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Temporal variation of traffic on highways and the development of accurate temporal allocation factors for air pollution analyses

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HIGHLIGHTS

- Temporal variation in traffic volume affects emissions and pollutant exposures.
- Annual traffic volume can be apportioned to the hour using temporal allocation factors.
- Temporal allocation factors (TAFs) must separate passenger and commercial vehicles.
- TAFs must separate weekdays, Saturdays, Sundays and observed holidays.
- Most variation in traffic flows can be addressed using appropriate TAFs.

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ABSTRACT

Traffic activity encompasses the number, mix, speed and acceleration of vehicles on roadways. The temporal pattern and variation of traffic activity reflects vehicle use, congestion and safety issues, and it represents a major influence on emissions and concentrations of traffic-related air pollutants. Accurate characterization of vehicle flows is critical in analyzing and modeling urban and local-scale pollutants, especially in near-road environments and traffic corridors. This study describes methods to improve the characterization of temporal variation of traffic activity. Annual, monthly, daily and hourly temporal allocation factors (TAFs), which describe the expected temporal variation in traffic activity, were developed using four years of hourly traffic activity data recorded at 14 continuous counting stations across the Detroit, Michigan, U.S. region. Five sites also provided vehicle classification. TAF-based models provide a simple means to apportion annual average estimates of traffic volume to hourly estimates. The analysis shows the need to separate TAFs for total and commercial vehicles, and weekdays, Saturdays, Sundays and observed holidays. Using either site-specific or urban-wide TAFs, nearly all of the variation in historical traffic activity at the street scale could be explained; unexplained variation was attributed to adverse weather, traffic accidents and construction. The methods and results presented in this paper can improve air quality dispersion modeling of mobile sources, and can be used to evaluate and model temporal variation in ambient air quality monitoring data and exposure estimates.

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1. Introduction

Traffic activity encompasses the number of vehicles per hour on a road section, vehicle mix (fraction of different types of vehicles), and vehicle speed and acceleration. Traffic activity is dynamic, varying with strong daily, weekly and seasonal patterns. This variation affects on-road vehicle emissions, and, along with changes in meteorological conditions that govern dispersion, can cause dramatic changes in concentration of traffic-related pollutants, especially near major roads (Gokhale, 2011; Kimbrough et al., 2013). Exposure to traffic-related pollutants has been associated with many adverse health effects (Health Effects Institute, 2010), and improved exposure estimates are needed to improve our understanding health impacts (Batterman, 2013; Brauer et al., 2013).

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Exposures have been estimated, at community to national scales, using geographic metrics (e.g., the proximity of homes to major roads), statistical modeling (e.g., land use regression), simulation modeling (e.g., dispersion models), and hybrid methods (Jerrett et al., 2005; Rioux et al., 2010; Pratt et al., 2014). Most of these methods do not account for temporal variation. In addition, the temporal profiles used to estimate hourly emissions may not reflect the travel patterns of heavy-duty and other vehicles (Lindhjem et al., 2012).

Many factors affect traffic activity, and these need to be considered when modeling on-road emissions. In most US cities, a large or dominant part of vehicle-miles-traveled (VMT) occurs on major roads. If the temporal variation in activity along these major roads can be accurately characterized, then modeling air quality and exposures in urban areas can be greatly improved. This paper presents a methodology for developing temporal allocation factors that account for nearly all variation in traffic activity along major roads in urban regions, and thus can greatly improve the accuracy of air quality modeling at the urban scale. This analysis is motivated by the need to improve exposure estimates of traffic-related air pollutants in epidemiology and other studies (Vette et al., 2013). Results are intended to increase the understanding of temporal variation in traffic-related exposures, and to improve modeling of mobile source emissions.

1.1. Estimating traffic activity

The preferred approach to estimate traffic activity uses continuous and site-specific monitoring of vehicle counts, ideally with additional information to determine vehicle classification. Continuous counting stations used for such measurements employ various technologies, e.g., embedded inductive loops, piezoelectric sensors, magnetic sensors, cameras, and radars (U.S Federal Highway Administration, 2013). Currently, most stations measure vehicle counts and do not provide classification data. Weigh-in-motion sensors, which can determine whether a vehicle is overweight as well as provide classification information, are being increasingly deployed at permanent monitoring sites. Counting stations providing long term data are usually permanent sites. Count and classification data collected at temporary sites are more common. Typically, these short-term counts are collected using tube counters and/or trained observers in field campaigns that last a few weekdays to a few weeks. Seasonal or monthly adjustments may be used to estimate the annual average daily traffic (AADT) volume. Similar approaches are used to estimate commercial annual average daily traffic (CAADT), which applies to vans, buses and trucks. In addition, traffic activity can be estimated using measurements at other locations, statistical forecasts, and simulation models, e.g., microsimulation (agent-based) and traffic-demand models. Video cameras and cell phone tracking provide additional data, primarily to monitor traffic congestion. While AADT estimates are available in many jurisdictions, continuous measurements are comparatively rare.

Given the AADT or CADT, hourly volumes can be estimated using a "bottom-up" approach by applying temporal allocation factors (TAFs), also called "temporal profiles" (Cook et al., 2008). TAFs are formulated at month-of-year, day-of-week, and hour-of-day levels and derived using historical data collected either locally or nationally. Multiplying the AADT by the TAFs allocates traffic volume to the hour. For example, TAFs reflect commuting patterns, which typically show morning and afternoon volume peaks (and often "rush hour" congestion) and a bimodal diurnal profile, while truck volumes peak during the workday, and some truck drivers may schedule routes and work times to avoid rush hours. The true activity will depend on vehicle type, road type, location, weather and other factors.

In the U.S., TAFs compiled in 1985 for the National Acid Precipitation Assessment Program used four profiles and considered two vehicle classes – light-duty gasoline vehicles, and all vehicle classes; (Fratt et al., 1990; Cook et al., 2008). A single profile was used for seasons (classes combined), two profiles for day-of-week (separating weekends and weekdays), and one profile for hour-of-day (classes combined). Later, a national FHWA database of vehicle activity was used to develop 24 profiles. These profiles were developed for eight vehicle classes by day-of-week (each day of the week), weekday hour-of-day, and weekend hour-of-day (Pollack et al., 2006). Other profiles have been incorporated into the SMOKE modeling system (http://www.cmascenter.org/smoke/), and the current national average profiles provide hourly weekday and weekend profiles for different vehicle classes; work is underway to separate Saturday and Sunday profiles. As shown later, generic profiles can mischaracterize activity on individual roadways or in specific communities.

2. Methods

Data processing and analysis involved obtaining, cleaning and filtering the traffic activity data, calculating monthly and daily volume averages at each counting site, determining TAFs, and determining normalized volumes that represent the volume expected for each day, week and season. We then provide a descriptive analysis of temporal patterns, identify factors that caused volumes to alter from expected values, test for differences between sites, and compare the performance of the TAF-based model using an independent dataset.

2.1. Traffic monitoring sites

Hourly data from 13 permanent counting stations in southeast Michigan for the period of 2009 through 2012 were obtained from the Michigan Department of Transportation (MDOT). These data represent actual vehicle volumes (not weight truck counts or passenger car equivalents, PCEs), and were reviewed and quality checked by MDOT staff. Short-term counts providing classification were obtained for these sites from MDOT from the Traffic Monitoring Information System (http://mdotnetpublic.state.mi.us/tmispublic/Search.aspx). To measure total vehicle counts, nine of the sites used induction loops, which sense the presence of the vehicle by induced eddy currents. Four of the sites used weigh-in-motion sensors, which derive the weight of each axle by measuring the vertical force. The latter data were processed to obtain counts in the 13 FHWA vehicle classes (1 = motor cycles; 2 = passenger cars; 3 = other two-axles, four tire single unit vehicles; 4 = buses; 5 = two axles, six tire, single unit trucks; 6 = three axles, single unit trucks; 7 = four or more axles, single unit trucks; 8 = three or four axles, single trailer trucks; 9 = five axles, single trailer trucks; 11 = five or less axles, multi trailer trucks; 12 = six axles, multi trailer trucks; 13 = seven or more axles, multi trailer trucks). More details are provided in Supplemental information Table S1.

Data for the 14th site (on I-96) from September 29, 2010 through June 19, 2011 were obtained from the Federal Highway Administration (FHWA, personal communication). This site used two radar systems (SS-125, Wavetronix SmartSensorHD, Kansas City, MO, USA), considered the "next generation" traffic instrumentation, installed on opposite sides of the highway. Vehicle counts in six length bins (0–10, 10–20, 20–30, 30–40, 40–50, >50 ft length), along with the average and 85th percentile vehicle speed, were provided on a 5 min basis for each of the 10 lanes at this location. Data quality objectives for this instrumentation were accuracy within 20%, 95% confidence interval within ±20%, and data

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