Science of the Total Environment 450–451 (2013) 307–316

Contents lists available at SciVerse ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Air pollution and health risks due to vehicle traffic

Kai Zhang [a], Stuart Batterman [b,*]

[a] Division of Epidemiology, Human Genetics and Environmental Sciences, University of Texas School of Public Health, Houston, TX 77030, USA
[b] Dept. of Environmental Health Sciences, University of Michigan, Ann Arbor, MI 48109-2029, USA

HIGHLIGHTS

► Congestion and additional traffic can significantly increase exposures and risks.
► Risks and exposures are not proportional to traffic volumes.
► Incremental risks depend on site-specific factors including road type.

ARTICLE INFO

Article history:
Received 6 April 2011
Received in revised form 17 January 2013
Accepted 24 January 2013

Keywords:
Congestion
Morbidity
Mortality
NO_2
Risk assessment
Traffic-related air pollution

ABSTRACT

Traffic congestion increases vehicle emissions and degrades ambient air quality, and recent studies have shown excess morbidity and mortality for drivers, commuters and individuals living near major roadways. Presently, our understanding of the air pollution impacts from congestion on roads is very limited. This study demonstrates an approach to characterize risks of traffic for on- and near-road populations. Simulation modeling was used to estimate on- and near-road NO_2 concentrations and health risks for freeway and arterial scenarios attributable to traffic for different traffic volumes during rush hour periods. The modeling used emission factors from two different models (Comprehensive Modal Emissions Model and Motor Vehicle Emissions Factor Model version 6.2), an empirical traffic speed–volume relationship, the California Line Source Dispersion Model, an empirical NO_2–NO_x relationship, estimated travel time changes during congestion, and concentration–response relationships from the literature, which give emergency doctor visits, hospital admissions and mortality attributed to NO_2 exposure. An incremental analysis, which expresses the change in health risks for small increases in traffic volume, showed non-linear effects. For a freeway, "U" shaped trends of incremental risks were predicted for on-road populations, and incremental risks are flat at low traffic volumes for near-road populations. For an arterial road, incremental risks increased sharply for both on- and near-road populations as traffic increased. These patterns result from changes in emission factors, the NO_2–NO_x relationship, the travel delay for the on-road population, and the extended duration of rush hour for the near-road population. This study suggests that health risks from congestion are potentially significant, and that additional traffic can significantly increase risks, depending on the type of road and other factors. Further, evaluations of risk associated with congestion must consider travel time, the duration of rush-hour, congestion-specific emission estimates, and uncertainties.

1. Introduction

Traffic on roads has significantly increased in the U.S. and elsewhere over the past 20 years (Schrank and Lomax, 2007). In many areas, vehicle emissions have become the dominant source of air pollutants, including carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs) or hydrocarbons (HCs), nitrogen oxides (NO_x), and particulate matter (PM) (Transportation Research Board (TRB), 2002). The increasing severity and duration of traffic congestion have the potential to greatly increase pollutant emissions and to degrade air quality, particularly near large roadways. These emissions contribute to risks of morbidity and mortality for drivers, commuters and individuals living near roadways, as shown by epidemiological studies, evaluations of proposed vehicle emission standards, and environmental impact assessments for specific road projects (World Health Organization (WHO), 2005; Health Effects Institute (HEI), 2010).

It is useful to separate traffic-associated pollutant impacts and risks into two categories. First, "congestion-free" impacts refer to impacts of traffic at volumes below the level that produces significant congestion. In this case, each additional vehicle added to the road does not substantially alter traffic patterns, e.g., the speed and travel time of other vehicles are unaffected, and thus vehicle emission factors do not depend on traffic volume. As a result, the marginal impact of an additional vehicle is equal to the average impact of the vehicle fleet. This is not necessarily true during congestion, the

* Corresponding author. Tel.: +1 734 763 8095.
E-mail address: stuartb@umich.edu (S. Batterman).

0048-9697/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.01.074

second category considered. While there are many definitions, congestion is often defined as periods when traffic volume exceeds road capacity. (Other definitions use a speed threshold, a percentage of free-flow speed of a roadway, or other indicator.) The present study focuses on what might be called "recurring congestion," specifically, congestion caused by high traffic volumes during weekday peak "rush hour" periods. However, traffic volume is treated as a continuous variable, and strict definitions of congestion are not needed.

In the present analysis, "congestion-related" impacts incorporate multiple interactions that occur with congestion. First, congestion lowers the average speed, which increases travel time and exposure on a per vehicle basis. This effect can be considerable, e.g., the average annual travel delay for a traveler making rush hour trips in the U.S. was 38 h in 2005, based on 437 urban areas (Schrank and Lomax, 2007). Second, congestion diminishes dispersion of vehicle-related pollutants since vehicle-induced turbulence depends on vehicle speed (Benson, 1989). Thus, lower vehicle speeds can increase pollutant concentrations from roadway sources. Third, congestion can change driving patterns, resulting in an increased number of speedups, slowdowns, stops and starts, which increase emissions compared to "cruise" conditions, especially with high power acceleration. For example, Sjodin et al. (1998) showed up to 4-, 3- and 2-fold increases in CO, HC and NO_x emissions, respectively, with congestion (average speed of 13 miles per hour, mph; 1 mph = 1.61 km per hour) compared to uncongested conditions (average speed, 38–44 mph). Thus, it is important to separate congestion-free and congestion-related impacts since emissions, impacts and risks can differ greatly, and because such analyses can better inform decisions related to traffic and air quality management, as well as impact and risk assessments.

Few evaluations of congestion-related impacts have been undertaken, and available studies have essentially combined congestion and non-congestion related impacts. Tonne et al. (2008) predicted that the congestion charging zone in London, where drivers must pay fees when their vehicles enter this area, would gain 183 years-of-life per 100,000 population in the congestion charging zone itself and a total of 1,888 years-of-life in the greater London area. Eliasson et al. (2009) estimated that a similar zone in Stockholm would avoid 20–25 deaths annually due to traffic-related air pollution in the inner city, and 25–30 deaths annually in the metropolitan area, which contains 1.4 million inhabitants. Both studies indicate that congestion pricing is beneficial in reducing traffic-related health impacts, but congestion-free and congestion-related impacts were not separated. These European studies focused on congestion charging zones, which are uncommon in the U.S., and the vehicle mix and fleet emission characteristics may differ substantially from those in the U.S. Using a different approach that examined shifts in time activity patterns (TAPs: the amount of time spent at various locations and related activities) due to travel delays along with literature values of exposure concentrations in relevant microenvironments, we estimated that a 30 min day^{-1} travel delay accounted for $21 \pm 12\%$ of the exposure to benzene and $14 \pm 8\%$ of $PM_{2.5}$ for a typical working adult on weekdays (Zhang and Batterman, 2009). Levy et al. (2010) estimated that the estimated public health cost of mortality attributable to congestion in 83 U.S. cities in 2000 was $31 billion (2007 dollars). This study used a macro-level approach to estimate traffic volume, which was then linked to the Motor Vehicle Emissions Factor Model 6.2 (MOBILE6.2) (EPA, 2003), thus providing a snapshot of congestion. However, congestion is dynamic and varies with time, space, weather and other factors (Downs, 2004). Overall, these studies suggest that congestion represents a substantial share of exposure to drivers and commuters, with potentially significant risks and impacts on health.

This study investigates the magnitude of air pollution impacts and health risks to on- and near-road populations that might occur due to recurring congestion, such as Monday through Friday rush hour traffic. Recurring congestion can result in repeated and chronic exposures, and an increase in long term health risks. "Incident congestion," such as that caused by an accident or disabled vehicle, is not addressed, although such events may also be important for certain acute health outcomes, e.g., asthma exacerbation. This study utilizes predictive risk assessment techniques, namely, simulation models for traffic, emissions, pollutant dispersion and risk, and an incremental analysis that evaluates congestion-free and congestion-related impacts. After describing the approach, two case studies are used to analyze air pollution impacts and risks. A limited sensitivity analysis is conducted to examine impacts of key parameters on the estimated incremental risk. The merits of the various approaches that might be used to estimate congestion impacts conclude the analysis.

2. Methods

2.1. Approach

Risk assessment methods, depicted in Fig. 1, are used to estimate health risks due to traffic for two scenarios. In brief, vehicle emissions are used as an input to a dispersion model to estimate concentrations, which are then multiplied by exposure time and a risk factor representing the concentration–response relationship. While some exposure and risk assessments utilize time activity patterns (TAPs) or human activity patterns, for simplicity we consider only exposure durations in traffic microenvironments, which include the delays due to traffic congestion. An incremental analysis is used to estimate the marginal impacts of increases in traffic volume. Such analyses are widely used in economic models to examine effects of small changes of an input on outcomes of interest; they also represent one of the classical "sensitivity analysis" techniques used to identify key variables in modeling systems (Trueman, 2007). One difference here, however, is that a wide range of traffic flows is examined over which relationships are expected to vary considerably.

2.2. Case studies

Two case studies or scenarios were developed to examine associations between traffic volume, exposures and health risks. The first, a freeway scenario, models an 8 km long segment of interstate I-94 in Ann Arbor, MI (Fig. S1), which was selected for a field study in which instantaneous emission rates were modeled. This segment had a permanent traffic recorder (PTR) operated by the Michigan Department of Transportation (MDOT). The portion of the segment west of US-23 had two lanes in each direction; the segment to the east had three lanes in each direction. The annual average daily traffic (AADT) volumes for these segments were 78,300 and 91,300 vehicles day^{-1} in west and east directions, respectively (MDOT, 2008). During the field study described in Zhang et al. (2011), traffic volumes were 3099 and 4040 vehicles per hour (vph) in morning and afternoon rush hour periods, respectively. The vehicle mix (8% heavy duty trucks and 92% light duty vehicles) during rush hour was based on PTR records from October, 2007 (Southeast Michigan Council of Governments (SEMCOG), 2006), and was assumed to be constant. The southeast Michigan vehicle age distribution was assumed to represent the fleet. The traffic volume in the incremental analysis was allowed to vary from 1000 to 10,000 vph. Given that design capacity is 2000 vehicles h^{-1} lane^{-1} for a freeway (SEMCOG, 2004), the upper volume represents about 120% of road capacity. In addition to the freeway scenario with an incremental analysis, a scenario using observed volumes on I-94 during rush hour was modeled to demonstrate the spatial and temporal patterns of predicted pollutant levels.

An arterial scenario was also modeled. This used a segment along Grand River Boulevard (M-5) in Detroit, which is 8.5 km long and includes two lanes per direction and a central turning lane (Fig. S2). The AADT volumes for the segment west of M-39 and east of M-39 were 23,800 and 19,200 vehicles day^{-1}, respectively (MDOT, 2009). The regional vehicle mix and age distribution described above were used. Traffic volumes ranged from 1000 to 4000 vph (about 120% of road capacity; design capacity is 825 vehicles h^{-1} lane^{-1} for an arterial road; SEMCOG, 2004).