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Can traffic management strategies improve urban air quality? A review of the evidence

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ABSTRACT

This paper reviews the effectiveness of traffic management strategies (TMS) for mitigating emissions, ambient concentrations, human exposure, and health effects of traffic-related air pollution in urban areas. The objective is to summarize the evidence base for a range of moderate-scale strategies broadly relevant to municipal and regional government decision-making. A systematic literature search was carried out to identify empirical studies of TMS effects on emissions, air quality, exposure, or health. Identified studies were reviewed to assess the state of evidence that TMS can improve urban air quality and pollution-related health outcomes for exposed populations. Overall, the evidence base is weak for these effects. There is limited evidence of effects on emissions for 7 of the 22 studied strategies, and limited evidence of effects on air quality for 2 of the strategies: area road pricing and low emission zones. Insufficient evidence exists for all other TMS and effects. Existing evidence suggests that aggressive area-based TMS such as low emission zones are needed to generate substantial air quality benefits, and that TMS must be implemented with care to avoid unintended detrimental and rebound effects. The evidence base is limited by a lack of ex post evaluations of implemented strategies, lack of evaluation of exposure and health impacts, small intervention effects relative to the influences of other factors, and insufficient evaluation of spillover and indirect effects. Evolving vehicle fleets add further uncertainty to the long-range effects of TMS on air quality. Effects of TMS on measured population exposure and public health outcomes have not been well-studied. An evidence-based approach to transportation systems planning necessitates additional resource allocation to ex post evaluations and performance monitoring for air quality impacts of traffic management strategies.

1. Introduction

On-road motor vehicles are a major source of air pollution in cities. There is a large and long-established body of literature demonstrating substantial negative health effects for urban populations exposed to traffic-related air pollution. In addition, our knowledge about the health impacts of exposure to certain components of motor vehicle emissions is still evolving, especially for small particles and toxic compounds. Various efforts are underway in urban areas around the world to mitigate the impacts of traffic-related air pollution. Those efforts are typically focused on development and deployment of new vehicle and fuel technologies and on management of traffic and travel activity. Through decades of efforts, substantial reductions in vehicle emission rates have been

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Table 1
Categorization of traffic management strategies used in this review.

Operating restrictions & pricing	RCP	Road, congestion and cordon pricing: tolling, distance pricing, or pricing based on time-of-day or congestion levels
	LEZ	Low/zero emission zones and eco-zones: pricing or restrictions based on emissions status of vehicles
	VOR	Vehicle operating and access restrictions: by zone, time-of-day, or route
	PKM	Parking management: supply and pricing strategies
Lane management	HOL	High occupancy vehicle (HOV), High Occupancy Toll (HOT), and eco-lanes
	TBL	Truck and/or bus lanes
	LCC	Lane capacity changes (road diets, peak shoulder running)
Speed management	LSL	Lower speed limits
	VSL	Variable speed limits
	SCD	Speed control devices: traffic calming such as humps, chicanes, micro-roundabouts
	SED	Speed enforcement devices & programs
	ED	Eco-driving, eco-routing (not requiring significant new technology)
Traffic flow control	RM	Ramp meters
	ETC	Electronic toll collection
	IMS	Incident management systems
	ICD	Intersection control device: roundabout, signal, stop signs, etc.
	TST	Traffic signal timing: signal coordination, adaptive signal systems, transit signal priority, etc.
Trip reduction strategies	SRP	Shared-ride programs: carpool/vanpool/rideshare programs, incentives, and services
	EP	Employer programs for trip reduction: flex-time, telework
	TI	Transit improvements: pricing, service quality, etc.
	PBF	Pedestrian and bicycle facilities: roadway & trip-end facilities
	OM	Outreach & marketing (to reduce auto use)

achieved in some countries, largely through vehicle and fuel regulations and technology development. However, traffic-related air pollution still poses a substantial public health risk in many cities around the world, including in North America where emissions rates have decreased dramatically (Beelen et al., 2014; Brauer et al., 2012; Cheng et al., 2016; Denier van der Gon et al., 2013; Grigoratos and Martini, 2015; Health Effects Institute, 2010; Lelieveld et al., 2015; McDonald et al., 2013; Moussa et al., 2016; Pascal et al., 2013; U.S. U.S. Environmental Protection Agency, 2015).

This paper reviews the effectiveness of traffic management strategies (TMS) for mitigating emissions, ambient concentrations, human exposure, and health effects of traffic-related air pollution in urban areas. The objective of this paper is to summarize the evidence base for a range of moderate-scale strategies broadly relevant to municipal and regional government decision-making, particularly in the North American context. From the perspective of a city or region seeking direct and immediate action to reduce traffic impacts on air quality, only a subset of potential mitigation strategies is available or viable within typical governance structures. Examples include vehicle operating restrictions, road pricing, traffic operations improvements, traffic calming, and soft measures such as the promotion of active transportation and carpooling. TMS that involve extensive capital investments, such as new transit lines or roadways, are beyond the scope of the review, as are strategies focused on vehicle and fuel technology (e.g. vehicle and engine emission regulations), which are typically implemented at higher levels of government and affected by broader economic and technical factors.

A systematic literature search is carried out to identify empirical studies of TMS effects on emissions, air quality, exposure, or health. Identified studies are reviewed to characterize the state of evidence that TMS can improve urban air quality and pollution-related health outcomes. Knowledge gaps, methodological issues, and implications for practice and research are discussed.

1.1. Traffic management strategy categorization

The categorization of TMS in this review (Table 1) is distilled from taxonomies of Travel Demand Management (TDM) strategies, Transportation Control Measures (TCM), Congestion Mitigation and Air Quality Improvement Program (CMAQ) projects, and other relevant analyses (Adler et al., 2012; Battelle and Texas Transportation Institute, 2014; Cambridge Systematics, 2009; Hitchcock et al., 2014; Hodges and Potter, 2010; ICF International, 2006; Litman, 2003; U.S. U.S. Environmental Protection Agency, 2011a, b). Inevitably, there is some potential for strategies to cross over multiple categories. In addition, the following strategies are beyond the scope of the review and so excluded from the categorization: large infrastructure projects such as new transit lines and roadways, new vehicle and fuel technologies, new transportation services and sub-systems such as bike-share car-share systems, anti-idling infrastructure such as truck stop electrification, land use planning, shielding strategies to reduce exposure such as noise and vegetative barriers, as well as strategies not within the scope of direct action by municipal and regional governments (e.g. fuel prices).

1.2. Principal effects pathways

The principal effects pathways through which TMS can lead to pollution-related health effects are illustrated in Fig. 1. Only effects within the scope of this review are illustrated, so pathways such as health effects through changes in physical activity resulting from travel mode choices and access to healthcare are excluded (Brown et al., 2017; Neutens, 2015). TMS can influence travel activity (the number of trips generated and their distribution in space and time), travel mode choices (principally single-occupant vehicles versus multi-occupant vehicles, public transit, or non-motorized modes), vehicle speeds (including speed dynamics such as accelerations and

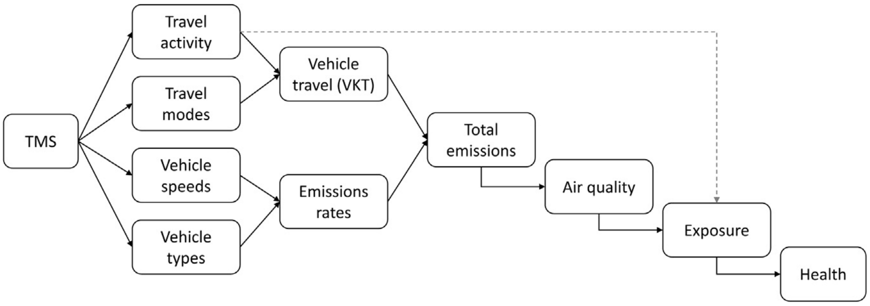

Fig. 1. Principal effects pathways for TMS to influence traffic-related emissions, air quality, and pollution-related health effects.

idling, influenced through traffic conditions and driver behaviour), and vehicle types (including engine and fuel characteristics, influenced through vehicle ownership, usage and maintenance decisions). There are also interactions among these effects, not illustrated in the figure, such as the influence of traffic speed on mode choices.

TMS effects on emissions can then be distilled to two primary mechanisms: net changes in the total amount of vehicle kilometers traveled (VKT) and average emissions rates (mass per VKT). VKT is primarily affected through travel activity and mode choice modifications, while emissions rates are primarily affected through vehicle and fuel type, and speed modifications (including traffic dynamics). Total emissions changes, then, are the product of these two factors. Changes in total emissions lead to air quality effects through atmospheric processes, particularly dispersion and transformation, mediated by the spatial and temporal distributions of emissions, background concentrations, emissions from other sources, and meteorology. Changes in ambient air quality lead to population exposure effects, depending on the spatial and temporal distributions of air quality changes and population activities. Most indirect effects of TMS are not illustrated in Fig. 1, except for the potential for changes in travel activity to lead to changes in pollution exposure. This is particularly relevant because time spent in transportation microenvironments are often the highest-concentration exposure periods of the day (Dons et al., 2012; Fruin et al., 2004; Weichenthal et al., 2015).

Finally, changes in air pollution exposure resulting from TMS are expected to modify air health effects for exposed populations, mediated by numerous personal and environmental factors. For simplification, the intermediate steps of pollutant inhalation and uptake/absorption are excluded from the illustration. However, those factors can be particularly relevant when comparing exposure and health risks for active and non-active travel modes (Bigazzi and Figliozzi, 2014). Such an assessment would entail evaluation of personal air pollution doses and then health effects through dose-response functions. All the reviewed literature below uses the simpler approach of connecting environmental exposure concentrations directly to health outcomes through exposure-response functions.

2. Existing reviews and overviews

Several existing reviews and overviews are relevant to the current work, although none directly address the state of evidence that TMS lead to urban air quality improvements. Some reviews examine the effects of TMS on emissions, but not on air quality (ICF International, 2006; Kalra et al., 2012; Porter et al., 2010; U.S. U.S. Environmental Protection Agency, 2011a). Several of the reviews only address greenhouse gas (GHG) emissions. There are differences in how traffic and vehicle dynamics can affect GHG emissions compared to local non-GHG air pollutant emissions. For example, fine particulate matter and hydrocarbon emission rates can be more sensitive to traffic congestion than GHG emissions (Bigazzi and Figliozzi, 2012). Thus, effects of traffic management on emissions of GHGs are likely to be different from effects on local air pollutants.

Porter et al. (2010) report good cost-effectiveness of speed limit reductions, traffic signal improvements, and incident management programs for multi-pollutant emissions reductions, but poor cost-effectiveness of transit service improvements. They also find that cost-effectiveness depends strongly on the context and implementation, and that traffic volume/demand responses to the strategies are uncertain and may reduce the estimated emissions benefits. Insufficient information was available to evaluate many strategies, including intersection design, traveler information, ramp metering, pricing, and managed lanes.

Hatcher et al. (2014) summarize the estimated effects of intelligent transportation system (ITS) projects using a database of 1,668 project summaries maintained by the U.S. Department of Transportation. Emissions impacts are included, but the results depend on self-reported, modeled project outcomes, which are subject to large uncertainties. A similar report for ERTICO - ITS Europe concludes that traffic signal improvements, variable speed limits, and parking guidance systems could generate GHG emissions reductions, but based on very limited evidence (Pandazis and Winder, 2015).

Several broad-scale scenario studies have been conducted to evaluate the potential emissions effects of implementing traffic management and other transportation strategies (Cambridge Systematics, 2009; Dierkers et al., 2008; U.S. U.S. Environmental Protection Agency, 2011b). Cambridge Systematics (2009) estimates that a full set of operations and ITS improvements could achieve less than 1% GHG emissions reduction in the U.S., while lower speed limits, eco-driving, and road pricing combined could achieve 1–4% reductions. Hodges and Potter (2010) assess several traffic management strategies, including congestion pricing and a national 55 mile/hour speed limit on U.S. highways, with estimated U.S. GHG emissions reductions of 1–3%.

A report from the U.K. reviews mitigation strategies for traffic effects on air quality, but not systematically (Hitchcock et al., 2014). The authors find that most strategies have small effects on air quality and a “comprehensive and potentially radical package of measures will be required if real improvements in air quality are to be seen.” A recent review of freight emissions in Canada also includes some air quality impacts, but does not provide a systematic review and addresses few traffic management strategies (ICF International, 2015). Their findings suggest that geographic operating restrictions can be effective in reducing truck-related air quality impacts, along with various approaches to renewing and improving the vehicle fleet.

The U.S. CMAQ program has generated a large database of projects that involve traffic management for air quality objectives, and a series of CMAQ project evaluations with renewals of CMAQ funding (Battelle and Texas Transportation Institute, 2014; Grant et al., 2008; Regan et al., 2009; Transportation Research Board, 2002). CMAQ project data have also been used in a meta-analysis of cost-effectiveness for emissions reductions (Puckett et al., 2015). The most recent CMAQ program evaluation included a review of emissions estimation methods for a sample of 72 CMAQ projects out of more than 8,000. The evaluation found that before-and-after studies of CMAQ projects are rare and that “emissions impacts of the projects depend greatly on the accuracy of [vehicle travel] reduction estimates, which were not always well-documented” (Battelle and Texas Transportation Institute, 2014). A reliance on self-reported, ex ante project evaluations is a caveat to conclusions drawn from CMAQ project data.

3. Methods

3.1. Literature search

A literature search was conducted using TRID (http://trid.trb.org/), a transportation research database that integrates the Transportation Research Board Transportation Research Information Services (TRIS) Database and the Organisation for Economic Co-operation and Development Joint Transport Research Centre's International Transport Research Documentation (ITRD) Database, Google Scholar (http://scholar.google.com/), and ProQuest Summon. The search terms for all three search tools were every combination of [Term 1] AND [Term 2], where [Term 1] was traffic management, transportation control measure, traffic calming, traffic signal, demand management, lane management, managed lane, pricing, parking management, congestion mitigation and air quality improvement, CMAQ, or shar*, and [Term 2] was emissions, air quality, pollution, or health. Thus, there were 48 searches on each tool (12 [Term 1] × 4 [Term 2]). Publication date for the searches was set at 2005-present. Based on preliminary searches, the term “exposure” was not used due to the dominance of safety-related documents in the search results; verification searches with the term “exposure” did not reveal any additional relevant publications. All returned documents from TRID and the first 200 documents per search, sorted by relevance, from ProQuest Summon and Google Scholar were imported to reference management software (Zotero) and duplicates removed. Reference lists of included documents were also searched, as well as federal agency websites in the U.S. and Canada (Transport Canada, Environment and Climate Change Canada, the U.S. Environmental protection agency, and the U.S. Federal Highway Administration). Online searches were executed September 30 through October 17, 2016, with additional references added through December 7, 2016.

To be included in the final set of documents, studies had to meet all of the following criteria, adapted from (Brown et al., 2015):

1. Be written in English;
2. Be a primary study, not a synthesis or review;
3. Be in the public domain, as a peer-reviewed academic journal article, a conference paper, or a government report or commissioned document (i.e. the ‘grey’ literature);
4. Study effects of a TMS as categorized and scoped in Table 1;
5. Use at least some observed data (pertaining to traffic, emissions, air quality, or health) from a real-world implementation of a TMS;
6. Present results (modeled or measured) on changes in fuel consumption, pollution emissions, air quality, pollution exposure, or health attributable to the TMS.

The online search returned 19,596 raw hits that were distilled to 5,841 unique documents in the reference management software. A citation and title review of all these documents identified 583 relevant documents. Another 32 were added from other sources to yield 615 documents for full-text extraction and review. Of these 615 documents, 65 were ultimately selected for inclusion in the review, based on the six criteria above. The 550 exclusions were due to: a TMS not implemented or no measured data, violating criterion #5 (N = 252); no strategy assessed (N = 49) or an out-of-scope strategy (N = 85), violating criterion #4; overview or review documents, violating criterion #2 (N = 64); no evaluation of pollution-related effects, violating criterion #6 (N = 56); and other issues, including criteria #1 and #3 (N = 44). Inclusion/exclusion status for all 615 full-text reviewed documents, grouped by TMS, is given in Table S1 in the Supplementary Material.

The document selection process can be summarized as follows:

- Raw hits from database search: 19,596
  - Duplicates removed: 13,755
- Citations examined for relevance: 5,841
  - Excluded as not a relevant study: 5,258
  - Added from other sources: 32
- Full text retrieved and reviewed: 615

- ○ Excluded as not meeting all six criteria: 550
- Included in final review summary: 65

3.2. Evaluation of TMS effectiveness

A weight of evidence approach is used to assess whether the available information is sufficient to evaluate the air quality benefits of TMS. Table S2 in the Supplementary Material gives the full TMS evaluation criteria and scales. The weight of evidence for emissions, air quality, exposure, and health benefits is evaluated using Weight of Evidence Levels (WEL) developed from previous reviews, particularly (Health Effects Institute, 2010):

1. Sufficient Evidence of an Effect
   Evidence is sufficient to conclude that there is a positive effect of implementing the TMS on the identified outcome. This level may be met if several studies that are free of bias and confounding show a consistent significant association, and there are also studies reporting intermediate effects that support the existence of an effects pathway.
2. Limited Evidence of an Effect
   Evidence is suggestive of an effect of the TMS on the identified outcome but is limited because chance, bias, and confounding cannot be confidently ruled out. This level may be appropriate if there are few studies, the results are not consistent among studies, and/or the effects pathway is not clear.
3. Insufficient Evidence of an Effect
   The available studies provide insufficient or substantially inconsistent evidence as to the effect of the TMS on the identified outcome. This level of evidence indicates a lack of adequate information, not necessarily a lack of a real effect (van Erp et al., 2012).
4. Limited Evidence of No Effect
   Several studies with adequate controls and scope show no association between implementation of the TMS and the identified outcome. The suggested lack of effect is limited to the context and conditions of those studies. It is still possible that the TMS may have an effect in other applications.

The WEL are assigned based on the reviewed studies. Additional evaluation criteria including expected magnitude of effects, implementation issues, cost effectiveness, and ancillary effects are based on the reviewed studies, existing review documents described in Section 2 above, and additional literature.

4. Results

4.1. Literature search results

Fig. 2 categorizes documents that were full-text reviewed by studied TMS and inclusion/exclusion status. Of the 615 full-text

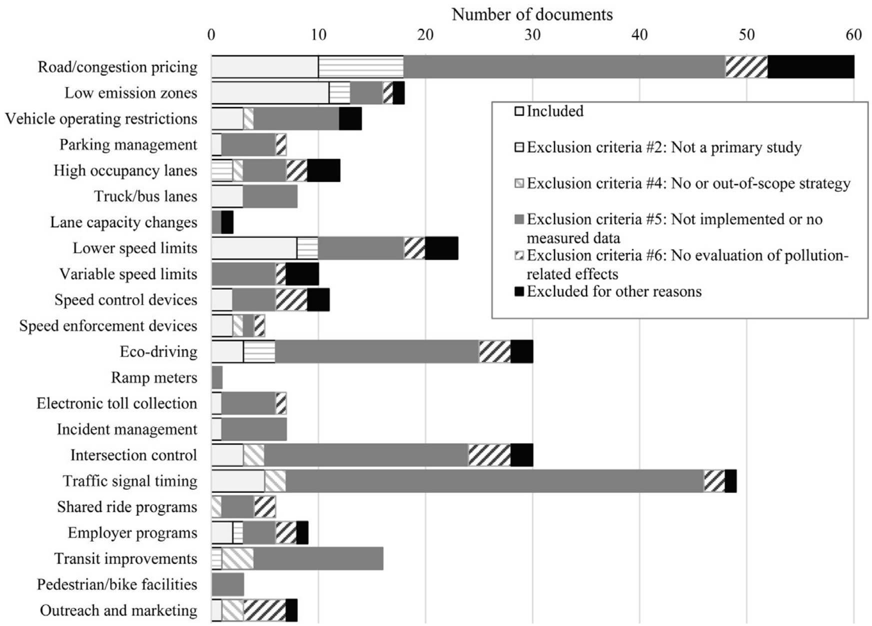

Fig. 2. Number of full-text reviewed documents by TMS and inclusion/exclusion status.

Table 2
Studies included in the final review.

Field (based on publication source)	Documents
Transportation	(Ahn et al., 2009; Alam et al., 2014; Barth and Boriboonsomsin, 2009; Bel et al., 2015; Blake, 2008; Cascetta et al., 2010; Chen et al., 2012; Chong-White et al., 2012, p.; Chou et al., 2010; Chu, 2015; Coelho et al., 2005; Day et al., 2011; Ellison et al., 2013; Fernandes et al., 2016; Garcia-Castro et al., 2014; Hallmark et al., 2011; Herzog et al., 2006; Hu et al., 2014; Innamaa and Penttinen, 2014; Jazcilevich et al., 2015; Joy and Schreffler, 2015; Kendrick et al., 2014; Koenders et al., 2012; Malina and Scheffler, 2015; Nelson et al., 2007; Percoco, 2013; Rotaris et al., 2010; Strömberg and Karlsson, 2013; Sun et al., 2014; Xu et al., 2013)
Environmental science	(Atkinson et al., 2009; Baldasano et al., 2010; Barratt et al., 2007; Beevers and Carslaw, 2005; Boogaard et al., 2012; Cai and Xie, 2011; Dijkema et al., 2008; Ferreira et al., 2015; Invernizzi et al., 2011; Johansson et al., 2009; Keuken et al., 2010, 2012; Norman et al., 2016; Owen, 2005; Panteliadis et al., 2014; Qadir et al., 2013; SLB Analysis, 2006; Titos et al., 2015; Wang et al., 2010; Yao et al., 2013)
Economics and public policy	(Asensio et al., 2014; Castillo-Manzano et al., 2014; Davis, 2008; Fontes et al., 2015; Gallego et al., 2013; Peters and Kramer, 2005; Teague et al., 2015; Wolff, 2014)
Health	(Burman and Johansson, 2010; Cesaroni et al., 2012; Fensterer et al., 2014; Rich et al., 2015; Tonne et al., 2008)
General	(Ma and He, 2016; Morfeld et al., 2014)

reviewed documents, Fig. 2 shows only the 336 that address single in-scope TMS; the remaining 279 documents address multiple TMS (180) or no in-scope TMS (99). The most frequently-studied TMS use pricing, engineering (intersection control devices and traffic signal timing), behavioural (eco-driving), and policy (speed limits) approaches. The importance of criterion #5 (use at least some observed data from a real-world implementation of a TMS) is a major exclusion factor for most TMS. Excluding studies that relied solely on modeling simulations reduces the number of documents by more than half for most TMS. Outreach and marketing, a purely behavioural approach, is a notable exception. Operations and infrastructure-oriented strategies such as transit improvements, pedestrian and bicycle facilities, ramp meters, electronic toll collection, incident management systems, intersection control devices, and traffic signal timing are particularly lacking in empirical studies. Methodological issues with simulation studies of air quality effects are discussed below.

The 65 documents included in the final review are categorized in Table 2 by field of study based on publication source. Table 3 gives the number of final review documents by field and by their use of measured, modeled, or no data for the assessment of traffic, emissions, air quality, and exposure outcomes. The included studies are dominated by transportation (46%) and environmental science (31%) fields. Most studies (75%) use measured traffic data, especially in transportation, as could be expected. Emissions data are also used in most studies (65%), more often modeled than measured by a factor of 5. Air quality data are used in slightly fewer studies (60%), more often measured than modeled by a factor of almost 3. These differences in techniques reflect the high cost and complexity of directly measuring on-road emissions (Ropkins et al., 2009) and the existence of already-established traffic and air quality monitoring programs in most major urban areas in developed countries. Exposure is infrequently assessed (6% of studies) and only modeled. Many studies in the broader literature have used directly-measured personal exposure data for traffic-related air pollutants (Health Effects Institute, 2010; Kaur and Nieuwenhuijsen, 2009), but not studies assessing the effects of TMS explicitly. Much of the personal exposure literature examines differences in exposure by travel mode as opposed to effects of system interventions.

Table S3 in the Supplementary Material expands on Table 3 by giving the number of final review documents by TMS, field, and utilization of traffic, emissions, air quality, and exposure data. Operating restrictions and pricing strategies (other than parking management) have been the focus of most Economics, Health, and General studies. Environmental science studies have also focused on operating restrictions and pricing strategies, as well as lower speed limits. Transportation studies have focused on speed management and flow control strategies as well as low emission zones. Pricing, operating restrictions, low emission zones and lower speed limit strategies are frequently studied with traffic and air quality data, whereas most other studies only assess effects on emissions. Exposure assessments are rare, and mostly limited to studies of pricing and low emission zones.

Table 3
Number of final review documents by field and utilization of traffic, emissions, air quality, and exposure data[a].

		Traffic data			Emissions data			Air quality data			Exposure data		
Field of study	Total	Msr	Mod	NA	Msr	Mod	NA	Msr	Mod	NA	Msr	Mod	NA
Transportation	30	27	2	1	5	19	6	6	0	24	0	0	30
Environmental science	20	15	0	5	0	11	9	14	4	2	0	2	18
Economics & public policy	8	4	0	4	2	2	4	4	4	0	0	0	8
Health	5	3	0	2	0	3	2	3	2	0	0	2	3
General	2	0	0	2	0	0	2	2	0	0	0	0	2
Total:	65	49	2	14	7	35	23	29	10	26	0	4	61

[a] Msr (measured data used in the analysis), Mod (modeled data used in the analysis), NA (not assessed in the study).

Table 4
TMS evaluation results.

TMS	Weight of Evidence				Effects and Implementation					
	Reduces total emissions	Improves air quality	Reduces population exposure	Improves health	Expected traffic emissions reductions	Expected local air quality improvements	Cost and complexity of implementation	Cost effectiveness (air quality)	Co-benefits	Risk of negative impacts
Operating restrictions & pricing										
RCP	Lim	Lim/Ins[a]	Ins	Ins	< 50%	< 25%	Me	Me	+ +	+
LEZ	Ins	Lim	Ins	Ins	< 50%	< 25%	Me	Me	+ +	+
VOR	Lim	Ins	Ins	Ins	[b]	[b]	Hi	Lo	+	+ +
PKM	Ins	Ins	Ins	Ins	< 20%	NA	Me	Hi	+	+
Lane management										
HOL	Ins	Ins	Ins	Ins	NA	NA	Me-Hi	Lo	+	–
TBL	Ins	Ins	Ins	Ins	NA	NA	Lo-Me	NA	+	–
LCC	Ins	Ins	Ins	Ins	NA	NA	Me-Hi	NA	+	+
Speed management										
LSL	Lim	Ins	Ins	Ins	< 20%	< 10%	Lo-Me	Hi	+ +	+ +
VSL	Ins	Ins	Ins	Ins	< 20%	< 10%	Me	Me	+ +	–
SCD	Ins	Ins	Ins	Ins	< 20%	< 10%	Lo	NA	+ +	–
SED	Ins	Ins	Ins	Ins	< 20%	< 10%	Lo-Me	NA	+	–
ED	Lim	Ins	Ins	Ins	< 20%	NA	Lo	Hi	+	–
Flow control										
RM	Ins	Ins	Ins	Ins	NA	NA	Me-Hi	NA	+ +	+
ETC	Ins	Ins	Ins	Ins	NA	NA	Me-Hi	NA	+ +	–
IMS	Ins	Ins	Ins	Ins	< 20%	NA	Me	Me	+ +	–
ICD	Lim	Ins	Ins	Ins	< 50%	NA	Hi	Lo	+	+
TST	Lim	Ins	Ins	Ins	< 20%	NA	Lo-Me	Me	+ +	+
Trip reduction strategies										
SRP	Ins	Ins	Ins	Ins	< 20%	NA	Lo	Lo-Me	+	–
EP	Lim	Ins	Ins	Ins	< 20%	NA	Lo-Me	Lo-Me	+	–
TI	Ins	Ins	Ins	Ins	< 20%	NA	Me-Hi	Lo-Me	+	–
PBF	Ins	Ins	Ins	Ins	< 20%	NA	Lo-Me	Me-Hi	+ +	–
OM	Ins	Ins	Ins	Ins	< 20%	< 10%	Lo	Me	+	–

TMS– ED: Eco-driving, eco-routing; EP: Employer programs for trip reduction; ETC: Electronic toll collection; HOL: High occupancy lanes; ICD: Intersection control device; IMS: Incident management & traveler information systems; LCC: Lane capacity change; LEZ: Low/zero emission zones, eco-zones; LSL: Lower speed limits; OM: Outreach & marketing; PBF: Pedestrian and bicycle facilities; PKM: Parking management; RCP: Road, congestion and cordon pricing; RM: Ramp meters; SCD: Speed control devices; SED: Speed enforcement devices & programs; SRP: Shared-ride programs; TBL: Truck and/or bus lanes; TI: Transit improvements; TST: Traffic signal timing; VOR: Vehicle operating and access restrictions; VSL: Variable speed limits
Weight of evidence & Effects and implementation– Hi: high; Ins: Insufficient Evidence of an Effect; Lim: Limited Evidence of an Effect; Lo: low; Me: medium; NA: not assessed due to insufficient information; + +: likely; +: possible; -: unlikely (see Section 3.2 and Table S2)

[a] Limited for area pricing, Insufficient for facility pricing.

[b] A wide range has been reported, depending on the scope of the VOR; emissions reductions from < 20% to > 50% and air quality improvements from < 10% to > 25%.

4.2. TMS evaluation results

Table 4 gives the results of the TMS evaluations; details of all evaluations are given in the Supplementary Material. The WEL for exposure and health effects is Insufficient for all TMS. Four studies made coarse estimates of exposure, but no studies measured exposure, and only one measured health outcomes. Many more studies included air quality evaluations, but no strategies are considered to have Sufficient empirical evidence of an effect on air quality due to various limitations. There is Limited evidence of an effect on air quality for two TMS: area road pricing and low emission zones. Evidence for air quality effects of all other TMS is Insufficient. Evidence for emissions effects is stronger, with 7 TMS having Limited evidence of an effect; evidence of emissions effects for the other 15 TMS is Insufficient. Sufficient evidence was not found for any of the reviewed TMS effects. Methodological issues in the studies that limit the evidence base are discussed in the next section.

The magnitude of expected emissions and air quality improvements associated with TMS is generally small (< 10%) when it could be assessed (Table 4 and Table S2 in Supplementary Material). The more restrictive operations and pricing strategies (road, congestion, and cordon pricing, low emission zones, and vehicle operating and access restrictions) and intersection control devices show greater potential. Nonetheless, the TMS with potentially medium or large magnitude of benefits (> 10%) are associated with higher cost and complexity of implementation and lower cost effectiveness. All 22 TMS have possible or likely co-benefits, often in terms of mobility and safety, and 9 of them (including all those with potentially medium or large magnitude of benefits) have possible or likely negative impacts as well.

Table 5 summarizes the main emissions effects pathways for each TMS, as illustrated in Fig. 1. Some potential trade-offs and

Table 5
Summary of primary emissions effects pathway elements for TMS (see Fig. 1)[a].

	Travel activity	Travel modes	Vehicle speeds	Vehicle types	Vehicle travel (VKT)	Emissions rates (per VKT)	Total emissions
Operating restrictions & pricing							
RCP	+	+	+		+	+	+
LEZ	+			+	+	+	+
VOR	+				+		+
PKM	+	+			+		+
Lane management							
HOL		+	+	+	+	+	+
TBL			+			+	+
LCC	+	+	–		+	–	
Speed management							
LSL			+			+	+
VSL			+			+	+
SCD	+		–		+	–	
SED			+			+	+
ED			+			+	+
Flow control							
RM			+			+	+
ETC			+			+	+
IMS			+			+	+
ICD			+			+	+
TST			+			+	+
Trip reduction strategies							
SRP		+			+		+
EP	+	+			+		+
TI		+	+		+	+	+
PBF		+			+		+
OM	+	+			+		+

ED: Eco-driving, eco-routing; EP: Employer programs for trip reduction; ETC: Electronic toll collection; HOL: High occupancy lanes; ICD: Intersection control device; IMS: Incident management & traveler information systems; LCC: Lane capacity change; LEZ: Low/zero emission zones, eco-zones; LSL: Lower speed limits; OM: Outreach & marketing; PBF: Pedestrian and bicycle facilities; PKM: Parking management; RCP: Road, congestion and cordon pricing; RM: Ramp meters; SCD: Speed control devices; SED: Speed enforcement devices & programs; SRP: Shared-ride programs; TBL: Truck and/or bus lanes; TI: Transit improvements; TST: Traffic signal timing; VOR: Vehicle operating and access restrictions; VSL: Variable speed limits.

[a] effects summarized as beneficial (+), detrimental (-), or unchanged/unknown/undetermined ().

offsetting effects (particularly induced demand, discussed below) are not included in the table. There is a rough balance between strategies that reduce VKT and those that reduce emissions rates. The two strategies with limited evidence for air quality improvements provide both VKT and emissions rate benefits. The three strategies with potentially medium or large air quality benefits are expected to reduce VKT, and two of them reduce emissions rates as well. Trade-offs are expected between the direct effects of both lane capacity changes and speed control devices. These two TMS may help reduce traffic volumes, while leading to higher emissions rates.

4.3. Methodological issues in assessing TMS effects on air quality

There are systematic differences in methods applied to assess TMS effects by field of study. Transportation studies are most often ex ante assessments of proposed interventions (before the event, based on forecasts), and predominantly apply bottom-up modeling chains to simulate effects of a strategy. Many transportation studies apply modeling tools widely used in transportation planning and traffic engineering to forecast traffic conditions, and then use the forecasted traffic conditions as inputs to emissions and sometimes air quality models. The transportation modeling tools are not primarily developed to generate inputs for emissions models, and their accuracy in an emissions and/or air quality modeling framework is an active area of research (Ghafghazi and Hatzopoulou, 2014; Jie et al., 2013; Smit et al., 2010). In addition, many studies use average-speed emissions models that only capture limited aspects of the influence of traffic dynamics on emissions (Smit et al., 2008). Economics and public policy studies are more often ex post assessments of implemented policies (after the event, based on measured performance) that use econometric/regression techniques to estimate the effect of policy variables on measured air quality data. Environmental science studies are often a blend between the transportation and economic approaches, with some traffic and emissions modeling, as well as air quality measurements and modeling.

The following five sub-sections discuss key challenges that were identified in this review for assessing TMS effects on air quality and health: 1) lack of implementation and ex post evaluation, 2) lack of exposure and health assessment, 3) small intervention effects relative to the influence of exogenous factors, 4) opportunities for spillover and indirect effects, and 5) uncertain long term effects with evolving vehicle fleets and urban systems. Additional references on methodological issues in assessing emissions and air quality impacts of transportation strategies include Section 5 of (Battelle and Texas Transportation Institute, 2014), Appendix A of (Hodges and Potter, 2010), and van Erp et al. (2012).

4.3.1. Lack of implementation and ex post evaluation

Ex ante assessment of the effects of traffic management strategies on traffic conditions is challenging due to the complexity of endogenous and exogenous factors. When this uncertainty is fed into emissions, air quality, exposure, and health impacts models, each with their own complexities and uncertainties, the precision of simulated or forecasted impacts on air quality and health can be less reliable. Furthermore, most simulation studies do not use stochastic approaches or quantify uncertainty, and traffic impacts on air quality can be small relative to model uncertainty (Vardoulakis et al., 2008). Ex ante evaluations of projects by local government agencies can be further limited by insufficient resources to model the full complexity of project impacts (Grote et al., 2016). This high uncertainty in modeled effects of TMS-like traffic interventions presents a significant challenge for policy-making (Int Panis et al., 2011).

Ex post evaluations are needed to build the evidence base for air quality benefits of TMS. Modeling is useful, but some "ground truth" observation of intervention effects is also needed owing to the complex array of travel behaviours that can be impacted by traffic interventions (Burt et al., 2010). A review of CMAQ projects found that most project analyses depended on modeling approaches alone due to the cost and complexity of field measurements (Battelle and Texas Transportation Institute, 2014). That review revealed no before-and-after study of a CMAQ-funded project, and only ten before-and-after studies of CMAQ-eligible projects – a small amount of ex post validation for a program with almost US$2 billion in annual funding.

4.3.2. Lack of exposure and health assessment

There has been little measurement of exposure or health impacts associated with the implementation of TMS. The broader epidemiology and environmental health literature assesses health effects of exposure to traffic-related air pollution (Chen et al., 2017; Health Effects Institute, 2010; Peters et al., 2013; Shah et al., 2012), but rarely the effects of transportation interventions. The reviewed studies that do assess exposure and health impacts apply exposure response functions to ambient average concentrations and residential population data. This approach neglects the dynamics of population activity and air quality throughout the day and year, including the effects of some TMS on exposure through changes in travel activity (Figure 1).

Most reviewed studies that assess air quality examine criteria air pollutants for which monitoring data are readily available. Field measurement studies are needed to determine TMS effects on other pollutants. No evidence was found for effects of TMS on ultrafine particles, for example, which are increasingly of concern for traffic-related health impacts (Cheng et al., 2016; Knibbs et al., 2011). Furthermore, most studies use air quality data from monitoring stations, which are generally representative of ambient regional levels but do not fully reflect near-road exposures. Additional monitoring stations targeting near-road environments or road-impacted environments, and close to TMS intervention sites, are necessary to measure local or street-level variations in air pollution. Moreover, establishing stations at least a year prior to an intervention would allow for more robust pre-implementation observations.

The focus on emissions in most reviewed studies is likely due to the additional data and models required to evaluate air quality, exposure, and health impacts. Further, the detection or identification of traffic-related health impacts, for example via epidemiological studies, is inherently more complex. In addition, air quality and exposure are generally out of scope of studies that investigate only GHG effects. Changes in fuel consumption and GHG emissions are often associated with changes in air pollutant emissions, but do not translate to proportional changes in air quality due to atmospheric photochemical processes.

4.3.3. Small effects relative to the influence of exogenous factors

When measured air quality concentrations are used in the reviewed studies, the effects of TMS are generally small ($< 10\%$ changes in ambient concentrations) and not always statistically significant. Measuring small impacts on air quality is challenging given the complexity of exogenous factors also influencing traffic emissions and air quality. Major intervening factors include non-traffic emissions sources (industry, residential heating, wildfires, etc.), vehicle fleet variability, fuel formulations, meteorology, and more. In order to achieve measurable changes in air quality the traffic interventions must be large, but large interventions are the least common and have the most potential confounding factors (Sun et al., 2014). The small effect size of traffic management on air quality is likely a key factor in the WEL results in Table 4.

4.3.4. Opportunities for spillover and indirect effects

Travelers respond to transportation system interventions in many ways over varying time scales, and estimating the full breadth of travel impacts is challenging. Similarly, analysis of the emissions effects of transportation interventions requires assessment of many effects pathways (Wolfermann et al., 2015). For example, TMS that reduce emissions rates by mitigating congestion and increasing speeds (e.g., via increased road capacity or ITS strategies) can be counter-acted by increased traffic volumes through induced demand (Bigazzi and Figliozzi, 2012). Induced demand is consistently under-evaluated in traffic modeling studies and a major source of uncertainty in TMS effects on emissions and air quality (Hodges and Potter, 2010; Kalra et al., 2012). Modeling studies are often optimistic by reporting fixed-volume emissions effects or emissions effects per-vehicle or per-VKT. Some types of traffic interventions are not as vulnerable to induced demand, but could have indirect effects through traffic diversion to other facilities, such as area pricing and vehicle operating restrictions. In addition, life cycle effects, although more of an issue for GHG emissions, can also be relevant for air quality and are another often-neglected source of uncertainty (Kolosz et al., 2013; Patey et al., 2008). Many of the studies in this review suffer from incomplete consideration of spillover and indirect traffic effects, as discussed further for individual TMS in the Supplementary Material.

4.3.5. Uncertain long term effects with evolving vehicle fleets and urban systems

Many health effects from exposure to traffic-related air pollution are long-term outcomes. Due to evolving vehicle fleets and urban systems, evidence of air quality and health impacts from past interventions might not be representative of future performance. One example is advanced vehicle powertrain technologies such as hybrid and electric vehicles. The emissions from these types of vehicles are less subject to the inefficiencies of congested driving, and so have less potential emissions benefits from congestion mitigation and traffic flow improvements than conventional internal combustion engine vehicles (Bigazzi and Clifton, 2015). Thus, as the vehicle fleet evolves, emissions benefits of TMS targeting vehicle speeds (see Table 5) might deteriorate. Similarly, a shift toward electric and low emissions passenger vehicles would magnify the importance of strategies targeting heavy-duty vehicles (e.g., truck and bus lanes). The advent of autonomous vehicles, too, would likely alter the potential air quality benefits from TMS targeting traffic operations efficiency such as ramp meters, variable speed limits, and eco-driving. Modeling studies can be useful for forecasting TMS effects in these future scenarios, but should still be supported by some empirical evidence from relevant implemented strategies.

5. Conclusions

This paper summarizes the state of evidence that traffic management strategies have provided emissions, air quality, exposure, and pollution-related health benefits, based on ex post monitoring data. Overall, the evidence base is weak for these effects. A previous review of the literature on traffic management and air quality in 1998 highlighted “the lack of hard evidence in terms of changes in air quality, with most of the studies relying on modelling rather than monitoring” (Cloke et al., 1998). In the intervening 18 years, the situation has not greatly changed.

There is limited evidence of effects on emissions for seven of the studied strategies, and limited evidence of effects on air quality for two of the strategies: area road pricing and low emission zones. Insufficient evidence exists for all other TMS and effects. The lack of evidence for TMS effects does not indicate that TMS cannot generate air quality and health benefits (van Erp et al., 2012). Rather, the evidence base is limited primarily by a lack of ex post (before-and-after) evaluations of real world strategies, lack of evaluation of exposure and health impacts, small intervention effects relative to the influences of other factors, and insufficient evaluation of spillover and indirect effects. Evolving vehicle fleets and urban systems add further uncertainty to the long-range effects of TMS on air quality. TMS may provide air quality benefits, but these effects have not been well-studied. Effects of TMS on population exposure and public health outcomes have generally not been characterized, particularly with measured rather than modelled data.

Existing evidence indicates that the magnitude of potential air quality benefits from TMS is likely modest, although substantial health benefits could be generated for large populations over extended periods of time. Aggressive TMS, or combinations of multiple smaller TMS, are needed to generate substantial air quality benefits. Road/congestion pricing and low emission zones in European city centers appear to be moderately successful in improving air quality. The European implementations were complemented with robust and enhanced transit services, which was likely important to their success and public acceptance. As strong area road pricing and low emission zones have not yet been implemented in North America, the acceptability and potential efficacy of those strategies in American or Canadian cities is unknown. Public acceptance and compliance is an issue for many of the TMS, possibly warranting broader outreach and marketing strategies at multiple levels of government to increase public awareness and understanding of the effects of traffic on air quality and health. Strategies should be implemented with care to avoid unintended detrimental and rebound effects.

Although there is insufficient evidence that many of the TMS measurably improve air quality, the evidence for emissions reductions is stronger, and many TMS have potential co-benefits with low risk of negative effects. Thus, approaches such as speed management strategies and trip reduction strategies are likely worth pursuing if resources are available. Some of the TMS could also be pursued for climate change goals (GHG reductions), with potential (yet unproven) air quality benefits.

It should be noted that there are promising approaches outside the scope of this review that can potentially generate urban air quality and health benefits, including car-share systems (Kent, 2014; Martin and Shaheen, 2011), bike-share systems (Fishman et al., 2015; Stuart et al., 2010; Zhou et al., 2010), and new transit systems (Castro et al., 2010; Wang et al., 2012). Alternatively, while the focus of this review was health benefits through emissions reductions, barrier and shielding strategies can be effective in reducing near-road exposure to traffic-related air pollution through infrastructure, vegetation, or vehicle cabin protection (Baldauf et al., 2008; Brantley et al., 2014; Tong et al., 2016). Additionally, as stated in the Introduction, vehicle and fuel regulation and technology development have been successful in greatly reducing emissions rates in many countries, though traffic-related air pollution is still a public health risk (Brauer et al., 2012; Health Effects Institute, 2010; McDonald et al., 2013; U.S. U.S. Environmental Protection Agency, 2015; von Stackelberg et al., 2013).

Robust research on the impacts of TMS on air quality, exposure, and public health is needed to fully evaluate the efficacy and cost-effectiveness of these projects. An evidence-based approach to transportation systems planning requires resource allocation to multiple stages of project evaluation, including ex ante modeling, pilot studies, implementation monitoring, ex post evaluations, and ongoing performance review. The results of this review suggest an over-reliance on the first two stages of evaluation for transportation projects – particularly ex ante modeling. Long-term programs such as CMAQ and large-scale projects such as congestion pricing zones would benefit from dedicating resources to ex post evaluations to ensure effectiveness (van Erp et al., 2012). There is also a need for ex post case studies of smaller-scale projects that can be used as an evidence base in efforts to address localized air quality issues, such as around schools or parks.

With increasing focus on performance-based and data-driven program delivery, there is a need for municipal and regional guidance on appropriate air quality and emissions-related performance monitoring methods, particularly for calculating project-attributable effects. Currently there is some consistency in emissions estimation methods, but less consistency in traffic and travel modeling methods, particularly for induced and diverted traffic demand (Battelle and Texas Transportation Institute, 2014; Burt et al., 2010). Among other factors, future research evaluating TMS effects on air quality and health should consider: 1) demand effects of strategies targeting traffic speeds, and speed effects of strategies targeting traffic demand, 2) traffic diversion effects on parallel or alternative facilities, 3) exposure impacts of projects that affect travel/activity patterns, and 4) long-range impacts with evolving vehicle fleets, including powertrain technologies, fuel sources, and automation.

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Appendix A. Supporting information

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References

Adler, K., Bowen, B., Mahendra, A., Simons, M., E, 2012. Travel activity and emissions impacts of implementing transportation control measures. TDM Rev. 10–22.
Ahn, K., Rakha, H., Ahmed, 2009. A field evaluation case study of the environmental and energy impacts of traffic calming. Transp. Res. Part D: Transp. Environ. 14, 411–424.
Alam, A., Diab, E., El-Geneidy, A., Hatzopoulou, M., M, 2014. A simulation of transit bus emissions along an urban corridor: evaluating changes under various service improvement strategies. Transp. Res. Part D: Transp. Environ. 31, 189–198.
Asensio, J., Gómez-Lobo, A., Matas, A., 2014. How effective are policies to reduce gasoline consumption? Evaluating a set of measures in Spain. Energy Econ. 42, 34–42. http://dx.doi.org/10.1016/j.eneco.2013.11.011.
Atkinson, R.W., Barratt, B., Armstrong, B., Anderson, H.R., 2009. The impact of the congestion charging scheme on ambient air pollution concentrations in London. Atmos. Environ. 43, 5493–5500. http://dx.doi.org/10.1016/j.atmosenv.2009.07.023.
Baldasano, J.M., Gonçalves, M., Soret, A., Jiménez-Guerrero, P., 2010. Air pollution impacts of speed limitation measures in large cities: the need for improving traffic data in a metropolitan area. Atmos. Environ. 44, 2997–3006. http://dx.doi.org/10.1016/j.atmosenv.2010.05.013.
Baldauf, R., Thoma, E., Khlystov, A., Isakov, V., Bowker, G., Long, T., Snow, R., 2008. Impacts of noise barriers on near-road air quality. Atmos. Environ. 42, 7502–7507.
Barratt, B., Atkinson, R., Ross Anderson, H., Beevers, S., 2007. Investigation into the use of the CUSUM technique in identifying changes in mean air pollution levels following introduction of a traffic management scheme. Atmos. Environ. 41, 1784–1791. http://dx.doi.org/10.1016/j.atmosenv.2006.09.052.
Barth, M., Boriboonsomsin, K., 2009. Energy and emissions impacts of a freeway-based dynamic eco-driving system. Transp. Res. Part D: Transp. Environ. 14, 400–410. http://dx.doi.org/10.1016/j.trd.2009.01.004.
Battelle, Texas Transportation Institute, 2014. Air Quality and Congestion Mitigation Measure Outcomes Assessment Study: Final Technical Report (No. FHWA-HEP-15-002). U.S. Federal Highway Administration, Washington, D.C.
Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z.J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., Vineis, P., Xun, W.W., Katsouyanni, K., Dimakopoulou, K., Oudin, A., Forsberg, B., Modig, L., Havulinna, A.S., Lanki, T., Turunen, A., Oftedal, B., Nystad, W., Nafstad, P., De Faire, U., Pedersen, N.L., Östenson, C.-G., Fratiglioni, L., Penell, J., Korek, M., Pershagen, G., Eriksen, K.T., Overvad, K., Ellermann, T., Eeftens, M., Peeters, P.H., Meliefste, K., Wang, M., Bueno-de-Mesquita, B., Sugiri, D., Krämer, U., Heinrich, J., de Hoogh, K., Key, T., Peters, A., Hampel, R., Concin, H., Nagel, G., Ineichen, A., Schaffner, E., Probst-Hensch, N., Künzli, N., Schindler, C., Schikowski, T., Adam, M., Phuleria, H., Vilier, A., Clavel-Chapelon, F., Declercq, C., Grioni, S., Krogh, V., Tsai, M.-Y., Ricceri, F., Sacerdote, C., Galassi, C., Migliore, E., Ranzi, A., Cesaroni, G., Badaloni, C., Forastiere, F., Tamayo, I., Amiano, P., Dorronsoro, M., Katsoulis, M., Trichopoulou, A., Brunekreef, B., Hoek, G., 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet 383, 785–795. http://dx.doi.org/10.1016/S0140-6736(13)62158-3.
Beevers, S.D., Carslaw, D.C., 2005. The impact of congestion charging on vehicle emissions in London. Atmos. Environ. 39, 1–5.
Bel, G., Bolancé, C., Guillén, M., Rosell, J., 2015. The environmental effects of changing speed limits: a quantile regression approach. Transp. Res. Part D: Transp. Environ. 36, 76–85.
Bigazzi, A.Y., Clifton, K.J., 2015. Modeling the effects of congestion on fuel economy for advanced power train vehicles. Transp. Plan. Technol. 38, 149–161. http://dx.doi.org/10.1080/03081060.2014.997449.
Bigazzi, A.Y., Figliozzi, M.A., 2014. Review of urban bicyclists' intake and uptake of traffic-related air pollution. Transp. Rev. 34, 221–245. http://dx.doi.org/10.1080/01441647.2014.897772.
Bigazzi, A.Y., Figliozzi, M.A., 2012. Congestion and emissions mitigation: a comparison of capacity, demand, and vehicle based strategies. Transp. Res. Part D: Transp. Environ. 17, 538–547. http://dx.doi.org/10.1016/j.trd.2012.06.008.
Blake, P., 2008. Reducing greenhouse emissions by improving traffic signal operations. p. 15.
Boogaard, H., Janssen, N.A.H., Fischer, P.H., Kos, G.P.A., Weijers, E.P., Cassee, F.R., van der Zee, S.C., de Hartog, J.J., Meliefste, K., Wang, M., Brunekreef, B., Hoek, G., 2012. Impact of low emission zones and local traffic policies on ambient air pollution concentrations. Sci. Total Environ. 435–436, 132–140. http://dx.doi.org/10.1016/j.scitotenv.2012.06.089.
Brantley, H.L., Hagler, G.S.W., Deshmukh, J., Baldauf, P., R.W, 2014. Field assessment of the effects of roadside vegetation on near-road black carbon and particulate matter. Sci. Total Environ. 468–469, 120–129. http://dx.doi.org/10.1016/j.scitotenv.2013.08.001.
Brauer, M., Reynolds, C.C.O., Hystad, P., 2012. Traffic-related air pollution and health: a Canadian perspective on scientific evidence and potential exposure-mitigation strategies. Health Canada.
Brown, V., Moodie, M., Carter, R., 2017. Evidence for associations between traffic calming and safety and active transport or obesity: A scoping review. J. Transp. Health. http://dx.doi.org/10.1016/j.jth.2017.02.011. (In press).
Brown, V., Moodie, M., Carter, R., 2015. Congestion pricing and active transport – evidence from five opportunities for natural experiment. J. Transp. Health 2, 568–579.
Burman, L., Johansson, C., 2010. The effects of the congestion tax on emissions and air quality: evaluation until, and including, the year 2008. SLB, Stockholm, Sweden.
Burt, M., Sowell, G., Crawford, J., Carlson, T., 2010. Synthesis of Congestion Pricing-Related Environmental Impact Analyses – Final Report.
Cai, H., Xie, S., 2011. Traffic-related air pollution modeling during the 2008 Beijing Olympic Games: the effects of an odd-even day traffic restriction scheme. Sci. Total Environ. 409, 1935–1948. http://dx.doi.org/10.1016/j.scitotenv.2011.01.025.
Cambridge Systematics, 2009. Moving Cooler: An analysis of transportation strategies for reducing greenhouse gas emissions (No. 9780874201185). Urban Land Institute.
Cascetta, E., Punzo, V., Sorvillo, R., 2010. Impact on vehicle speeds and pollutant emissions of a fully automated section speed control scheme on the Naples urban motorway, Presented at In: Proceedings of the the 89th Annual Meeting of the Transportation Research Board, Washington, D.C.
Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal-Tercero, D.J., 2014. Temporary speed limit changes: An econometric estimation of the effects of the Spanish Energy

Efficiency and Saving Plan. Economic Modelling, XVI edition of the Applied Economics Meeting 2013 In: Proceedings of the Applied Economics Meeting, June 6–7, 2013. University of Granada, Spain 44, Supplement 1, S68–S76. doi: http://dx.doi.org/10.1016/j.econmod.2014.01.032.
Castro, C., Carvalho de, Fernando, Strambi, O., 2010. Assessing Net Effect on Emissions of Implementation of Bus Rapid Transit System in São Paulo, Brazil: Case Study and Some Hypothetical Scenarios. p. 17.
Cesaroni, G., Boogaard, H., Jonkers, S., Porta, D., Badaloni, C., Cattani, G., Forastiere, F., Hoek, G., 2012. Health benefits of traffic-related air pollution reduction in different socioeconomic groups: the effect of low-emission zoning in Rome. Occup. Environ. Med. 69, 133–139. http://dx.doi.org/10.1136/oem.2010.063750.
Chen, H., Kwong, J.C., Copes, R., Tu, K., Villeneuve, P.J., van Donkelaar, A., Hystad, P., Martin, R.V., Murray, B.J., Jessiman, B., Wilton, A.S., Kopp, A., Burnett, R.T., 2017. Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study. Lancet 389, 718–726. http://dx.doi.org/10.1016/S0140-6736(16)32399-6.
Chen, X., Yu, L., Song, G., Xian, C., 2012. Comparative study of emissions from bus rapid transit and conventional bus systems: case study from Beijing. Transp. Res. Rec.: J. Transp. Res. Board 11–20 (pp).
Cheng, H., Saffari, A., Sioutas, C., Forman, H.J., Morgan, T.E., Finch, C.E., 2016. Nanoscale particulate matter from urban traffic rapidly induces oxidative stress and inflammation in olfactory epithelium with concomitant effects on brain. Environ. Health Perspect. 124, 1537–1546. http://dx.doi.org/10.1289/EHP134.
Chong-White, C., Millar, G., Shaw, S., 2012. SCATS and the Environment Study: Definitive Results. p. 14.
Chou, C., Miller-Hooks, E., Promisel, I., 2010. Benefit-cost analysis of freeway service patrol programs: methodology and case study. Adv. Transp. Stud. 20.
Chu, S., 2015. Car restraint policies and mileage in Singapore. Transp. Res. Part A: Policy Pract. 77, 404–412.
Cloke, J., Boulter, P., Davies, G.P., Hickman, A.J., Layfield, R.E., Mccrae, I.S., Nelson, P.M., 1998. Traffic management and air quality research programme: final report. TRL REPORT 327.
Coelho, M.C., Farias, T.L., Rouphail, N.M., 2005. Impact of speed control traffic signals on pollutant emissions. Transp. Res. Part D 10, 323–340. http://dx.doi.org/10.1016/j.trd.2005.04.005.
Davis, L.W., 2008. The effect of driving restrictions on air quality in Mexico City. J. Political Econ. 116, 38–81. http://dx.doi.org/10.1086/529398.
Day, C., Brennan, T., Hainen, A., Remias, S., Premachandra, H., Sturdevant, J., Richards, G., Premachandra, M., Wasson, J., Bullock, D., 2011. Reliability, flexibility, and environmental impact of alternative objective functions for arterial offset optimization. Transp. Res. Rec.: J. Transp. Res. Board 8–22 (pp).
Denier van der Gon, H.A.C., Gerlofs-Nijland, M.E., Gehrig, R., Gustafsson, M., Janssen, N., Harrison, R.M., Hulskotte, J., Johansson, C., Jozwicka, M., Keuken, M., Krijgsheld, K., Ntziachristos, L., Riediker, M., Cassee, F.R., 2013. The policy relevance of wear emissions from road transport, now and in the future—an international workshop report and consensus statement. J. Air Waste Manag. Assoc. 63, 136–149. http://dx.doi.org/10.1080/10962247.2012.741055.
Dierkers, G., Silsbe, E., Stott, S., Winkelman, S., Wubben, M., 2008. CCAP Transportation Emissions Guidebook. Part One: Land Use, Transit & Travel Demand Management.
Dijkema, M.B.A., van der Zee, S.C., Brunekreef, B., van Strien, R.T., 2008. Air quality effects of an urban highway speed limit reduction. Atmos. Environ. 42, 9098–9105. http://dx.doi.org/10.1016/j.atmosenv.2008.09.039.
Dons, E., Int Panis, L., Van Poppel, M., Theunis, J., Wets, G., 2012. Personal exposure to Black Carbon in transport microenvironments. Atmos. Environ. 55, 392–398. http://dx.doi.org/10.1016/j.atmosenv.2012.03.020.
Ellison, R.B., Greaves, S.P., Hensher, D.A., 2013. Five years of London's low emission zone: effects on vehicle fleet composition and air quality. Transp. Res. Part D: Transp. Environ. 23, 25–33.
Fensterer, V., Kuchenhoff, H., Maier, V., Wichmann, H., Breitner, S., Peters, A., Gu, J., Cyrys, J., 2014. Evaluation of the impact of low emission zone and heavy traffic ban in Munich (Germany) on the reduction of PM_{10} in ambient air. Int. J. Environ. Res. Public Health 11, 5094–5112.
Fernandes, P., Pereira, S.R., Bandeira, J.M., Vasconcelos, L., Silva, A.B., Coelho, M.C., 2016. Driving around turbo-roundabouts vs. conventional roundabouts: are there advantages regarding pollutant emissions? Int. J. Sustain. Transp. 10, 847–860.
Ferreira, F., Gomes, P., Tente, H., Carvalho, A.C., Pereira, P., Monjardino, J., 2015. Air quality improvements following implementation of Lisbon's Low Emission Zone. Atmos. Environ. 122, 373–381. http://dx.doi.org/10.1016/j.atmosenv.2015.09.064.
Fishman, E., Washington, S., Haworth, N., 2015. Bikeshare's impact on active travel: evidence from the United States, Great Britain, and Australia. J. Transp. Health 2, 135–142.
Fontes, T., Pereira, S.R., Bandeira, J.M., Coelho, M.C., 2015. Assessment of the effectiveness of fuel and toll pricing policies in motorway emissions: an ex-post analysis. Res. Transp. Econ. 51, 83–93.
Fruin, S.A., Winer, A.M., Rodes, C.E., 2004. Black carbon concentrations in California vehicles and estimation of in-vehicle diesel exhaust particulate matter exposures. Atmos. Environ. 38, 4123–4133. http://dx.doi.org/10.1016/j.atmosenv.2004.04.026.
Gallego, F., Montero, J.-P., Salas, C., 2013. The effect of transport policies on car use: evidence from Latin American cities. J. Public Econ. 107, 47–62. http://dx.doi.org/10.1016/j.jpubeco.2013.08.007.
Garcia-Castro, A., Monzon, A., Valdes, C., 2014. ICT measures to reduce CO2 emissions in metropolitan areas: the case study of Madrid. p. 9.
Ghafghazi, G., Hatzopoulou, M., 2014. Simulating the environmental effects of isolated and area-wide traffic calming schemes using traffic simulation and microscopic emission modeling. Transportation 41, 633. http://dx.doi.org/10.1007/s11116-014-9513-x.
Grant, M., Kuzmyak, R., Shoup, L., Hsu, E., Krolik, T., Ernst, D., 2008. SAFETEA-LU 1808: cmaq Evaluation and Assessment, Phase I Final Report (No. FHWA-HEP-08-019). Federal Highway Administration, Washington, D.C.
Grigoratos, T., Martini, G., 2015. Brake wear particle emissions: a review. Environ. Sci. Pollut. Res 22, 2491–2504. http://dx.doi.org/10.1007/s11356-014-3696-8.
Grote, M., Williams, I., Preston, J., Kemp, S., 2016. Including congestion effects in urban road traffic CO_2 emissions modelling: do Local Government Authorities have the right options? Transp. Res. Part D: Transp. Environ. 43, 95–106. http://dx.doi.org/10.1016/j.trd.2015.12.010.
Hallmark, S., Wang, B., Mudgal, A., Isebrands, H., 2011. On-road evaluation of emission impacts of roundabouts. Transp. Res. Rec.: J. Transp. Res. Board pp 226–233.
Hatcher, G., Burnier, C., Greer, E., Hardesty, D., Hicks, D., Jacobi, A., Lowrance, C., Mercer, M., 2014. Intelligent Transportation Systems Benefits, Costs, and Lessons Learned: 2014 Update Report.
Health Effects Institute, 2010. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects (Special Report No. Special Report 17). Health Effects Institute, Boston, MA.
Herzog, E., Bricka, S., Audette, L., Rockwell, J., 2006. Do employee commuter benefits reduce vehicle emissions and fuel consumption? results of the fall 2004 survey of best workplaces for commuters. Transp. Res. Rec.: J. Transp. Res. Board 34–41.
Hitchcock, G., Conlan, B., Kay, D., Brannigan, C., Newman, D., 2014. Air Quality and Road Transport: Impacts and Solutions. Royal Automobile Club Foundation, London, UK.
Hodges, T., Potter, J., 2010. Transportation's Role in Reducing U.S. Greenhouse Gas Emissions: Volume 1: Synthesis Report and Volume 2: Technical Report. U.S. Department of Transportation,, Washington, D.C.
Hu, W., McCartt, A., Jermakian, J., Mandavilli, S., 2014. Public opinion, traffic performance, the environment, and safety after construction of double-lane roundabouts. Transp. Res. Rec.: J. Transp. Res. Board 47–55.
ICF International, 2015. Options to Address Air Pollutant and Greenhouse Gas Emissions from In-use Heavy Duty On-road and Off-road Diesel Vehicles and Engines (No. PN1561). Canadian Council of Ministers of the Environment.
ICF International, 2006. Multi-Pollutant Emissions Benefits of Transportation Strategies (No. FHWA-HEP-07-004). U.S. Federal Highway Admininstration, Washington, D.C.
Innamaa, S., Penttinen, M., 2014. Impacts of a green-driving application in city buses on fuel consumption, speeding and passenger comfort. IET Intell. Transp. Syst. 8, 435–444. http://dx.doi.org/10.1049/iet-its.2013.0039.
Int Panis, L., Beckx, C., Broekx, S., De Vlieger, I., Schrooten, L., Degraeuwe, B., Pelkmans, L., 2011. PM, NOx and CO_2 emission reductions from speed management policies in Europe. Transp. Policy 18, 32–37. http://dx.doi.org/10.1016/j.tranpol.2010.05.005.
Invernizzi, G., Ruprecht, A., Mazza, R., De Marco, C., Močnik, G., Sioutas, C., Westerdahl, D., 2011. Measurement of black carbon concentration as an indicator of air quality benefits of traffic restriction policies within the ecopass zone in Milan, Italy. Atmos. Environ. 45, 3522–3527. http://dx.doi.org/10.1016/j.atmosenv.2011.04.008.

Jazcilevich, A., Mares Vázquez, J., María, Ramírez, P., López, Pérez, I., Rosas, 2015. Economic-environmental analysis of traffic-calming devices. Transp. Res. Part D: Transp. Environ. 36, 86–95.
Jie, L., van Zuylen, H., Chen, Y., Viti, F., Wilmink, I., 2013. Calibration of a microscopic simulation model for emission calculation. Transp. Res. Part C: Emerg. Technol. 31, 172–184.
Johansson, C., Burman, L., Forsberg, B., 2009. The effects of congestions tax on air quality and health. Atmospheric Environment, Urban Air QualitySelected Papers from In: Proceedings of the 6th International Conference on Urban Air Quality 43, pp. 4843–4854. doi: http://dx.doi.org/10.1016/j.atmosenv.2008.09.015.
Joy, B., Schreffler, E., 2015. Evaluation of demand responsive parking pricing in San Francisco: effects on vehicular travel. Air Pollut., Fuel Consum. 20.
Kalra, N., Ecola, L., Keefe, R., Weatherford, B., Wachs, M., Plumeau, P., Lawe, S., Smith, C., 2012. Reference Sourcebook for Reducing Greenhouse Gas Emissions from Transportation Sources.
Kaur, S., Nieuwenhuijsen, M.J., 2009. Determinants of personal exposure to $PM_{2.5}$, ultrafine particle counts, and CO in a transport microenvironment. Environ. Sci. Technol. 43, 4737–4743. http://dx.doi.org/10.1021/es803199z.
Kendrick, C., M., Urowsky, D., Rotich, W., Koonce, P., George, L., 2014. Effect of Reducing Maximum Cycle Length on Roadside Air Quality and Travel Times on a Corridor in Portland, OR. p. 20.
Kent, J.L., 2014. Carsharing as active transport: what are the potential health benefits? J. Transp. Health 1, 54–62.
Keuken, M.P., Jonkers, S., Wilmink, I.R., Wesseling, J., 2010. Reduced NOx and PM_{10} emissions on urban motorways in The Netherlands by 80km/h speed management. Sci. Total Environ. 408, 2517–2526. http://dx.doi.org/10.1016/j.scitotenv.2010.03.008.
Keuken, M.P., Jonkers, S., Zandveld, P., Voogt, M., Elshout van den, S., 2012. Elemental carbon as an indicator for evaluating the impact of traffic measures on air quality and health. Atmos. Environ. 61, 1–8. http://dx.doi.org/10.1016/j.atmosenv.2012.07.009.
Knibbs, L.D., Cole-Hunter, T., Morawska, L., 2011. A review of commuter exposure to ultrafine particles and its health effects. Atmos. Environ. 45, 2611–2622. http://dx.doi.org/10.1016/j.atmosenv.2011.02.065.
Koenders, E., Blom, G., Lorenzo, R., Blanco, 2012. Energy Efficient Intersection Control: Pilot Evaluation Results. p. 8p.
Kolosz, B., Grant-Muller, S., Djemame, K., 2013. Modelling uncertainty in the sustainability of Intelligent Transport Systems for highways using probabilistic data fusion. Environ. Model. Softw. 49, 78–97. http://dx.doi.org/10.1016/j.envsoft.2013.07.011.
Lelieveld, J., Evans, J.S., Fnais, M., Giannadaki, D., Pozzer, A., 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525, 367–371. http://dx.doi.org/10.1038/nature15371.
Litman, T., 2003. The Online TDM Encyclopedia: mobility management information gateway. Transp. Policy, Urban Transp. Policy Instrum. 10, 245–249. http://dx.doi.org/10.1016/S0967-070X(03)00025-8.
Ma, H., He, G., 2016. Effects of the post-olympics driving restrictions on air quality in Beijing. Sustainability 8, 902. http://dx.doi.org/10.3390/su8090902.
Malina, C., Scheffler, F., 2015. The impact of low emission zones on particulate matter concentration and public health. Transp. Res. Part A: Policy Pract. 77, 372–385.
Martin, E.W., Shaheen, S.A., 2011. Greenhouse gas emission impacts of carsharing in North America. IEEE Trans. Intell. Transp. Syst. 12, 1074–1086.
McDonald, B.C., Gentner, D.R., Goldstein, A.H., Harley, R.A., 2013. Long-term trends in motor vehicle emissions in U.S. urban areas. Environ. Sci. Technol. 47, 10022–10031. http://dx.doi.org/10.1021/es401034z.
Morfeld, P., Groneberg, D.A., Spallek, M.F., 2014. Effectiveness of low emission zones: large scale analysis of changes in environmental NO_2, NO and NOx Concentrations in 17 German Cities. PLoS One 9, e102999. http://dx.doi.org/10.1371/journal.pone.0102999.
Moussa, S.G., Leithead, A., Li, S.-M., Chan, T.W., Wentzell, J.J.B., Stroud, C., Zhang, J., Lee, P., Lu, G., Brook, J.R., Hayden, K., Narayan, J., Liggio, J., 2016. Emissions of hydrogen cyanide from on-road gasoline and diesel vehicles. Atmos. Environ. 131, 185–195. http://dx.doi.org/10.1016/j.atmosenv.2016.01.050.
Nelson, P., Safirova, E., Walls, M., 2007. Telecommuting and environmental policy: lessons from the ecommute program. Transp. Res. Part D: Transp. Environ. 12, 195–207.
Neutens, T., 2015. Accessibility, equity and health care: review and research directions for transport geographers. J. Transp. Geogr. 43, 14–27. http://dx.doi.org/10.1016/j.jtrangeo.2014.12.006.
Norman, M., Sundvor, I., Denby, B.R., Johansson, C., 2016. Modelling road dust emission abatement measures using the NORTRIP model: vehicle speed and studded tyre reduction. Atmos. Environ. 134, 96–108. http://dx.doi.org/10.1016/j.atmosenv.2016.03.035.
Owen, B., 2005. Air quality impacts of speed-restriction zones for road traffic. Sci. Total Environ. 340, 13–22. http://dx.doi.org/10.1016/j.scitotenv.2004.08.011.
Pandazis, J., Winder, A., 2015. Study of intelligent transport systems for reducing CO_2 emissions for passenger cars. ERTICO - ITS Europe, Brussels, Belgium.
Panteliadis, P., Strak, M., Hoek, G., Weijers, E., van der Zee, S., Dijkema, M., 2014. Implementation of a low emission zone and evaluation of effects on air quality by long-term monitoring. Atmos. Environ. 86, 113–119. http://dx.doi.org/10.1016/j.atmosenv.2013.12.035.
Pascal, M., Corso, M., Chanel, O., Declercq, C., Badaloni, C., Cesaroni, G., Henschel, S., Meister, K., Haluza, D., Martin-Olmedo, P., Medina, S., 2013. Assessing the public health impacts of urban air pollution in 25 European cities: results of the Aphekom project. Sci. Total Environ. 449, 390–400. http://dx.doi.org/10.1016/j.scitotenv.2013.01.077.
Patey, I., Conquest, J., Holt, A., 2008. Assessing "carbon balance" of intelligent transport systems. In: Proceedings of the Institution of Civil Engineers - Engineering Sustainability 161, pp.181–184.
Percoco, M., 2013. Is road pricing effective in abating pollution? Evidence from Milan. Transp. Res. Part D: Transp. Environ. 25, 112–118.
Peters, A., Klot, S. von, Mittleman, M.A., Meisinger, C., Hörmann, A., Kuch, B., Wichmann, H.E., 2013. Triggering of acute myocardial infarction by different means of transportation. Eur. J. Prev. Cardiol. 20, 750–758. http://dx.doi.org/10.1177/2047487312446672.
Peters, J.R., Kramer, J.K., 2005. Seasonal variation in the environmental effects of toll collection evidence from the garden State Parkway. Public Work. Manag. Policy 9, 287–291. http://dx.doi.org/10.1177/1087724X05274792.
Porter, C., Kall, D., Selin, T., Baker, R., Kishan, S., Preusse, D., Stanard, A., 2010. Evaluate the Interactions between Transportation-Related Particulate Matter, Ozone, Air Toxics, Climate Change, and Other Air-Pollutant Control Strategies (NCHRP No. 25–25, Task 59). Transportation Research Board, Washington, D.C.
Puckett, S.M., Noel, G., Jackson, L., Marjoncu, E., Razo, M., Reed, E., 2015. Congestion Mitigation and Air Quality (CMAQ) Improvement Program: Cost-Effectiveness Tables Development and Methodology. U.S. Federal Highway Administration, Washington, D.C.
Qadir, R.M., Abbaszade, G., Schnelle-Kreis, J., Chow, J.C., Zimmermann, R., 2013. Concentrations and source contributions of particulate organic matter before and after implementation of a low emission zone in Munich, Germany. Environ. Pollut. 175, 158–167. http://dx.doi.org/10.1016/j.envpol.2013.01.002.
Regan, T., Murphy, E., Hines, M., 2009. SAFETEA-LU 1808: cmaq Evaluation and Assessment, Phase II Final Report (No. FHWA-HEP-09-026). Federal Highway Administration, Washington, D.C.
Rich, D.Q., Liu, K., Zhang, J., Thurston, S.W., 2015. Differences in birth weight associated with the 2008 Beijing Olympics air pollution reduction: results from a natural experiment. Environ. Health Perspect. (Online) 123, 880.
Ropkins, K., Beebe, J., Li, H., Daham, B., Tate, J., Bell, M., Andrews, G., 2009. Real-world vehicle exhaust emissions monitoring: review and critical discussion. Crit. Rev. Environ. Sci. Technol. 39, 79–152.
Rotaris, L., Danielis, R., Marcucci, E., Massiani, J., 2010. The urban road pricing scheme to curb pollution in Milan, Italy: description, impacts and preliminary cost–benefit analysis assessment. Transp. Res. Part A: Policy Pract. 44, 359–375. http://dx.doi.org/10.1016/j.tra.2010.03.008.
Shah, A.S., Langrish, J.P., Nair, H., McAllister, D.A., Hunter, A.L., Donaldson, K., Newby, D.E., Mills, N.L., 2012. Global association of air pollution and heart failure: a systematic review and meta-analysis. Lancet 382, 1039–1048. http://dx.doi.org/10.1016/S0140-6736(13)60898-3.
SLB Analysis, 2006. The Stockholm Trial. Effects on air quality and health. City of Stockholm Environment and Health Administration. (No. SLB report 4: 2006). SLB, Stockholm, Sweden.
Smit, R., Brown, A.L., Chan, Y.C., 2008. Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow? Environ. Model. Softw. 23, 1262–1270.
Smit, R., Ntziachristos, L., Boulter, P., 2010. Validation of road vehicle and traffic emission models – A review and meta-analysis. Atmos. Environ. 44, 2943–2953. http://dx.doi.org/10.1016/j.atmosenv.2010.05.022.
Strömberg, H.K., Karlsson, I.C.M., 2013. Comparative effects of eco-driving initiatives aimed at urban bus drivers – results from a field trial. Transp. Res. Part D: Transp. Environ. 22, 28–33. http://dx.doi.org/10.1016/j.trd.2013.02.011.

Stuart, A., L., Lin, P.-S., Lee, C., Yu, H., Chen, H., 2010. Assessing Air Quality Impacts of Managed Lanes.
Sun, C., Zheng, S., Wang, R., 2014. Restricting driving for better traffic and clearer skies: did it work in Beijing? Transp. Policy 32, 34–41. http://dx.doi.org/10.1016/j.tranpol.2013.12.010.
Teague, W.Seth, Zick, C.D., Smith, K.R., 2015. Soft transport policies and ground-level ozone: an evaluation of the "Clear the Air Challenge" in Salt Lake City. Policy Stud. J. 43, 399–415.
Titos, G., Lyamani, H., Drinovec, L., Olmo, F.J., Močnik, G., Alados-Arboledas, L., 2015. Evaluation of the impact of transportation changes on air quality. Atmos. Environ. 114, 19–31. http://dx.doi.org/10.1016/j.atmosenv.2015.05.027.
Tong, Z., Baldauf, R.W., Isakov, V., Deshmukh, P., Max Zhang, K., 2016. Roadside vegetation barrier designs to mitigate near-road air pollution impacts. Sci. Total Environ. 541, 920–927. http://dx.doi.org/10.1016/j.scitotenv.2015.09.067.
Tonne, C., Beevers, S., Armstrong, B., Kelly, F., 2008. Air pollution and mortality benefits of the London Congestion Charge: spatial and socioeconomic inequalities. Occup. Environ. Med. 65, 620–627.
Transportation Research Board, 2002. The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience (Special Report No. 264). National Academies, Washington, D.C.
U.S. Environmental Protection Agency, 2015. 2011 National Air Toxics Assessment (2011 NATA). Washington, D.C.
U.S. Environmental Protection Agency, 2011a. Transportation Control Measures: an Information Document for Developing and Implementing Emissions Reductions Programs (No. EPA-430-R-09-040). U.S. Environmental Protection Agency, Washington, D.C.
U.S. Environmental Protection Agency, 2011b. Potential Changes in Emissions Due to Improvements in Travel Efficiency - Final Report (No. EPA-420-R-11-003). Washington, D.C.
van Erp, A.M., Kelly, F.J., Demerjian, K.L., Pope, C.A., 2012. Progress in research to assess the effectiveness of air quality interventions towards improving public health. Air Qual., Atmosphere, Health 5, 217. http://dx.doi.org/10.1007/s11869-010-0127-y.
Vardoulakis, S., Chalabi, Z., Fletcher, T., Grundy, C., 2008. Impact and uncertainty of a traffic management intervention: population exposure to polycyclic aromatic hydrocarbons. Sci. Total Environ. 394, 244–251. http://dx.doi.org/10.1016/j.scitotenv.2008.01.037.
von Stackelberg, K., Buonocore, J., Bhave, P.V., Schwartz, J.A., 2013. Public health impacts of secondary particulate formation from aromatic hydrocarbons in gasoline. Environ. Health 12, 19. http://dx.doi.org/10.1186/1476-069X-12-19.
Wang, S., Zhao, M., Xing, J., Wu, Y., Zhou, Y., Lei, Y., He, K., Fu, L., Hao, J., 2010. Quantifying the air pollutants emission reduction during the 2008 olympic games in Beijing. Environ. Sci. Technol. 44, 2490–2496.
Wang, Z., Wang, J., He, D., 2012. Transit policies and potential carbon dioxide emission impacts: some insights from China's recent transit priority policies. Transp. Res. Rec.: J. Transp. Res. Board 98–104.
Weichenthal, S., Van Ryswyk, K., Kulka, R., Sun, L., Wallace, L., Joseph, L., 2015. In-vehicle exposures to particulate air pollution in canadian metropolitan areas: the urban transportation exposure study. Environ. Sci. Technol. 49, 597–605. http://dx.doi.org/10.1021/es504043a.
Wolfermann, A., Gade, K., Jonkers, E., 2015. Impact of ITS on CO_2 emissions – the contribution of a standardised assessment framework. IET Intell. Transp. Syst. 9, 515–522.
Wolff, H., 2014. Keep your clunker in the suburb: low-emission zones and adoption of green vehicles. Econ. J 124, F481–F512. http://dx.doi.org/10.1111/ecoj.12091.
Xu, Y., Elango, V., Guensler, R., Khoeini, S., 2013. Idle monitoring, real-time intervention, and emission reductions from Cobb County, Georgia, school buses. Transp. Res. Rec.: J. Transp. Res. Board pp 59–65.
Yao, Z., Zhang, Y., Shen, X., Wang, X., 2013. Impacts of temporary traffic control measures on vehicular emissions during the Asian Games in Guangzhou, China. J. Air Waste Manag. Assoc. 63, 11.
Zhou, Y., Wu, Y., Yang, L., Fu, L., He, K., Wang, S., Hao, J., Chen, J., Li, C., 2010. The impact of transportation control measures on emission reductions during the 2008 Olympic Games in Beijing, China. Atmos. Environ. 44, 285–293. http://dx.doi.org/10.1016/j.atmosenv.2009.10.040.