Accounting for Vehicular Emissions in Managing Networks of Traffic and Transit

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Research Question

Transportation is a major contributor of greenhouse gas emissions, and these emissions are increasingly a consideration in decisions regarding the design and management of urban transportation systems. Many urban street networks are known to exhibit a robust relationship between average vehicle flow and average vehicle density known as the Macroscopic Fundamental Diagram (MFD), which characterizes congested and hypercongested traffic conditions that develop as streets become crowded. Decisions about whether to operate buses in mixed traffic or in dedicated lanes as well as equilibrium travel choices resulting from pricing incentives affect the traffic conditions for cars and the operating conditions for transit. By linking macroscopic traffic models with emission models that account for the driving cycles of cars and buses, this paper seeks to quantify the effect of efficient lane allocation and pricing schemes on system-wide emissions of greenhouse gases.

Methodology

This paper connects models of network traffic and equilibrium with models of emissions associated with the driving cycles of cars and transit vehicles. The MFD describes a robust relationship between vehicle accumulation and average flow in a network, which also implies the average speed of vehicles (Daganzo, 2007). This macroscopic approach has been the basis of studies of traffic dynamics (Arnott, 2013; Fosgerau, 2015) and multimodal equilibrium with cars and transit (Gonzales and Daganzo, 2012; Gonzales, 2015) allowing for hypercongested traffic states in which increasing accumulations of vehicles result in decreased flow. Most of the engineering and economic studies of network-wide traffic focus on quantifying travel times and monetary costs of capital and operations.

State of the art emission models require detailed information about vehicle trajectories, such as the sequence of second-by-second speeds and accelerations that constitute a vehicle’s driving cycle in a network (Barth et al., 2000; Rakha et al., 2000). A simplified approach to emission modeling is to define the driving cycle in terms of driving modes: cruising, idling, acceleration, and deceleration (Shabihkhani and Gonzales, 2014). The driving cycle is affected by the traffic conditions in the network, and these components can be predicted for cars based on the MFD traffic state and for transit by also considering the design of the route in terms of stop spacing, headway, and whether buses operate in mixed traffic or dedicated lanes. The approach used for this paper is to use connect MFD-based analysis of traffic conditions in user equilibrium and system optimum conditions with emission factors that are associated with the driving cycles of cars and transit in these cases. An application of the model is demonstrated with a numerical example is presented based on the measured MFD of Yokohama, Japan (Geroliminis and Daganzo, 2008) and emission factors obtained by calculating the vehicle specific power for cars (Frey et al., 2008) and buses (Frey et al., 2007).
Results

The results of the paper show that incentivizing the use of transit is an effective way to reduce emissions from transportation. Optimal pricing strategies are compared for two objectives: minimizing the generalized cost of operations and travel time; and minimizing emissions. For low values of demand, when traffic conditions are uncongested even when all users travel by car, there is a trade-off between the generalized cost and the emissions. At these low demands, it is costly to reduce emissions by incentivizing travelers to use transit, because travel times are greater in transit than driving in free-flowing traffic. At higher demands, it is cost-effective to incentivize transit use in order to avoid hypercongested traffic conditions, and the elimination of wasteful hypercongestion is also beneficial for greenhouse gas emissions.

In a numerical application based on the measured MFD of Yokohama, Japan, the system optimum for minimizing emissions reduced emissions by more than 85% for most levels of demand compared to the unpriced user equilibrium. For levels of demand that result in hypercongestion in unpriced user equilibrium, the system optimum for minimizing the generalized cost results in greenhouse gas emissions reductions by more than 55%. The paper demonstrates a method for quantifying the costs of reducing emissions and shows that optimized pricing to minimize user and agency costs can achieve substantial emission reduction benefits compared to the unpriced equilibrium while also reducing system costs.

References
