Figure 2.
NO_x emissions for junctions

average suggests. This may be down to the nature of the signalised junction and in certain situations, a red light was presented to the driver and as a result, the driver began to decelerate, thus resulting in a higher percentage of time spent in the deceleration phase and thus an increase in overall emissions attributed to this phase. Likewise, less time may be spent in this phase when a green light is presented and this will result in lower CO_2 emissions for this run.

From these data we can see that there is an increase in the levels of NO_x being produced by the vehicle while operating on the roundabout during acceleration and deceleration when compared to that of the signalised junction. These data are in line with the results seen for the production of the CO_2, for the idling and the deceleration phases. However, the NO_x levels for the deceleration phase are markedly greater in the acceleration phase. The reason for this is that greater amounts of NO_x are produced when the engine is operating in the accelerating mode, as there is a requirement to produce a greater power output through the combustion of greater volumes of fuel. Form the data provided, we can see that there are large variations in the level of confidence observed in these readings. This may be down to the fact that slight changes in the engine's performance result in significant changes in the amount of this emission produced. Due to this fact, slight variations in driving style will result in large variations in the output data.

What is most interesting from all the compiled data is the fact that overall, the emissions achieved through the signalised junction are significantly lower than those through the roundabout. This is slightly contrary to the commonly held beliefs whereby the junction which allows for a freer movement of traffic will in turn reduce emissions. Due to this fact it may be deemed prudent to reassess these findings by carrying out more extensive investigations of these junctions at various times of the day to attempt to further verify these findings.

Summary and conclusions

The data collected rely on genuine driving behaviour and the results gained from this are therefore representative of reality. The literature gap can be noticed here. Most research is based on mean speeds and uniform acceleration patterns. Previous studies have not considered real-driving behaviour and are for that reason often unsuitable for use by responsible agencies to manage air quality. This paper describes a method for measuring exhaust emissions for petrol vehicles. The method was applied to two junctions with different control systems. The results showed that acceleration brings the highest emission of NO_x pollutant independently of the junction type. The data provided cannot be used to estimate emission rates at other junctions without additional data and verification. Each junction has different geometrical properties and traffic composition and should be considered separately. All analyses, graphs and figures are based on on-road measurements data. The findings may be helpful when designing traffic management strategies or traffic signal coordination. Traffic light junctions can be designed so that the delay and amount of pollution from idling vehicles will be minimised. Improper signal phasing and inadequate signal timing can contribute to increases in emissions.

The need to reduce and manage the emissions of pollutants from vehicles is becoming increasingly important. Good traffic management is one of the tools that are in use to manage emissions from vehicles. However, some recommendations for further research can be made here, namely, that the sample of junctions studied should be increased and that different times of the day, including the morning peak hours, should be included. In addition, looking at the different routes through the junction, and recording the state of the signals through them would be very useful for the analysis.

References

Bonsall, P., Shires, J., Link, H. and Becker, A. (2007), "Complex congestion charging – an assessment of motorists' comprehension and the impact on their driving behaviour", Presented at European Transport Conference, Noordwijkerhout, The Netherlands, 17-19 October.

Boulter, P.G., Latham, S. and Ainge, M. (1999), "Driving cycles for measuring passenger car emissions on roads with traffic calming measures", *Science of the Total Environment*, Vol. 235 Nos 1-3, pp. 77-89.

de Palma, A., Lindsey, R. and Proost, S. (2007), "Investment and the use of tax and toll revenues in the transport sector: the research agenda", *Research in Transportation Economics*, Vol. 19, pp. 1-26.

Jara-Díaz, S.R. and Gschwender, A. (2005), "Making pricing work in public transport provision", in Button, K. and Hensher, D. (Eds), *Handbook of Transport Strategy, Policy and Institutions*, Pergamon Press, Oxford, pp. 447-459.

Mandavilli, S., Rys, M.J. and Russell, E.R. (2008), "Environmental impact of modern roundabouts", *International Journal of Industrial Ergonomics*, Vol. 38 No. 2, pp. 135-142.

Muñoz, J.C. and Ortúzar, J.D. (2008), "Transantiago: the fall and rise of a radical public transport intervention", in Saleh, W. and Sammer, G. (Eds), *Travel Demand Management and Road User Pricing: Success, Failure and Feasibility*, Ashgate Publishing, Aldershot, pp. 151-171.

Performance Box (PB) (2012), available at: www.performancebox.co.uk/performance_meter.html

Saleh, W. and Sammer, G. (Eds) (2009), *Travel Demand Management and Road User Pricing: Success, Failure and Feasibility*, Ashgate Publishing, Aldershot, pp. 73-89.

Saleh, W., Kumar, R., Kirby, H. and Kumar, P. (2009), "Real world driving cycle for motorcycles in Edinburgh", *Transportation Research Part D: Transport and Environment*, Vol. 14 No. 5, pp. 326-333.

Salter, R.J. and Hounsell, N.B. (1996), *Highway Traffic Analysis and Design*, 3rd ed., Palgrave Macmillan, Hampshire.

Stewart, K. (2009), "Modelling impacts of tolling systems with multiple user classes", in Saleh, W. and Sammer, G. (Eds), *Travel Demand Management and Road User Pricing: Success, Failure and Feasibility*, Ashgate Publishing, Aldershot, pp. 73-87.

About the authors

Wafaa Saleh is a Reader in Transportation at the School and teaches a number of modules, including transport modelling, traffic engineering, transport and the environment and transport telematics. Saleh has gained wide experience in assessing impacts of transport schemes, sustainability and traffic demand management. Wafaa Saleh is the corresponding author and can be contacted at: w.saleh@napier.ac.uk

Alistair Lawson teaches software engineering and applications development, and has a wide range of research and knowledge transfer experience in instrumentation, data collection, data analysis, computer modelling, visualisation and simulation for a range of domains, including mobility, robotics, and transport.