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Inhalation of motor vehicle emissions: effects of urban population and land area

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Abstract

Urban population density may influence transportation demand, e.g., as expressed through average daily vehicle-kilometers traveled in private motor vehicles per capita. In turn, changes in transportation demand influence total passenger vehicle emissions to which populations are exposed. Population density can also influence the fraction of total emissions that are inhaled by the exposed urban population. Equations are presented that describe these relationships for an idealized representation of an urban area. Using analytic solutions to these equations, we investigate the effect of three changes in urban population and urban land area (infill, sprawl, and constant-density growth) on per capita inhalation intake of primary pollutants from passenger vehicles. For the system considered, the magnitude of these effects depends on density–emissions elasticity (ε_e), a normalized derivative relating change in population density to change in vehicle emissions. For example, based on the idealized representation of the emissions-to-intake relationship presented herein, if urban population increases, then per capita intake is less with infill development than with constant-density growth if ε_e is <-0.5, while for $\varepsilon_e > -0.5$, the reverse is true.

Keywords: Population density; Infill; Sprawl; Land-use planning; Transportation planning; Smart growth

1. Introduction

Motor vehicles are a major source of the criteria pollutants and hazardous air pollutants that are ubiquitous to urban areas in the US and worldwide. Traditionally, air-quality engineers have investigated the connection between transportation demand (measured, for example, in terms of total vehicle-miles traveled) and emissions, and between emissions and ambient concentrations. Recently, air-quality managers have begun to consider the extent to which urban planning may reduce transportation demand and motor vehicle emissions. Increasing population density is expected to reduce average daily vehicle-kilometers traveled in private motor vehicles per capita (VKT) for several reasons (Ewing and Cervero, 2001). For example, increasing

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population density increases accessibility: people in more dense areas do not need to travel as far to reach common destinations such as stores, theaters, and employment centers (Cervero, 1997; Levinson, 1998). Public transit and nonmotorized private transportation such as walking and biking have higher mode shares in more densely populated regions (Crane, 2000; Messenger and Ewing, 1996). Certain disincentives to driving, such as congestion delays and limited parking availability, occur more frequently in densely populated areas.

A broad definition for infill development is "any type of new development that occurs within existing built-up areas" (US EPA, 1999a). The potential association between density and VKT has led some planners to implement policies to accommodate growing urban population that encourage infill development rather than sprawl (APA, 2002; Burchell et al., 2002; US EPA, 2001a). To understand the air-quality impacts of such policies, two questions can be considered: (1) Under what circumstances does increasing population density reduce vehicle emissions? (2) Under what circumstances does reducing emissions by increasing population density reduce people's inhalation intake of vehicle emissions? A few publications have commented on these questions. An international study of motor vehicle use concluded that "whilst *per capita* [transportation] emissions may be higher in the low-density automobile-dependent regions, the rate of [transportation] emissions per urbanized hectare [is] clearly lower. We thus have the situation in the high-density cities… where emissions output is highly concentrated. This leads to more concentrated impacts and higher exposure…" (Kenworthy and Laube, 2002). Cervero (2000) summarizes the dilemma: "exposure levels (and thus health risks) are lower with sprawl, but tailpipe emissions and fossil-fuel consumption are greatly increased."

Many urban areas are growing in population or land area or both, and this growth may impact emissions and emissions-to-intake relationships. Such impact will vary with urban conditions (e.g., urban population) and with the nature of growth. To our knowledge, no prior research has quantified how changes in urban land area and urban population would affect the population inhalation of transportation emissions. Nor has previous research addressed the necessary conditions such that increased population density is accompanied by reduced inhalation of vehicle emissions. This paper contributes to filling these gaps. In addition to offering insights for air-quality management and urban planning, our work can inform expectations in the absence of strong planning.

We start with the premise that population inhalation of vehicle pollutants is more appropriate than emissions or individual exposures as an indicator of the health impacts attributable to air pollution (Bennett et al., 2002). In this paper, we develop and present an exploratory analysis that considers a hypothetical, idealized representation of an urban area. Using this representation, we investigate, quantitatively and parametrically, how three changes in urban land area and urban population influence population inhalation of motor vehicle emissions: (1) increasing population while land area remains constant (denoted "infill" in this paper), (2) increasing land area while population remains constant ("sprawl"), and (3) increasing land area and population while density remains constant ("constant-density growth"). Note that as employed in this paper, these terms have a narrower and more precisely defined scope than in common usage.

There is debate in the literature as to whether and how much population density and other aspects of urban form influence VKT. Some investigations have found that increasing density reduces VKT while others have found no connection (Badoe and Miller, 2000). Some research suggests that the correlation between density and VKT is not causal, but rather that density serves as a proxy for income, which is itself causally connected to VKT (Boarnet and Sarmiento, 1998). Others disagree, finding that both density and income are important (Kenworthy and Laube, 2002). This paper does not take a position on this debate. Because there is variability and uncertainty in the impact of density on VKT and vehicle emissions (Badoe and Miller, 2000; Gordon and Richardson, 1997), we allow a range of values (including zero) for the density–emissions elasticity, and we identify the minimum elasticity necessary for a given change in urban population and land area to reduce intake.

2. Methods

Because this paper represents the first attempt to quantify the relationship between population density and the inhalation intake of primary traffic-related air pollutants, we aim for a direct approach that clarifies underlying relationships, aids in elucidating causal connections, and permits the problem to be analytically tractable. We consider population density, passenger vehicle emissions, attributable ambient concentrations for primary pollutants, and the resulting attributable intake per capita. Below we describe our method for connecting these elements of the source–intake relationship for primary pollutants from motor vehicles.

2.1. Density–emissions elasticity

Population density has the potential to influence vehicle emissions (Holtzclaw et al., 2002) as well as the fraction of emissions inhaled by people (Lai et al., 2000). Population density is a key aspect of urban form, and one that can be influenced by urban planning.