

WORKSHOP ON TRAFFIC, HEALTH, AND INFRASTRUCTURE PLANNING  
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BACKGROUND INFORMATION SUMMARY DOCUMENT

**MOTOR VEHICLE-RELATED EXPOSURES TO AIR POLLUTION:  
CURRENT UNDERSTANDING**

**INTRODUCTION**

An expanding body of air pollutant measurement data and epidemiological studies indicates, perhaps not surprisingly, that pollutant concentrations near major highways can be quite high. Motor vehicle emissions, which are the primary source of the air pollutant mixture near roadways, comprise a complex mixture of both gases and particles. Because these components undergo numerous dispersion and transformation processes in the atmosphere following their release from motor vehicles, these complex physical and chemical processes both influence the pollutant mixture adjacent to roadways and determine its profile of spatial and temporal variation. This section focuses on current approaches for characterizing the air pollutant exposures for individuals located near roadways. It reviews recent studies to evaluate the air pollutant mixture near roadways, particularly the contribution by fine and ultrafine particles, and exposure assessment methodology for estimating air pollutant concentrations for persons who live or work near roadways.

**CHARACTERIZING AIR POLLUTION NEAR ROADWAYS**

Emission inventories indicate that motor vehicles are the principal sources of fine and ultrafine particles in the atmosphere of urban areas (Hitchins et al., 2000; Zhu et al., 2002). The majority of particles emitted by vehicles are in the ultrafine size range (20-130 nanometers [nm] for diesel engines [Morawska et al., 1998] and 20-60 nm for gasoline engines [Ristovski et al., 1998]). Consequently, to address concerns about proximity to roadways and the potential health effects, data are needed not only for emissions of ultrafine particles but also for the behavior of ultrafine particles after emission and their transport away from busy roadways and freeways.

The first studies of particle concentrations near roadways were conducted in Australia in the late 1990s (Hitchins et al., 2000). The investigators reported that, with the exception of measurements close to the road (within approximately 15 meters [m]), horizontal profile measurements did not indicate statistically significant differences among fine particle number concentrations at ground-level distances up to 200 m away from the road. More recently, Zhu et al. (2002) measured particle size distributions and concentrations of gaseous co-pollutants in the proximity of the Interstate 405 (I-405) freeway in west Los Angeles, which is primarily used by gasoline-powered vehicles. Measurements were obtained 30 m, 60 m, 90 m, 150 m, and 300 m downwind, and 300 m upwind, from I-405. At each sampling location, concentrations of carbon monoxide (CO), black carbon (BC), and particle mass were also measured. Under these conditions, decreasing concentrations of CO, BC, and particle number correlated well with increasing distance from the freeway. Particle number concentrations from 6 nm to 220 nm decreased exponentially with downwind distance from the freeway. These data showed that both atmospheric dispersion and coagulation contributed to the rapid decrease in particle number concentrations and changes in particle size distribution with increasing distance from the freeway. Ultrafine particle number concentration measured at 300 m downwind from the freeway was indistinguishable from upwind background concentration.

Zhu et al. (2002) obtained similar data in sites in the vicinity of freeway I-710, which is used extensively by heavy-duty diesel vehicles. The most notable difference between the I-405 and I-710 sites was that elemental carbon (EC) levels were highest in the I-710 freeway, an expected finding due to higher EC emissions from diesel engines compared to gasoline engines. Similar to the results from the I-405 study, the sharpest decreases in particle concentrations with distance from the freeway were observed for particles in the sub-20 nm category.

Measurements of particle number size distribution for the range from 11 nm to 452 nm were reported on the side of the busy Marylebone Road in central London between April 1998 and August 2001 by Charron and Harrison (2003). These data were also analyzed to evaluate the influence of meteorological factors on different size fractions and on the overall size distributions. Some meteorological parameters, such as low temperatures and high relative humidity, are known to favor formation of new particles. For example, in the morning and during the night when temperatures are lower and relative humidity levels are higher, lower temperature conditions favor the generation of small particles. This strong dependence on temperature further suggests that very small particles are not emitted initially from motor vehicles, but are formed during the cooling and dilution of motor vehicle exhaust. However, a correlation between the formation of new particles and the higher relative humidity levels present during the morning and night was not found. Higher water content in the atmosphere would be expected to favor homogeneous binary nucleation of sulfuric acid and water, while ternary nucleation involving ammonia would be expected to be independent of relative humidity. Furthermore, possible nucleation from organic compounds might not be influenced by relative humidity. The lack of dependence of small particle levels on relative humidity levels suggests that binary nucleation from sulfuric acid and water is not a major factor in particle formation.

The effect of season on the characteristics of particles near freeways was also investigated in a study by Zhu et al (2004). The decay rates of CO and BC concentrations were slightly greater in summer than in winter for both the I-405 and I-710 freeways, suggesting a weaker atmospheric dilution effect in winter. Particle number concentrations in the size range between 6 nm and 12 nm was significantly higher in winter than in summer; the associated concentration in that size range decreased at a slower rate in winter than in summer. The surface area concentrations in the size range of 6 nm to 220 nm were consistently higher in summer for all sampling locations. These results suggest that wintertime conditions favor increased particle formation, possibly due to increased condensation of organic vapors, coupled with decreased atmospheric mixing depth. These findings are consistent with the observations of Charron and Harrison (2003).

Zhang et al. (2004) demonstrated that condensation, evaporation, and dilution were major factors for altering aerosol size distribution, while coagulation and deposition played minor roles. Seasonal effects were significant; winters were generally less dynamic than summers. A large number of particles grew in diameters to larger than the 10 nm range in the interval between 30 m and 90 m downwind of the freeways. Beyond 90 m, some particle sizes decreased to the less than 10 nm range and while others continued growing to greater than 100 nm due to competition between partial pressure and vapor pressure. Therefore, people who live or work within approximately 90 m of roadways are exposed to a pollutant mixture that has particle size and distribution compositions that differ from the pollutant mixture to which people who live or work further away from roadways are exposed. Particle compositions likely change dramatically as components respond to decreasing gas-phase concentrations as a result of dilution.

The presence of elevated concentrations of particles and gaseous pollutants from motor vehicles near freeways raises concerns about the magnitude of exposures of individuals during their commutes and about the health implications of these exposures. Time spent in and near vehicles is a significant route of exposure to air pollution, but few studies of ultrafine particulate matter (UFP) concentrations in

vehicle-related settings have been conducted, especially inside moving vehicles. Westerdahl and colleagues (2003) obtained measurements on a variety of streets and freeways in Los Angeles between February and April 2003. As expected, diesel-powered vehicles were often a major source of high UFPM count concentrations, especially for measurements collected directly behind a moving vehicle. Interestingly, gasoline-powered vehicles also produced comparably high UFPM counts, particularly when the vehicles were older. The measurements were highest when vehicles were accelerating hard or starting from a standing start, such as from a stoplight, and when vehicles were driving at high speeds or accelerating at high speeds. Due to the ubiquitous nature of gasoline-powered vehicles and the frequency of such types of driving, they may be the predominant source of in-vehicle, roadway, and near-roadway UFPM concentrations. UFPM concentrations can be greater by at least an order of magnitude on freeways with diesel traffic or primarily gasoline engine traffic compared to urban background measurements.

## **CHARACTERIZING HUMAN EXPOSURES NEAR ROADWAYS**

The methodology of exposure assessment is used to characterize actual exposures that can occur when individuals near roadways inhale the complex mixture of particles and gases emitted from motor vehicles. As previously discussed, numerous factors influence the formation and composition of the air pollutant mixture near roadways. Ambient air pollution can also exhibit temporal variability that can contribute to variations in exposures. This variability reflects long-term trends in air quality, seasonal variations in air pollutant concentrations, day-to-day variability, as well as diurnal variations in air pollution levels. Depending on the time-base of the exposure assessment, it may or may not be necessary to account for these different categories of temporal variability.

An individual's exposure to motor vehicle-related air pollution will also depend on the activity patterns of the individual in question, the interaction between these activities and traffic sources, and the penetration of the pollutant into indoor environments. Throughout a given day, individuals may be subjected to very different levels of exposure to traffic-related pollutants depending on where they spend their time and their proximity to traffic sources.

Specific tools and techniques are available for estimating exposures to motor vehicle pollution. They can be broadly categorized as 1) surrogate techniques, 2) modeling techniques, and 3) measurement techniques; they are discussed in more detail below. In many cases, exposure assessment can involve use of several of these approaches to assess the distribution of error for the primary exposure estimates.

### **Surrogate Techniques**

One exposure assessment method is the surrogate approach. This approach uses gross indicators for the relative concentrations of air pollutants to which an individual or population may be exposed. Examples of the surrogate approach include self-reported (subjective) measures of nearby traffic intensity or local knowledge of congested roads (Ciccone et al., 1998; Duhme et al., 1996; Weiland et al., 1994), objective measures, such as traffic density on the street of residence (Savitz & Feingold, 1989), total traffic within a certain radius of a residence (Edwards et al., 1994; English et al., 1999; Wilkinson et al., 1999), distance-weighted traffic density (Langholz et al., 2002); and distance between a residence and the nearest highway or busy road (Brunekreef et al., 1997; Livingstone et al., 1996; van Vliet et al., 1997).

These examples focus not only on the number of vehicles in use and the level of congestion but also incorporate some measure of proximity. However, many other variables that ultimately determine an individual's air pollutant exposure are not reflected in these metrics. Depending on the objective of the exposure assessment, such surrogates may be adequate for their intended use.

## **Modeling Techniques**

Modeling techniques can be divided into two basic categories: 1) regression modeling approaches using geographic information systems (GIS) and 2) dispersion modeling.

### ***Regression Modeling Approaches***

Researchers are increasingly relying on regression modeling to estimate individual exposures for epidemiological studies. Typically, GIS are used to compute independent variables for inclusion in these regression models. Two examples of these approaches are the Traffic-Related Air Pollution on Childhood Asthma (TRAPCA) and Small Area Variations in Air Pollution and Health (SAVIAH) studies.

Exposure assessment approaches were developed for the TRAPCA study (Brauer et al., 2002; Brauer et al., 2003) and SAVIAH study (D. J. Briggs et al., 1997; D. J. Briggs et al., 2000; Lebet et al., 2000) as an approach for estimating individual exposures to air pollutants in large epidemiological studies. The TRAPCA and SAVIAH approaches allow for individual exposures to be modeled based on regression of measured air pollutant concentrations against surrogate variables in a GIS framework. The specific use of traffic-related surrogate variables provides exposure estimates that are specific to traffic-related pollutants.

The basic approach employed in the SAVIAH and TRAPCA studies involves measurement of long-term average air pollution concentrations at monitoring sites specifically selected to characterize the complete range of within-city variability in air pollution concentrations. At these same monitoring locations, geographic variables (e.g., traffic and population density) were calculated. A regression model then relates the measured air pollutant concentrations with the geographic data to predict air pollutant concentrations for additional locations where no monitoring data are available, such as the home addresses of study participants. Address locations of cohort members are input into the regression model and exposure estimates are calculated for each individual address within a GIS framework. Lifetime exposure histories for cohort members can be calculated for those who move by computing new exposure estimates for each new address.

Several challenges are involved in using GIS-based information in estimating exposure. For example, geocoding services may not accurately or consistently place addresses in their actual physical locations. Because of near-field pollutant distribution observed along roadways, address locations of study participants must be geocoded within an accuracy of 20-30 meters. Moreover, the road network used to model traffic exposure must be consistent with the database used to geocode addresses.

### ***Dispersion Modeling***

For dispersion models, emissions parameters are input into dispersion or other types of atmospheric models to predict the concentrations of pollutants at individual “receptor” points. For example, CALINE 4, built on Gaussian dispersion models, can predict the concentrations of air pollutants downwind of a road segment using emission factors (emissions/length of road) and meteorological data (Benson, 1984). Dispersion models require large amounts of location-specific input data, such as detailed information on the specific composition of the motor vehicle fleet, the specific emissions of representative vehicle types, traffic volumes, and detailed meteorological and topographical information. Because the vehicle emissions estimates for this modeling approach are based on laboratory testing, they may not provide an accurate representation of real-world driving conditions. In addition, accurate estimates of emissions for some air pollutants may not be possible currently.

## Measurement Techniques

Measurement techniques utilize actual measurements of traffic-related air pollution based on data collected from air quality monitoring networks or personal samplers. By working directly with measured concentrations of pollution, these techniques avoid the many complexities involved in estimating motor vehicle emissions and the subsequent transport and dispersion of pollutants. However, there are challenges in making these estimates and they have limitations.

Numerous epidemiological studies have relied on ambient monitoring data to determine average exposure levels. The American Cancer Society study (Pope et al., 2002) and the Harvard Six Cities study (Dockery et al., 1993), two of the most widely cited studies on the chronic health effects of particulate air pollution, used a limited number of long-term average pollution concentration values for each urban area. In some cases, the investigators relied on pre-existing ambient monitoring networks to characterize the exposure of study subjects. Subsequent studies have taken a more targeted approach.

A limited number of studies have assessed exposure by conducting extensive ambient monitoring throughout the entire region of interest, such as at multiple grid locations or at the home address of all study subjects (Hirsch et al., 1999; Kramer et al., 2000). Researchers have also interpolated ambient concentrations based on measurements collected by air quality monitoring networks (Brown et al., 1994). Interpolation of monitoring data is generally not able to identify small-scale variations in concentrations given the density of most typical monitoring networks and given the spatial distribution of traffic sources.

There is a growing appreciation of the spatial variability in air pollution concentrations within urbanized areas (Bernard et al., 1997; Cyrus, Heinrich et al., 1998; Lebet et al., 2000; Raaschou-Nielsen, 2000). Recent information has suggested greater than expected levels of within-city variation in ambient air pollutant concentrations. Previously it had been assumed for ozone and particles that ambient concentrations were relatively homogeneous within urban areas (Burton et al., 1996). Several recent studies have documented important within-city variation of concentration of other pollutants, especially related to proximity to motorized traffic and location within the city, e.g. center versus suburb (Bernard et al., 1997; Cyrus et al., 1998; Gilbert et al., 2003; Raaschou-Nielsen, 2000). In addition, researchers are finding elevated concentrations of pollution in micro-environments. For example, studies conducted on California roadways have measured pollutant levels several times higher within vehicles compared to the air outside of the vehicle (Rodes et al.; SCAQMD, 1999).

Capturing spatial variability is perhaps the greatest challenge in conducting a risk assessment or epidemiological study. Ideally, a personal exposure monitor that could follow an individual throughout the day would be used to measure exposure. However, technical and practical factors limit this approach, particularly when conducting a long-term exposure assessment and when estimating exposures for large populations. Temporal variability can also impact health effects. Although epidemiological studies often rely on 24-hour average pollutant concentrations for assessing exposure, a finer temporal resolution may be informative of the relationship between exposure and the resulting health effects. In contrast, a long-term cancer study may only require average annual pollutant concentrations.

Attributing exposure to key source-specific pollutants is also challenging. Exposure to diesel exhaust is a major public health concern, but identifying a diesel-specific marker outside the occupational setting is subject to some debate, and efforts are underway to identify a “signature” of emitted compounds unique to diesel exhaust (Health Effects Institute, 2003). Approaches that combine chemical signatures with spatial and temporal data may prove to be especially useful. Assuming that researchers can develop a reasonable estimate of the pollutant concentrations at a given location along with source signatures, they must still address the activity patterns of the population under study.

In summary, sound approaches for both evaluating and quantifying air pollutant composition near roadways and for assessing those exposures are essential to evaluate the environmental conditions of individuals who live and work near roadways and their potential health effects.

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