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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 CO_2e, 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, $\varepsilon_{\bar{e}}^{\bar{v}}$, of average emissions rate, $\bar{e}$, to average travel speed, $\bar{v}$, is expressed$\varepsilon_{\bar{e}}^{\bar{v}} = \frac{\bar{v}}{\bar{e}} \cdot \frac{\partial \bar{e}}{\partial \bar{v}}$.

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 $\varepsilon_{E}^{\bar{v}}$ 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 $\gamma_q^{\overline{v}}$, which is dependent on average travel speed, vehicle fleet composition, and ESC parameters. Three distinct scenarios are possible: (a) if $\eta_q^{\overline{v}} < \gamma_q^{\overline{v}}$ 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 $\overline{e}$, VBS decrease emissions as $\frac{\partial E}{\partial \overline{e}} = q$ (from Eq. (5)), and thus $\varepsilon_E^{\overline{e}} = 1$. 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 $\frac{\partial E}{\partial q} = \overline{e}$ (from Eq. (5)), or $\varepsilon_E^{q} = 1$. But DBS also relate to congestion through the CBS analysis. When $\eta_q^{\overline{v}} > \gamma_q^{\overline{v}}$, average speed-based efficiency alone cannot reduce emissions because of induced travel demand. From the DBS perspective, when $\eta_q^{\overline{v}} > \gamma_q^{\overline{v}}$ 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 CO_2e 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 $a_{i,j}$,

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. 30–40 mph) can be expected to increase emissions of CO_2e, 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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