Can Roadway Design be used to Mitigate Air Quality Impacts from Traffic?

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BACKGROUND

In recent years, a consensus has emerged that exposures to traffic emissions increases risks of adverse health effects for populations living, working or going to school near large roadways.[1,2,3,4] Near-roadway air pollution is characterized by elevated levels of traffic-generated compounds compared to overall urban background levels with the gradual decrease in concentrations within several hundred meters of the road.[5,6,7,8]

Traffic-generated compounds impact air quality through three major pathways: vehicle running emissions of gaseous and particulate compounds, secondary formation during plume transport of gases and particles, and mechanical processes that abrade particles from brakes, tires, and the road surface. Carbon monoxide (CO), nitric oxides (NO_x), and volatile organic compounds (VOCs), as well as PM constituents such as polycyclic aromatic hydrocarbons (PAHs) and black carbon (BC) are among the numerous compounds that have been identified at elevated concentrations near large roads.

Emission reduction programs implemented by government agencies throughout the world have significantly reduced emission rates of air pollutants from motor vehicles. Since 1970 in the U.S., average per vehicle emissions have been reduced by over 90% for VOCs, and over 80% for PM_{10} and NO_x. In spite of these reductions, motor vehicles still significantly contribute to pollution in urban areas, often due to large increases in vehicle use offsetting per vehicle emission reductions. Furthermore, emissions from some vehicle-associated sources (e.g. brake and tire wear) are not regulated, and pollutants generated from these sources may also increase in the future with increased vehicle use.

Populations near roads are exposed to this mixture of primary emissions and secondarily formed pollutants. Approximately 30 to 45% of urban populations in the U.S. are likely exposed to elevated pollution levels near roads.[4] In many countries with densely populated urban areas this figure is likely to be even higher.

DISCUSSION

Roadway design influences on near-road air quality

In addition to U. S. emission standards, recent research has shown that transportation agencies may have opportunities for reductions in air pollutant exposures experienced by near-road populations. These opportunities include roadway design options that affect pollutant transport and dispersion such as the roadway configuration and the presence of roadside structures.

Roadway configuration. Wind tunnel assessments have been reported that compared a number of roadway configuration scenarios.[9] These studies indicate that at-grade roadways experience the least amount of pollutant mixing if no other structures exist near the road. However, cut section roads, whether vertical or sloped walls, will increase the turbulence in air flow resulting from winds into and along the cut section, increasing pollutant mixing and dispersion, and resulting in lower near-road concentrations. In addition, as winds flow up and out of a cut section, the plume will be elevated compared with at-grade road conditions.

Field measurements have also shown the potential impacts of roadway design on near-road air quality. Size-resolved PM lead samples collected upwind and downwind of five urban freeways in Los Angeles with differing road configurations (at-grade, sloped cut section, and elevated fill section) also indicated that cut sections resulted in lower near-road concentrations than the other scenarios.[10,11] This study also suggested that elevated, fill-section roadways could result in higher downwind pollutant concentrations than at-grade sections when the plume reaches ground level. In addition to affecting wind flow, this study suggested that changing roadway configurations may also affect the momentum and buoyancy of the traffic emissions due to vehicle-induced turbulence and vehicular exhaust heat, parameters which could not be assessed in the wind tunnel study.

Roadside features. Structures that impact pollutant transport and dispersion may also be present near the road, such as noise barriers, vegetation, and buildings. These features also affect pollutant concentrations around the structure by blocking initial dispersion and increasing turbulence and mixing of the emitted pollutants downwind of the road.

Noise barriers reduce noise levels from traffic by blocking and deflecting the sound waves. These barriers also affect air pollutant dispersion, leading to increased vertical mixing due to the upward deflection of air flow caused by the structure. Studies suggest that this upward deflection of air can create a recirculation cavity downwind of the barrier containing a well-mixed, and often lower, zone of pollution concentrations. Air quality impacts from noise barriers have been identified in modeling, wind tunnel, and field measurements.[7,9,12] However, some studies suggest that noise barriers adjacent to a road may also inhibit air movement off the road, leading to elevated on-road pollutant concentrations.

Vegetation stands also affect near-road pollutant concentrations similarly to noise barriers. The complex and porous structure of trees and bushes can increase air turbulence and promote mixing and dispersion as air flows through and around the vegetation. Vegetation may also reduce pollutant concentrations by enhancing deposition of certain pollutants on leaves and branches. Modeling, wind tunnel, and field measurements have evaluated the role of vegetation on pollutant concentrations.[9,12,13,14] Variables such as the vegetation type, height, and thickness will influence the extent of mixing and deposition experienced at the site, although specific interrelationships of these factors have not been identified. In addition, the porosity of vegetation may promote wind flow off the road and thus not lead to elevated on-road pollutant concentrations that may occur with noise barriers.

Policy Implications of Roadway Design Options

Natural and man-made structures' influence on dispersion of traffic-emitted pollutants enables transportation planners and engineers to design roadways that reduce air pollutant exposures for nearby populations. Governmental entities involved in regulating the development of land along highways may also consider the impact of roadway design in decisions on building and access permits. The following sections present policy implications and applications of roadway design options using U.S. examples, although these options can be applicable to many parts of the world.

The consideration of roadway design in determining the air quality impacts of existing roads, or new road projects, can allow future planners to estimate the benefits of roadway design decisions. Constructing a fill or at-grade section roadway in populated areas could result in greater downwind impacts than cut sections. In addition, a transportation project engineer may consider preserving mature vegetation as a means of mitigating adverse air quality impacts. Alternatively, planners may add vegetative and concrete barriers to existing roadways to mitigate the current impact of traffic emissions.

Air quality impacts of project design could also allow consideration of vegetative plantings throughout urban areas as a means of reducing population exposures to existing and planned emissions from motor vehicles. These considerations at a broader urban scale allow project design elements to be integrated into urban air quality planning. For example, the U.S. Forest Service developed online tools allowing urban areas to survey and assess tree populations and estimate the uptake of air and water pollutants from trees.[15] Surface characteristics, such as tree canopy area, also influence the magnitude and extent of urban heat island effects.[16] Changes in surface roughness for a single project will also affect local meteorology, influencing dispersion from all nearby air pollutant sources.[17] Together, coordination of planning on roadway design options between projects and jurisdictions could be useful in improving urban air quality.

Air quality policy analysis of the effects of traffic emissions on nearby populations relies heavily on available air quality models and guidelines. In the U.S., the National Environmental Policy Act (NEPA) requires government agencies consider the environmental impacts of major projects. The transportation conformity program in the U.S. requires transportation plans, programs, and projects to “conform to” the goals established in State Implementation Plans (SIPs) for areas designated as either nonattainment or maintenance for the National Ambient Air Quality Standards (NAAQS) for CO, PM2.5, PM10, ozone and NO2. Thus, conformity ensures that transportation activities will not cause new air quality violations, worsen existing violations, or delay timely attainment of the NAAQS. Project-level analyses, known as “hot spot analyses,” are required for projects that are either funded or approved by the U.S. Federal Highway Administration (FHWA) or Federal Transit Administration (FTA) in CO, PM2.5 and PM10 nonattainment and maintenance areas.

Under both NEPA and project-level conformity analyses, the primary air quality analysis method is the use of dispersion models. At present, the U.S. EPA recommended models contain simple algorithms for assessing the impacts of cut and fill roadway segments and none for roadside features. Qualitatively, discussions of the effects of roadway design on dispersion and downwind pollutant concentrations may be useful for consideration in project planning and design. The future development of validated techniques for modeling the influence of roadway design will enable consideration of design decisions to be employed quantitatively in analyses conducted under NEPA and transportation conformity.

In most areas of the U.S., the state department of transportation (DOT) and municipal government has overlapping responsibilities and authorities over land use development along roads. While city governments typically regulate the development of land through zoning, building codes, and permitting, the DOT often has authority over land immediately adjacent to highways. The two levels of jurisdiction tend to focus on different aims, with municipal governments often promoting economic development and the DOT seeking to preserve highway right-of-way for safety or future highway expansion. Coordination between local governments and DOTs can be a successful means of implementing approaches that allow development to proceed while minimizing impacts on congestion.[18]

The consideration of air quality benefits of roadway design options may also present opportunities in these situations. Transportation project sponsors may be able to use sections of right-of-way to improve nearby air quality and noise levels, subject to government standards.

One additional set of policies may be informed by the implications of the studies discussed in this paper. In the state of California, proposed new school construction near major roadways must demonstrate that "neither short-term nor long-term exposure poses significant health risks to pupils".[19] In some California jurisdictions, land developers must demonstrate that ambient concentrations of air toxics from proposed development will not result in increased cancer risks.[20] Consideration and quantification of roadway design may offer developers new tools. In the absence of such mitigation techniques, development incentives may be relocated to "greenfield" sites with lower traffic volumes, but greater travel distances for users of the development.

Design options discussed in this paper could also be a component of voluntary programs designed to lower environmental impacts from transportation. The Green Highways Partnership in the U.S. integrates public and private interests and employs sustainable planning, design, construction, maintenance, and materials recycling to build highways (www.greenhighways.org). Many land developers are implementing low impact development (LID) practices and technologies to simultaneously conserve and protect natural resource systems and reduce infrastructure costs. LID practices include preserving existing vegetation on development sites, avoiding construction in environmentally sensitive areas, and using more compact street layouts. Roadway design considerations to reduce elevated pollutant concentrations near roads can also be included with other LID practices.

Recent studies suggest lower regional emissions associated with "compact growth" land use (Frank et al., 2000; Stone et al., 2007; Johnston et al., 2001).[21,22,23] However, compact growth often brings people into greater proximity to emission sources, leading to the possibility of greater exposures to traffic-generated pollutants despite lower overall emissions from the transportation system. The mitigation options presented in this paper may allow compact growth and higher population density urban designs without increased pollutant exposures.

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Potential Figures for Article:

Figure 1. Wind tunnel study comparing downwind pollutant concentrations under multiple roadway design scenarios.[9] For this figure, the distance from the road is scaled to the height of the noise barrier evaluated (6 meters in the example shown); thus, the distances listed along the x-axis should be multiplied by a factor of 6 to get the actual distance (in meters) from the road edge. The figure suggests that traffic emissions in a cut section with a noise barrier (6m in height) at the top resulted in the lowest downwind air pollutant concentrations for the scenarios evaluated. The impact of vegetation on near-road concentrations could not be evaluated in this study.

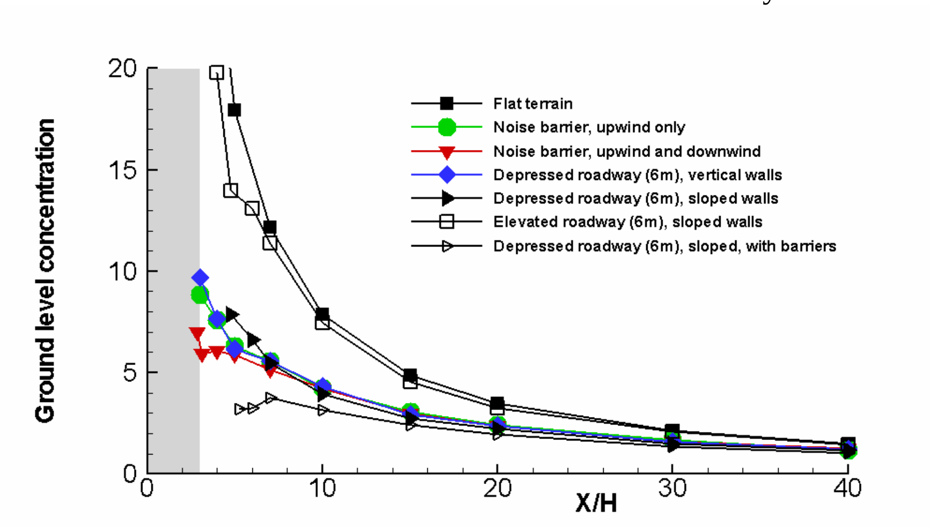

Figure 2. Lead transects downwind of Los Angeles freeways sorted by freeway configuration.[10] The results indicate that cut section roadways result in the lowest pollutant concentrations. At the field study locations evaluated, the fill sections experienced lower concentrations adjacent to the road, but higher concentrations further downwind.

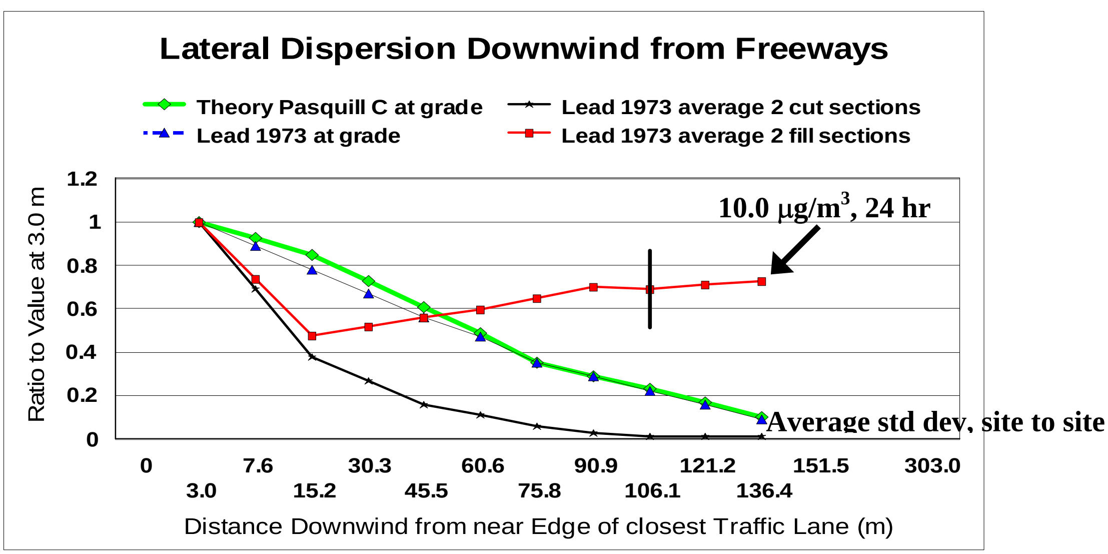

Figure 3. Mobile monitoring measurements of 20 nm size particle number concentrations present at varying distances from the road for an at-grade roadway with no obstructions (open field), behind only a noise barrier (noise barrier only), and behind a noise barrier with mature vegetation (noise barrier & vegetation). The barrier & vegetation scenario also included the presence of some detached, single-story buildings. Bars represent 95 percent confidence intervals for each distance.[9]

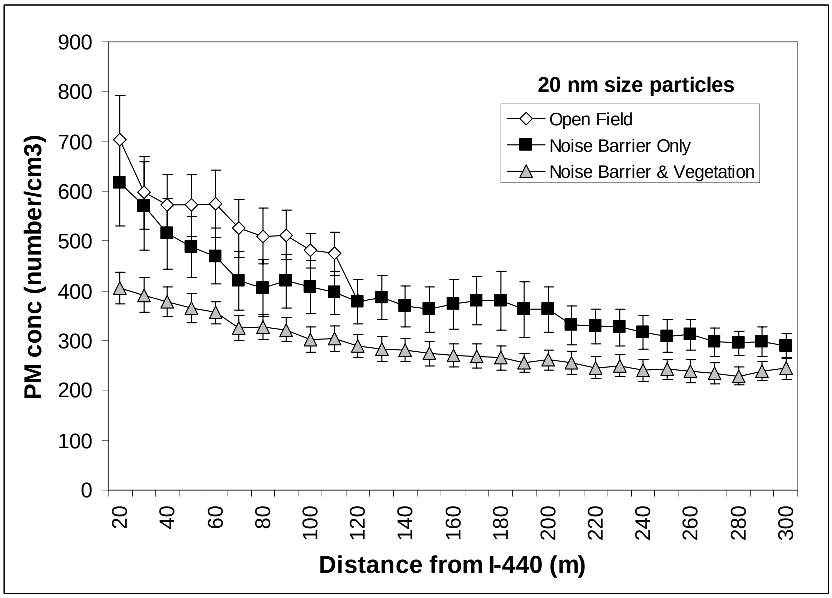

Figure 4. Fraction of fine (< 0.25 μm diameter) particles surviving passage through 2 m of redwood branches and needles as a function of wind velocity.[14]