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Congestion and emissions mitigation: A comparison of capacity, demand, and vehicle based strategies

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Abstract

Capacity, demand, and vehicle based emissions reduction strategies are compared for several pollutants employing aggregate US congestion and vehicle fleet condition data. We find that congestion mitigation does not inevitably lead to reduced emissions; the net effect of mitigation depends on the balance of induced travel demand and increased vehicle efficiency that in turn depend on the pollutant, congestion level, and fleet composition. In the long run, capacity-based congestion improvements within certain speed intervals can reasonably be expected to increase emissions of CO₂e, CO, and NO_x through increased vehicle travel volume. Better opportunities for emissions reductions exist for HC and PM_{2.5} emissions, and on more heavily congested arterials. Advanced-efficiency vehicles with emissions rates that are less sensitive to congestion than conventional vehicles generate less emissions co-benefits from congestion mitigation.

Highlights

- ▶ Traffic emissions co-benefits from congestion mitigation are not guaranteed.
- ▶ Long-term demand elasticity is a key variable to estimate net emissions reductions.
- ▶ Hydrocarbon and fine particulate emissions are most likely to decrease.
- ▶ Advanced efficiency vehicles reduce expected emissions co-benefits.
- ▶ Demand and vehicle based emissions-reduction strategies can be more attractive.

Introduction

In many cases, emissions reductions are cited as an implicit benefit of congestion mitigation without proper justification or quantification of the benefits. For example, the US Federal Highway Administration's Congestion Mitigation and Air Quality (CMAQ) improvement program suggests a clear co-beneficial

relationship. If congestion mitigation is to be tied to air quality goals, we need better understanding of congestion impacts on motor vehicle emissions.

Vehicle emissions from motorized transportation have an established role in decreasing urban air quality and increasing atmospheric greenhouse gases. Concurrently, roadway congestion impacts urban areas throughout the world with varying economic, social, and environmental costs. But the full effects of traffic congestion on motor vehicle emissions are still not well quantified due to the existence of feedback effects and complex interactions. Potential changes in travel behavior or vehicle technology are two factors that complicate the evaluation of congestion mitigation effects on future emissions.

An important consideration to evaluate the impact of congestion mitigation measures on emissions is the effect of induced travel demand volume resulting from travel time savings. A report by Dowling (2005) used travel demand modeling to estimate the air quality effects of traffic flow improvements. The conclusion of the report states that more research is needed “to better understand the conditions under which traffic-flow improvements contribute to an overall net increase or decrease in vehicle emissions.” Other, more focused research on a limited spatial scale has shown that induced demand from individual traffic flow improvements can entirely offset emissions rate reductions (Stathopoulos and Noland, 2003, Noland and Quddus, 2006).

Capacity-based strategies (CBSs) for reducing emissions ease congestion by increasing a roadway’s vehicle throughput capacity and so increase vehicle operating efficiency. CBS can increase capacity by increasing physical lane-miles or by increasing existing roadway utilization through traffic flow improvements. The desired emissions benefit of congestion mitigation through CBS is reduced marginal emissions rates at higher average traffic speeds. However, it has the potential to generate induced vehicle travel demand.

Alternative strategies for reducing emissions can be vehicle based strategies (VBS) or demand based strategies (DBS). VBS directly target emissions through cleaner vehicles and fuels or more efficient driving. DBS, such as road pricing, reduce emissions by reducing vehicle travel volume and can reduce congestion simultaneously.

Here we investigate the broad conditions in which emissions co-benefits can be expected from congestion mitigation and compare capacity, demand, and vehicle based emissions reduction strategies. In particular, we study the effects of travel demand elasticity, the consequences of advanced vehicles in the fleet, and the role of light-duty and heavy-duty vehicles across types of pollutants. The methodological framework allows for a parsimonious estimation of net emissions effects at the aggregated level.

Section snippets

Methodological framework

The concept of elasticity is employed to set up the conditions that lead to positive or negative net emissions changes. The elasticity, $\epsilon_{\bar{e}}^{\bar{v}}$, of average emissions rate, \bar{e} , to average travel speed, \bar{v} , is expressed $\epsilon_{\bar{e}}^{\bar{v}} = \frac{\bar{v}}{\bar{e}} \cdot \frac{\partial \bar{e}}{\partial \bar{v}}$.

The average vehicle emissions rate in mass per unit distance of travel is denoted as \bar{e} , and emissions from all on-road vehicles in mass per unit length of road, per unit of time is denoted as E . If the vehicle travel

demand volume on a roadway is q (in vehicle...

Emissions impacts of CBS

The long-term net emissions effects of CBS can be estimated as $\varepsilon_{\bar{E}}^{\bar{v}}$ from Eq. (3), with modeled values for a_i and an expected value for travel demand elasticity, $\eta_q^{\bar{v}}$ (which is highly uncertain). To estimate only the sign of net changes in emissions it is only necessary to determine the value of the break-even demand elasticity $\gamma_q^{\bar{v}}$, which is dependent on average travel speed, vehicle fleet composition, and ESC parameters. Three distinct scenarios are possible: (a) if $\eta_q^{\bar{v}} < \gamma_q^{\bar{v}}$ then CBS will...

The impacts of more efficient vehicles (VBS)

The results in Section 3 are for conventional internal combustion engine (ICE) vehicles only – the vast majority of the existing on-road fleet (US Environmental Protection Agency, 2009b). We now examine the effects of introducing advanced vehicles in the fleet, a form of VBS. By reducing \bar{e} , VBS decrease emissions as $\frac{\partial E}{\partial \bar{e}} = q$ (from Eq. (5)), and thus $\varepsilon_{\bar{E}}^{\bar{e}} = 1$. But VBS can also impact the efficacy of CBS for emissions reductions. Let vehicle class $j=c$ be all conventional ICE vehicles, vehicle class ...

Travel volume reductions and emissions

In terms of the methodological framework, by reducing q , DBS decrease emissions as $\frac{\partial E}{\partial q} = \bar{e}$ (from Eq. (5)), or $\varepsilon_{\bar{E}}^q = 1$. But DBS also relate to congestion through the CBS analysis. When $\eta_q^{\bar{v}} > \gamma_q^{\bar{v}}$, average speed-based efficiency alone cannot reduce emissions because of induced travel demand. From the DBS perspective, when $\eta_q^{\bar{v}} > \gamma_q^{\bar{v}}$ a capacity decrease (i.e. “road diet”) can reduce emissions if the suppressed travel demand volume offsets higher vehicle emission rates at lower average travel speeds....

Comparing strategies for emissions reductions

Initially we look at freeways, comparing VBS and DBS to CBS that increase congested speeds as indicated by a level-of-service (LOS) change.² The comparison is presented as the amount of a VBS or DBS that would achieve equivalent emissions reductions to the CBS. Results for CO₂e emissions are shown in ...

Vehicle class-specific strategies

The distinct emissions performance of LD and HD vehicles raises the potential for emissions co-benefits from more focused congestion mitigation strategies that address vehicle classes separately. As a comparison of congestion and emissions mitigation approaches and their class-specific effects, Table 4 shows a short list of emissions mitigation strategies with their expected direct impacts on the key variables of this analysis: travel speed v_j , travel volume q_j , emissions rate parameters a_{ij}, \dots

Conclusions

We find that congestion mitigation does not inevitably lead to reduced emissions, and that the net effect of congestion mitigation will greatly depend on the type of emissions being analyzed. In the long run, capacity-based congestion reductions within certain speed intervals (e.g. 30–40mph) can be expected to increase emissions of CO₂e, CO, and NO_x through increased vehicle travel volume. Wider speed ranges will see increased emissions in more specific conditions. Vehicle emissions of HC and PM...

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References (12)

R.B. Noland *et al.*

[Flow improvements and vehicle emissions: effects of trip generation and emission control technology](#)

Transportation Research Part D (2006)

S.D. Beevers *et al.*

[The impact of congestion charging on vehicle emissions in London](#)

Atmospheric Environment (2005)

M. Barth *et al.*

[Real-world carbon dioxide impacts of traffic congestion](#)

Transportation Research Record (2008)

M. Barth *et al.*

[Estimating emissions and fuel consumption for different levels of freeway congestion](#)

Transportation Research Record (1999)

R.G. Dowling

[Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide \(NCHRP No. 535\)](#) (2005)

C. Samaras *et al.*

[Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: implications for policy](#)

Environmental Science & Technology (2008)

There are more references available in the full text version of this article.

Cited by (33)

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Citation Excerpt :

...Congestion mitigation is of everlasting importance for travel demand management (TDM), and different measures have been taken to identify solutions to reduce car use (Bigazzi and Figliozzi, 2012; Choo and Mokhtarian, 2008; Fujii and Taniguchi, 2005; Noland and Lem, 2002; Percoco, 2013; Taylor, 2004)...

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Children's exposure to BC and PM pollution, and respiratory tract deposits during commuting trips to school

2022, Ecotoxicology and Environmental Safety

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...This result indicated that the environmental concentration of a given air pollutant was the main factor driving personal exposure to it (Qiu et al., 2019; Hofman et al., 2018). Consistent with other studies (Onat et al., 2019; Bigazzi and Figliozzi, 2012), meteorological variables variously impacted pollutant exposure under the differing modes of transportation used by children. Wind speed was a significant factor determining exposure to BC when commuting in a private car (explaining 10.9% of its variation) and on the e-bike (explaining 28% of its variation), whereas it was negligible when walking...

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2021, Socio-Economic Planning Sciences

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...Traffic congestion can result in an increasing number of rear-end crashes [3] and severe crashes; increased traffic congestion levels are also associated with the increasing number of fatal and severe injury crashes [4]. Emissions and air quality, particularly from commercial vehicles, can also suffer from increasing traffic congestion levels [5–7]. Traffic congestion is particularly a significant problem in urban areas; in 2010, 80.7% of the U.S. population lived in urban areas [8], which significantly affects traffic congestion and travel time delays [9]...

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...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)....

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2017, Transportation Research Part C: Emerging Technologies

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