Air pollution: outdoor air quality and health

Draft Evidence review 2 on: Traffic management and enforcement, and financial incentives and disincentives

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1 Introduction

This evidence review is the second of a series conducted to support the development of guideline on road transport related air pollution. The scope for the guideline is available here.

This review addresses Topic 2: Traffic management and enforcement, and financial incentives and disincentives, as set out in the review protocols. The following questions were included in this topic:

Review question 5: Are traffic management systems and signal coordination interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Review question 6: Are zoning interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Review question 7: Are parking restrictions and charges effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Review question 8: Are vehicle 'idling' restrictions and charges, including waiting and loading restrictions, effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

2 Methods

This review was conducted according to the methods set out in Developing NICE guidelines: the manual (NICE 2014).

2.1 Review questions

Review question 5: Are traffic management systems and signal coordination interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Review question 6: Are zoning interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

2.2 Searching, screening, data extraction and quality assessment

See Review 1, Section 2.2 for details.

3 Results

3.1 Flow of literature through the review

23 studies were included in the current evidence review. The flow of literature and a brief summary of reasons for exclusion at full text for all the reviews is included in Review 1, Section 3.

3.2 Characteristics of the included studies

Full details of the included studies are given in the evidence tables in Appendix 1. Table 3.2.1 (RQ5) and Table 3.2.2 (RQ6) below shows in which country the studies were conducted, and provides a brief summary of the interventions and settings investigated in these studies.

3.2.1 Review question 5: Are traffic management systems and signal coordination interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

First author, year	Design	Country	Setting	Intervention	QA rating
Vehicle bans or restrictions					
Casale, 2009	Controlled study	Italy	City centre	Vehicle bans or restrictions	-
Lee, 2005	Controlled before and after study	Republic of Korea	City wide	Vehicle bans or restrictions	-
Levy, 2006	Before and after study	USA	City centre	Vehicle bans or restrictions	+
Levy, 2013	Before and after study	Israel	City wide	Vehicle bans or restrictions	-
Quiros, 2013	Before and after study	USA	Major freeway in a city	Vehicle bans or restrictions	+
Traffic calming measures					
Layfield, 2003	Controlled before and after study	UK	Residential area	traffic calming	−
Owen	Controlled before and after study	UK	Residential area	Traffic calming	−
Ahn, 2009	Modelling study	US	General urban	traffic calming	−
Boulter, 2001	Modelling study	UK	General urban	traffic calming	−
Ghafghazi, 2014	Modelling study	Canada	General urban	traffic calming	+

First author, year	Design	Country	Setting	Intervention	QA rating
Ghafghazi, 2015	Modelling study	Canada	General urban	traffic calming	+

3.2.2 Review question 6: Are zoning interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Effectiveness

First author, year	Design	Country	Setting	Intervention	QA rating
Congestion charge schemes					
Atkinson, 2009	Controlled before and after study	UK	City wide	Congestion charge scheme	−
Kelly, 2011	Controlled before and after	UK	City wide	Congestion charge scheme	−
Invernizzi, 2011	Controlled study	Italy	City centre	Congestion charge scheme / vehicle ban / Pedestrian zone	−
Low emission zones					
Boogaard, 2012	Controlled before and after study	Netherlands	5 cities	Low emission zone	+
Jones, 2012	Controlled before and after study	UK	City wide	Low emission zone	−
Morfeld, 2014	Controlled before and after study	Germany	17 cities	Low emission zone	+
Panteliadis, 2014	Controlled before and after study	Netherlands	City centre	Low emission zone	+
Qadir, 2013	Before and after study	Germany	City centre	Low emission zone	−
Fensterer, 2014	Controlled before and after study	Germany	City centre	Low emission zone	+
Speed management zones					
Dijkema, 2009	Controlled before and after study	Netherlands	Urban highway	Speed management zone	+
Keuken, 2010	Before and after study	Netherlands	Urban Motorway	Speed management zone	−

Cost Effectiveness

First author, year	Design	Country	Setting	Population	Intervention / comparator	Outcomes	QA rating
Congestion charging							
Elliasson 2006	[2]CBA	Sweden	Stockholm	General	Congestion Charge	Social value cost and benefits	+
Rotaris et al, 2010	CBA	Italy	Milan	General	Congestion Charge / Urban road pricing scheme	Social value cost and benefits	+

3.3 Study Findings

3.3.1 Review question 5: Are traffic management systems and signal coordination interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Ten studies were included in the review. Overall, the quality of the studies was moderate to poor with 6 studies graded [−] and 4 studies graded [+] (see Table 3.2.1).

Studies were grouped by the intervention the study assessed:

- Vehicle bans or restrictions (5 studies)
- Traffic calming measures (5 studies)

Vehicle bans or restrictions

Casale et al (2009[5], −) examined the effect of 'ecological days' on particulate levels in Turin. 'Ecological days' (typically Sundays) were days when vehicle restrictions were in force from 10:00 to 19:00. The ZTL (Zona a Traffico Limitato) extended over 1.03km^2 and included 12,500 inhabitants. Restrictions applied to diesel and gasoline (petrol) vehicles, with exceptions for public transport, emergency and 'operative'

[2] Cost benefit analysis

vehicles. Decrease in traffic was around 18,000 vehicles per day (around 30-40% of daily traffic volume).

188 airborne samples were collected from 5 outdoor sites: 2 inside the ZTL; the others on the margins where vehicles were not restricted. Samples were collected from Thursday to Tuesday over 7 weeks between April 2004 and February 2005. For each day, PM (particulate matter) means and standard deviation were calculated of 10 measurements taken between 19:00 and 20:00 (at the end of the traffic restriction period). Weeks 1-5 (April, May, June, September and November 2004) coincided with traffic limitations, while there were no limitations during weeks 6 and 7 (July 2004 and February 2005).

There were no generalized, significant improvements in PM_{10} from the traffic-limitation on Sundays during ecological weeks with the exception of week 2 (May 2004) and 5 (Nov 2004). Summary statistics are not provided.

The authors note that PM levels in cities do not simply reflect road closures and local traffic but is associated with mid and long range atmospheric transport. They suggest that an enlargement of the restricted area would be more useful than more frequent or severe traffic limitations.

Lee et al (2005[16], –) looked at the impact on urban air quality of restrictions on passenger vehicles imposed in Busan (South Korea) during the Asian Games in 2002. Busan is the second largest city in South Korea, with a population of 3.8 million.

The intervention consisted of a ban on passenger vehicles based on the last number in the vehicle title number. Vehicles with an odd final number were allowed to operate on odd numbered days, and even on even days only. Changes in vehicle numbers were calculated by counting the number of passenger vehicles passing through 6 sites during the 16 days of operation compared to measurements made immediately before and after the games. Vehicles were counted during three periods: morning rush hour (07:30-09:30), day hour (12:00-14:00) and afternoon rush hour (17:30-19:30) for alternate 10 minute periods (10 min count period followed by 10 min break). Vehicle speeds were recorded on major roads using speed measurement guns.

Air pollution levels were also measured in Ulsan, a port city 30 km from Busan with similar meteorological conditions.

The concentrations measured on rainy days with precipitation above 3.5 mm per day were excluded to evaluate the net effects of the alternate operation of passenger vehicles.

The analysis shows that average levels of nitrogen dioxide (NO_2) and PM_{10} increased significantly (47.8% increase (standard deviation 25.1%) for NO_2, 53.8% increase (standard deviation 14.8%) for PM_{10}) during the period of the intervention compared to those in the period before. Air pollution levels also increased in Ulsan during the AG compared to before, however, the degree of increase was less than that in Busan (increase of 17.2% for NO_2 and 36.3% for PM_{10}).

The authors note that the main cause of the increases in measured pollutants was strongly related to a change of meteorological conditions; reduction in average daily ambient ventilation index, maximum mixing height, and wind velocity during the alternate operation period.

Levy et al (2006[18]+) examined the impact of road closures on air quality within a city during the 2004 Democratic National Convention (DNC) in Boston.

The DNC was held from 26-29 July 2004. Approximately 40 miles of road were closed for some period of time (generally from 4pm to midnight) around the city during that period, including a major highway and multiple surface and feeder roads.

Sampling sites were chosen to represent hypothesised impacts from the Democratic National Convention on changes in traffic volume. Four categories of sites were identified:

- Sites with hypothesized concentration decreases: Proximate to a closed-down road or highway but not proximate to an identified alternate route.
- Sites with hypothesized concentration increases: Proximate to an identified alternate route but not a closed down road.
- Sites with no change hypothesized: Geographically isolated from the road closures or alternate routes.

- Site with unclear impacts a priori: Site with multiple countervailing influences. For example, measurements taken near a highway without road closures could have concentration decreases if overall traffic were reduced, but could have concentration increases if these roads were used as alternate routes to downtown Boston.

NO_2 concentrations were measured at 40 sampling sites with passive filter badges. Badges were swapped weekly at each sampling site, providing samples corresponding to the week before, during and after the Democratic National Convention. Duplicate samples and field blanks were used at 10% of sites, selected by random number generation.

Table 1. NO_2 concentrations (ppb) during DNC and non-DNC weeks, stratified by a priori traffic classification

Category	Median concentration and range, DNC	Median concentration and range, non-DNC*	Median concentration ratio (DNC/non-DNC) and range
1 – Hypothesized decrease (n = 7)	**7 (3-16)**	**10 (6-20)**	**0.58 (0.27-2.0)**
2 – Hypothesized increase (n = 9)	**14 (7-19)**	**12 (3-15)**	**1.15 (0.51-1.88)**
3 – Hypothesized no change (n = 11)	11 (6-19)	12 (7-17)	0.88 (0.82-1.23)
4 – Unclear impacts a priori (n = 7)	7 (6-9)	12 (4-18)	0.70 (0.38-2.4)

*Average of concentration the week before and after the Democratic National Convention

Those sites for which traffic was anticipated to decrease had a median concentration ratio of 0.58 ($p=0.10$), versus median ratios of 0.88 ($p=0.79$) for "no change" sites and 1.15 ($p=0.13$) for sites where traffic was expected to increase.

The authors note that as the analysis was for a relatively small number of days from the week of the Democratic National Convention and the weeks before and after, general meteorological trends corresponding to the sampling period might influence the findings. There were no obvious patterns from evaluation of local data, but significant rainfall immediately prior to the DNC could have influenced concentration trends in following days. They note that wind speeds and ozone concentrations were both lower during the Democratic National Convention, factors that would tend to increase near-source traffic contribution to NO_2. This might result in the estimated impact being an underestimate of the true impact of road closures.

Sites were classified a priori and there was no empirical traffic count data to confirm or clarify the impact of closures.

Levy et al (2013[17]–) used the dramatic short term changes associated with the Jewish holiday of Day of Atonement (DA) in Israel to examine changes in emissions and air quality.

On the National Jewish holiday of Day of Atonement (DA) there is the cessation of nearly all vehicular (with the exception of on-duty emergency vehicles), commercial, industrial and recreational activities for approximately a 25 hour period.

Two sites in Tel Aviv with a population of approximately 1.2 million were examined:

- Tel Aviv central bus station (CBS) - a heavily polluted urban core with busy traffic and intensive commercial activities.
- Urban Background site - sited in a residential area of Tel Aviv (UBG)
- A third site in the town of Modi'in, 27 km east of Tel Aviv with a population of approximately 40,000 residents (DWN)

Levels of NO_2 during a 9 day period centring on the Day of Atonement were compared over a 15 year period (1998-2012). The daily maximum recorded levels of NO_2 reduced by 83% at the CBS site (from 41.2ppbv to 7.0ppbv), 77% (from 25.1 to 5.8ppbv) at DWN and 62% (from 27.4 to 10.5ppbv) at UBG.

The authors note that a variety of day-to-day meteorological factors may influence air quality and these vary between years making it difficult to isolate the net effect of the Day of Atonement on ambient concentrations with statistical significance, given that the Day of Atonement occurs only once a year and records only exist from the late 1990's. Emission reductions also occur from reductions in industrial, recreational and commercial activity. To examine the effect of meteorological factors they also carried out an in-depth study of a single year (2001), selected because of persistent meteorological conditions and emission patterns on the days preceding the Day of Atonement. 30 minute averages for meteorological parameters and pollutant concentrations were examined. At the CBS site NO_2 levels dropped from a peak of

45ppbv (parts per billion by volume) by 80% to as low as 9ppbv. At the other sites, levels dropped from around 20ppbv to less than 5ppbv for most of the day, with peaks at 13 and 11ppvb at UBG and DWN respectively (a reduction of 50-75%). A 37% reduction in PM_{10} from a daily maximum of over 150µg/m3 to 95µg/m3 was also seen at CBS. Measurements of PM_{10} at other sites were either not available or were incomplete.

Quiros et al (2013[22], +) evaluated the effect of a major road closure on air pollutant levels. In 2011, a section of a major freeway in Los Angeles (the I-405) was closed for 36 hours from midnight Friday until midday on the Sunday (15-17 July) as part of an improvement project. The I-405 is a major freeway (10 lanes) carrying approximately 380,000 vehicles/day. During closure, northbound lanes were completely closed for 16km and southbound lanes for 8km and was then restricted to one lane. A parallel road, Sepulveda, remained open.

The closure resulted in reduced traffic flow on the I-405 on Saturday 16th July was reduced by 90%, and on Sunday 17th by 40%. Traffic flow on Sepulveda was reduced by 20% from non-closure conditions, indicating an absolute traffic flow reduction in the transit corridor.

Pollutants were measured at two fixed sites, one upwind and one downwind of the road. Measurements of particle number concentration (PNC), $PM_{2.5}$ and black carbon (BC) were conducted between 10:00 and 20:00 for 3 consecutive Friday-Sunday periods, pre, during and post-closure. Fixed-site measurements were conducted upwind and downwind of the freeway for all campaign days.

Results are presented in the form of charts and it is not possible to extract further data. Summary information is presented in the text and reported here. Upwind median PNCs ranged from 2000 – 6000 particles cm^{-3} with no substantial trends with respect to day of the week, indicating no direct influence from the freeway emissions.

Downwind PNCs ranged between 5000 and 11000 particles cm^{-3} during non-closure days and around 4000 during closure. PNCs were 31%(Friday), 83% (Saturday) and 63% (Sunday) lower during closure conditions.

Upwind $PM_{2.5}$ for the closure period was 55% (Friday), 39% (Saturday), and 49% (Sunday) lower for the closure, compared with the post-closure period.

Downwind BC was 25% (Friday), 62% (Saturday) and 65% (Sunday) lower for the closure, compared with the post-closure period. There was a decrease in PNCs, $PM_{2.5}$ and BC concentrations after the intervention was applied.

Closure of the I-405 led to basin-wide freeway traffic reductions. These extended as far north as Fresno (380km) and as far south as Oceanside (160km). Ambient monitoring of $PM_{2.5}$ indicated decreases of between 18 and 36%, indicating that the closure led to regional traffic reduction contributing to an overall average 25% reduction in $PM_{2.5}$ observed in multiple locations.

Evidence statement 5.1: variable effect of traffic restrictions on air pollution

There was moderate evidence from 5 studies (3 (–)from Italy[5], Korea[16] and Israel[17]; 2(+) from USA[18, 22]) to suggest that restrictions or bans have little effect on particulate and nitrogen oxides unless they restrict the volume of traffic substantially. Bans varied in scale. They included small scale closures, weekend exclusions[5], alternate number restrictions[16], extensive urban road closures[18], closure of a single extremely large road[22] and a cessation of nearly all vehicular, commercial and recreational activity for a short period[17].

Outcomes indicate that small scale or partial restrictions[5, 16] were unable to demonstrate a positive effect and in 1 case[16], restrictions were associated with a significant increase in air pollutants (mean NO_2 level increased by 47.8%, PM_{10} by 53.8%).

Larger scale restrictions on traffic produced measurable reductions in particulates and nitrogen oxides. Where the restrictions were partial[18] local positive changes in NO_2 air quality mirrored changes predicted using expected changes in traffic flow and volume (median concentration ratio before and after of 0.58 (p=0.10), versus median ratios of 0.88 (p=0.79) for "no change" sites and 1.15 (p=0.13) for sites where traffic was expected to increase). Substantial changes (temporary closure of a major freeway, I-405) resulting in regional traffic reduction showed reductions in traffic pollutants contributing to an overall average 25% reduction in $PM_{2.5}$ observed in multiple locations[22]. Short term cessation of vehicular, recreational and commercial activity[17] led to reductions in peak levels of NO_2 of between 62% and 83% at 3 sites (reductions in minimum levels of between 83% and 93%) and a 37% reduction in PM_{10}.

Applicability. The studies are from Italy, Korea, Israel and the USA. Interventions include city based restrictions, short term changes based on specific events or factors and state-wide cessation of activities. The applicability of these interventions varies considerably, as does the ability of local agencies to implement them. However, the evidence in terms of the air quality response to changes of different magnitudes, is applicable to England. Hence this evidence is partially applicable.

5. Casale et al. 2009 (−)

16. Lee et al. 2005 (−)

17. Levy et al. 2013 (−)

18. Levy et al. 2006 (+)

22. Quiros et al. 2013 (+)

Traffic calming measures – evaluation of schemes

The Methleys Home Zone in Leeds is one of nine home zone schemes in a pilot programme set up by the Department for Transport (**Layfield et al, 2003[15],** –). The pilot aimed to evaluate the potential benefits, particularly in regard to shared road space, of a wide range of home zones in different parts of England and Wales.

The Methleys contains about 300 terraced properties in a grid pattern housing with little or no garden space. About 30% of households have children under 17 years of age. Car ownership is relatively low (about 60% of households) and most parking is on-street.

Key measures implemented included:

- ‘Gateway’ treatments with road narrowing and home zone signing at the principal entry points to the home zone;
- New shared road surface, incorporating coloured block paving and extensive planting;
- Traffic calming on key streets to manage speeds in these areas.

Shared surfaces were raised to footway level and accessed by short ramps. Vehicles have to negotiate staggered planting areas designed to reduce the forward ‘free view’. Vehicles are restricted to single lane working near the planted areas.

NO_2 measurements were carried out using diffusion tubes mounted around 2.5m from the ground the kerbside at four sites where people might be expected to be exposed to air pollution. A car park of a council building was used as a control site. Diffusion tubes were exposed for two weeks over a three month period before (31 May 2000 – 7 Nov 2000) and three months after (29 May 2002 – 4 Nov 2002). Both before and after periods show seasonal variation with factors such as weather conditions affecting concentrations. Sampling tubes from site 1 were continually stolen during the ‘before’ survey so monitoring at that site was discontinued from 21 September 2001.

Mean NO_2 concentrations for each two week period before and after the installation of the Home Zone were all below the annual mean Air Quality Standard of 40μg/m^3. Changes between the before and after period at all sites are shown below.

Table 2. Mean NO_2 concentrations at monitoring sites, Methleys

Monitoring site	Before	After	μg m^3	%
1 Methley Drive South	11.78	13.40	1.62	+14
2 Methley Drive North	16.32	13.13	-3.19	-20
3 Blake Grove East	18.58	15.85	-2.73	-15
4 Blake Grove West	18.15	16.03	-2.12	-12
5 (Urban background control site)	14.43	13.62	-0.81	-6

The control site showed a decrease in NO_2 concentration of 6%, whereas 3 kerbside sites showed a decrease in concentration ranging 12% to 20%. Site 1 showed an increase of 14%. None of these changes, however, were statistically significant. The authors note that the loss of data from the 'before' survey due to the theft of tubes may have partially influenced this result (levels tended to be higher in the later part of the survey than the earlier so loss of the later part may have artificially reduced the mean concentration in the 'before' survey for site 1).

A second [−] quality paper examines the impact on air quality of 6 20mph zones in North West of England (**Owen 2005**[24]). Each of the zones is approximately 0.5x0.5 km. Traffic signs and humps were used to reduce speeds to 20mph.

At 2 sites (Sefton and Warrington), NO_2 diffusion tubes were used for consecutive 1-month periods for 5 months before implementation of the zone and for 12 months after. For the other 4 sites (Darwen, Oldham, Salford and Trafford), single monthly averages were measured before implementation and at 3 months and 12 months after implementation. Two post implementation periods were used to allow for traffic adjustment following implementation. Three NO_2 diffusion tubes were used at each site (3 sites per zone plus one control) and for each monitoring period. Mean values before and after implementation were calculated.

Concentrations of NO_2 measured at the Sefton sites decreased after implementation of the 20mph zone at all sites including the control site. However, the decreases were relatively small, between 4% (47.2µg/m3 – 45.1µg/m3) and 13% (44.4µg/m3 – 38.7µg/m3), and within the range of uncertainty for the measurements of this pollutant using diffusion tubes (F25%). Levels at Warrington increased at all 4 sites (including the control) by between 1% (42.3µg/m3 – 42.7µg/m3) and 10% (42.7µg/m3 – 46.9µg/m3). At the 4 locations where single monthly averages were measured NO2 levels generally followed similar patterns to the concentrations recorded at the control sites outside the zone. The changes observed between before and after implementation of the 20mph zones were generally within the error of margin of the measurement techniques used and therefore not significant.

Evidence statement 5.2. No effect seen from area wide traffic calming scheme

There is weak evidence from 2 controlled before and after studies from the UK[15, 24] (both [−] quality) showing no impact of the implementation of a home zone scheme (consisting of traffic calming measures, gateway treatments, shared road surfaces and measures to reduce speed) on NO_2 levels. One study[15] found no significant impact on NO_2 concentrations, with decreases at the control site and at 3 of four implementation sites. The reductions at these sites were slightly greater than those at the control (12-20%, between -2.12μg/m^3 to -3.19μg/m^3, compared with 6%, -0.81μg/m^3), with an increase of 1.62μg/m^3 at the 4th site (this may have been influenced by the loss of data from part of the 'before' survey at that site). None of the changes were statistically significant. The other study[24] found small decreases (between 4% (47.2μg/m^3 – 45.1μg/m^3) and 13% (44.4μg/m^3 – 38.7μg/m^3)) at one site and increases of between 1% (42.3μg/m^3 – 42.7μg/m^3) and 10% (42.7μg/m^3 – 46.9μg/m^3) at the second. Sites where single monthly averages were taken generally followed the changes seen outside the zone. Changes were generally within the margin of error of the measurement techniques used.

Applicability: the studies were carried out in the UK and so are applicable.

15 Layfield 2013 (−)

24 Owen 2005 (−)

Traffic calming – modelling studies

Ghafghazi (2014[9], +) used a microscopic traffic simulation and emission modelling system to quantify the effect of different types of traffic calming measures on vehicle emissions. The authors aimed to examine the effects on traffic volumes, speeds and emissions.

The study area is within a neighbourhood covering 8.1km^2 in Montreal ('The Plateau'). It is a dense neighbourhood with large volumes of through traffic. The study area is a small sub-area within the Plateau and is a residential area bounded by four main arterial roads.

Eight traffic calming scenarios were used. These were:

- Scenarios 1 -3: 17 speed bumps on a major residential street. Each scenario entailed speed bumps on a different street.
- Scenario 4: network wide speed limit of 30k/h

- Scenario 5: 17 speed bumps on each of four streets. This in essence combines 1-3, together with an additional street
- Scenario 6: 17 speed humps on all 4 streets treated in scenario 5
- Scenario 7: 17 speed humps on all 4 streets treated in scenario 5 plus network wide speed limit of 30 k/h (scenarios 6+4)
- Scenario 8: 17 speed bumps on all 4 streets plus network wide 30k/h speed limit (scenarios 5+4)

In these scenarios, speed bumps (scenarios 1-3, 5 and 8) were raised areas in the roadway pavement surface less than 0.3m in width, crossed at speeds of 5-10k/h. Speed humps (scenarios 6 and 7) were 3-4m in width, crossed at speeds of 25-30m/h. The network speed limit of 30k/h applied to every residential streets which included most streets in the area other than major arteries.

In general, total emissions of NOx are higher compared to the base case. Emission rates are higher, indicating increased emissions from changes in speed. Emission rate increases are smaller in the scenarios where only one corridor is traffic calmed (scenarios 1-3). Both speed bumps and speed humps lead to higher emissions when combined with a lower speed limit. Average increases for isolated traffic calming measures across the network were 1.5% and 2.2% for area wide schemes (significance not reported).

Table 3. Emission of pollutants with various traffic calming scenarios

	NOx (Kg)	**VKT**	**NOx (g/VKT)**
Base case	3.57	9751	0.336
Scenario 1	3.60	9690	0.372
Scenario 2	3.62	9744	0.372
Scenario 3	3.61	9739	0.371
Scenario 4	3.53	9738	0.362
Scenario 5	3.78	9775	0.387
Scenario 6	3.62	9733	0.372
Scenario 7	3.53	9683	0.364
Scenario 8	3.74	9691	0.386

Note: the paper reports base case emissions of NOx as 3.57 (given in the table above). Using the data on VKT and NOx g/VKT gives a figure of 3.28kg, lower than total emissions from any of the scenarios considered.

Total distance travelled decreases but emission rate of NOx increases due to changes in driving speeds and changes in speed. Area wide calming increases emissions on the treated road and also worsens emissions across the network.

Speed bumps (that cause a greater slowing) increase emissions more than speed humps, particularly on the treated sections.

Ghafghazi (2015[10], +) expands on the earlier paper (Ghafghazi 2014[9]) to include dispersion modelling using the Danish Operational Street Pollution Model[3]. This required inputs for street configuration, meteorological data, background concentrations, emission factors, and traffic data. Dispersion modelling was examined for 31 days in October 2011 using data from an airport meteorological station 10 km from the study area. In this paper the 8 scenarios are replaced with 7; the imposition of a speed limit alone is not considered. NOx concentrations were calculated for each of 6 links in each corridor for the base-case and each of the traffic calmed scenarios.

Traffic calming using speed bumps lead to higher NO_2 concentrations than speed humps. The largest increase in NO_2 compared to the base-case scenario was 9.9%. Under scenarios 5 and 6 (where there were area wide speed humps) 9 out of 36 segments saw a fall in NO_2 concentrations (less than 2%). As changes in drive cycles with humps were not as substantial as those with speed bumps the resulting increase in emissions is not large enough to offset the reduction in traffic volumes on the corridors with changes.

The authors note that traffic calming measures have a smaller effect on NO_2 concentrations than on NOx emissions. Average NO_2 levels increased by between 0.1% and 10% with respect to the base-case scenario while NOx emissions varied by between 5% and 160%. Speed bumps (resulting in higher speed reductions) produced higher increases than speed humps.

Ahn (2009, −) used GPS technology to provide information about second-by-second in-field driver behaviour. This is coupled with microscopic fuel consumption and emission models to capture energy and emission impacts of the changes. The study examined the energy and environmental effects of traffic calming measures on three streets. On two (31st Street and Broadview Drive), data were collected before and after the installation of traffic calming measures and the other (Key Boulevard) provided a comparison between uncontrolled intersections and various traffic calming

[3] http://envs.au.dk/en/knowledge/air/models/ospm/ospm-description/

measures. Key Boulevard and 31st Street are in Arlington, Broadview Drive in Ashburn. All are in Northern Virginia.

Four types of traffic calming measures were included. These were:

- Traffic circles: a raised island 5-8m in diameter
- Speed humps: a raised area 7 – 10 cm high and 3.6 – 4.2 long extending across the roadway pavement surface
- Speed lumps: similar to speed humps but leave gaps to allow large wheel based vehicles to travel through unimpeded
- Speed bumps: 12-15 cm high and 30 cm long.

Measures on the three roads were as follows:

- Key Boulevard: 1.2 km with three uncontrolled intersections, one four-way stop controlled intersection, four traffic circles and three intersections with three speed humps. Speed limit is 40km/h
- 31st Street: 0.7km with four local accessible side streets with five speed lumps. Speed limit is 40km/h
- Broadview Drive: 160m with two speed bumps. Speed limit is 25km/h.

A VT-Micro model was used to estimate fuel consumption and emission rates and to predict the effects on energy and air quality associated with the different traffic calming measures. The model used three vehicle types representing a normal vehicle type, a Light Duty vehicle and a high emitter.

Measurements on Key Boulevard showed the average intersection speed for traffic circles was 28km/h and for speed humps was 27km/h. The modelling demonstrated increases in fuel consumption and emissions of NOx compared to the base case with no junction controls. NO_x emissions were 264% of base-case for junctions with stop controls, 110% for speed humps and 56% for traffic circles (absolute numbers not given).

Emissions of NOx increase in the two streets after installation of traffic calming measures for the normal vehicle (24.3-48.2 g/100m for speed lumps, 16.6-19.8g/100m for speed bumps) and light duty vehicle (8.3-9.3g/100m for speed lumps, 5-5.3g/100m for speed bumps). Emissions of NOx from the high emitter vehicle increased at one site (199.6-205.7g/100m, speed lumps) but decreased at the second site 132.3-130.0g/100m, speed bumps).

Boulter (2001)[4] [−] investigated the effects of different traffic calming measures on the exhaust emissions of passenger cars by modelling emissions from vehicles passing physical traffic calming features. The 9 types of traffic calming measures were:

- A: 75mm-high flat top road humps
- B:80mm-high round top road humps
- C:1.7m-wide speed cushion
- D: Combined pinch point and speed cushion
- E: 100mm-high raised junction
- F: Chicane
- G: Build-out
- H: Mini-roundabout
- I: 1.9m-wide speed cushion

Speed estimates were produced from measurements taken before and after the implementation of the first five measures in the list above. The authors were unable to identify sites where the final four measures (chicanes, a build out, a mini-roundabout and a 1.9m-wide speed cushion) were to be installed during the study time frame such that before and after measurements could be carried out. They therefore used speed measurements at sites where these measures had already been introduced.

The impacts on emissions were determined using driving cycles and a chassis dynamometer. Fifteen vehicles were used, 12 petrol and 3 diesel. The petrol vehicles were divided into 6 classes – small (<1.4l), medium (1.4-1.7l) and large (>1.7l), each with and without catalyst. The three diesel cars were medium sized Euro 1 compliant.

The overall effect of traffic calming measures was an increase in emissions of pollutants, particularly for diesel cars (see table below). Emissions of NO_x increased by 1% for non-catalyst petrol vehicles, by 8% for petrol vehicles with catalysts and by

28% for diesel vehicles. Emission of particulates were only available for diesel vehicles (30%). Authors report that both results for diesel vehicles were significant at the 95% level (data not given).

Table 4. Percentage change in emission of NOx by class of vehicle

Traffic calming measure	Petrol non-catalyst cars						Petrol catalyst cars						Diesel cars		
	Small		Medium		Large		Small		Medium		Large		1	2	3
A	+27	+7	+22	+43	+13	+13	0	+94	+80	+69	+9	+159	+31	+41	+44
B	+10	+2	+16	+22	+6	-14	+8	-14	+37	+48	+17	0	+24	+53	+45
C	+19	+19	+22	+23	+15	+18	+63		+27	+3	+25	+138	+22	+28	+30
D	+3	+1	+1	+6	+11	+8	+22	-43	+19	+68	+8	+58	+16	+25	+25
E	+15	-4	+7	+2	-1	-15	-23	-38	-37	+35	-57	-21	+39	+41	+37
F	-16	-30	-21	-22	-6	-16	+4	-25	-70	+57	-10	-27	+17	+27	+17
G	+10	-17	-20	-1	-8	-16	-7	-34	+5	-9	+20	-7	+13	+26	+21
H	+10	-3	+13	+16	-4	-3	+6	-16	+84	-16	-12	+42	+26	+38	+52
I	-22	-31	-21	-3	-22	-20	-38	-2	-52	+44	-36	+7	+1	+30	+30

Note: each result represents the change in emissions for a vehicle from the class indicated before and after traffic calming. The individual cars are not all the same vehicle but are from the appropriate class of vehicle.

The impact of a given scheme on NOx emissions varied with the vehicle type. The authors suggest that for petrol cars schemes G (build-out) and I (1.9m-wide speed cushions) tended to be have a relatively low impact, whereas schemes A (flat-top hump) and B (round-top hump) tended to have a high overall impact. The relative impacts of the remaining schemes tended to vary. For diesel cars, schemes D (pinch point/speed cushion) and scheme G (build-out) tended to have a lower impact than the other schemes, and scheme A (flat-top hump) tended to have a high impact. There was a general but weak trend for the impacts of the traffic calming measures incorporating vertical deflections (i.e. road humps and raised junction) to be higher than those incorporating horizontal deflections or a requirement to give way. This may be related to the fact that in the second instance the measures were studied in isolation, whereas the vertical deflections were repeated at fairly regular intervals.

The authors note that it would have been difficult to detect an impact of each traffic calming measure on ambient air pollution. To examine the potential impact on air quality, minimum and maximum traffic-weighted changes in emissions from the study were used in the DMRB dispersion model to predict changes to air quality. They note that traffic related pollutants (including NO2) at 10m and beyond the centre of the road were well below the level set in the National Air Quality Standard (1997). It is very unlikely that the observed increases in emissions would have resulted in air quality falling below the standard.

Evidence statement 5.3: increases in exhaust emissions following traffic calming

Evidence from 4 modelling studies (2 [+] from Canada[9,10], 1 [−] from the US[1] and one [−] from the UK[14]) examined the effect of traffic calming on vehicle emissions and air quality. Isolated and area wide traffic calming measures tended to increase emissions of NOx (between 0.1% and 10%[9,10]; 28% increase for diesel vehicles[4]). Changes in NOx emissions varied considerably between individual vehicles[4, 1]. Area-wide schemes resulted in increases of 3.8% for CO_2 and 2.2% for NOx[9, 10].

Increases in emissions are greater where traffic calming measures produce larger reductions in speed[9, 1]

The overall effect of traffic calming measures was an increase in emissions of pollutants, particularly for diesel cars.

Applicability: the studies are from Canada, the US and the UK and so are partially applicable.

9. Ghafghazi (2014)

10. Ghafghazi (2015)

1. Ahn (2009)

4. Boulter (2001)

3.3.2 Review question 6: Are zoning interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Thirteen studies were included in the review. Overall, the quality of the studies was moderate to poor, with 6 studies graded as [−] and 7 studies graded [+] (see Table 3.2.2).

Studies were grouped by the intervention the study assessed:

- Congestion charge / road pricing schemes (5 studies, 2 of which were cost effectiveness)
- Low emission zones (6 studies)
- Speed management zones (2 studies)

Congestion charge schemes

Atkinson et al (2012, −)[2] examined the impact of the introduction of a congestion charging scheme in central London. The paper considered oxides of nitrogen and PM_{10}.

The scheme operates via a charge on 4-wheeled vehicles entering the congestion charging zone during the period Monday-Friday between 07:00 to 18:00.

Pollutant concentrations were measured at roadside and background monitoring sites in the London Air Quality Network (LAQN).

Background concentrations of NO_2 rose at the 3 monitoring sites within the congestion charging zone (from 32.7 to 29.0ppb (12.8%), 30.8 to 30.5ppb (1%) and 25.1 to 26.9ppb (7.2%)). There was a small increase in NO_2 at the 7 control monitoring sites (average of 0.2%). PM_{10} levels at the only monitoring site inside the congestion charging zone fell by 15.4% (from 35.6 – 30.1 µg/m^3) while the average fall at the 3 control sites was 0.8%.

The implementation of the congestion charging scheme coincided with a number of other transport changes which could have an impact on air quality. These included the expansion of bus lanes, introduction of larger ‘bendy’ buses, fitting of particle traps to diesel buses, increased bus frequency and changes to traffic light phases. These were not restricted to the congestion charging. The authors note that these concurrent changes make it difficult to attribute the identified reductions in background PM_{10} and NOx to the implementation of the congestion charging scheme.

A second report (**Kelly, 2011**[13]**,** −) reported the same data from the introduction of the congestion charging scheme (see above). It expanded on this to examine changes in oxidative potential of PM_{10} emissions both around the introduction of the congestion charging scheme and spatially. However, this analysis is outside the scope of this review.

Invernizzi (2011[11], −) looked at the effect of a charging zone (Ecopass) and central pedestrian zone on PM and BC on three main roads in Milan. Each road runs from the outskirts of the city to the centre and consists of 3 segments:

- An outer zone with no traffic restrictions.
- An intermediate congestion charge zone (Ecopass) zone requiring diesel vehicles prior to EURO4 tier and vehicles conforming to EURO4 tier without a particulate filter to pay a toll between 08:00 and 20:00.
- A central pedestrianised zone (around the Duomo square where the three roads end). This zone represents 4.5% of the Municipality; 8.2km^2 out of 181km^2.

The study was carried out on 19th, 21st and 29th of July. Particulate concentrations were measured at fixed monitoring stations located on the 3 radial roads at one site in each section. Mean levels of PM_{10} at two fixed stations did not show significant differences (see table below). However, BC concentrations were significantly different between the three zones on each day ($p<0.0001$, except for no-restriction vs Ecopass on 29th July, $p=0.006$) (see table below).

Table 11. Particulate mass concentrations in three zones

Site locations	July 19th		July 21st		July 29th	
	Mean BC (SD)	**24hr mean PM_{10}**	**Mean BC (SD)**	**24hr mean PM_{10}**	**Mean BC (SD)**	**24hr mean PM_{10}**
Pedestrian zone	1.6 (0.4)		2.0 (0.5)		1.5 (0.5)	
Ecopass zone	3.1 (1.7)	20	2.8 (1.4)	34	2.6 (1.9)	18
No restriction zone	6.3 (2.9)	20	5.2 (2.3)	32	3.3 (1.9)	16

Evidence statement 6.1. Evidence of limited effect on charging schemes on air quality

There is weak evidence from 2 studies (2[2,13] reporting data from the same intervention) (all (−), 2 from UK[2,13,] and 1 from Italy[11]) to suggest no impact on NO_2 or PM_{10} from charging schemes; however one study[11] found a significant reduction in BC from increasing levels of vehicle restriction.

Atkinson[2] and Kelly[13] report the same data relating to changes following the imposition of the London congestion charge. Background concentrations of NO_2 rose at the 3 monitoring sites within the congestion charging zone (by 12.8%, 1% and 7.2%). There was a small increase in NO_2 at the 7 control monitoring sites (average of 0.2%). PM_{10} levels at the only monitoring site inside the congestion charging zone fell by 15.4% while the average fall at the 3 control sites was 0.8%. The authors note that other concurrent transport related changes make it difficult to attribute these changes to the congestion charging scheme. A study by Invernizzi in Milan[11] examined changes across 3 zones associated with a charge on 3 main roads and the pedestrianisation of the centre of the city. This showed significant BC concentration reductions between the three zones on each day ($p<0.0001$, except for no-restriction vs Ecopass on 29th July, $p=0.006$). Mean levels of $PM_{10,\ 2.5,\ 1}$ did not show significant differences; nor did 24hr mean concentrations of PM_{10} measured at two fixed stations.

Applicability: the studies of the London congestion charge scheme are applicable; the study in Milan is potentially replicable in England. However, potential differences in the vehicle fleet and in urban design make this partially applicable to England.

2 Atkinson et al 2009 (−)

13 Kelly et al 2011 (−)

11 Invernizzi et al 2011 (−)

Congestion charging - cost effectiveness studies

A paper by **Elliason (2006[7], +)** presents a CBA of the Stockholm congestion charging system based on observed (rather than modelled) data. The Stockholm congestion charge is based on automatic recognition of vehicles as they cross 18 control points located at city entrances and exits. Charges vary from 10-20 Swedish

Kroner (SEK) (10 SEK was about 1.10 Euros) depending on time and is the same in both directions. The maximum amount payable per vehicle per day is 60SEK. There is no charge in the evenings or at night or on Saturdays, Sundays, public holidays and the day before public holidays. There are exemptions for some vehicles and some journeys (taxis, buses, alternative-fuel vehicles, traffic between the island of Lidingo and the rest of the country) meaning that around 30% of journeys are free.

Factors included in the evaluation were:

- Changes in travel time
- Reliability of travel time
- 'adjustment costs' (losses for travellers leaving the roads or adjusting their behaviour in other ways)
- Paid congestion charges
- Changes in greenhouse gas emissions
- Health and environmental effects
- Changes in road safety
- Operational costs
- Changes in public transit revenues
- Changes in public transit capacity
- Changes in revenues from fuel taxes
- Changes in road maintenance costs

Data on travel patterns, including travel times and flows, is obtained from automated systems allowing consistency checking to ensure observed changes are not short term alterations in travel patterns. Measurements for 867 links were available, these represent 40% of vehicle kilometres travelled (VKT) in the county and nearly 60% of VKT in the central parts. Remaining travel times were calculated based on traffic flows. Time gains from the measured sections accounted for 80% of the total time gains.

Emission reductions are estimated as CO_2 and 'other emissions' (not specified). This gives reductions of between 1.4% and 2.8% in the county and between 10% and 14% in the more densely populated city centre. The author estimates a value of 22mSEK/year from this from a combination of health benefits and reduced pollution and environmental damage (not specified). The health benefit is given as 5 life-years saved per year for Stockholm county as a whole.

In addition, reductions in traffic casualties are also estimated. The expected reduction in 'traffic accidents' is estimated at 3.6% with the number of people killed and severely injured decreasing by around 15 a year. Slight injuries are expected to fall by just over 50 per year. Total values of reductions in injuries is given as 125mSEK/year.

Overall changes in costs and benefits are shown in the table below.

Table 12. Costs for all categories, Stockholm congestion charge

Category	Loss/gain (million SEK/year)
Shorter travel times	496
More reliable travel times	78
Loss for evicted car drivers, gain for new car drivers	-68
Paid congestion charges	-763
Consumer surplus total	**-257**
Less greenhouse gas emissions	64
Health and environmental effects	22
Increased traffic safety	125
Other effects, total	**211**
Paid congestion charges	763
Operational costs for charging system (including reinvestment and maintenance)	-220
Increased public transport revenues	184
Necessary increase in public transport capacity	-64
Decreased revenues from fuel taxes	-53
Decreased road maintenance costs	1
Public costs and revenues, total	**611**
Marginal cost of public funds, shadow price of public funds	**118**
Total socioeconomic surplus excluding investment cost	**683**

The authors note that the congestion charge produces a net social benefit of just under 700mSEK/year, around 500mSEK/year of which coming from savings to travel time (see table above).

The paper notes that there was an additional investment cost of around 1,900mSEK in setting up the scheme. This is estimated to be recovered in financial terms in around 3.5 years as the net financial surplus is around 540mSEK/year. Using an assumed lifespan of 20 years as a cautious estimate (running costs include reinvestment and maintenance costs) and a discount rate of 4% (the Swedish recommended discount rate) gives a net present value ratio of 4.3.

A paper by **Rotaris et al (2010[23], +)** gives a cost-benefit analysis of the Milan congestion charge (Eco-pass).

The Milan Ecopass scheme charges vehicles entering an area 8 km2 between 7.30 and 19.30 daily. The charge is set according to Euro emission standard classes and no differentiation is made according to time of entry. LPG/CNG/Hybrid vehicles are exempt, as are petrol vehicles of Euro III or more recent and diesel vehicles of Euro IV and more recent. Charges vary from €2 for petrol vehicles in Euro classes I-II to €10 for diesel cars in Euro 0, goods vehicles in Euro O-II and diesel buses in Euro O-III. 50% rebates are given for the first 50 entries a year and 40% for the next 50. Discounts are also given for residents of the tolled areas, and motorcycles, scooters, public service vehicles are exempt. Exemptions are also given between 10.00 and 16.00 for vehicles exclusively transporting perishable and refrigerated food products.

Reductions in air emissions were obtained from changes in numbers of vehicles entering the charge area before and after introduction of the charge. PM_{10} is estimated to have been reduced by 18%, NOx by 17% and CO_2 by 14%. Traffic is reported to have reduced by 12.3% inside the charge area and by 3.6% outside.

Costs and benefits for various types of road user (passenger vehicles, freight vehicles, public transport) as well as social costs (collisions, carbon dioxide and PM and NOx emissions) and costs to wider administrations (fuel duty, VAT, tolls, infrastructure and parking revenues) are calculated. Details of these calculations are not included in the paper.

Table 13. Costs and benefits of Milan Ecopass scheme (Million €)

Category	Sub-category	Travel time and reliability	Operating costs	Other costs and services	Financial impacts (excluding penalties	Total (million €)
Car, freight vehicles, taxi	**Passenger**	11.4	0.5	-5.9	-7.2	-1.2
	Freight	1.2	0.1	-1.0	-5.2	-4.9
Bus and tram	**Passenger**	5.6				5.6
Deterred trips	**Passenger**			-2.7		-2.7
	Freight			-0.4		-0.4
Social costs	**Collisions**			8.4		8.4
	CO_2			0.7		0.7
	NOx and PM_{10}			1.3		1.3
Administrations (city, region, state)	**Fuel duty**				-2.2	-2.2
	VAT				-0.8	-0.8
	Tolls		-7		12.4	5.4
	Infrastructure			-0.6		-0.6
	Parking revenues				-1.5	-1.5
Private parking	**Net revenues**				-1.0	-1.0
Total		18.2	-6.5	-0.2	-5.6	6.0

The authors note an annual net benefit of €6 million. Social cost savings amount to €10.4million; the bulk of this comes from savings from injuries (€8.4million). The figures for infrastructure and maintenance (€7m and €0.6m) are based on informal sources. The authors include sensitivity analyse using values 40% higher and lower than the ones recommended. They note that in all three scenarios there is a net benefit (total benefits are between €1.5m and €10.6m).

Evidence statement 6.2: cost-effectiveness of congestion or road pricing schemes

Two studies (one [+] from Sweden[7] and one [+] from Italy[23]) identified that congestion charging or road pricing schemes are considered to have a greater benefit than cost[7,23]. In the main benefits were not air pollution specific and included traffic flow[7], accident reduction[23] and travel time saving[23]; some environmental[7] and air pollution[23] benefits were noted but were not of the magnitude anticipated.

Applicability: One study was undertaken in the Sweden and the other in Italy so the results are partially applicable to the UK.

7 Elliason 2006 (+)

23 Rotaris et al. 2010 (+)

Low emission zones

From July 2007 to October 2008 low emission zones (LEZ) were gradually implemented in several Dutch cities (**Boogaard, 2012**, +)[3]. The policy was directed at banning 'old' trucks from entering parts of the centre of certain cities with the aim of achieving compliance with EU standards for PM and NO_2. Initially, only EURO-0 and EURO-I trucks were forbidden, whereas EURO-II and EURO-III trucks were only allowed if they were retrofitted. EURO-II and EURO-III trucks were largely tolerated until 2008/2009. In addition, since 2010 all EURO-II trucks were forbidden, and EURO-III trucks were only allowed if retrofitted with particulate filters and if not older than 8 years.

Measurements of air pollutants were conducted simultaneously at street, urban background and suburban background locations over two 6-month periods in 2008, before the implementation of the intervention, and in 2010, after implementation.

Measurements were taken at 8 major streets and 5 urban background locations (one in each of five cities in the Netherlands: Amsterdam, Den Bosch, The Hague, Tilburg and Utrecht) located within a LEZ. An additional urban background location was selected as a reference location to adjust for temporal variation (not in the LEZ).

The largest reduction was seen in The Hague (Stille Veerkade) where additional changes based on the traffic circulation plan were implemented to reroute traffic from busy to ‘less busy’ streets. This site saw a reduction of around 6-9000 vehicles per 24hrs.

All pollutant concentrations were lower in 2010 than in 2008. Average concentration decreases of PM_{10}, $PM_{2.5}$ and NOx were significant across this period in both control and LEZ areas. However, the decreases for traffic related pollutants ('soot' (a measure of PM_{10} absorbance) NO_2 and NOx) did not differ significantly between the average of the major streets and suburban locations, suggesting no measurable effect from the implementation of the LEZ. Average PM_{10} concentrations decreased by 3.1µg/m^3 in street locations, by 4.0µg/m^3 in urban background locations and 3.3µg/m^3 in suburban background locations. For $PM_{2.5}$ reductions were 5.1µg/m^3, 3.9µg/m^3 and 2.7µg/m^3. For NO_2 reductions were 1.5 g/m^3, 3.4 g/m^3 and 4.5µg/m^3.

The authors suggest a variety of possible explanations for the failure to find an effect on traffic related indicators of the implementation of the LEZ. These were: 1) the real effect being too small to measure because the LEZ only targeted trucks and not private cars and vans, 2) smaller differences between EURO-classes than originally modelled, 3) some effect of LEZ policies before the onset of baseline measurements due to a gradual implementation from July 2007, 4) the effect of other changes brought in over the same time period, 5) small changes being masked by a general economic decline (with reduction in emissions from reduced industrial and vehicular activity), 6) too short a time to see an effect of the changes, 7) the influence of subtle meteorological changes.

Jones et al (2012[12], −) examined the effect of the introduction of a LEZ on airborne particle concentrations. The London LEZ was enforced for heavy goods vehicles (HGVs) greater than 12 tonnes from February 2008, and for other goods vehicles, buses and coaches greater than 3.5 tonnes from July 2008. The LEZ applies to vehicles using diesel and biodiesel fuels, and requires HGVs to comply with the EURO III emission standard for particulate matter, or better. From December 2007, legislation required that diesel and super-unleaded petrol sold in the UK (from sites selling in excess of 3x106litres/year) should be 'sulphur free' (less that 10ppm sulphur), with all UK highway vehicle fuel being sulphur free by 1 January 2009. 59.7% of diesel sold in 2007 was sulphur free.

PNC monitoring was carried out at three sites: a roadside site in central London, an urban background site in a residential area of London and an urban centre site in Birmingham.

There were reductions in PNC at all three sites. Reduction at the London roadside site was 59% (83,400-34,400 per cm^3); at the urban background site was 39% (23,400-14,300 per cm^3) and at the Birmingham urban centre site was 30% (18,600-12,900 per cm^3).

There was some difference in the direction of effect at different sites for PM_{10} with a slight decrease in PM_{10} concentrations at the London urban background site (19.4-18.2µg/m^3) compared with a slight increase in concentrations at the London roadside site (34.8-35.8µg/m^3).

The authors note the reductions seen in PNC occurred around the time of the introduction of sulphur free diesel fuel and the introduction of the LEZ for HGVs. The authors report that the geographically widespread reductions in PNC seen may be due to fuel changes (to low sulphur diesel), although it is not possible to exclude a minor influence on PNC at the London sites from to the introduction of the London LEZ in relation to heavy diesel vehicles.

Morfeld (2014[19], +) looked at the impact on NO_2 levels in LEZ across Germany. LEZ were included if they had:

- monitoring stations that operated before and after the LEZ introduction and measured inside the LEZ area (index stations) and
- monitoring stations that operated before and after the LEZ introduction and measured outside the LEZ area – in a circle around the centre with a radius of about 25 km – and if outside the city area in no other LEZ (reference stations) and
- monitoring stations that measure NO_2 or NO by continuous measurements or diffuse samplers.

A total of 17 LEZ out of 34 in operation at the end of 2009 were included. The restrictions excluded diesel vehicles below EURO 2 without particulate reduction systems and petrol vehicles below EURO 1 without appropriate exhaust gas catalytic converters. The LEZs varied in size from 5.2 km^2 (Augsburg) to 207 km^2 (Stuttgart).

NO_2 was measured both as half hourly average values and as longer term averages over 4 weeks. Data analysis included data to control for large-scale meteorological and seasonal effects, for time dependent effects and for regression to the mean effects. Meteorological changes (height of inversion base, wind velocity and precipitation), school holidays, period of environmental bonuses[4] and periods when trucks were not allowed to enter the area where the measurement station was located were included in an extended second set of analysis.

On average, NO_2 concentrations were between 50 μg/m^3 and 52 μg/m^3 at the index stations and between 26 μg/m^3 and 27 μg/m^3 at the reference stations. The differences at the stations varied substantially in a range of hundreds of μg/m^3 upwards and downwards. There was a small decrease in NO_2 concentrations post intervention as detected by both the index and reference monitoring stations. A comparison of mean differences at index and reference stations indicated a crude LEZ effect estimate of about −1 μg/m^3. The authors note statistically significant mean LEZ effects on NO_2, concentrations (reductions) of between −1 and −2 μg/m^3 (a reduction of 2 to 4%).

The authors performed a sensitivity analysis looking only at monitoring stations characterised as ‘traffic’ stations (160 of 192). Using the extended analysis produced a slightly larger effect of −2.26μg/m^3 (compared to −1.73μg/m^3) on the four week average levels; −2.35μg/m^3 for 30 minute periods.

Panteliadis (2014[20], +) et al examined the implementation of a Low Emission Zone in Amsterdam. Heavy duty vehicles (Euro class 0, I and II) were prohibited from entering central Amsterdam after January 2009, and Euro III vehicles not equipped with a particulate filter after January 2010.

One roadside and one urban background station located within the LEZ were selected as monitoring sites. Traffic contribution was calculated by subtracting the background concentration from a monitoring station within the LEZ.

Overall, reductions were seen for all pollutants post-LEZ implementation. Greater reductions were seen for the roadside station (53.73-50.45μg/m^3 for NO_2; 28.65 to 25.95μg/m^3 for PM_{10}) and the traffic contribution (22.14 to 19.67 μg/m^3 for NO_2 4.33

[4] A ‘bonus’ was paid to car owners between 14/1/2009 and 2/11/2009 if they bought a new car with a reduced exhaust emission

to 2.79µg/m^3 for PM_{10}) concentrations compared to the urban background (31.51 to 30.79 g/m^3).

Both the crude regression analysis and the adjusted analysis (for type of day, wind direction and wind speed) showed statistically significant reductions in traffic contribution concentrations for pollutants post intervention. After adjusting for wind direction and speed and for time of day the LEZ accounted for reductions of 4.9% for NO_2, 6.4% for NO_x, and 5.8% for PM_{10}.

The authors identify a number of possible limitations. These include the method of calculating the traffic contribution. Using PM_{10} data from 4 regional background stations outside the LEZ suggested a possible underestimation of the effect of the LEZ. The effect on other pollutants could not be examined due to lack of data from outside the LEZ. Other factors which may have biased the effect include a general decrease in traffic, emission reductions from improved vehicle technology, other national and local policies and reduced economic activity may explain in part the observed improvement in air quality.

Qadir et al (2013[21], −) examined the effect of a Low Emission Zone (LEZ) in Munich on particulates. The first stage of the LEZ (October 2008) allowed vehicles with emission requirement of Euro 2, Euro 3 and Euro 4 only to enter the inner city. The second stage of LEZ started in October 2010, allowing vehicles with emission requirement Euro 3 and Euro 4 only to go through the LEZ area. The study examined samples of $PM_{2.5}$ collected every third day from October 2006 to February 2007 (before implementation of the LEZ) and from October 2009 to February 2010 (after implementation).

The sampler was located within the LEZ near to a main road with approximately 41,000 passing vehicles per day. No information on changes in traffic volume or composition are given.

The contribution of traffic sources to total $PM_{2.5}$ decreased by about 60% following the implementation of the LEZ, decreasing from 1.1 to 0.5µg/m^3.

Fensterer (2014[8],+) examined the impact of the Munich LEZ. The zone covers around 44km^2 or 14% of the city area and 32% of the population. The initial restriction was to ban transit of vehicles heavier than 3.5 tons through the city area (1/2/2008). The second stage of (1 October 2008) excludes vehicles classed as Euro 1 (or worse) from entering or driving within the area of the LEZ. From 1 October 2010 all vehicles in Euro 2 were excluded from the LEZ.

PM_{10} data was collected at two monitoring sites within the LEZ. The study compared PM_{10} concentrations measured prior to the implementation of any air quality measures (period 1) with PM_{10} levels measured after the measures became effective (period 2).

At both urban stations, a decrease of PM_{10} in period 2 (compared to period 1) was observed.

The decrease at Prinzregentenstrasse was 27.2 to 23.4μg/m^3 (−14.0%) in summer, 30.8 to 21.6 μg/m^3 (−1.9%) in winter. At Lothstrasse it was 21.3 to 20.8 μg/m^3 (−2.3%) in summer, 28.3 to 27.6 μg/m^3 (−2.5%) in winter). At the reference station reduction in the summer was from 19.3 to 18.9 μg/m^3 (−2.1%) in summer, with an increase from 24.3 to 24.5 μg/m^3 (0.8%) in winter.

The comparison of the PM_{10} concentrations (adjusted for exposure at the reference station, wind direction, day of the week, time of the day and public holidays) showed a statistically significant reduction in PM_{10} concentrations at both sites. The reduction was higher at the street site (Prinzregentenstrasse) compared with the urban background site (Lothstrasse).

Table 20. Change of PM_{10} concentration in period 2 (Oct 2008-Sept 2010) when compared to period 1 (Feb 2006-Jan 2008) at Prinzregentenstrasse and Lothstrasse (adjusted for exposure at the reference station, wind direction, day of the week, time of the day and public holidays)

Measurement station	Summer			Winter			Winter/summer combined		
	Effect	CI	p-value	Effect	CI	p-value	Effect	CI	p-value
Prinzregentenstrasse	-19.63%	-22.75% to -16.52%	<0.001	-6.80%	-10.14 to -3.47	<0.001	-13%	Not given	<0.001
Lothstrasse	-5.73%	-7.71% to -3.74	<0.001	-3.18%	-5.24 to -1.11%	0.003	-4.5%	Not given	<0.001

Evidence statement 6.3: Effect of low emission zones

Moderate evidence from 6 studies (2 from the Netherlands[2, 20] (both (+), 3 from Germany (1 (−)[21,], 2(+)[19, 8] and 1(−) from the UK[12]) suggests that low emission zones can have a small but potentially statistically significant reduction effect on vehicular contribution to air pollution and on air quality. Attributing a change to an intervention is made more difficult by the dominance of regional background contribution, the small size of the real air quality change from small scale schemes and the occurrence of other changes at the same time.

Three studies looked at low emission zones that restricted heavy vehicles only[3, 12, 20]. One[20] found reductions in NO_2 and particulates in streets used by large numbers of heavy duty diesel vehicles. Two[3,12] did not find changes in particles or nitrogen oxides attributable to the LEZ.

Three studies[21, 19, 8] (all from Germany) looked at low emission zones that included cars as well as heavy goods vehicles. All 3 found small (but sometimes significant) positive changes in vehicle related pollutants and air quality.

Boogaard[3] (Netherlands, +) found that decreases for traffic related pollutants (PM_{10}, NOx) did not differ significantly between the average of the major streets and suburban locations, suggesting no measurable effect from the implementation of the LEZ restricting heavy vehicles (Euro III with particulate filters) in 5 cities in the Netherlands.

Jones[12] (UK, −) found reductions in PNC a roadside and an urban background site in London with restrictions on heavy vehicles (Euro III without particulate filter) (59% (83,400 – 34,400 particles/cm^3) and 39% (23,400 – 14,300 particles/cm^3) respectively). Reductions of 30% (18,600 particles/cm^3 – 12,900 particles/cm^3) were seen at a control urban background site in Birmingham. The changes coincided with reductions in sulphur in fuel which may have been responsible for the observed changes.

Panteliadis[20] (Netherlands, +) found the LEZ in Amsterdam (Euro III with particulate filter for heavy vehicles) accounted for reductions of 4.9% for NO_2 (−2.47μg/m^3), and 5.8% for PM_{10} (−1.67μg/m^3) (both $p < 0.05$) at a location used by large numbers of buses and heavy duty vehicles (690 out of 15,000).

Qadir[21] (Germany, −) found the contribution of traffic sources to total $PM_{2.5}$ decreased by about 60% following the implementation of the LEZ in Munich (Euro 4 including cars), decreasing from 1.1 to 0.5μg/m^3.

Morfeld[19] (Germany, +) found statistically significant (but small) mean reductions of NO_2 of at most −2 μg/m^3 (around −4%) across 17 LEZ (all petrol vehicles below Euro 1 without appropriate exhaust gas catalytic converters, all diesel vehicles below Euro 2 without particulate reduction systems). The change at 'traffic' stations was −2.26μg/m^3 (compared to −1.73μg/m^3) on the four week average levels; −2.35μg/m^3

for 30 minute periods.

Fensterer[8](Germany, +) found reductions in PM_{10} (summer) of 14.0% (27.1-23.4μg/m3) at a roadside site in the Munich LEZ compared with reductions of 2.3% (21.3-20.8μg/m^3) at an urban background site and 2.1% (19.3-18.9μg/m^3) at a site outside the LEZ. Reductions in winter were 1.9% (30.8 μg/m^3- 30.2 μg/m^3), 2.5% (28.3 μg/m^3 – 27.6 μg/m^3) and 0.8% (24.3 μg/m^3 – 24.5 μg/m^3) respectively.

Applicability: the studies were carried out in the UK, Germany and the Netherlands. There may be differences in the make-up of the vehicle fleet in different countries which may affect the outcomes of interventions. Thus the evidence is partially applicable.

3 Boogaard et al. 2012 (+)

12 Jones et al. 2012 (−)

21 Qadir et al. 2013 (−)

20 Panteliadis et al. 2014 (+)

19 Morfeld et al. 2014 (+)

8 Fensterer et al. 2014 (+)

Speed management zones

Dijkema et al (2009[6], +) assessed whether a policy to lower the maximum speed limit from 100 (~62 mph) to 80kph (~50 mph) reduces traffic related air pollution.

The intervention (November 2005) took place on one of the busiest roads in Amsterdam, a 3 lane highway in each direction. The maximum speed on the western section was limited from 100 to 80kph [for around 6km carrying around 92,000 vehicles per day]. It is lined with apartment buildings at around 20m on each side. PM_{10} was measured using a roadside station 6.7m from the edge and 2.7m above the highway. A southern section was used as a comparison site. No changes to the speed limit were made here. There are a number of differences between the two sections. The southern section carries around 140,000 vehicles per day and is located in a relatively open area next to a river with no adjoining buildings. The monitoring station here is located 8.0m from the road edge. Despite the higher traffic volume on the southern section, the western has higher air pollution concentrations due to its more enclosed location. Pre and post data was compared for the year before and after interventions (excluding August).

Table 21. Concentrations of air pollutants due to traffic (roadside minus daily mean background) in Amsterdam, one year prior to the intervention

		N	**Mean**	**Range (min-max)**
PM_{10} (µg m^{-3})	Highway West	331	8.18	(-2.40 - 23.95)
	Highway South	330	3.67	(-9.60 - 13.20)

Table 22. Concentrations of air pollutants due to traffic (roadside minus daily mean background) in Amsterdam, one year post intervention

		N	Mean	Range (min-max)
PM_{10} (µg m^{-3})	Highway West	327	5.75	(-6.00 to 24.30)
	Highway South	316	2.63	(-25.55 to 13.60)

The traffic contribution (roadside minus daily mean background) reduced at both sites following implementation of the reduced speed limit. At the control site it fell from 3.67 to 2.63µg/m^3, at the intervention site from 8.18 to 5.75µg/m^3. The authors note the concentration of PM_{10} was significantly reduced (−2.34µg/m^3, 95%CI −3.13 to −1.55µg/m^3) when the intervention was applied.

Table 23. Speed limit intervention effects on PM_{10} (concentration at roadside minus urban background)

	With intervention		**Without intervention**	
PM_{10} (µg m^{-3}) (crude)	Change	95% CI	Change	95% CI
	-2.34*	-3.13 to -1.55	-0.63	-1.41to 0.16
PM_{10} (µg m^{-3}) (adjusted)	-2.20	-2.98 to -1.43	-0.97	-1.68 to -0.25

* $p<0.05$

Traffic flow on both sections changed over the period of the study. At both sites traffic decreased slightly (by 1823 vehicles per day at A10W and 1981 vehicles per day at A10S – approximately 2% of total traffic flow). Congestion was higher at A10W but did not change with reducing the speed limit. Congestion increases slightly at the A10S.

Two weeks before the intervention was implemented, solid noise barriers were installed along the western highway section. These were installed in the gaps between the existing high-rise buildings. As the monitoring station was between the road and the installed screens it is possible that there could have been an underestimation of the effect on air quality by causing an increase in pollutant concentration by reducing the dispersion of pollutants.

Keuken et al (2010[14], −) evaluated the effect of speed restriction on NO_2 and PM_{10} emissions from motorways in urban areas in Rotterdam and Amsterdam, Netherlands. In Rotterdam, the speed limit before the intervention was 100km/h; in Amsterdam it was already 80km/h, but without strict enforcement. After the intervention the speed limit was strictly enforced at 80km/h.

Two methods of examining the effect on pollutants were used. The first involved air quality monitoring of pollutants, the second estimated the effect on emissions from changes in traffic dynamics.

Air quality monitoring was performed from April until November 2005 (before implementation of the speed management zones) and from November 2005 until November 2006 (after implementation).

Changes in air quality were evaluated by direct measurement of PM_{10} and NOx levels at the monitoring stations as well as by applying emission factors to the traffic flow measured by traffic counts from induction loops in the road surface. Construction activities near the monitoring locations in Amsterdam meant that the results for PM_{10} were not reliable.

Changes in speed limit resulted in changes in traffic dynamics and the percentage of traffic volume that was free-flowing or congested. This, together with emission factors for private vehicles, vans and trucks, was used to estimate the emission reductions following imposition of the speed limit change.

Following the imposition of the 80kph limit the percentage of traffic at both sites which was congested (and hence undergoing more accelerations and decelerations) was reduced. This data, together with emission factors under different driving conditions, was used to calculate a percentage emission reduction factor.

Table 25. Modelled emission reductions (%) of PM_{10} and NOx at the 80km/h zones

		Emission reduction (%)	
		Air quality monitoring	**Traffic dynamics**
Amsterdam	**PM_{10}**	-	20
	NOx	32	24
Rotterdam	**PM_{10}**	8	16
	NOx	30	21

Based on air quality monitoring in combination with dispersion modelling, the study showed an average 8% reduction in PM_{10} and 30% reduction in NO_x emissions following speed management. These results are not significant for PM_{10}, which the authors attribute to the relatively low ratio of traffic contribution and the background concentration. Results from traffic dynamics and emission models showed reductions of around 15-20% for PM_{10} and 20-25% for NO_x for Amsterdam and Rotterdam.

The authors note that the study shows that speed management with strict enforcement is an effective measure for reducing traffic emissions from motorways. The emission reduction depends on the impact of speed management on traffic dynamics so that the larger the reduction in traffic congestion before and after speed management the larger the emission reduction.

Evidence statement 6.4: Evidence of effect on traffic contribution to air quality from motorway speed restrictions.

There is weak evidence from 2 studies[6, 14] (both from the Netherlands, 1−, 1+) that speed limits and enforcement on urban motorways have a small positive effect on PM_{10} and NO_2. The emission reduction depends on the impact of speed management on traffic dynamics so that the larger the reduction in traffic congestion the larger the emission reduction.

Dijkema[6] (+) examined the effect of an 80kph limit in Amsterdam. The study found that traffic contribution to PM_{10} concentrations decreased by 2.2μg/m3 (95% confidence interval 1.43-2.98μg/m^3 (27%) after taking traffic flow, congestion and wind direction into account. Concentrations of PM_{10} also fell at the control site (by 0.97μg/m^3, 95% confidence interval -1.68 to -0.25). The difference in effect between the intervened and non-intervened sites was 'statistically significant' (no data reported). No significant effect on NOx was seen.

Keuken[14] (−) modelled an average 8% reduction in PM_{10} and 30% reduction in NOx emissions following speed management. These results are not significant for PM_{10}.

Applicability: both studies were carried out in the Netherlands; however they would be replicable in the UK and so are partially applicable.

6 Dijkema et al. 2008 (+)

14 Keuken et al. 2010 (−)

4 Discussion

4.1 Strengths and limitations of the review

Overall, the quality of the studies was mixed. Of 15 studies included in this review 6 scored [+] moderate quality. Many studies were only able to examine air quality at a limited number of sites and for relatively short periods of time. Identification of appropriate control or comparison sites is frequently difficult, and local characteristics of intervention sites can make it difficult apply findings beyond the individual situation.

The contribution of other factors, such as regional sources of pollution, make it difficult to ascribe relatively small changes to the intervention under examination, while longer term temporal changes can also compound the difficulty. Frequently, the intervention under consideration is not the only change that may have influenced air quality, and may not even be the only transport related change occurring concurrent with the study dates.

Further detail of the strengths and weaknesses of individual studies can be found in the evidence tables (Appendix 4).

4.2 Applicability

Most of the reviewed studies were from outside the UK. While the types of approaches used in the studies (charging schemes, low emission zones, speed management zone, vehicle bans, pedestrian zones, traffic calming zones) can be replicated in this country, specifics such as climate and the make-up of the vehicle fleet may be very different, thus the evidence is often only partially applicability to the UK.

4.3 Gaps in the evidence

4.3.1 Review question 5: Are traffic management systems and signal coordination interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

We set out to find evidence of the effectiveness of:

- Road signs, traffic signals and road markings
- Lane control
- Traffic calming measures
- Vehicle bans or restrictions
- Elements of routes (e.g. positioning of traffic lights)
- Roadside emission testing

No evidence was found in relation to road signs, signals or markings; lane control; elements of routes such as positioning of traffic lights or roadside emission testing.

4.3.2 Review question 6: Are zoning interventions effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

We aimed to find evidence of the effectiveness of:

- Congestion charging
- cordons or zones
- distance-based charging
- speed management zones
- keep clear zones
- time-based charging
- toll road charging.

No evidence (or very limited evidence) was found in relation to keep clear zones, time based charging or toll road charging.

No evidence was found relating to questions 7 and 8 Review question 7: Are parking restrictions and charges effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

Review question 8: Are vehicle 'idling' restrictions and charges, including waiting and loading restrictions, effective and cost effective at reducing the health impact of, or people's exposure to, traffic-related air pollution?

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