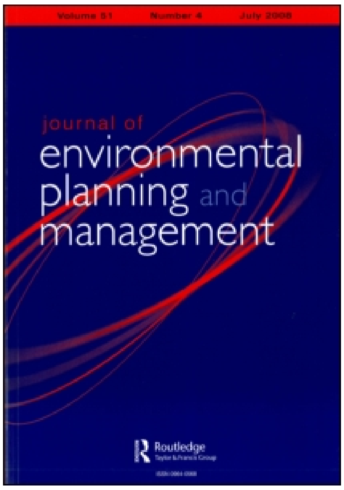


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# Proximal exposure of public schools and students to major roadways: a nationwide US survey

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# Proximal exposure of public schools and students to major roadways: a nationwide US survey

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This study addresses the effect of urban planning and road development on the health risk of students attending schools near major roadways. The proximity of public schools and students was quantified to Interstate, US and state highways in nine large Metropolitan Statistical Areas (MSA) of the USA. In total among the surveyed schools and students, over 30% fell within 400 m of a major roadway and over 10% were within 100 m. For some MSAs almost half of the student population attended schools near (≤400m) major roadways, resulting in a potentially increased risk for asthma and other chronic respiratory problems, especially in schools representing the urban fringe locale. It was concluded that proximity of major roadways should be an important factor in considering sites for new schools and developing policies for reducing the exposure in existing schools. The findings provide an important reference point for coordinating future urban development, transportation and environmental policies.

**Keywords:** proximal exposure; traffic; major roadways; public schools; air pollutants



## 1. Introduction

Effective land use and road development patterns are necessary to protect the health of school-age children. Elevated levels of air pollutants from traffic exhaust, including nitrogen dioxide ($NO_2$), carbon monoxide (CO), volatile organic carbon (VOC) and particulate matter (PM), near major roadways are associated with adverse childhood health effects, such as respiratory allergies, decreased lung function, bronchitis and asthma exacerbation (Rutishauser *et al*. 1990, Edwards *et al*. 1994, Pershagen *et al*. 1995, van Vliet *et al*. 1997, Venn *et al*. 2001, Brauer *et al*. 2002, Nicolai *et al*. 2003, Kim *et al*. 2004, Gauderman *et al*. 2005, Ryan *et al*. 2005, McConnell *et al*. 2006). Children are especially susceptible as their lungs are growing until adulthood, they breathe with 50% more air per pound of body weight than adults and develop respiratory infections more often than adults (USEPA 2002, ALA 2004).

International studies have shown many health risks for children from traffic-related pollutants. Children exposed to high-traffic roadways had substantial deficits in 8-year lung development (Gauderman *et al*. 2007), and a higher prevalence of most respiratory

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symptoms (Oosterlee *et al.* 1996). A hospital asthma-admissions survey in Birmingham, UK, revealed that the subjects were more likely to live near roads with traffic of $>24{,}000$ cars/day (Edwards *et al.* 1994). Dutch researchers indicated that cough, wheeze, runny nose and asthma were significantly more often reported for children living within 100 m from freeways, and that black smoke from truck traffic measured in schools was significantly associated with chronic respiratory symptoms (Janssen *et al.* 2003). A Swedish study suggested that exposure to combustion products containing $NO_2$ may be of particular importance for the development of wheezing bronchitis in girls (Pershagen *et al.* 1995). Asthma and wheeze in Southern Californian school children were strongly associated with residential proximity to major roads, with the effects larger in girls (Gauderman *et al.* 2005, McConnell *et al.* 2006).

Truck routes generally run along major roadways aerosolising diesel exhaust particles (DEP), a respirable fraction with a peak size distribution in the ultrafine/nano-scale range representing a specific health-relevant exposure source. Having significant penetration to peripheral airways, DEP are linked to aggravating respiratory conditions (e.g. asthma and bronchitis), cancer and other major health effects (USEPA 2002). Children have been identified among the groups with greatest health risks from DEP exposure (ALA, 2000). Studies in the Netherlands found that increased respiratory problems due to air pollution were associated with traffic intensity of trucks (more than automobiles), particularly in children living close ($<300$ m) to the motorways (Brunekreef *et al.* 1997, Janssen *et al.* 2003). Truck traffic intensity and the concentration of black smoke, a marker of DEP, measured in schools are significantly associated with chronic respiratory symptoms (van Vliet *et al.* 1997).

When estimating childhood exposure to traffic-related pollutants and the consequent respiratory symptoms, investigators have generally considered primary residences. However, exposure in schools seems essential for determining the children's overall exposure. As students spend almost 30% of a school day in the classroom and considerable time on school grounds participating in sports and other before/after-school activities (Stevenson and Nerison-Low 1997), school attendance may result in a large daily inhalation dose of traffic pollutants. Children who exercise regularly in smoggy areas increase their chances of developing asthma three-fold compared to those in areas with cleaner air (McConnell *et al.* 2002). In cities, the issue is even more relevant: according to Green *et al.* (2004), the percentage of public schools near busy roads in California was 13 times higher in cities with populations $\geq$200,000 people than in rural areas. Therefore, the location of metropolitan school sites is important for assessing children's potential health risks.

American studies which examined the proximity of schools (Green *et al.* 2004, Environmental Defense 2006, Wu and Batterman 2006) or licensed childcare facilities (Houston *et al.* 2006) to major roadways, have been limited to a few specific areas, such as the states of California and North Carolina and the city of Detroit. To the authors' knowledge, no study has addressed this issue at a national or international level. Consequently, the health risk associated with proximity of schools to major traffic arteries has not received sufficient consideration in the development, planning and management of major urban environments.

This survey examined major metropolitan areas with respect to the fraction and demographics of schools and students within 100 and 400 m of major roadways. The association of proximity to race and school locale was also investigated. Furthermore, the potential implementations of the proximity study findings for school- and city-planning and environmental policy management are discussed.

## 2. Materials and methods

### 2.1. Selection of metropolitan areas and roads

Using a stratified random cluster sampling procedure, nine Metropolitan Statistical Areas (MSAs) with a population over 1 million residents (US Census 2007a) were chosen representing each of the nine divisions of the USA (US Census 2007b). Generally, an MSA is defined by the US Federal Office of Management and Budget (OMB) as the counties containing the core urban area (with a $\geq$50,000 population in one or more large population nuclei) and any adjacent counties with a high degree of social and economic integration with the urban core. MSAs' counties were determined from the most current population estimates for cities (USOMB 2006).

Major roads within each MSA were defined as 'Interstate' or 'US Highway' or 'State Highway', to consistently reflect main truck and traffic routes. For each MSA the density of major roadways was determined as the ratio of the total centreline length of major roads (miles) to the area (square miles).



### 2.2. School statistics

School data were obtained from the US Department of Education's National Center for Education Statistics (NCES), through the Common Core of Data (CCD) (NCES 2007). The CCD is the primary database on public elementary and secondary education, updated annually. The most recent public school data were available for the 2004–2005 school year. The study database, developed from the CCD, included the following information for each school: (1) location address and county; (2) school type (according to the ordinary or special instructional needs of students); (3) total enrolment; (4) racial distribution; (5) grade span; and (6) locale.

Schools with students in one or more grade level, pre-kindergarten to grade 12, were included. Those designated as 'Regular', 'Special Education' or 'Vocational' were incorporated but 'Other/Alternative' were not (to avoid double-sampling). Schools with unreported enrolment and racial distribution were excluded. In schools that reported racial distribution but not enrolment, the numbers per racial category were combined to produce the total enrolment. Overall, 0–5% of the surveyed schools per MSA were removed due to lack of enrolment data. Students classifying themselves as American Indian/Alaskan Native were accounted for but their contribution to the total student population was only 0.03–1.5% per MSA.

All schools were assigned a locale (Central City, Urban Fringe or Rural) derived from the codes (L1–L8) of the NCES classification system (NCES 2007) that provides the physical location represented by an address matched against a geographic database maintained by the US Census Bureau. Schools labelled L1-Large City or L2-Mid-size City were grouped into the category 'Central City'; schools labelled L3-Urban Fringe of a Large City or L4-Urban Fringe of a Mid-size City were grouped into the category 'Urban Fringe'; schools labelled as L8-Rural Inside MSA were classified as 'Rural'. Other NCES codes, L5–L7, were not applicable, as these were outside an MSA.

### 2.3. Proximal exposure assessment

The complete road network for each MSA was obtained using Topologically Integrated Geographic Encoding and Referencing (TIGER) line files (US Census 2000). Major roads were defined as having a road prefix of 'IS', 'USHY' or 'STHY' indicating a federal

Interstate, US highway, or state highway, respectively. The addresses of all schools in each MSA were geocoded using EZLocate (TeleAtlas Inc., Menlo Park, CA). The distance to the nearest Interstate and the nearest US or state highway was estimated using ArcGIS software (version 9.0; Environmental Systems Research Institute Inc., Redlands, CA).

Based on practical considerations and several studies on the environmental exposure assessment and exposure-health relationship, two distances were established, 100 and 400 m, as measures of proximal exposure to air pollutants originated on major roadways. Particulate sulphur concentrations have been shown to decrease by half between 50 and 100 m from a highway but persisted until 400 m (Reponen *et al.* 2003). Van Vliet *et al.* (1997) referred to 100 m as a benchmark distance from freeways to identify chronic respiratory symptoms in school children. Ultra fine particles have been found elevated above background concentrations up to $\sim$300 m from roadways with the most rapid decline within 150 m (Hitchins *et al.* 2000, Zhu *et al.* 2002a, 2002b). There is evidence about the exposure-health association at distances as high as 500 m (Edwards *et al.* 1994, Gauderman *et al.* 2007). A 400-m distance from major roadways was established for classifying exposed children in several studies (Ryan *et al.* 2005, LeMasters *et al.* 2006, Gauderman *et al.* 2007).

For each MSA and X = 100 and 400 m, the number of exposed schools and students relative to the total numbers of schools and students was determined, respectively. Thus, the percentage of proximal exposure was calculated as

$$\mathrm{PE} = \frac{\text{Number of schools/students within X meters of an Interstate, US, or State Highway}}{\text{Total number of schools/students of the MSA}}$$

For comparison purposes, area-based population exposure estimates at a distance of X = 400 m from a major roadway were also calculated for each MSA as the area factor:

$$\mathrm{A_F} = \frac{\text{Land area within X meters of an Interstate, US, or State Highway}}{\text{Total land area of the MSA}}$$

This approach assumes an equal population distribution within an MSA and is a first-approximation estimate. A PE greater than the $A_F$ was regarded as a relatively elevated exposure of students while in school as compared to other locations within a corridor from $-$X to $+$X (both sides).

### 2.4. *Statistical analysis*

Cities were arranged from East to West (Table 1) in order to examine potential regional trends using general linear regression. The difference in percentages of schools and students within each MSA were tested using a *z*-test for differences in proportions. Racial differences and the locale distribution of schools were compared across the nine MSAs using the Wilcoxon Signed-Rank Test. Significance was defined as two-sided $p < 0.05$ for all analyses. Analyses were conducted using the Statistical Analysis System (SAS Version 9.1.3; SAS Institute Inc., Cary, NC).

### 2.5. *Limitations*

A study limitation was related to the Geographic Information System (GIS), which allows relatively quick computation of distance between geocoded school addresses and the

Table 1. Proximity of metropolitan public schools and students to major roadways defined as Interstate, US, or State highways.

| Metropolitan Statistical Area (arranged from East to West) | Percentage of schools/students in close proximity to an Interstate, US or state highway | | | |
|---|---|---|---|---|
| | ≤400 m | | ≤100 m | |
| | Schools | Students | Schools | Students |
| Boston-Cambridge-Quincy, MA-NH | 43.9 | 44.4 | 18.5 | 18.9 |
| Philadelphia-Camden-Wilmington, PA-NJ-DE-MD | 41.5 | 41.3 | 17.6 | 18.0 |
| Atlanta-Sandy Springs-Marietta, GA | 38.4 | 35.9 | 18.2 | 17.6 |
| Cincinnati-Middletown, OH-KY-IN | 38.5 | 38.1 | 18.3 | 19.0 |
| Memphis, TN-MS-AR | 35.7 | 32.8 | 14.3 | 13.1 |
| Minneapolis-St. Paul-Bloomington, MN-WI | 38.1 | 35.7 | 10.9 | 9.7 |
| San Antonio, TX | 25.2 | 22.0 | 6.8 | 7.3 |
| Denver-Aurora, CO | 26.3 | 23.1 | 7.6 | 5.2 |
| Los Angeles-Long Beach-Santa Ana, CA | 19.5 | 20.5 | 3.2 | 3.5 |
| Total (for the 9 MSAs) | 33.0 | 30.4 | 11.9 | 10.8 |



centreline of major roadways. Street geocoding has been found to have a median error of 41 m and 95th percentile of 137 m (Zandbergen 2007). As the approach applied in this study does not differentiate between wider and narrower roads, the distance from a school is calculated to the centreline but not to the curb of the highway. In addition, a school property is not a single point, as assumed by the geocoding process. The actual position of the students can be anywhere on the school grounds, which may have characteristic dimensions exceeding 100 m. While GIS has been shown to slightly over-estimate potentially exposed residence-locations (Zandbergen 2007), the approximation for school locations allowed no buffer zone for building/property area and therefore leads to consistent underestimation. The inherent accuracy limitations of the geocoding process made this study more challenging than those based on residence locations (with small-area lots). In this context, the data for proximal exposure at ≤400 m are probably more representative. In addition to the above limitations, the presented approach does not incorporate factors such as climate, wind-direction and elevation that may affect the proximal exposure.

## 3. Results

A total of 8803 public schools, comprising 6,017,222 students, were assigned to the nine MSAs. These MSAs represented approximately 25% (39,275,241/158,137,439) of the US population living in large (>1,000,000 people) metropolitan areas.

As seen in Table 1, a considerable percentage of schools and students had a potentially high exposure to air pollutants originating from major roadways. Among all students and schools evaluated in the nine MSAs, >30% fell within 400 m of a major roadway and >10% were within 100 m. When plotting the percentages of schools and students per MSA from East to West, there was a significant ($p < 0.01$) linear decrease in proximal exposure. Thus Boston, compared to Los Angeles, had more than twice the number of students (and schools) within 400 m, 44.4% versus 20.5%, and nearly six times more within 100 m, 18.9% versus 3.5%.

For every MSA, the percentages of schools and students in close proximity to a major roadway were analysed for Interstates and US/state highways separately (Figure 1). The majority of proximal exposure among the nine MSAs occurred near US and state highways, exceeding that of Interstates by a factor of about 1.5 to 14 for ≤400 m, and almost 2 to 70 for ≤100 m. From East to West nationwide, the percentages of public schools/students in close proximity to US or state highways decreased linearly (at ≤400 m: $R^2 = 0.85$ for schools, $R^2 = 0.87$ for students; at ≤100 m: $R^2 = 0.90$ for schools, $R^2 = 0.91$ for students). The corresponding percentages for Interstates increased linearly (at ≤400 m: $R^2 = 0.82$ for schools, $R^2 = 0.72$ for students; at ≤100 m: $R^2 = 0.80$ for

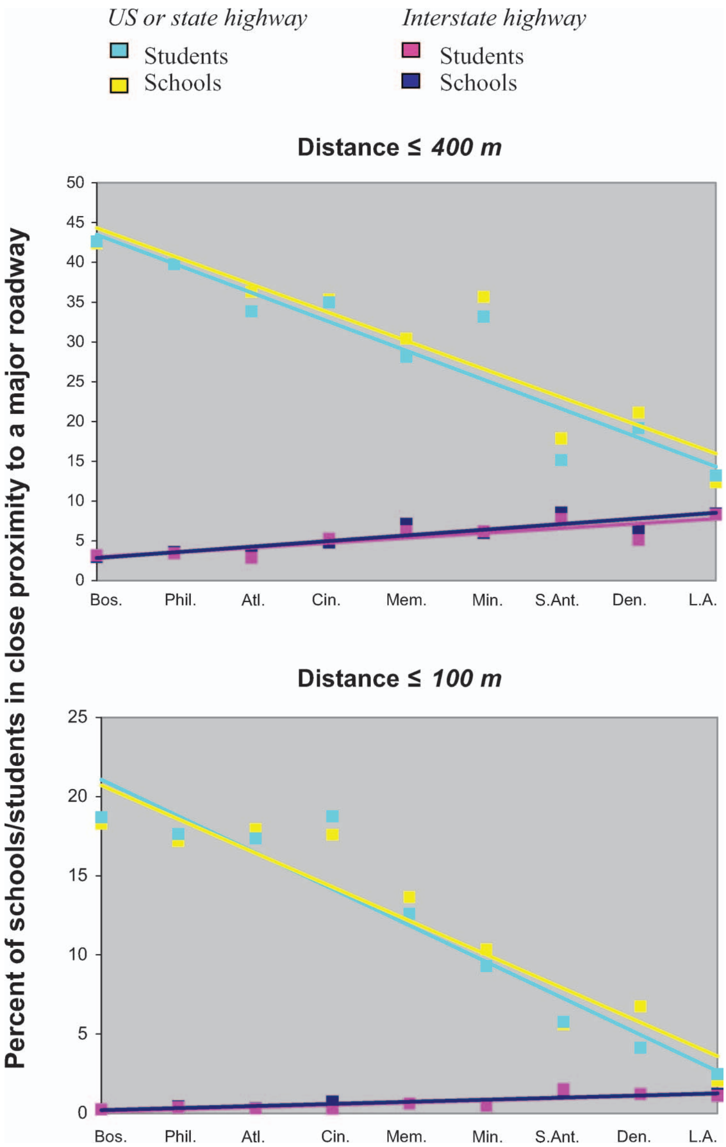


Figure 1. Proximity of metropolitan public schools and students to an Interstate highway versus a US or state highway.

schools, $R^2 = 0.68$ for students) with a strong statistical significance ($p < 0.01$) for both distances. The overall decrease in proximal exposure (with respect to all major roadways) presented in Table 1 reflects the small contribution of the Interstate highways relative to US/state highways (Figure 1).

Throughout this study, the proximity results calculated based on the number of public schools within each MSA were very similar to the corresponding results calculated based on student enrolment. The analysis of data presented in Table 1, for example, shows that there is no statistically significant difference between the percentages of schools and students within any MSA, except for Denver at $\leq$100 m.

The proximal exposure of students while at schools located at $\leq$400 m was compared to the area-based population exposure estimate calculated for each MSA. The former was found to be significantly ($p < 0.01$) higher than the latter with $PE/A_F$ ranging from 1.5 in Philadelphia to 3.2 in San Antonio. On average, public school students showed a twice-greater percentage of proximal exposure than the area-based estimate calculated for the overall population.

The study determined the percentage of students within each racial group attending schools within 100 and 400 m of a major roadway (Table 2). Pairwise comparisons were made between each racial group across the nine MSAs by hypothesising that the percentage of students in two given races were equal and tested using the Wilcoxon Signed Rank test. Overall, Caucasian students were significantly more likely to be attending schools at $\leq$400 m from major roadways than Hispanic students ($p = 0.04$). No other significant association between racial category and proximity was established. However, in the majority of MSAs a higher percentage of Caucasian students were enrolled in schools located near major roadways than African American students: in seven MSAs for $\leq$100 m and six MSAs for $\leq$400 m. Although no race was consistently closer to major roadways across all surveyed MSAs, within each MSA there were significant proximity differences by racial category. Chi-square tests showed that for each racial category, there was at least one surveyed MSA in which this race had a significantly higher percentage of exposed students (either within 100 or 400 m) than all other races.

Figure 2 presents the breakdown of schools by locale. Most of the exposed schools were classified as urban fringe, significantly outnumbering the two other locale categories in six MSAs (Boston, Philadelphia, Atlanta, Cincinnati, Minneapolis and Denver) for $\leq$400 m, and in five MSAs (Boston, Philadelphia, Atlanta, Cincinnati and Minneapolis) for $\leq$100 m. Over half of the exposed schools were designated as urban fringe in the four Eastern-most metropolitan areas for X = 400 m (Boston, Philadelphia, Atlanta and Cincinnati) and in the two Eastern-most areas (Boston and Philadelphia) for X = 100 m. The locale distributions of exposed schools may, in part, reflect those of all schools (exposed and non-exposed) built in the MSAs. For example, among the 8803 schools evaluated in this study, over 55% were urban fringe.

When plotted East to West, the statistically significant decrease in proximity among the nine tested MSAs may be attributed to a significant linear decrease ($R^2 = 0.7$, $p < 0.01$) in schools of the urban fringe category from Boston to Los Angeles (Figure 2). The percentage of schools classified as rural or central city within 400 m or 100 m of a highway remained generally constant, showing no significant trend from East to West.

The percentage of schools in 100- and 400-m proximity within each locale category were also analysed for each MSA (Table 3). In every case for $\leq$100 m, and nearly every case for $\leq$400 m (with Atlanta and San Antonio as exceptions), a significantly higher percentage of rural schools appeared in close proximity to major roadways than were in the central city ($p < 0.01$ at $\leq$400 and $\leq$100 m) or urban fringe ($p < 0.02$ at $\leq$400

Table 2. Percentage of students within each racial group attending schools within 100 and 400 m of a major roadway.

| Metropolitan Statistical Area (arranged from East to West) | Distance | Percentage of students in each racial group enrolled near an Interstate, US or state highway | | | |
|---|---|---|---|---|---|
| | | Asian | African American | Hispanic | Caucasian |
| Boston-Cambridge-Quincy, | ≤400m | 45.9 | 34.9 | 43.8 | 45.7 |
| MA-NH | ≤100m | 16.1 | 11.4 | 14.8 | 20.6 |
| Philadelphia-Camden-Wilmington, | ≤400m | 40.0 | 40.5 | 34.1 | 43.2 |
| PA-NJ-DE-MD | ≤100m | 20.4 | 15.6 | 13.6 | 19.9 |
| Atlanta-Sandy Springs-Marietta, | ≤400m | 31.7 | 36.2 | 34.7 | 36.6 |
| GA | ≤100m | 14.5 | 13.6 | 16.4 | 14.5 |
| Cincinnati-Middletown, | ≤400m | 37.7 | 32.1 | 42.7 | 39.4 |
| OH-KY-IN | ≤100m | 16.1 | 10.3 | 21.2 | 21.2 |
| Memphis, TN-MS-AR | ≤400m | 26.8 | 49.3 | 32.2 | 40.9 |
| | ≤100m | 6.8 | 22.3 | 10.6 | 13.3 |
| Minneapolis-St. Paul-Bloomington, | ≤400m | 39.5 | 40.2 | 39.4 | 33.7 |
| MN-WI | ≤100m | 12.2 | 10.6 | 7.5 | 9.5 |
| San Antonio, TX | ≤400m | 9.2 | 12.3 | 22.5 | 24.6 |
| | ≤100m | 2.4 | 2.2 | 2.2 | 9.2 |
| Denver-Aurora, CO | ≤400m | 17.5 | 18.5 | 25.8 | 21.4 |
| | ≤100m | 3.0 | 5.0 | 4.6 | 7.1 |
| Los Angeles-Long Beach-Santa | ≤400m | 18.2 | 20.3 | 21.9 | 16.0 |
| Ana, CA | ≤100m | 2.5 | 3.4 | 3.7 | 2.8 |

and ≤100 m) locales. In seven MSAs nearly half or more rural schools were at ≤400 m of a highway. There were no significant differences between the central city and urban fringe locales. In total, among the nine MSAs, 45.4% (431/950) of rural schools were built within 400 m of a highway, while only 29.3% (877/2992) of central city schools and 32.9% (1600/4860) of urban fringe schools were at this distance. Clearly, while a higher percentage of rural schools were built within close proximity to major roadways, this percentage does not represent a major contribution to the total, as there are relatively few schools classified as rural within an MSA.

## 4. Discussion

A large percentage of public schools and students (~1/5 to 1/2, depending on the metropolitan area) were found in close proximity (≤400 m) to Interstate, US or state highways. These roadways are of particular relevance because they are major arteries for diesel-powered vehicles and motor vehicle traffic, contributing greatly to air pollution nationwide. For some large MSAs (Boston and Philadelphia), almost half of the student population attended schools within 400 m of major roadways. This proximity may result in an increased risk of acute and chronic respiratory disorders. A particular health risk applies to those children whose schools are located within 100 m of a major roadway. In four MSAs (Boston, Philadelphia, Atlanta and Cincinnati) almost 20% of students attended schools within this corridor. Overall, approximately one-third of the students in the evaluated MSAs may be at increased risk because of where they attend school. This is alarming considering previously established associations between specific health effects and the proximal exposure to roadways.

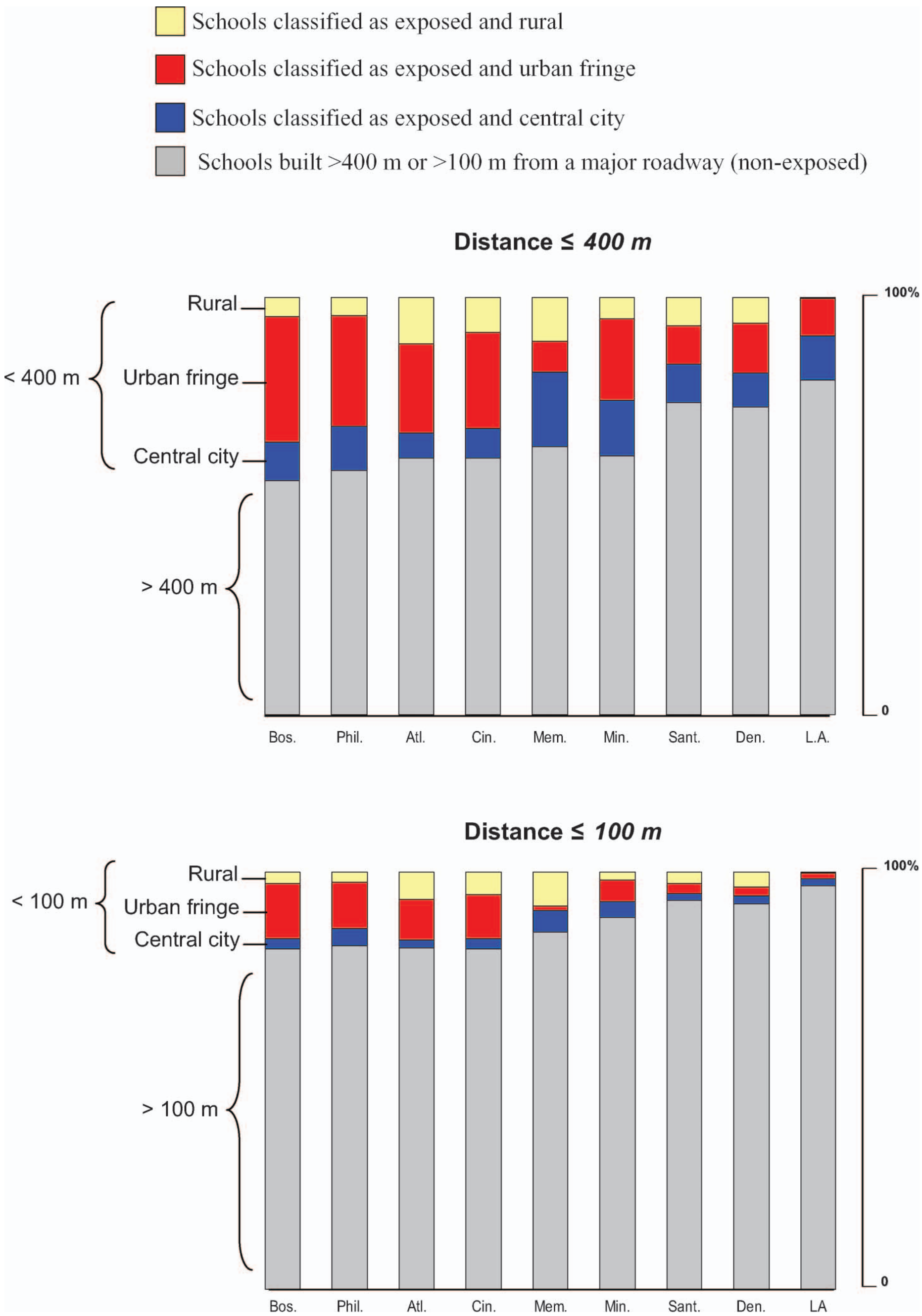


Figure 2. Locale specification for metropolitan public schools relative to an Interstate, US or state highway (non-exposed versus locale-specific exposed).

Even for Los Angeles, showing the lowest percentage of schools/students near major roadways (Table 1), approximately 20% fell within a 400 m distance. This 20% may considerably underestimate the actual exposure to traffic pollutants, compared to other

Table 3. Percentage of schools in each locale built near an Interstate, US or state highway.

| Metropolitan Statistical Area (arranged from East to West) | Percentage of schools in each locale built near an Interstate, US or state highway | | | | | |
|---|---|---|---|---|---|---|
| | ≤400 m | | | ≤100 m | | |
| | Central city | Urban fringe | Rural | Central city | Urban fringe | Rural |
| Boston-Cambridge-Quincy, MA-NH | 38.3 | 44.6 | 54.0 | 10.8 | 19.5 | 33.0 |
| Philadelphia-Camden-Wilmington, PA-NJ-DE-MD | 39.5 | 41.9 | 45.0 | 14.9 | 17.4 | 26.4 |
| Atlanta-Sandy Springs-Marietta, GA | 50.9 | 32.9 | 47.6 | 16.4 | 15.1 | 27.6 |
| Cincinnati-Middletown, OH-KY-IN | 33.9 | 39.4 | 40.4 | 11.3 | 18.3 | 25.4 |
| Memphis, TN-MS-AR | 31.7 | 28.6 | 58.6 | 8.9 | 4.8 | 44.8 |
| Minneapolis-St. Paul- Bloomington, MN-WI | 41.2 | 35.1 | 42.9 | 11.5 | 9.5 | 15.1 |
| San Antonio, TX | 15.4 | 42.3 | 36.3 | 2.8 | 11.5 | 14.3 |
| Denver-Aurora, CO | 26.0 | 21.5 | 48.8 | 5.8 | 4.1 | 28.1 |
| Los Angeles-Long Beach-Santa Ana, CA | 21.5 | 17.9 | 25.0 | 3.2 | 3.0 | 12.5 |
| Total (for the 9 MSAs) | 29.3 | 32.9 | 45.4 | 7.6 | 11.9 | 25.4 |

MSAs, because highways in Los Angeles are particularly characterised by a large number of lanes and high traffic intensity (factors not included in this study). As distances from schools were measured to the centreline but not the kerb of the highway, some wide multi-lane highways of Los Angeles could take up a large portion of a 100- or a 400-m distance. Therefore, many schools, which were actually in a close proximity to peripheral highway traffic, appeared beyond the 100- or 400-m limit to the centreline of roadways.

Although students' proximity to Interstates was found to be less than to US/state highways, Interstates have heavier traffic and the schools near these major arteries may be subjected to the most considerable emissions. The schools in close proximity to Interstate highways were few, but the students of these schools are likely to be exposed to higher levels of traffic-related pollution.

Assuming that the population is uniformly distributed within each MSA, it was found that public school students compared to the general population were more likely to be near major roadways (PE $>$ $A_F$). While this area-based population estimate is perhaps too simplistic and acknowledged to be a first-approximation type modelling, it seems sufficient for comparison purposes. Better alternatives would need to account for the heterogeneity of a metropolitan population by estimating the population-weighted average distance to major roadways.

Most of the geographic trends identified in this study may be attributed to urban development including westward expansion, road improvement strategies, and the rapid growth of metropolitan areas ('urban sprawl'). In the first half of the twentieth century, an influx of people moved into cities in search of well-paid factory jobs, and by 1920 more Americans lived in cities than on farms. Lacking affordable transportation, they worked and resided in small urban clumps. To increase mobility within and between urbanised areas, the Federal Roadways Acts of 1916 and 1921 resulted in 200,000 miles of primary roads, including a US highway network (Gillham 2002). With the country settling from East to West, more developed cities were in the East and the highway network decreased in road-density East-to-West. Even today, the population density (US Census 2006), as well as the density of highways (US Department of Transportation 2007) has a decreasing trend from East to West, with the exception of the West Coast. In order to individually characterise each MSA surveyed in this study, the density of major roadways was calculated as:

$$\rho_{\text{MSA}} = \frac{\text{Total centreline miles of Interstate, US, and State Highways}}{\text{Total land area of the MSA}}$$

It was noticeable that $\rho_{\text{MSA}}$ had a decreasing trend from East to West, ranging from 0.16–0.28 mile/mile$^2$ (Denver, San Antonio and Los Angeles) to 0.61–0.66 mile/mile$^2$ (Philadelphia and Boston). This formula has limitations for characterising the traffic exposure in the MSA (e.g. it does not account for total lane miles or the traffic intensity measured as vehicle miles travelled). Figure 3, in which each point represents a specific MSA, shows a strong association between the proximal exposure to all major highways (for schools at $\leq$400 m) and the respective road density ($p = 0.003$, $R^2 = 0.66$, $\beta_0 = 38.8$), suggesting that the road density differences between regions may have a direct impact on the proximal exposure of public school students. Interestingly, proximity of schools specifically to Interstates shows an opposite trend: an increase from East to West (Figure 1). The reason for the apparent increase (although its contribution to the overall traffic proximal exposure is small) remains to be determined.

The rapid expansion of metropolitan areas in recent years, termed 'urban sprawl', seems to be associated with the consistent building of schools near highways. The federal and state transportation spending increase, starting from the 1920s, had a profound impact on the pace and shape of metropolitan growth (Katz 2002). The improvement and construction of highways from the city centres outward increased access between the city

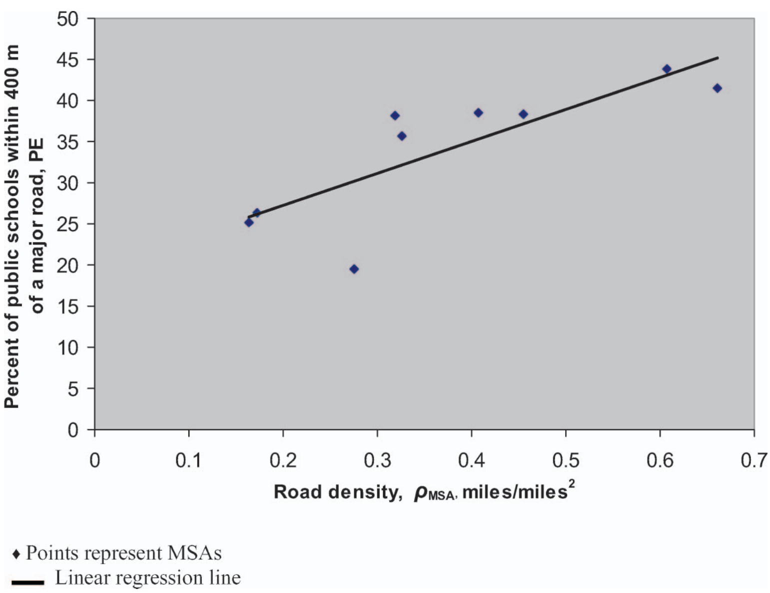


Figure 3. Proximal exposure in public schools for each MSA, plotted against its respective road density.

and suburbs, allowing for more commuting from suburban homes to city jobs and increasing residences beyond old city limits (Gillham 2002). As travel time and costs affect the land use and infrastructure development (including the locations where the public schools were built), most growth spread outward along existing highways, clumping into small communities outside the central city (Gillham 2002). Accessible, large schools were built along main roads connecting communities outside of the central city to decrease the per-pupil cost. Many older, smaller schools built before the new Interstate, US and state highways (and therefore not necessarily alongside them) had lower attendance and soon became obsolete (Punke 1934). Today, suburbs have a greater share of the country's population, and begin looking more like the urban centres (Katz 2002). Meanwhile, the rural sections of metropolitan areas are facing the same development trends once seen for suburbs close to the central city. Schools and community infrastructure were and are being built near main arterial roadways emitting from the central city. This development may explain the finding here that rural locales have the highest percentage of schools in close proximity to major roadways (approximately half at $\leq$400 m), compared to central city and urban fringe locales (Table 3), which have, over time, built a network of smaller roads off main routes to serve schools and residences.

The finding that the largest percentage of schools within a 400-m distance is generally in the urban fringe may be attributed to accelerated growth of city suburbs since the 1920s (Frumkin 2002). By the 1990s, the number of families with children increased in the suburbs (20.1%) at twice the rate of the central city (10.4%) (Katz 2002), and today over half of Americans live in the suburbs. Thus, it is not surprising that most proximal exposure for schools occurs in the 'Urban Fringe' because this area has the most schools, fastest development, and largest increase of school-age children.

Previous studies in North Carolina and California have determined the distance of public schools (Green *et al.* 2004; Environmental Defense, 2006) or licensed childcare facilities (Houston *et al.* 2006) from major roadways statewide. The percentage of public schools built within 400 m from major roadways in the Eastern MSAs seems to be slightly lower but generally match the results found in North Carolina, where 50% of schools were within a quarter mile of an Interstate, US or NC highway. The California studies (Green *et al.*, 2004, Houston *et al.* 2006) used 150 m as benchmark of proximity to freeways, highways, major arterial roads and large collector roads. Their calculations were made using the Highway Performance Monitoring System (HPMS, maintained by the California Department of Transportation) as a traffic database, which distinguishes between roads by intensity of traffic (average vehicles per day), adjusted for day-of-week, seasonal and growth factors. While this type of road-classification allows for a more accurate assessment of roadways with highest vehicle-related emission rates, HPMS-equivalent data are not available nationwide. Green *et al.* (2004) reported that 12.4% of California public school students had medium to high exposure ($\geq$25,000 vehicles) to traffic within 150 m. These results are consistent with the data here for students' proximal exposure at $\leq$100 m (10.8%) nationwide. However, the findings for Los Angeles, as well as two other western MSAs (Denver and San Antonio) revealed lower proximal exposure (3.5–7.4%) – partly due to the measuring distance being 50 m closer to roadways. Houston *et al.* (2006) found that 25% of licensed childcare facilities, accounting for 28% of children, had medium to high exposure ($\geq$25,000 vehicles) at 150 m. These numbers are within the ranges established in this study for the average proximal exposure nationwide: 10.8% at 100 m to 30.4% at 400 m for students. The quoted California studies accounted for both school- and student-related demographics and exposure, while the survey in North Carolina focused on schools. Similar to the findings here for most of MSAs, both

California studies reported that the percentages of buildings and children exposed to nearby traffic were close to each other.

Percentages of exposed schools and students representing the 'Central city' category, which were obtained here for 100 and 400-m corridors in different MSAs, were generally comparable to those reported in a Detroit study for 'urban core areas' (Wu and Batterman 2006) (7.2% for schools and 7.6% for students). The referred study used 150 m as the proximity benchmark and an average annual daily traffic of $\geq$50,000 vehicles as the high-traffic road definition.

The association between race and proximal exposure to air pollutants generated in highways, reported in this study, may not be consistent with other reports addressing race and ambient pollution in general. Several studies have examined environmental justice, with respect to air pollution, and found that race may play an explanatory role in health-risk distribution, while other studies failed to find race/ethnicity as an important predictor of health outcomes (see e.g. review by Schweitzer and Valenzuela 2004). Morello-Frosch *et al.* (2002), for example, reported that minority students, especially Hispanics, in Southern California were more likely than Caucasians to attend schools in locations with higher estimated respiratory risks modelled from concentrations of outdoor air pollutants. However, this finding may reflect pollution from non-mobile sources, as well as from stop-and-go traffic on smaller roads, which are not dealt with in the study. The results were also compared to Gunier *et al.* (2003) study, which reported that non-whites are more likely to be exposed to high traffic density. The current study did not observe a significant association between racial groups and proximities to major roadways, except that Caucasian students were significantly more likely to attend schools $\leq$100 m of major roadways than Hispanic students. In addition, in seven MSAs, a higher percentage of white students was enrolled at $\leq$400 m than African Americans. Studies such as Gunier *et al.* (2003), showing that minority children are exposed to higher levels of air pollution (particularly from major roadways) than whites, are based on children's residence-locations. However, these residence-data do not necessarily reflect exposure at schools. In some – but certainly not all – MSAs evaluated in the current study, African American, Hispanic or Asian racial-categories had the highest percentage of students in close proximity to major roadways.

When utilising Green *et al.* (2004) study for comparison to the results, it was found that although the authors reported that in California "disproportionate numbers of nonwhite ... students attend schools near high traffic volumes" (p. 64), their data clearly show that the percentage of exposed non-Hispanic white students is consistently higher than either Asian or African American at every calculated area and is second only to Hispanic students. The latter, at least partially, reflects the racial makeup in California and does not contradict our findings.

## 5. Conclusion: implications for future school- and city-planning

Determining the proximal exposure of public school students representing all US regions and divisions provides a valuable reference point for evaluating environmental justice, assessing health risk, and creating effective urban development and transportation patterns. As a commonly used surrogate exposure measure, proximity to pollution sources can be linked to various health effects observed in metropolitan school children. Despite its limitations, this study demonstrates that a striking number of schools and students are regularly exposed to traffic emissions from nearby highways. Thus, the proximal exposure data obtained in this study should serve as broad scientific evidence to substantiate potential policy changes.

Policy makers need effective strategies for (a) the building of new schools in relation to major roadways and (b) reducing the exposure to traffic-related air pollution in existing schools.

Local traffic emissions should be a factor in considering sites for new schools so that effective urban planning can parallel effective public health policy. Sports fields, playgrounds and other on-school sites for outdoor activities should be built farthest from major roadways. In California, for example, legislation has already been passed, prohibiting the building of new schools within 500 ft (168 m) of a busy road (California State Legislature 2003). Additionally, a Bill requiring highway entrance/exit ramps to be at least 1000 ft (305 m) from schools is currently moving through New Jersey's State Legislature, having been overwhelmingly passed in its Assembly (New Jersey State Legislature 2007). Although health risk mitigation through appropriate urban planning seems viable, it does not address the population exposed at schools *already* built near major roadways. To reduce health risks in those schools, adequate air filtration and ventilation systems should be installed and properly operated to reduce the penetration of ambient air pollutants (Morawska 2007).

Most critically, public policy should continue reducing and moderating traffic emissions, particularly DEP. Progressively stricter rules for gasoline and diesel fuel quality have helped reduce emissions in recent years (USEPA 2007). Although major roads play an important role in the US economy, the nationwide implications of the growing transportation infrastructure should be examined from the environmental health perspective, addressing the exposure of school students to air pollution from major roadways. This will help create and manage a better built environment in major metropolitan areas in the USA and other countries by promoting balance between economic and health considerations (Morawska *et al.* 1995, Frumkin 2005, Kjellstrom *et al.* 2007).



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