Environmental Justice in Transportation Planning

David J. Forkenbrock and Lisa A. Schweitzer

The massive investments in transportation facilities over recent decades have enabled great progress in the efficient movement of people and goods. As time has passed, however, it has become increasingly clear that the expanded transportation facilities have not benefited everyone; that, in fact, they have made some populations, often low-income or minority people, worse off. For example, unacceptable noise or air pollution levels may burden their neighborhoods.

Environmental justice is concerned with a variety of public policy efforts to ensure that the adverse human health or environmental effects of governmental activities do not fall disproportionately upon minority populations and low-income populations. In the realm of transportation, environmental justice requires that transportation system changes, such as road improvements, be studied carefully to identify the nature, extent, and incidence of probable consequences, both favorable and adverse.

This article explores methods for assessing the environmental effects from transportation system changes. By comparing the spatial incidence of such effects with the locations of low-income populations and minority populations, it is possible to assess whether they would adversely and disproportionately affect those populations. Our intent is to help clarify, for those likely to be affected by changes in the transportation system, what types and magnitudes of consequences can be expected. A methodology that can help those affected learn about the possible consequences of such changes could enable them to recognize which ones would affect them most seriously. Putting that knowledge in the hands of those who would be affected can promote environmental justice by enabling better informed negotiations to take place.

Federal Policy

Environmental justice became federal policy on February 11, 1994, when President William Clinton signed Executive Order 12898 (President, Procla-
mation 1994). The order identified the U.S. Environmental Protection Agency (U.S. EPA) as the agency responsible for coordinating the administration, interpretation, and enforcement of programs, activities, and policies related to environmental justice. All major federal departments and agencies were directed to establish internal directives that would ensure the spirit of the order was reflected in the full range of their activities.

On June 29, 1995, the U.S. Department of Transportation (U.S. DOT) published a proposed order (U.S. DOT 1995) to address the environmental justice policy objectives laid out in Executive Order 12898. Following a period of public comment, the U.S. DOT issued its final order on April 15, 1997 (U.S. DOT 1997). In a manner consistent with the president's executive order, the U.S. DOT order specifically addresses environmental justice for minority populations (defined as black, Hispanic, Asian American, American Indian, or Alaskan Native) and low-income populations (having median household incomes below U.S. Department of Health and Human Services poverty guidelines). (These are referred to here as protected populations.) The central objective of the order is to ensure that all federally funded transportation-related programs, policies, or activities have the potential to adversely affect human health or the environment or planning and programming processes that explicitly consider the effects on minority populations and low-income populations.

The U.S. DOT order emphasizes that the public, including members of minority populations and low-income populations, must have access to public information about a program's effects on human health or the environment. Early in the development of a program, policy, or activity, the order requires four actions:

- identify and evaluate environmental, public health, and interrelated social and economic effects;
- propose measures to avoid, minimize, and/or mitigate disproportionately high and adverse environmental and public health effects and interrelated social and economic effects;
- consider alternatives when they would enable disproportionately high and adverse effects to be avoided and/or minimized; and
- elicit public involvement, including soliciting input from affected minority and low-income populations, to consider alternatives.

In summary, when significant changes to transportation systems are considered, the U.S. DOT order adds a requirement to the traditional feasibility analyses. When minority populations or low-income populations would be adversely and disproportionately affected by a project, before the project can go forward it must be clearly established that the project is not only meritorious, but also less harmful to those protected populations than other alternatives would be.

A Trial Application: Waterloo, Iowa

To develop workable approaches for estimating a variety of consequences relevant to environmental justice, a trial application was essential. We chose not to conduct a full-scale investment analysis of an actual proposed transportation system investment because many elements of such an analysis would not be germane to the objectives of this research. To keep the research focused, the methods and approaches we developed were applied to an existing urban arterial. For an actual investment analysis, this arterial could constitute the base case (or do-nothing alternative). Field testing methods and approaches in this way ensured their workability and appropriateness for evaluating an actual investment scenario.

Seeking an urban arterial within a Midwestern city that was as racially and economically diverse as possible, we selected Waterloo, Iowa. Waterloo is a city in northeastern Iowa that had a population in 1990 of 66,467. Black Hawk County (the Waterloo Metropolitan Statistical Area or MSA) had a 1990 population of 123,798. Table 1 shows that the city is more racially diverse and has a lower median income than is generally the case in the metropolitan areas of Iowa.

Running north and south through the center of Waterloo is U.S. Highway 63, the corridor used in our analysis. North of the city center this route runs through racially mixed and low-income neighborhoods. This study modeled air pollution and noise at a typical major intersection on this portion of U.S. Highway 63 and ex-

<table>
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<tr>
<th>TABLE 1. Demographic and socioeconomic characteristics of Waterloo, Iowa</th>
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<tr>
<td>Percent of population</td>
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<td>-----------------------</td>
</tr>
<tr>
<td>City of Waterloo</td>
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<tr>
<td>Waterloo MSA</td>
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<tr>
<td>Metropolitan Iowa*</td>
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* Metropolitan areas include all counties that are part of metropolitan statistical areas. Figures are weighted values for all metropolitan counties.

Source: Bureau of the Census (1992, Database C90STF3A, metropolitan statistical area and place summary levels).
examined such phenomena as children crossing the route on their way to and from school. Although no changes to U.S. Highway 63 are under consideration, the corridor is a favorable location for a trial application of the methods and approaches developed in this research.

**Analyzing Effects Related to Environmental Justice**

The U.S. DOT order mandates that a wide range of environmental, social, and economic effects be considered when evaluating a possible change in the transportation system. Some effects, particularly air pollution and noise, require computer-based quantitative modeling. Other effects must be treated more qualitatively. Figure 1 depicts the general categories of effects that are salient for environmental justice. This article focuses on the first two—changes in air quality and changes in noise level.

**Identification of Protected Populations**

To evaluate the distributional consequences of transportation system changes for low-income populations and minority populations, first one must identify where these protected populations reside and travel. Knowing the race and income composition of small geographic units of analysis allows one to evaluate whether and how the effects of a system change would disproportionately affect these populations.

**Unit of Analysis: The Census Block.** The most common unit of analysis within urban areas, the census tract, would not allow a sufficiently fine-grained analysis for our purpose. Tracts are defined to include approximately 3,000 people who are as similar as possible in their demographic and socioeconomic characteristics. To evaluate the distributional impacts of a particular transportation system change, a much smaller unit of analysis is desirable. People in one part of a tract may be significantly affected, while those in another part are not. Another reason that smaller units of analysis are preferred is that generally they are more homogeneous. Census block groups are the next smaller scale of analysis. Although the U.S. Census provides far less data at the block group level than at the tract level, reasonably extensive data on ethnicity and income are available, along with a variety of other household characteristics. On average, block groups contain approximately thirty census blocks.

Models of area-wide travel demand enable analysts to estimate the magnitude of travel cost savings at the level of traffic analysis zones (TAZs). A TAZ is a defined geographic area, usually about ten to twenty times the size of a census block. To estimate the prevalent travel patterns of specific groups in a particular TAZ, a travel demand model is easily applied. In many urban areas, TAZs are aggregations of census blocks. As a result, general travel patterns—trips beginning and ending in the respective TAZs—can be analyzed in the context of population characteristics. In the central areas of Waterloo, however, there are about twenty census blocks per TAZ, so TAZ-based analyses involve a degree of aggregation.

A strong argument can be made that to adequately evaluate the proportionate impacts of transportation system changes on minority populations and low-income populations, it is best to conduct the analysis at the census block level, the smallest level of aggregation. In the more densely populated residential areas within many cities, a census block is only the size of a city block. Because the Census Bureau must protect the privacy of individuals, only a limited number of socioeconomic variables (not including income data) are available at the census block level.

Fortunately, data on race are provided at the census block level. Figure 2 depicts the relative concentrations of the minority population among census blocks in Waterloo; the figure's large-scale section shows census blocks along U.S. Highway 63. From the figure, one can see that data at the census block level allow spatial disaggregation precise enough to analyze differing effects of transportation rights-of-way on a fairly small band around a given transportation project.

**Estimating Income Levels.** In its environmental justice order, the U.S. DOT defines a low-income person as one "whose median household income is below the Department of Health and Human Services poverty guidelines" (U.S. DOT 1997, 18380). The U.S. EPA also suggests using the poverty level to delimit low income (U.S. EPA 1996b, Sect. 2.1.2). Poverty data are not available at the census block level, but are available at the block.
group level. Good estimates at the census block level of the percentage of persons living in households with incomes below the poverty level can be derived from block group data. Estimates in this analysis are for 1989, the year on which all income levels reported in the 1990 census are based.\textsuperscript{5}

To estimate at the census block level the percentage of people living in households with incomes below the poverty level, we used several socioeconomic variables available at both the census block and block group levels, and established a statistical relationship between those variables and the percentage of people at the block group level living in households with incomes below the poverty line. After experiments with alternative socioeconomic variables available at both levels of aggregation, we estimated a regression equation for the Waterloo MSA that uses three variables at the block group level to predict the percentage of block group residents living in households with incomes under the poverty level. The equation is:

\[
P = 69.8865 - 0.0002651v - 0.5318b - 0.4800e
\]

where:

- \( P \) = percentage of persons in households with annual incomes below the poverty line
- \( v \) = median home value
- \( b \) = percentage of homes that are owner-occupied
- \( e \) = percentage of population over 65 years old.

The \( r^2 = 0.650 \), F-level = 80.99 (0.0000), \( n = 130 \) block groups; values in parentheses are significance levels.

The equation is a useful estimation tool because it accounts for about two-thirds of the variation in low-income percentages among the Waterloo MSA’s 130 census block groups. Specifically, it enables one to estimate the percentage of people within each census block who live in households with annual incomes below the poverty line, by multiplying the three coefficients by corresponding predictor variable values for each of the 3,855 census blocks in the Waterloo MSA. Figure 3 shows estimates of these percentages both for much of the Waterloo MSA and for a portion of the U.S. Highway 63 corridor.\textsuperscript{3}

Changes in Air Quality

Levels of vehicle-generated pollutants normally are highest near roadways (Balogh, Larson, and Mannering 1993, 32; Nakai, Nitta, and Maeda 1995, 127). Wind and precipitation generally disperse pollutants downwind and possibly downhill from a roadway. Although dispersion varies with local weather conditions, most pollutants tend to reach background (normal) levels between 500 and 1,000 meters from the roadway (FHWA 1978, 180–1).

Exposure to most forms of pollutants has much more severe consequences for persons with respiratory problems (Schwartz and Dockery 1992, 602–3; Balogh, Larson, and Mannering 1993, 25; U.S. EPA 1996a). We have documented variations in susceptibility to respiratory problems among populations distinguished by race and income. After a review of federal standards for various types of air pollution, their respective generation rates are summarized by motor vehicle category. The models available to predict pollution levels at specific distances from a roadway are described and assessed. Results of these models can be superimposed on maps that depict characteristics of the resident population.

Our analytic approach examines the major categories of vehicle-generated air pollution, one at a time.\textsuperscript{3} It is important to stress, however, that researchers have yet to determine the magnitude of the synergistic health effects from simultaneous exposure to more than one pollutant (Cotton 1993, 3088; Head 1995, 46). Although the prevailing threshold amounts of various air pollutants matter greatly, these variations cannot be factored into the methods of analysis presented in this article. Note, however, that a given amount of vehicle-generated air pollution becomes more critical when threshold levels are high than when the prevailing air quality is good. Several primary categories of vehicle-generated air pollutants are discussed in turn.

Particulate Matter

Particulate matter (particulates) are essentially very small pieces of grit. Particulates found in the road environment range from 0.1–0.2 micrometers (microns) to more than ten times that size.\textsuperscript{4} Although the predominant source of vehicle-generated particulates is exhaust emissions, particulates also result from brake and tire wear. Then, too, vehicles stir up road dust, which is a form of “fugitive” dust. Small and Kazi (1995) concluded that all measurable air pollutants, particulates very well may be the most detrimental to human health. Schwartz et al. (1996) linked increased exposures to particulate matter under 10 microns (termed PM\textsubscript{10}) to higher mortality rates.

Different fuels release particles of varying sizes.\textsuperscript{5} All particulates from diesel engines are less than 10 microns in aerodynamic diameter, and 73 percent are under 0.2 microns. For vehicles burning unleaded gasoline and equipped with catalytic converters, the respective percentages are 97 and 87 (Balogh, Larson, and Mannering 1993, 26). Small and large particulates disperse differently and have different health effects. Larger particulates fall to the ground quickly and, if aspirated, are usu-
ally caught easily in the upper respiratory system. Fine particulates (those of 2.5 micrometers or smaller, referred to as PM$_{2.5}$), however, can remain suspended in the air for days or even weeks and can travel deeply into the lungs (Schwartz and Dockery 1992, 602–3; Balogh, Larson, and Manering 1993, 25; U.S. EPA 1996a).

Among the persons most adversely affected by particulates are those suffering from asthma. Asthma rates are negatively correlated with income. People in households earning less than $10,000 a year have a higher rate of reported cases of asthma than those in households with higher incomes (Adams and Marano 1995, Table 59, 87–90). The asthma mortality rate for African Americans is six times that for white Americans (U.S. EPA 1996a).

**Carbon Monoxide**

When vehicles burn fuel, they emit carbon monoxide (CO). Carbon monoxide production is higher at low air-to-fuel ratios, which occur when an auto is started (especially in cold weather), idling, or improperly tuned (U.S. EPA 1993, 1). According to Small and Kazimi (1995, 9), transportation contributes 66 percent of all carbon monoxide emissions.

Carbon monoxide forms carboxyhemoglobin in the lungs, reducing the flow of oxygen in the bloodstream (U.S. EPA 1995a). Carbon monoxide is therefore especially dangerous to persons who have difficulty getting adequate oxygen when they breathe. People most at risk from carbon monoxide exposure are those with heart disease, followed by those with anemia or other blood disorders and those with chronic lung disease. African Americans have higher death rates from heart disease than whites do in every age cohort except over 85 years (National Center for Health Statistics 1995, Table 37, 126–8). American Indian, Asian, or Hispanic people have lower death rates from heart disease than either whites or African Americans do. Heart disease death rates are lower overall for women, but show the same trends with respect to race. To be completely accurate, then: death rates from heart disease are not higher for all minority groups than for whites. For both genders, age is a larger factor than race in heart disease deaths.

**Nitrogen Oxides and Ozone**

Nitrogen oxides (NO$_x$) are released from fuel combustion and can cause upper respiratory irritation, as well as lower resistance to pneumonia and streptococcus. Exposures of greater than one part per million (ppm) can irritate airways, pulmonary effects can occur at exposures above two ppm. Some asthmatics are sensitive to exposures above 0.6 ppm (Schlesinger 1992, 424, 437).

Nitrogen oxides react with volatile organic compounds (VOCs are composed mainly of hydrocarbons, emitted primarily as unburned petroleum) in the presence of heat and sunlight to form ozone. Because the rate of the reaction depends on the intensity of heat and sunlight, ozone formation is worse in summer.

Ozone has many of the same health effects as particulates. According to the U.S. EPA (1996a), ozone can cause acute respiratory problems and temporary reductions in lung capacity of 15 to 20 percent in healthy adults. Unlike the situation for inert pollutants such as carbon monoxide, it is infeasible to model with confidence the dispersion of reactive pollutants such as nitrous oxides and ozone. In this analysis reactive pollutants therefore are not modeled.

**Sulfur Dioxide**

Sulfur oxides, primarily sulfur dioxide (SO$_2$), are emitted from vehicles powered by diesel engines and, to a lesser degree, from gasoline engines. Sulfur dioxide is a serious irritant to asthmatic people; others may be annoyed by its unpleasant smell or taste (U.S. EPA 1994a, 10). It also contributes to particulate formation and acid rain. Under most conditions, motor vehicles account for a relatively small portion of sulfur dioxide; perhaps the most important effect of vehicle-generated sulfur dioxide is its role in particulate formation, which is generally of greatest concern to human health. Because particulate matter was addressed explicitly, we do not consider sulfur dioxide separately.

**Modeling Air Pollution**

The regulation of air pollution continually evolves as researchers discover more and more about its health effects and dispersion patterns. Table 2 is a summary of current federal standards for the pollutants discussed here. Note that all pollutants are not measured in the same way; for some, like particulates, the U.S. EPA uses a mass measure of concentration (micrograms per cubic meter or (g/m$^3$), while for others, it uses a count measure such as parts per million (ppm).

Available evidence strongly suggests that transportation-related pollutants have health effects and that some protected populations have higher rates of health problems related to these pollutants. The practice of correlating pollutant concentrations with at-risk populations has been common in epidemiology and public health planning for some time. Wadden, Farley, and Carnow (1976) developed a methodology for correlating the likely presence of air pollutants with the residential locations of people susceptible to the types of health problems made worse by air pollution. The authors used average emission rates on highway corridors weighted...
by proximity of susceptible populations as a rating index for comparing a set of alternative highway alignments in northern Illinois.

In recent years, geographic information system (GIS) computer software has significantly improved our ability to evaluate the spatial patterns of air pollution emanating from motor vehicles. Medina (1994) formulated a framework for the integration of computer-aided design (CAD), GIS, transportation, and air quality models. Collins (1996) combined a pollution dispersion model with GIS to map air pollution. Such an integrative approach has three main advantages for an environmental justice analysis:

- high resolution mapping,
- ability to model many road segments, and
- capacity to link pollutants to sociodemographic indicators.

Figure 4 summarizes our methodology for estimating the extent to which PM$_{10}$ and carbon monoxide emissions disproportionately affect minority populations and low-income populations along U.S. Highway 63. There are three key steps: modeling vehicle emissions, modeling pollution dispersion, and mapping concentrations of pollutants relative to the location of protected populations.

**Modeling Vehicle Emissions.** The federal MOBILE5 model (developed by the U.S. EPA) was used to estimate carbon monoxide emissions. The design of MOBILE5 allows the analyst to change an array of factors such as traffic speed, percentage of cold starts, traffic mix, adjustments for inspection and maintenance programs, temperature, and the year of the analysis to account for demonstrated improvements in vehicle emission rates (U.S. EPA 1994b). To model vehicle-generated PM$_{10}$ emissions, we used U.S. EPA’s PARTS model. The local conditions that are input to PARTS are similar to those for MOBILE5, but in addition to region, modeling year, and flow speed, the model allows one to specify the percentage, by type, of road silt (loose dirt) on the road.

Numerous researchers have documented the limitations of virtually all emission models. Small and Kazimi (1995, 11) contend that MOBILE5 underestimates the emission levels of carbon monoxide in tunnel conditions. One reason they suggest for this possible underestimation is that the model may underrepresent the frequency and severity of gross polluters (e.g., very poorly tuned engines). Analysts can, however, vary the overall traffic volume as well as the traffic mix in MOBILE5, suggesting that part of the problem may be with the accuracy of traffic mix data. Despite the criticisms, this model does provide useful information on the amount of pollution generated by vehicles on a roadway.
Table 3 shows estimates of 1992 emission levels for three general types of vehicles. The difference in emissions between a gasoline auto and a heavy-duty diesel truck illustrates how varying types of vehicular traffic on the roadway influence the total emission level for all types of pollutants. Emissions vary with vehicle speed as well as with vehicle type. Carbon monoxide emissions are much higher at intersections, where vehicles spend time idling; acceleration and deceleration at intersections also create more pollution than the steady speed cruising that occurs at mid-block (Matzoros and Van Vlier 1992, 316).

**Modeling Pollution Dispersion.** Emissions models can be used to ascertain the level of pollutants from vehicles on the roadway under varying conditions. A dispersion model can then be applied to indicate how different pollutants are moved about by wind and rain. The most common type of dispersion model is Gaussian diffusion, which is based on the probable motion of pollutants treated as "particles" rather than as molecules. The dispersion of inert gases, like carbon monoxide, may be estimated using this approach. Particle dispersion is in essence an estimate of particle trajectory influenced by local weather and terrain. Most dispersion models treat roadways as "line sources" of pollutants, meaning that the level of pollutants is assumed to be constant along each segment of road.

A system of models developed by the California Department of Transportation (Caltrans), known as CALINE models, are line-source models based on Gaussian diffusion. When emission rates, meteorology and site geometry are specified, one Caltrans model, CAL3QHCR, can predict pollutant concentrations from receptors (locations) within 150 meters of the roadway and can model air quality near intersections (Benson 1994; Eckhoff and Braverman 1995). We applied this model in estimating the dispersion of both PM$_{10}$ and carbon monoxide near an intersection on U.S. Highway 63 in Waterloo. In the trial application, average winter temperature, number precipitation days, and prevailing wind speed and direction were obtained from the National Climatic Data Center of the U.S. Department of Commerce.

**Mapping Concentrations of Pollutants.** Assuming that census block-level characteristics of race and income apply to households quite uniformly across the block, one can map the location of protected populations in relation to pollution levels. For the sake of brevity, only two of the four applicable maps are included in figure 5: the amount of PM$_{10}$ and the percentage of minority population, and the level of carbon monoxide and the percentage of minority population. The contours in figure 5 are the quartile values existing at this intersection for particulates and carbon monoxide, respectively. The graphics show that concentrations of pollutants at this intersection along the U.S. Highway 63 corridor in Waterloo are below federal standards. In the case of PM$_{10}$, the federal standard is a maximum annual mean of 50 µg/m$^3$, but during the heaviest hour of traffic, the analysis shows a maximum concentration of only 12.5 µg/m$^3$. The maximum estimated carbon monoxide concentration during this hour near the center of the intersection is 31 ppm, which is below the federal standard of 35 ppm per one-hour maximum concentration.

Another way of visualizing the pollution level of the landscape is by graphing the cross-sectional elevation at a chosen point. Using GIS software, we have generated a surface profile drawing by defining the endpoints of the profile. The software then calculates elevations at regular intervals between these points and draws the profile in a chart window. Figure 6 shows profile representations of the PM$_{10}$ and carbon monoxide gradients along a street intersecting U.S. Highway 63.

**Noise**

Noise is defined as unwanted or detrimental sound, and each area or neighborhood has an individual "noise signature," or consistent level of background noise (Stutz 1986, 329). Sound is measured in units called decibels (dB); measuring highway traffic noise involves an adjustment or weighting of high- and low-pitched sounds to approximate human hearing of these sounds. Adjusted sounds are called "A-weighted levels" (dBA). Zero dBA is the faintest sound humans can hear. To most people, noise that is 60 dBA (e.g., an air-conditioning unit) sounds twice as loud as noise at 50 dBA (e.g., a clothes dryer). Similarly, noise at 70 dBA (e.g., a pickup truck) is perceived to be four times as loud as noise at 30 dBA. In technical terms, the A-weighted decibel scale is logarithmic.

In surveys, residents have listed traffic noise as the most disruptive indoor problem caused by nearby highways (Williams and McCrae 1995, 80). How disruptive

<table>
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<tr>
<th>Vehicle class</th>
<th>CO</th>
<th>VOC</th>
<th>NO$_x$</th>
<th>PM$_{10}$</th>
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</thead>
<tbody>
<tr>
<td>Gasoline auto</td>
<td>13.00</td>
<td>3.757</td>
<td>1.260</td>
<td>0.011</td>
</tr>
<tr>
<td>Light-duty diesel truck</td>
<td>1.607</td>
<td>0.362</td>
<td>1.492</td>
<td>0.122</td>
</tr>
<tr>
<td>Heavy-duty diesel truck</td>
<td>9.326</td>
<td>2.356</td>
<td>15.683</td>
<td>2.359</td>
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traffic noise is depends on the volume, speed, and composition of the traffic. Traffic composition has the greatest effect: one combination truck produces as much noise at 55 miles per hour (mph) as 28 autos. A traffic stream moving at 65 mph is twice as loud as one traveling at 30 mph. Traffic volume has less effect: 2,000 vehicles per hour sounds only twice as loud as 200 vehicles per hour. Highway noise is considered moderate to severe at 60–90 dBA, and non-annoyance levels are often considered to be 55 dBA or less (FHWA 1992, 4–5).

Noise decreases at more than a linear rate with distance (Ishiyana, Tateisha, and Arai 1991, 69–70). Traffic noise (dependent on traffic mix, speed, and volume) tends to dwindle away from the road until it reaches background levels at about 1,000 feet from a highway source (Hokanson et al. 1981, 17). Second to distance, barriers (structures that, to a degree, block, deflect, and absorb noise) are likely to be the most important determinant of noise level. Because structures act as barriers, most noise impacts are absorbed by the first row of houses along a given transportation corridor (Stutz 1986, 333). The degree to which a building impedes traffic noise depends on the relation between the building’s height and the height of the noise source (Ishiyana, Tateisha, and Arai 1991, 66).

Effects of Noise

Depending on the individual, noise can cause sleep disturbance, communication interference, and general annoyance. Communication interference occurs when nearby traffic masks normal conversation, so that people strain to hear and be heard. “Annoyance” generally describes physical and psychological stress. Table 4 summarizes the results of increasing noise levels, including annoyance and communication interference.

Because people vary greatly in the degree to which they tolerate noise, an absolute change in noise level is not necessarily a predictor of annoyance. In the case of highway noise, for example, researchers have found that individual differences in noise tolerance explain more variance in comfort level than do differences in noise itself. Some individuals show high annoyance at 60 dBA,

<table>
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<th>TABLE 4. Effects of noise levels</th>
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<tr>
<td>Noise level (dBA)</td>
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<tr>
<td>55–64</td>
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<tr>
<td>65–69</td>
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<tr>
<td>70–79</td>
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<tr>
<td>Above 80</td>
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</table>

Source: Bureau of Transportation Statistics (1994, 169).
while others remain unconcerned at 80 dBA (Langdon 1985, 163–7). The intensity, duration, predictability, and controllability of noise are related to the negative effects of noise on each individual (Llewellyn 1981, 192–6). Even if noise levels are low on average, intermittent noise can be bothersome, especially for people who need to concentrate, rest, or maintain tranquility. Schools, nursing homes, hospitals, and churches are places where intermittent noise is particularly intrusive.

Governmental agencies set noise abatement criteria to levels that are appropriate to the time of day and the type of activity immediately adjacent to the roadway. For example, table 5 displays noise abatement criteria established by the Minnesota Pollution Control Agency. These criteria are based on the reasoning that maximum acceptable levels of traffic noise depend largely on the type of activity close to the roadway. Although sound intensity is measured in terms of decibels, noise models use a descriptive noise exceedance scale to show the overall effects of noise over time. There are three commonly used sound intensity descriptors:

- $L_{10}$: the noise level in dBA that is exceeded 10 percent of the time (e.g., six minutes per hour) during specified hours of the day. Those hours typically conform to daytime, evening, and night, with standards becoming more restrictive during later times of the day.

- $L_{50}$: the noise level in dBA that is exceeded 50 percent of the time during specified hours. The standards for $L_{50}$ tend to be more restrictive than for $L_{10}$ because of the greater exposure.

$L_{eq}$: a composite descriptor that takes into account the variance in noise over time. It is a scale that converts a varying noise level to a constant equivalent noise level. $L_{eq}$ for typical traffic conditions is about 3 dBA less than $L_{10}$ for the same conditions (FHWA 1992, 6).

**Modeling Noise**

A number of models are available for assessing noise levels. We selected MINNOISE to model the noise levels surrounding an intersection of existing U.S. Highway 63. MINNOISE is a noise propagation model derived from the Federal Highway Administration’s STAMINA model that the Minnesota Department of Transportation (Mn/...
DOT) has updated. MINNOISE computes $L_{eq}$, $L_{10}$, and $L_{20}$ noise levels.

Using data on traffic volume, mix, and speed, MINNOISE can estimate noise levels at constant flow speeds. To model stop-and-go traffic, the roadway is broken into segments; vehicles in a given segment are designated as accelerating, cruising, or decelerating. The speed over each segment is not an average (as for air modeling), but an “equivalent” or constant speed estimated by the initial vehicle speed at the beginning of the segment and the final vehicle speed at the end of it. This method is appropriate for uncongested roads only and is not recommended for roads with a low (E or F) level of service (Minnesota DOT 1991, 2).10

MINNOISE was used to estimate the likely severity of noise effects from the trial scenario along U.S. Highway 63. It should be stressed that the trial application does not consider any mitigating effects of adjacent topography or structures. Therefore, the resultant noise effects are likely to be overstated, but the approach can identify specific geographic areas that may exceed relevant federal or state criteria for noise level abatement. In order to simplify the model for Waterloo, we ignored minor intersections along the cruising segments of U.S. Highway 63. To further refine an evaluation of the intersection, one could add data on the position and height of barriers (primarily structures); the elevation of surrounding terrain; and the traffic mix, speed, and volume on intersecting streets. These refinements would increase the accuracy of noise estimates along U.S. Highway 63.

To create an interesting hypothetical scenario for the test intersection, heavy truck traffic was simulated on U.S. Highway 63 to approximate the effect if a significant amount of industrial development were to occur near this route. At low traffic speeds, the majority of noise at this intersection would come from vehicle engines and brakes. The model shows that even if there were to be a substantial increase in truck traffic on the road, maximum noise levels during the day would remain below federal standards. Figure 7 depicts the profile of the noise gradient along U.S. Highway 63 at the test intersection. At the very center of the highway, the noise level reaches a maximum value of 64 dBA, and at 1,000 feet from the centerline, it attenuates to a little less than 55 dBA.

Because of the flexibility of the GIS, it is possible to create maps either to display maximum estimated noise levels interposed with socio-demographic data as in figure 8, or to present the data in tables. Table 6 summarizes characteristics of the populations that reside within contours representing the maximum noise levels (dBA) for our scenario. Tables are useful supplements to map graphics, allowing one to answer the general question, “Are minority populations or low-income populations disproportionately affected?” The graphics, on the other hand, allow one to determine, “In which specific blocks should we focus mitigative measures to address the issue of disproportionate effects?” In this case, low-income households are not overrepresented among those exposed to $L_{10}$ or $L_{20}$ noise levels, but minority households clearly are.

**Conclusion**

For environmental justice to occur as transportation system changes are made, their probable consequences must be estimated and the results presented comprehensively to affected populations. This study blended census block data on race and income with spatial data on air quality and noise levels. By presenting both popu-
Figure 8. Maximum $L_{10}$ noise level and percentage of minority population, intersection along U.S. Highway 63.
TABLE 6. Population characteristics within noise contours, intersection along U.S. Highway 63

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Low-income</th>
<th>Minority</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_10</td>
<td>65</td>
<td>189</td>
</tr>
<tr>
<td>L_50</td>
<td>60</td>
<td>131</td>
</tr>
<tr>
<td>Waterloo</td>
<td>16.7</td>
<td>13.2</td>
</tr>
</tbody>
</table>

lation characteristics and the products of computer-based models in a map format, the study demonstrated how it is possible to determine whether air quality or noise effects would adversely and disproportionately affect minority populations or low-income populations.

A growing awareness of the pivotal role played by the transportation sector in the quality of life for low-income populations and minority populations has led environmental justice advocates to strongly emphasize that sector. This article presents a methodology to improve the quality of information available to all interested parties, including those who traditionally have had comparatively little knowledge about the consequences of proposed transportation system changes. It is clear that more work is needed to further upgrade our ability to generate the salient information. Also needed are better ways to include minority populations and low-income populations in the planning process from conceptualization to effectuation.

Environmental justice is a public policy objective that has the potential to significantly improve the quality of life for people whose interests often have been left behind as communities grow and change. The methods presented in this article represent a step toward a more equitable sharing of knowledge about the distribution of the benefits and costs brought about by investments in transportation systems.

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NOTES

1. Poverty thresholds vary by household size. In 1989, federally defined poverty thresholds were as follows: $6,310 for one person, $8,076 for two persons, $9,885 for three persons, $12,674 for four persons, $14,990 for five persons, $16,921 for six persons, $19,162 for seven persons, $21,328 for eight persons, and $25,480 for nine or more persons (Bureau of the Census 1994, Table 739).

REFERENCES


