The Near-Road Ambient Monitoring Network and Exposure Estimates for Health Studies

The transport sector is the largest source of NOx and CO emissions, and among the largest sources of PM2.5 and VOCs. As a result of EPA’s new near-road monitoring requirements, high-quality measurements of ambient NO2, CO, and PM2.5 concentrations will be available from more than 120 sites adjacent to major roads in over 100 cities nationwide in the next few years. This article discusses how data from the new network will provide opportunities to further develop, calibrate, and verify exposure assessment methods and models.

Near-Road Ambient Monitoring

While improvements in fuels, engines, and emission control systems have significantly reduced vehicle exhaust emissions, the transport sector remains the largest emitter of nitrogen oxides (NOx) and carbon monoxide (CO) in the United States and elsewhere, and mobile sources are major sources of other pollutants, including fine particulate matter (PM2.5) and volatile organic compounds (VOCs). These emissions are released at or near ground level and mostly in urban areas. Understanding the concentrations that result from traffic-related emissions is increasingly important for exposure, risk, epidemiologic, health impact assessment, and accountability studies conducted at project-level, intra-urban, multicity, and national scales.

The U.S. Environmental Protection Agency’s (EPA) new near-road ambient monitoring requirements will yield new data regarding concentrations of traffic-related air pollutants. As described by Weinstock et al. elsewhere in this issue of EM, near-road monitoring of NO2 is being required in larger metropolitan areas to support the revised National Ambient Air Quality Standard (NAAQS). These areas include the Core Based Statistical Areas (CBSAs) with populations over 500,000, which include about 102 cities. The smallest of these is the Portland/South Portland, Oregon CBSA (2012 population of 518,000); the largest is the New York/Newark/Jersey City CBSA (population of 19,832,000). Of these areas, the (approximately) 50 with populations exceeding one million also will require near-road monitoring of CO and PM2.5; these start with the Grand Rapids/Wyoming CBSA in western Michigan. A second near-road monitor will be required in about 21 of the largest CBSAs with populations over 2,500,000 or those that have roadway segments with traffic volumes exceeding 250,000 vehicles per day (AADT); these start with the Denver/Aurora/Lakewood CBSA (population 2,645,000). EPA also encourages states to measure other pollutants, meteorology and traffic volume.

The new monitoring requirements mean that high-quality and continuous (hourly) ambient monitoring data from more than 120 sites in over 100 cities nationwide will start streaming in the next few years. This article suggests ways to use these data that go beyond the compliance and policy activities related to the NO2 NAAQS, focusing on exposure assessment.

Importance of Traffic-Related Pollutant Exposure

Exposure to traffic-related air pollutants has been associated with adverse health effects that include exacerbation of asthma, asthma onset, impaired lung function, cardiovascular morbidity and mortality, adverse birth outcomes, and cognitive declines, although the epidemiologic and toxicologic evidence currently is considered sufficient to support causality for only some of the respiratory outcomes.
The new near-road ambient monitoring network will help to improve our understanding of the impacts of roadways on air quality in our communities, especially for on-road exposures along high traffic roads.
While the number of scientific investigations on traffic-related air pollutants is increasing, data for exposure assessment purposes are still not abundant; the data gap in developing countries is particularly large. Thus, there is a clear need for methods and data to better assess air pollution exposures from traffic sources, and to reduce the spatial and temporal errors in exposure estimates for subjects in epidemiologic and other studies. As described below, data from the near-road network will be used for these and other purposes.

An individual’s exposure to air pollutants can be defined as the time-integrated product of concentration and breathing rate, while exposure assessment is a description of the nature and size of populations exposed to a substance and the magnitude and duration of the exposure, expressed more succinctly as the “who,” “how much,” “how long,” “what,” and “where” questions. Health impacts are estimating by combining exposure and toxicity information. Health outcomes and cumulative risks depend on many community and individual level factors, as illustrated in Figure 1.11

It is particularly important to focus on vulnerable groups and communities that are susceptible to adverse health impacts due to personal, environmental, and socio-economic determinants. For air pollutants in general, these include age (i.e., young, old), (low) socio-economic position, and preexisting disease (e.g., cardiovascular and respiratory). For traffic-related air pollutants in particular, a key exposure determinant is the proximity of emission sources to frequented locations (e.g., residences, workplaces, schools, playgrounds), a result of historical and current land-use patterns (e.g., street layout, urban development, and traffic patterns). Because many or most residents in high-traffic areas are non-White and low income, people exposed to traffic-related air pollutants represent a vulnerable group.

Near-Road Monitoring and Exposure Assessment
The requirements for selecting near-road monitoring sites have been designed to detect peak (1-hour) NO2 levels. According to EPA, the near-road monitors are to be located within 50 m, and ideally within 20 m of the nearest high traffic lane. State and local agencies can consider “population exposure and/or likeness to other road segments throughout the CBSA” in siting decisions, suggesting that sites might be selected to give more representative measurements.
Data provided by the near-road monitoring network will be helpful for understanding pollutant exposure. However, the near-road network is not designed to yield data on population exposures to traffic-related air pollutants, specifically, the exposures that apply to many individuals over broad regions, much less the exposures experienced by vulnerable groups. Generally, the same types of limitations apply to data provided by central ambient monitoring sites, which often fail to fully capture local-scale pollutant variability due to their limited number and siting criteria.2,3 Exposure to traffic-related air pollutants occurs in on-road, near-field and far-field micro-environments. Figure 2 depicts recent NO2 data in these three microenvironments from Detroit, MI, showing hour-to-hour, day-to-day, and spatial variability, as discussed next.

**On-Road Exposure**

The first microenvironment important for exposure to traffic-related air pollutants is called the on-road environment, applying to commuters, pedestrians, cyclists, and workers such as police, truck drivers, and highway workers. (The term on-road is more encompassing than in-transit or in-cabin.) Individuals traveling and working on high traffic roads during traffic peaks are likely to be the most exposed.

On-road exposure affects individuals in vehicle cabins, which can provide a degree of sheltering and filtration for a portion of PM (but rarely vapors or gases), an area receiving recent attention for the ultrafine PM component of “fresh” vehicle exhaust.22,23 On-road exposure is also important for pedestrians, cyclists, and runners, who may experience considerably elevated exposures due to much higher breathing rates while exercising, as well as the lack of sheltering and filtration.25,26

The 2009 American Community survey27 gives statistics relevant for estimating the number of exposed individuals by transportation mode while commuting: 119 million persons used (private) cars, trucks, and vans; 7 million used public transportation;
4 million walked; and 375,000 bicycled. The average commute duration in 2009 (each way, all modes) was 25 minutes, and nearly twice as long for public transport. There are significant differences by region/city and by race/ethnicity. For example, among White/non-Hispanics, 92% drove alone or carpooled and 3.2% took public transit; among Black/African-American/non-Hispanics, 84% drove or carpooled, and 11.5% used public transit.

Although the duration of on-road exposure is short for most individuals, the higher on-road concentrations can result in a significant fraction of an individual's total exposure or dose.\textsuperscript{24,28} In addition, the longer duration of commutes by public transit for non-Whites, and the higher concentrations of PM often found in diesel buses typically used (sometimes due to self-pollution from the vehicle itself), reinforce the need to focus on vulnerable groups.

Will the near-road monitoring network provide information relevant for estimating on-road concentrations and exposure? As discussed by Lurmann et al. elsewhere in this issue of \textit{EM}, the prevailing meteorology and the few seconds needed to transport tailpipe exhaust emissions to the near-road monitor will affect NO\textsubscript{x}-O\textsubscript{3} chemistry and aerosol processes (e.g., nucleation, condensation, coagulation, evaporation). Thus, along with effects of cabin filtration, some differences between monitoring results and on-road exposures at the same road segment are expected.

Near-Field Exposure

The second microenvironment, and the one most widely analyzed to date, is the region within several hundred meters of major roads. Many people live, work, go to school, and recreate in this near-field microenvironment. Of all residence units in the United States, approximately 18% fall within 300 feet of a four-lane highway, railroad, or airport; the fraction increases to 22% and 25% for Hispanic and Black households, respectively.\textsuperscript{29} Ironically, numbers in the near-field group with potentially high exposure to traffic-related pollutants may grow due to trends encouraging transit-oriented development (TOD) and compact urban development, which are higher density and often mixed-use development located near transit facilities. Unfortunately, placement of TODs in (more polluted) transport corridors can increase exposure to traffic-related air pollutants.\textsuperscript{30,31}

Estimating concentrations and exposures of traffic-related air pollutants in the near-road environment involves several challenges. First, concentrations of traffic-related air pollutants show localized gradients, with levels decreasing sharply over a distance of several hundred meters from the road, depending on the pollutant and local conditions (e.g., land/building features and meteorology).\textsuperscript{5,32} Second, rapid changes in pollutant characteristics, including phase, chemical composition, and particle size occur over the same spatial scale.\textsuperscript{33}

Third, urban areas contain many other emission sources that emit the same pollutants, and there are few if any unique or consistent tracers of traffic-related air pollutants. The comingling of “background” and “regional” contributions from non-road, area, point and distant sources can make intra-urban differences small and exposure increments from traffic emissions difficult to distinguish for pollutants such as PM\textsubscript{2.5}. Fourth, traffic-related emission rates change dramatically over time, with time-of-day, day-of-week, seasonal, and multiyear trends in the rates and composition of emissions. Finally, both ambient monitoring and source modeling networks and datasets (e.g., emission inventories) have not had the spatial or temporal resolution needed to accurately characterize near-field exposures.
Researchers and practitioners have used a variety of creative and non-standard methods to tackle some of these challenges, including proximity assessments, statistical land-use regression models, source-oriented models incorporating mechanistic sub-models (e.g., for emissions, dispersion, transformation, exposure), spatial-temporal models, and hybrid models combining several approaches. These methods vary with respect to data requirements and their explanatory/predictive ability. For example, while easy to derive using a geographic information system (GIS), a significant drawback of proximity and traffic intensity measures is the omission of meteorology, vehicle emissions, and time-activity patterns (e.g., time spent away from the location considered). Model validation is a crucial part of the application of any method used to estimate near-field exposure.

How will the near-road monitoring network contribute to the challenge of estimating near-field exposures? Data from the network will provide opportunities to further develop, calibrate, and verify the exposure assessment methods discussed above. While the addition of one or two near-road sites to an urban-scale ambient monitoring network represents a limited expansion of a network’s spatial coverage (and is probably more relevant to on-road exposures as discussed earlier), the new data will provide opportunities to quantify concentrations (likely bounded between levels at near-road, population, and regional monitoring sites, as suggested by Figure 2), and should improve the ability to extrapolate and confirm estimates from source-oriented, spatio-temporal, and hybrid models.

**Far-Field Exposure**

Traffic-related air pollutant exposures also occur in areas relatively distant from both major roads and urban areas, which can be considered the far-field environment. Here, vehicle-related emissions become part of the “urban plume,” where they may participate in the formation of secondary pollutants, most notably O₃, but also secondary organic aerosols; other health concerns can include relatively long-lived primary pollutants associated with traffic, such as diesel exhaust PM and benzene. At this scale, data from the near-road monitoring network would not be representative of concentrations or exposures, although temporal patterns will reflect traffic (and meteorological) influences, as shown in Figure 2. Inverse modeling techniques using near-road concentration data and vehicle volumes, ideally measured hourly with vehicle classification data, can be used to estimate (local) emission factors and emission rates, complementing data in mobile source emission inventories and improving source-oriented modeling estimates.

**Conclusion**

Data from the new near-road ambient monitoring network will help improve our understanding of the impacts of major roadways on air quality in our communities. This will, in turn, improve exposure assessments that provide key information in health...
studies that have associated many adverse health effects with traffic-related air pollutants. The new data will be useful for estimating on- and near-road exposures, and for refining and verifying methods and models used to estimate population exposures, including vulnerable and susceptible groups.

References


17. Han, X.; Naeher, L.P. A review of traffic-related air pollution exposure assessment studies in the developing world; Environ. Int. 2006, 32 (1), 106.


