Title: Evaluating socioeconomic and racial differences in traffic-related metrics in the United States using a GIS approach

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Abstract

Previous studies have reported that lower-income and minority populations are more likely to live near major roads. **This study quantifies associations between socioeconomic status (SES), racial/ethnic variables, and traffic-related exposure metrics for the United States.** Using geographic information systems (GIS), traffic-related exposure metrics were represented by road and traffic densities at the census tract level. Spearman's correlation coefficients estimated relationships between socio-demographic variables and traffic-related exposure metrics, and ANOVA was performed to test for significant differences in socio-demographic variables for census tracts with low and high traffic-related metrics.

For all census tracts in the United States, %Whites, %Blacks and %Hispanics (percent of tract population) had correlation coefficients greater than 0.38 and 0.16 with road density and traffic density respectively. Regions and states had correlation coefficients as high as 0.78. Compared to tracts with low road and traffic densities (<25^{th} percentile), **tracts with high densities (>75^{th} percentile) had values of %Blacks and %Hispanics that were more than twice as high**, 20% greater poverty levels, and one third fewer White residents. Census tracts that had mid-level values for road and traffic densities had the most affluent characteristics. a **Results suggest that racial/ethnic and socioeconomic disparities exist on national level with respect to lower-income and minority populations living near high traffic and road density areas.**

Key words: road density, traffic density, traffic-related exposure, racial/ethnic and socioeconomic disparities, geographic information systems (GIS)

Introduction:

Mobile source emissions are a significant contributor to air pollution levels across the United States (U.S.). The U.S. Environmental Protection Agency (U.S. EPA) estimates that for 2007 national emission levels, on-road and off-road vehicles produced 68% of the carbon monoxide (CO), 34% of volatile organic compounds (VOCs), and 57% of nitrogen oxides (NO_x) (USEPA, 2008). Exposures to traffic emissions have been associated with multiple adverse health effects, including all-cause mortality (Gehring et al., 2006), cancer (Reynolds et al., 2004), cardiovascular (Finkelstein et al., 2005) and cardiopulmonary mortality (Hoek et al., 2002), adverse birth outcomes (Slama et al., 2007), and respiratory diseases (Burr et al., 2004) including children's asthma (Brauer et al., 2007; Morgenstern et al., 2008). These studies have used surrogates of traffic exposure such as proximity and traffic counts for epidemiological studies of health effects associated with vehicle exhaust.

Proximity to major roads has commonly served as an indicator, or representation, of near-road air pollutant concentrations and traffic-related exposures because of the relative consistency of spatial concentration gradients (Beelen et al., 2008; Gauderman et al., 2007). The highest air pollutant concentrations occur in the nearest 50 to 100m of a roadway, and elevated spatial gradients extend up to 500m (Zhu et al., 2002). For example, a study conducted at a busy expressway in Toronto reported that concentrations of NO_2 , and NO_x, exhibited a distance decay function and approached background concentrations within 400m, while O_3 had inverse pattern with higher concentrations further away from the expressway (Beckerman et al., 2008). In North American urban areas, 30% to 45% of the population lives or works in the exposure zone highly affected by traffic emissions, within a distance of up to 300m to 500m of a highway or major road (Health Effects Institute Panel on the Health Effects of Traffic-Related Air Pollution, 2010).

Multiple distances within the near-road exposure zone have been used to represent traffic exposure in epidemiological studies. Respiratory symptoms in children have been associated with distances up to 300m from major roads (Brunekreef et al., 1997), as well as 50m (Morgenstern et al., 2008), 75m (McConnell et al., 2006), 100m (Baumann et al., 2011; Venn et al., 2001) and 150m (Venn et al., 2001). Based on a cohort of adults 45-75 years old in Germany, Hoffmann and colleagues (2006; 2007) conducted two studies on residential exposure to traffic and found that the adjusted odds ratio (OR) for coronary heart disease (CHD) and coronary artery calcification (CAC) was significantly elevated to 1.85 (95% CI: 1.21-2.84) for participants living within 150m from a major road and 1.63 (95% CI: 1.14-2.33) for participants living within 50m compared to the ones living beyond 200m. Sensitivity analyses that evaluate various distances from major roads as indicators of exposure in epidemiological studies have yet to be fully examined.

The disproportionate distribution of air pollution sources and exposures in areas with lower-income and minority populations supports concerns of environmental injustice (Finkelstein et al., 2003; Jerrett et al., 2004). When compared to reference areas, disadvantaged neighborhoods with lower-income residents and people of color often bear disproportionate burdens from elevated pollutant concentrations, greater exposure to traffic emissions and increased incidences of adverse health endpoints. **Previous studies reported that schools near major roads tend to have higher percentages of minority students, and more students enrolled in a meal program and residing in poor areas, when compared to reference schools (Apelberg et al., 2005; Wu and Batterman, 2006).**Two studies in Southern California used emission inventories to assess lifetime cancer risks associated with air pollutant sources and found that transportation was most associated with cancer risks, especially among minority groups (Morello-Frosch et al., 2001; Pastor et al., 2005).

Geographic scale is an important consideration for environmental equity studies, particularly in analyzing near-road exposure. The selection of appropriate scale has been so challenging to capture the spatial gradients of traffic-related air pollutants due to the insufficient information available at finer scale such as 500m away from major roads. A few studies found that high-poverty census block groups in California with greater concentrations of African Americans and Hispanic children, were 2-3 times more likely to have higher traffic density measures based on vehicle miles traveled (VMT) per square mile (Gunier et al., 2003; Houston et al., 2004). Other studies evaluated associations between air pollution exposure, socio-demographic characteristics and cancer risks at the census tract level (Apelberg et al., 2005). In addition, census tract areas have been identified as an optimal scale to assess relationships between SES and health disparities because census tracts with population size of about 4,000 are designed to have homogeneous population characteristics and socioeconomic status (Tian et al., 2010).

Research to-date remains limited in examining demographic information in the context of traffic-related air pollution to better understand possible environmental justice concerns, and has primarily focused on air pollution from stationary sources instead. Based on our review of the literature, no studies have yet evaluated traffic-related exposure and the demographics of people living near roads for a large geographic area at census tract resolution, such as for the entire United States. The purpose of this study is to evaluate associations between socio-demographic characteristics and traffic-related exposure metrics (road and traffic densities) at the national, regional and state level.

Materials and Methods:

Due to the lack of air monitoring stations near roadways, other parameters were developed to characterize potential exposure to traffic emissions (Gunier et al., 2003). Two traffic indicators at the census tract level were used in this study: road density and traffic density (described below), because of their demonstrated correlations with measured mobile source pollutants (Gunier et al., 2003; Reynolds et al., 2002).

Road density is calculated as the ratio of road area to census tract area, which includes a buffer zone adjacent to the road, and is reported as a percent. In a childhood cancer study, Reynolds et al. (2002) utilized a similar road density metric based on the total length of a road within a block group as a proxy for exposure to traffic emissions. Road density in this study is highly correlated with the road density metric that is based on the total length of major roads (Spearman correlation coefficient: 0.93). Air pollutants related to traffic generally disperse and reach to regional background level within 300~500m away from roadways. Thus, the road density metric in this study takes into consideration the zone influenced by mobile-source emissions. Major road network datasets were obtained from ESRI (www.esri.com) and represent interstate, U.S. and state highways, and other major thoroughfares, which are classified based on feature classification codes. The basic assumption is that all major roads have the same impacted exposure zone regardless of the width of the major roads. We conducted sensitivity analyses of road densities that used buffer distances of 100m, 150m, 300m, and 500m.

Traffic density was estimated using the length of road segments and vehicle traffic counts. National traffic counts were obtained from the high performance monitoring system (HPMS) maintained by the Bureau of Transportation Statistics, which reports the average daily traffic counts for a given road segment and is compiled periodically from state-collected data. For each road segment, vehicle miles travelled (VMT) was calculated as the product of the road segment length and its average annual daily traffic (AADT). We estimated traffic density by summing VMT for all road segments within a census tract and dividing by the area of the census tract. **Traffic density has units of VMT per square mile per day shown in equation (1).** Two different road networks have been used to estimate road density and traffic density because only 35% portion of the major road network from ESRI has traffic count information recorded by HPMS.

$$\text{Traffic density} = \sum(\text{Length} * \text{AADT}) / \text{Area} \qquad (1)$$

Census tracts with zero values for road and traffic densities were considered separately from the other census tracts as a different exposure category because of their lack of major roads. Based on a quartile distribution of road and traffic densities, the non-zero census tracts were further categorized into four groups for reporting purposes. Census tracts with the lowest quartile (<25th percentile) were considered the reference group of low exposure; census tracts in the second quartile (<25th - 49th) were considered low-medium exposure; the third quartile (50th - 75th) were medium-high exposure; and the highest quartile (>75th) was defined as the high exposure group.

Socioeconomic and demographic variables at the census tract level were obtained from the 2000 Census. The three racial/ethnic variables, percent Whites (%Whites), percent Blacks

(%Blacks) and percent Hispanics (%Hispanics), were calculated as a ratio of the corresponding racial/ethnic population and the total census tract population. The three SES indicators included the percent of households under the poverty line, the percent population greater than 25 years old with less than a high school education, and the median household income. We evaluated relationships between the two traffic metrics and socio-demographic variables using Spearman correlation coefficients calculated with SAS 9.2 statistical software (SAS Institute, Cary, NC, USA). ANOVA was performed to test for significant differences in socio-demographic variables for census tracts with low and high traffic-related metrics.

Results:

Road density values ranged from 0 (very rural areas) to 100% (very metropolitan areas). The national average road density increased from 25% with a 100m buffer, to 34% for a 150m buffer, to 53% for a 300m buffer, and to 66% for a 500m buffer. The national average traffic density was 33,444 VMT per day per square mile. For the United States, national average socio-demographic variables based on all census tracts were 74% Whites, 14% Blacks, 12% Hispanics, 13% households below poverty level, 21% of people older than 25 with less than high school education, and an average median household income of $43,957.

Spearman correlation coefficients describing associations of road and traffic densities with racial/ethnic and SES variables for the United States are reported in Table 1. Correlation coefficients based on road density showed negligible differences for buffer distances between 100m and 500m. Thus, we selected the commonly used 300m buffer as the distance for the road density metric for further analyses. Racial/ethnic and SES variables were significantly correlated with road and traffic densities with *p*-value less than 0.001. Based on the 300m buffer, correlation coefficients of road density and traffic density with %Whites were -0.44 and -0.17, for %Blacks were 0.39 and 0.16, and for %Hispanics were 0.37 and 0.16 respectively. Negative coefficients indicate that tracts with higher %Whites had lower road and traffic densities. Compared to racial/ethnic variables, SES had relatively lower correlation coefficients for road and traffic density. The strongest correlation coefficients based on the SES indicators occurred for %Poverty. Median household income had a negative correlation coefficient of -0.07 for road density, and %Less than high school education had an insignificant correlation coefficient of 0.002 with $p > 0.05$. Overall, SES indicators were more related to road density than traffic density, and racial/ethnic variables had stronger associations than SES with the two traffic metrics.

The correlation coefficients between the traffic metrics, SES and racial/ethnic variables were spatially dependent, but remained significant ($p < 0.05$) for different regions of the United States (Table 2). According to the 2000 Census, the Northeast region has 13,180 census tracts, the Midwest has 16,451, the West has 13,681, and the South has 21,839. The Northeast region had correlation coefficients of -0.63 for %Whites, 0.53 for %Blacks and 0.60 for %Hispanics with road density. However, the South region had the lowest correlation coefficients of -0.33~ 0.31 for all racial/ethnic variables, suggesting perhaps those racial/ethnic groups are more spatially distributed in this region. Negative signs for the coefficients indicate that tracts with higher median household income and higher %Whites represent potentially lower traffic-related metrics. Among all the SES indicators, the Northeast region had the highest correlation coefficients between %Poverty and the traffic-related metrics. Compared to road density, the correlation between traffic density, SES and race was relatively weaker and in some cases was not significant. Among all the regions, the West had the highest correlation coefficients for traffic density with %Whites (-0.38), %Blacks (0.29) and %Hispanic (0.23). With regard to SES, road density had higher correlation coefficients than traffic density. For example, the West region had significant and slightly weaker relationships between traffic density and %Poverty (0.11), %Less than high school (0.13), and a low but negative correlation with Median household income (-0.05). The South and Midwest regions had coefficients for traffic density and SES indicators as low as 0.01 and *p*-values greater than 0.05, further demonstrating the spatial dependence.

The 10 states with the highest correlation coefficients between traffic-related metrics, SES indicators and race/ethnicity are shown in Table 3 with their respective values. These state-level correlation coefficients were more than twice as high as the ones for the regions. Specifically, correlation coefficients were substantially greater for associations between traffic density, the SES indicators and racial/ethnic variables. Moreover, coefficients for all the racial/ethnic variables and SES indicators had different strengths with the two traffic-related metrics based on the state, primarily owing to spatial distributions of race/ethnicity, SES indicators, and traffic-related measures among the states. For example, Maine had the highest correlation coefficient between %Blacks and the road density metric (0.78), but overall, Maine did not have the highest values for all SES indicators with the traffic density metric. Instead, Rhode Island ranked as the state with the highest overall correlation coefficients for road density with -0.74 for %Whites, 0.71 for %Blacks, 0.74 for %Hispanics, 0.70 for %Poverty, and -0.74 for household median income. Figure 1 illustrates the spatial distributions of road and traffic density, race/ethnicity, and the SES indicators for Rhode Island. The Providence metropolitan areas had the higher %Blacks, %Hispanics, and %Poverty, %Less than high school with the highest road density, compared to the surrounding rural areas with lower %Whites, higher median household income and higher traffic density. The top 10 states had relatively lower but still strong correlation coefficients for traffic density compared to road density. For traffic density, Iowa had the highest correlation coefficient of -0.48 for %Whites, Montana had the highest of 0.58 for %Blacks and New Hampshire had the highest for %Hispanics of 0.46. Rhode Island still had the highest coefficients overall for traffic density, with 0.41 for %Poverty, 0.38 for %Less than high school, and -0.46 for median household income (Table 3 and Figure 1).

All census tracts in the United States were further categorized into five groups including zero value and quartile distributions of non-zero values based on road and traffic densities. Table 4a shows the number of census tracts and the average values of the SES indicators and racial/ethnic variables among each group of traffic-related metrics including Zero, Low, Low-Medium, Medium-High, and High. Out of 65,334 census tracts, 175 (0.3%) had zero-values for road density and 14,271(21.8%) census tracts had zero-values for traffic density. On average, tracts with high road density (>75th percentile) had up to 3.4 times greater values for %Blacks and 3.3 times greater for %Hispanics compared to the low road density tracts (<25th percentile) (Table 4a). In contrast, average values for the SES indicators of %Poverty and %Less than high school had ratios of 1.5 and 1.2 respectively between the high and low road density categories. High road density tracts had one third less White residents (Ratio: 0.67) and slightly lower median household income than low road density tracts (Ratio: 0.95). The difference between high and low road density census tracts were significant at *p*-value of 0.05, tested by ANOVA. Surprisingly, both low-medium and medium-high groups had lowest poverty (%Poverty and %Less than high school education) and highest affluence (median household income) than the low and high road density tracts. Overall, the medium categories suggest greater affluence and education compared to the low and high road density groups of census tracts.

For traffic density, the average values of SES indicators and race/ethnicity were less than those for road density for all quartile categories (Table 4b). There were 14,271 census tracts (21.7%) with zero traffic density because not all major roads had recorded traffic count information from high performance monitoring system. The zero traffic density group had similar values to those for the high density group, with an average 66.5% Whites, 18.2% Blacks, 13.8% Hispanics, 13.3% below poverty, 20.8% less than high school education, and a $45,922 median household income. The high traffic density group had 2.7 times greater %Blacks and 2.6 times greater %Hispanics than the low traffic density group. As traffic density increased, %Whites decreased and %Blacks and %Hispanics increased correspondingly. High traffic density tracts had 1.2 times greater %Poverty, 1.1 times greater %Less than high school education. Median household income was slightly higher in high traffic density tracts. Ratios less than 1 indicate that higher %Whites were more likely to live in low traffic density areas. ANOVA tests revealed significant differences for census tracts with high and low traffic density. Although %Blacks and %Hispanics increased and %Whites decreased from the low to high groups, low-medium and medium-high traffic density groups had the lowest poverty and highest SES similar to road density.

Discussion and Conclusions:

By analyzing all census tracts in the United States, this research found that the two traffic metrics, road density and traffic density, were significantly correlated with race/ethnicity and SES indicators. We further found that the correlations spatially varied based on geographic regions and individual states, and were significant with correlation coefficients as high as 0.78. Minority populations and lower-income groups were more likely to live in census tracts with high road and traffic densities in contrast to Whites and affluent populations, suggesting a greater potential for exposure to traffic emissions. The two exposure surrogates of road and traffic density metrics could be utilized to evaluate health effects of road transportation-related air pollution exposure in epidemiological studies which need to consider SES and racial/ethnic confounders as well. **The study found that Black and Hispanic families with lower SES were more likely to live in census tracts with greater road and traffic densities compared to non-minority and higher-income populations. These results are consistent with prior studies that minority and lower-income neighborhoods are more likely to be associated with higher traffic exposures and greater health risks (Gunier et al., 2003; Houston et al., 2004); however, in contrast to the local-scale findings, results presented here are at the national scale.**

Census tracts with higher traffic-metric values had higher poverty levels compared to census tracts with lower values for traffic-metrics, whereas tracts within the mid-range of the traffic-metrics had the highest SES, which suggests that affluent individuals might have convenient access to transportation, but can afford areas that are less-impacted in terms of air quality and road noise exposure (Bayer et al. 2009; Carey and Semmens 2003). Bae and colleagues (2007) found that in the 1990s, single-family home developments in the freeway air-pollution shed (FAPS) of Seattle, Washington were five times larger with lower housing values compared to the 1980s. Correspondingly in the FAPS, the population of Blacks was two-three times higher, and the number of residents below poverty level was elevated 1.2-1.4 times compared to the corresponding urban growth area. Minority and lower-income groups had lower rent and housing costs at the cost of greater traffic-related exposure.

Sensitivity tests on the various buffer distances concluded that the correlation coefficients between road density, the SES indicators, and race/ethnicity did not vary much with buffer distance at the aggregate level. Empirical studies have shown that air pollutant concentrations decrease with distance and reach regional background levels within 300-500m from roadways (Zhu et al., 2002). Although buffer distances and proximity have been used as alternatives to exposure monitoring (Hoek et al., 2002; McConnell et al., 2006), few studies investigated what buffer distances should be used to categorize traffic exposure. For example, Ross et al. (2007) found that traffic within 300 and 500m buffer distances near $PM_{2.5}$ air monitors explained 33-47% of the variance in land use regression models. The sensitivity tests of buffer distance in this study supports that a 300m buffer is suitable to capture potential near-road exposures when using a buffer-based approach.

Results reveal a stronger association with the SES indicators, race/ethnicity and road density than with traffic density at the census tract level. First, the difference between correlation coefficients for the two traffic metrics signify that road density may capture more aspects of social structure than traffic density. For example, the Southern California Children's Health Study (CHS) (Eckel et al., 2011) found that length-of-road within the 50m - 200m buffer to the residence of the asthmatic children was the only significant indicator of the fractional concentration of nitric oxide in exhaled air, which is associated with traffic-related exposures. The length-of-road metric was similar to road density presented here, but the CHS did not find a correlation between length-of-road and other TRP metrics such as traffic density. The discrepancy for associations of socio-demographic variables between road density and traffic density may be explained in part by using two different road networks to calculate the road and traffic density metrics. The ESRI major

road layer that estimated road density contains interstates, state highways, major streets and other major thoroughfares and was well aligned with digital orthophotographs. However, annual average daily traffic (AADT) from HPMS includes only freeways, highways, principal arterials and minor collector roads, and no other road types. For the United States, the total length of the road network from HPMS (for traffic counts) was only 35% of the total length of the major roads from ESRI (used to calculate road density). This disagreement between road network data indicates that the use of HPMS could underestimate exposure to traffic emissions and reduce the corresponding associations with socio-demographic variables. Thus, future research warrants attention as to how road type impacts the estimate of traffic-related metrics.

The study has the following limitations. First, traffic density based on AADT did not take into account truck fraction, which is unavailable at the census tracts level. This could raise bias in the SES and racial differences for the traffic density metric because a census tract with more heavy duty vehicles could increase air pollution exposure compared to a lighter duty fleet. Second, there are a number of other factors that influence exposure to traffic but are beyond the scope of this study. These factors include meteorology (wind speed/direction, turbulent parameters, etc), topography, and the influence of the built environment (urban street canyons). However, the two area-based traffic metrics (road density and traffic density) have been empirically correlated with ambient monitoring data (Reynolds et al., 2002), which suggests that they are suitable surrogates for exposure as well.

Interactions between multiple social factors and increased exposure to pollution have placed lower-income and minority groups at potentially higher risk of adverse health effects, with traffic emissions as a contributing factor (Jerrett et al., 2001). Epidemiological research has focused in particular on susceptible life stages such as children and older adults. Previous studies reported that children who live near high-traffic major roads demonstrate increased incidences of respiratory symptoms, especially related to children’s asthma (Chang et al., 2009; Delfino et al., 2009). Studies on elderly subjects suggest that traffic particles had an adverse effect on heart rate variability and may alter autonomic balance, thus increasing cardiac risk (Adar et al., 2007; Schwartz et al., 2005). However, relationships between health risks and traffic exposure are not always apparent. For example, a study in California found no evidence of a significant association between traffic exposure and childhood cancer using road and traffic density metrics (Reynolds et al., 2004). More research is needed to quantify the relationships between exposure to mobile source emissions (type and quantity) and related health endpoints, to disentangle the health effects from air pollution exposure and SES, to understand the causality of traffic-related pollution on cardiovascular and respiratory diseases, and to more fully understand SES and race/ethnicity modifications to exposure and disease development. In 2011, U.S.EPA revised the NO_2 and CO National Ambient Air Quality Standards (NAAQS) and required the collocation of one CO monitor with a near-road NO_2 monitor in urban areas with population greater than one million (USEPA, 2011). The new monitoring network will provide data for comparison to the NAAQS and indicators such as those identified in this study. This network will also help characterize traffic-related exposure for people who live and work close to major roads.

This study has implications for traffic-related exposure assessments that target communities with higher percentage of lower-income and minority populations and focus on exposure reduction actions, especially in neighborhoods with high proportions of susceptible sub-populations such as children and the elderly. An example of exposure reduction actions in California includes California Senate Bill 352, which prohibits siting a school within 500ft (168m) of a freeway or other busy traffic corridor (California Department Education, 2004). Urban planning zoning remedies may be efficient exposure reduction initiatives by stipulating land-use regulations for new housing developments. Alternative transportation strategies such as promoting public transportation also hold great promise to improve air quality and reduce health risks from vehicle exhaust.

In summary, the evidence from this large national study suggests that minority groups and people with lower SES tend to live in census tracts with higher road and traffic density metrics, which may be more impacted by traffic-related emission sources. Further studies are warranted to evaluate the area-based traffic-related metrics with the air pollutant monitoring. More refined exposure metrics are needed to assess the effects of near roadway air pollution on the human health outcomes.

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