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Inequality in Accessibility to Amenities and Exposure to Hazards

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

Doctor of Philosophy

in Planning, Policy, and Design

by

Dongwoo Yang

Dissertation Committee:
Associate Professor Douglas Houston, Chair
Professor Victoria Basolo
Assistant Professor Jae Hong Kim

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DEDICATION

To

my mother, Gab Sik Yu
my sister and brother, Eunju and Dongju Yang
and
the memory of my father, Jung Sik Yang, December 15, 1943 to June 22, 2015

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ABSTRACT OF THE DISSERTATION

Inequality in Accessibility to Amenities and Exposure to Hazards

By

Dongwoo Yang

Doctor of Philosophy in Planning, Policy, and Design

University of California, Irvine, 2015

Associate Professor Douglas Houston, Chair

This dissertation proposes a heuristic theoretical framework for understanding dynamics that impact environmental health including social/built environmental settings, individual residents' behavioral patterns, location activity spaces (LAS), environmental quality, exposure, and health outcomes. I examined the relationships between factors included in the framework based on individuals' LASs, and represent a hypothetical geographic boundary in which an individual is expected to spend his/her time in daily life. In addition to the individual level exposure, I characterized built environmental quality for subsidized housing neighborhoods in Los Angeles and Orange Counties, which have not been the focus of previous affordable housing studies. In Chapter 2 and Chapter 4, I empirically demonstrated the framework for residents in neighborhoods near the Expo Right Rail Transit line and the Boyle Heights community in Los Angeles. With OLS regression analysis, I found that bigger LAS were associated with lower walkability, more non-residential land use, higher transit stop density, shorter length of residency, working out of home, and higher income. I examined the relationship between the probability of a census block group (BG) having at least one subsidized unit and associated BG built

environmental qualities. Based on logistic regression models, I found that subsidized housing units tended to be located in BGs with better transit access, lower walkability, more mixed-use, and lower air pollution concentrations.

CHAPTER 1. The Location, Activity, and Environmental Exposure (LAEX) Framework

Overview

This chapter provides a heuristic theoretical framework, and the subsequent chapters provide empirical application. The LAEX framework expands traditional concepts of environmental exposure by characterizing the intersections of social and built environmental quality, individual behavioral patterns, and external socioeconomic and institutional factors. The framework depict show these factors are inter-related, and how their relationships shape individuals' location and activity spaces (LASs).

1. Introduction

Environmental characteristics of places where individuals spend time influence health outcomes or health-related behaviors (Matthews and Yang, 2013). With respect to equal accessibility, related studies examine distributions of basic amenities required for sustaining people's well-being (i.e., employment facilities, shopping, education and recreational facilities), and show there tends to be lower availability of these facilities in socially disadvantaged neighborhoods (Holzer, 1991; Mendenhall et al., 2006; Shen, 2000). As the environment justice literature has shown, socially disadvantaged groups tend to be located in areas with more polluted by hazardous resources, including high-traffic freeways and polluting industries (Bevc et al., 2007; Forkenbrock and Schweitzer, 1999; Houston et al., 2008). Disadvantaged areas also tend to lack health-supporting built environmental features, such as parks, pedestrian friendly sidewalks, and recreational facilities (McAlexander et al., 2009; Sallis et al., 2009). Inequality also exists in the social environment, including the stability of neighborhoods, safety and crime, attachment to community, and socially supportive neighborhoods for residents (Levy and Woolley, 2007; Ludwig et al., 2001).

Despite rich empirical evidence on the relationship between environmental quality and health outcomes, few studies provide a guiding heuristic theoretical framework. Most environment health and planning studies provide fairly simple frameworks explaining factors which contribute to health outcomes. Some of them focused on the health impacts of the built environment (Ewing et al., 2003; Frank et al., 2005; Handy et al., 2002; Krieger et al., 2009; MacDonald et al., 2010; Sallis et al., 2009). Some studies examine the relationship between behavioral patterns and health outcomes (Frank et al., 2007; Jacobson et al., 2011; Wen et al., 2006). Housing and transportation studies examine the relationship between built environmental settings and behavioral patterns, such as travel behaviors and residential choice (Axhausen et al., 2001; Buliung et al., 2008; Sallis et al., 2009; Shen, 2000; Smith and Zenou, 2003; van Eck et al., 2005; Wachs and Kumagai, 1973). Since human beings create and alter built and social environments and environments influence human behavior simultaneously, a more integrated theoretical approach is needed to consider how the built environment, social environment, institutional program design, and behavioral patterns influence environmental health outcomes.

In addition, the existing literature about environmental health has been limited in its ability to measure exposure to environmental contexts. Most environment health studies assume aggregated geographic boundaries, (for instance, Census Tracts, Census Blocks, and Traffic Analysis Zone (TAZs)), as individual activity spaces. Such zonal approaches to estimating individual people's boundaries could result in ecological fallacy.

Because there is a difference in diurnal time activity by many factors (including occupation, gender, etc.), the use of these residential zones to classify activity locations could under- or over-estimate individuals' activity space boundaries which could cause under- or over-estimation of environmental exposure (Houston, 2014). With regards to the zonal approach, recent studies have sought to employ time-activity based approaches. The time-activity spaces represent areas where individual people actually or are more likely spend time within a given time budget (Hagerstrand, 1970; Kwan, 1999; Miller, 2005).

This chapter aims to provide a heuristic theoretical framework on environment health. The framework seeks to describe the relationships of four main factors: (1) external, (2) behavioral, (3) environmental, and (4) health outcomes.

2. Theoretical Framework

2.1 Background: Literature on Environmental Exposure and Health

Studies in the fields of environmental health sciences and urban planning have increasingly focused on the relationship between environmental quality of residential neighborhoods and daily activity spaces on health outcomes. Few studies, though, have provided a unifying framework to conceptualize the complex interrelationship between physical and social environments, human beings and their behavioral patterns, and associated health-related outcomes.

Several place-based environmental health studies have sought to provide insights on the interactions of health and environmental quality in places where people reside, commute, work, shop, and play. Health scientists have focused largely on spatial and temporal dimensions of the spaces people occupy and the quality of environmental loads within the extent of these spaces. A common methodological approach of existing studies has been to focus on residential neighborhood locations. It has been shown that physical and social environmental conditions of residential neighborhoods are associated with residents' health outcomes (Corburn et al., 2006; Diez-Roux, 2001), and risk of being harmed by crime and traffic accidents (Keels, 2008). Regarding neighborhood conditions and health outcomes, Corburn et al. (2006) examined neighborhood effects on asthma in New York City, NY. The social and physical neighborhood characteristics of the study included "household income, high percentage minority, public and inadequate housing, and multiple environmental pollution burdens" (Corburn et al., 2006). They sought to identify connections between childhood asthma hospitalization rates in a census tract and the physical and social environmental characteristics in the census tract, and found that low median household income at the census tract level, the percentage of minority population, and air pollution levels were associated with higher asthma hospitalization rates (Corburn et al., 2006). In terms of economic outcomes, Goetz (2010) tested the changes in neighborhood conditions before/after the redevelopment of a public HOPE VI housing development in Duluth, MN and its effects on residents' economic status. Changes in racial/ethnical composition, changes in poverty rates, and changes in median home values at the census tract level, and the number of friends, age, the number of children, gender, race/ethnicity, family health issues at the individual level, and employment status were used as explanatory variables (Goetz, 2010). However, the study found no significant relationship between neighborhood conditions and employment status (Goetz, 2010). Regarding safety, Keels (2008) tested whether a residential mobility program for public housing residents in Chicago, Illinois (the Gautreaux program) was effective in reducing children's participation in crime. The study found that the relocation of participants to suburban areas was associated with a lower possibility that boys got involved in criminal activities (Keels, 2008). In addition to the place-based studies, a growing number of recent studies of environmental health have sought to characterize diurnal environmental loads, influenced by non-residential activity by focusing individual people's behavioral patterns rather than focusing merely on residential locations (Chetwittayachan et al., 2002; Hess et al., 2010; Houston et al., 2011).

The location activity space (LAS) approach has recently been used to understand individual people's activity boundaries based on their time spent in given locations and the relationship of these activity spaces to health outcomes. LAS is the geographic boundary in which an individual person has or is likely to spend their time, and is measured based on the common places a person visits in daily life. Although used in only a small number of studies, LAS is less likely to cause measurement errors (which occur in studies using only residential neighborhood characteristics) and could provide a more complete characterization of the relationship of health outcomes, economic outcomes, and the risk of crime and traffic injuries. The characteristics of LAS have been associated with travel behaviors (Forer and Kivell, 1981; Kockelman, 1997), residential location choice (Ihlanfeldt, 1994; Johnson et al., 2002), and characteristics of occupational non-occupational activity, such as types and time allocation (Kim and Kwan, 2003; Kwan and Hong, 1998). These health-related factors, examined in terms of LASs, have been shown to be related to built environments (Chatman, 2003; Kockelman, 1997), institutional factors (Blumenberg, 2004; Oakley, 2008), individual, social and cultural factors (Stoll, 2005), and structural inequality (Rohe and Freeman, 2001). In their case study in Christchurch, New

Zealand, Forer and Kivell (1981) sought to characterize the extent of activity space and accessibility by analyzing space-time budgets across modes of transportation and the availability of facilities among housewives with young children. They found that the provision of public transportation plays an important role in shaping the extent and implications of activity spaces. This study shows that greater availability of public transport is related to wider geographic range of time-activity spaces and higher accessibility to amenities (Forer and Kivell, 1981). Kockelman (1997) indicated that built environmental factors an individual is exposed to are related to individual households' travel behaviors, which are influenced by activity spaces. Regarding modal choice, job availability within a 30 minute travel radius was negatively associated with personal vehicle choice, while it was positively related to walk/bike choice (Kockelman, 1997). In terms of institutional factors, housing policy is an important factor shaping people's neighborhood conditions or behavioral patterns. Oakley (2008) and Houston et al. (2012) examined the residential neighborhood of low-income housing developments with Low Income Tax Credit (LIHTC) compared to voucher-based subsidized housing units. Their studies suggest that LIHTC units are located with more transit-rich environments and greater mixed use land, which would could enhance the efficiency of residents' activity space, and that LIHTC units are still concentrated in lower SES (Houston et al., 2012; Oakley, 2008).

The concept of exposure, if broadly conceived, offers a foundation for a more integrated framework for understanding how the daily activity space people occupy relates to health outcomes and well-being. The concept of exposure traditionally emerged and has been developed in environment health sciences. It represents a dose of external environmental sources, mostly environmental hazards and societal stressors. Thus, exposure to the stressors implies a higher chance to yield negative physical and mental health outcomes. I propose a framework that extends the concept of exposure into interrelationship between human beings and other environmental factors that impact health, including environmental amenities and stressors. For instance, more inclusive environmental resources that affect health outcomes can, for instance, include job availability, education, shopping, recreational facilities, foods, social networks, community support as well as traditionally-accepted environmental factors, such as air pollution, noise, toxic materials, and safety and crime.

This dissertation extends the concept of exposure to understand how processes and contextual factors which have traditionally been examined within the fields of geography, sociology, economics, and planning – for instance, exposure to job opportunities, crime, affordable housing, transportation services, and institutional and political resources – are an important part of understanding how the amenities and hazards contained within daily spaces are related to health and well-being. The Location, Activity, and Environmental Exposure (LAEX) framework illustrates how LASs are related to external factors, behavioral patterns, environment contexts and health-related behavior and outcomes (Figure 1.1). The physical, societal, contextual environment determines behavioral patterns (travel behaviors, residential locational choices, and occupational/non-occupational activity, etc.). Built environment, institutional factors, structural inequality, and individual, social, and cultural factors are major components of the physical, societal, and contextual environment. Given behavioral patterns, individuals have their own spatial boundaries in urban space and these behavioral patterns shape the quality of their physical and social environment. With respect to the interrelation between individuals' LASs and the quality of physical and social environment, exposure can be interpreted as the general quality of environmental loads within individuals' LAS. Health-related behaviors and health status are linked to environmental exposure.

2.2 The Location, Activity, and Environmental Exposure (LAEX) Framework

In order to understand the extent and magnitude to which an individual is exposed to environmental quality, it is important to understand his/her behavioral patterns in urban space. Spatial scientists in the geography, transportation, and urban planning disciplines since the 1970s have contributed to the development of theoretical foundations by expounding on individual people's behavioral patterns by considering time budgeting and use. The concept of LAS emerged in the field of geography in the 1970's to understand and characterize where people travel and spend time over the course of the day (Hagerstrand, 1970). Given personal circumstances of time use and places where a person routinely conduct activities, his/her potential geographic boundaries are determined (Forer and Kivell, 1981; Hagerstrand, 1970; Kim and Kwan, 2003; Kwan and Hong, 1998; Miller, 2005, 1982; Weber and Kwan, 2002). LAS are influenced by travel behaviors, such as modes of transportation, travel time, residential location choice, and occupational/non-occupational activities.

The LAEX framework seeks to provide a more accurate understanding of the influence of LAS on exposure at an individual level in a way that takes advantages of advances in technologies of geographic information system (GIS) and spatial sciences (Figure 1.1). The construct of LAS provides new insights not available using more traditional residence- or fixed-place-based measures of accessibility/exposure common in health and spatial science research. Traditional studies of accessibility/exposure to urban opportunity/hazards have focused on 1) how many amenities/hazards are within the census tract or transportation analysis zone (TAZ) in which an individual resides or 2) how distant amenities/hazards are from an individual's home location. Such zone-based measurement creates an ecological fallacy because individuals in the same zone are assumed to have the same accessibility/exposure level (Axhausen et al., 2001; Forer and Kivell, 1981; Miller, 1982; Neutens et al., 2011). Such place-based measures are increasingly problematic, as transportation, mobility activity patterns, and social structures are increasingly complicated (Neutens et al., 2011). They also have substantial limitations in capturing variations of activity spaces by personal and household characteristics.

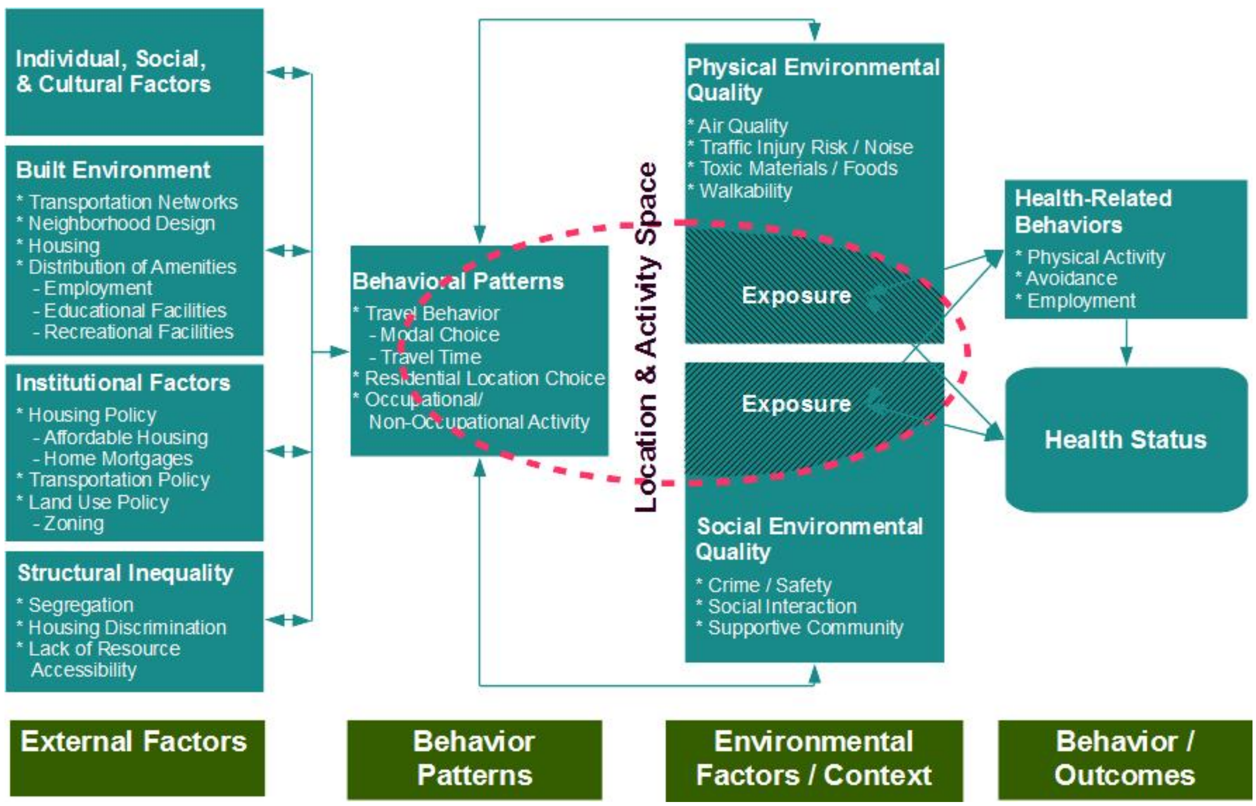

Figure 1.1 The Location, Activity, and Environmental Exposure (LAEX) Framework

2.2.1 External Factors Influence Behavioral Patterns

Important external factors, which influence the extent of an individual's LAS, include (1) built environment, (2) institutional interventions, (3) structural contexts, and (4) individual social, and cultural factors.

(1) Built environment and behavior

Transportation networks, neighborhood design, housing conditions, and the distribution of amenities can determine people's behavioral patterns. Transportation networks and infrastructure are key to shaping an individual's LAS. As traditional transportation studies suggest, transportation infrastructure determines people's travel behaviors, which are constrained by modal choice and travel time given an individual's time budget and resources (Carrasco and Miller, 2009; Kwan, 1999; Timmermans et al., 2002; van Eck et al., 2005). Modal choice and travel time are associated with an individual's decision making regarding residential location choice, and time spent in occupational and non-occupational activities. There have been space-time accessibility studies investigating the implication of transportation factors on an individual's LAS (Church and Marston, 2003; McCray and Brais, 2007; Scott and Horner, 2008). These studies assessed the impact of modal choice on the LASs and accessibility to opportunities. In their case study in the Netherlands, van Eck et al. (2005) assessed the impact of built environmental configurations on residents' travel behaviors, including travel distance and travel time efficiency. They showed that the average travel time was longer for the resident group in low-density suburban areas than for the group in denser areas. The resident group in more concentrated areas also had longer average travel distances than residents in the low-density suburban areas (van Eck et al., 2005). In addition, previous studies on the role of transportation in accessibility focus more on disparities and inequality in transportation resources and mobility (Carrasco and Miller, 2009; Church and Marston, 2003; Dijst et al., 2002; McCray and Brais, 2007; Scott and Horner, 2008). While inequality in accessibility due to modal restrictions has been a central focus of previous studies, a few studies have assessed the impact of changes in transportation infrastructure investment (i.e, new transit line or public transit schedule change) on an individual's LAS and space-time accessibility.

With respect to places where activities occur, the availability of amenities, such as employment, educational facilities, parks and open spaces, are related to locational patterns of residences and shape individuals' behavioral patterns and LASs. Within a distribution of amenities in urban space and their relation to each individual's residence, people make decisions regarding modes of transport based on resources and how long they desire to travel for activities essential for sustaining their life. Regarding land use composition, residents in areas with more diversity of land use or mixed-use tend to drive less and walk or bike more (Chatman, 2003).

Changes in design and layout of the built environment influence an individuals' LAS. Super blocks, structures, walls, incomplete connectivity of sidewalk, for instance, can hamper people who choose more active transportation, including walking or biking rather than driving, while human-scaled streets, blocks, and heights of buildings can encourage people to change modal choice and types of activities into more active transportation and leisure activities (Jacobs, 1961).

(2) Institutional factors and behavior

Decision making regarding housing, transportation, and land use policy influence individual's behavioral patterns. The built environment in urban space has been altered in significant ways as a result of government actions, ranging from federal government to local municipalities. Some impacted built environmental features are collective and locally consumed services, such as transportation infrastructure, subsidized housing, and land use, and are mainly provided by public interventions through general plans and other specific plans in citywide and fiscal distribution from federal government. Thus, government decisions play a significant role in shaping built environments influencing individual LASs.

Housing development and related policies are the primary institutional interventions in urban space that can provide substantial benefits or be detrimental to urban residents. Since housing location is one of the main factors influencing travel behaviors and activity, as explained in the previous section, decision making about housing development can influence proximity to nearby amenities and decisions about transportation may be subject to choices about the quality of living conditions. For this reason, some traditional housing studies, including those discussing subsidized housing programs, home mortgages, infill development and transit oriented development, have evaluated housing policy in terms of accessibility to amenities and social connections.

Transportation policy also influences travel behavior and residential locational choice, and can alter LASs. For people with less mobility, provision of more transportation services can extend their boundaries of activities.

Zoning and land use policy provide more comprehensive tools to control transportation infrastructure, housing, and availability of amenities, because it influences density, building heights and mass, and activity types. More homogeneous land use can lead to separation from other uses, resulting in more trips, increased travel time, and decreased in time spent for non-travel-related activities. In contrast, more mixed land use could encourage fewer trips, and more time spent on activities (Chatman, 2003; Frank and Pivo, 1994; van Eck et al., 2005).

(3) Structural inequality and behavior

Non-physical characteristics, such as socioeconomic contexts or individuals' demographic characteristics also influence the characteristic and extent of a person's LAS. Neighborhood social environments affect socially disadvantaged groups. Studies on neighborhood effects suggest that living in poorer neighborhoods can result in adverse outcomes for both adults and youth (Aneshensel and Sucoff, 1996; Ceballo and McLoyd, 2002; Lochner et al., 2003). Despite some efforts to find causal effects of neighborhood conditions based on experimental housing projects, such as Gautreaux and Moving to Opportunity, there is little evidence which demonstrates causality between neighborhood conditions and adverse outcomes.

Despite limited evidence with regards to causality, social environments of neighborhoods have been linked to people's living conditions and quality of life. Literature on neighborhood effects suggests an association exists between proximity to resources (employment, amenities, hazards, and social interactions) in a neighborhood where a person lives and life outcomes. Regarding access or exposure to neighborhood resources, studies suggest that neighborhood context matters and can produce adverse outcomes, after accounting for personal compositional factors (Jerrett and Finkelstein, 2005; Morello-Frosch and Lopez, 2006; Morello-Frosch et al., 2002; Osypuk and Acevedo-Garcia, 2010).

Studies of welfare recipient outcomes before and after welfare reform suggest that neighborhood contexts, including neighborhood poverty rates, income level, and proximity to job sites, are strongly related to welfare dependency, exit rate, employment status, and earnings (Bayer et al., 2008; Houston, 2005; Shroder, 2002). Neighborhood context seems to matter more to low-income, minority groups. Most studies suggest that neighborhood poverty, unemployment rates, and negative local market conditions are associated with longer welfare duration and lower exit rates (Allard and Danziger, 2003). Residential proximity to job sites has been shown to be related to higher employment rates and earnings (Allard and Danziger, 2003; Fernandez, 1994; Holzer and Reaser, 2000).

For many decades, suburbanization has been regarded a significant driver of personal achievements and prosperity (Jackson, 1985; Wilson, 1990). Neighborhood effects have been considered in two different aspects: economic status and health outcomes. Although there have been different arguments regarding neighborhood effects, most debates are related to those two aspects. Studies of neighborhood effects on a person or family's economic prosperity have been less conclusive, compared to those on health outcomes. Since economic activities tend to result from a more complex combination of internal personal wills and beliefs, the influence of external environmental factors on a person's economic activities remains unclear. Despite its complexity, the environmental conditions of neighborhoods have been more directly related to health outcomes.

Neighborhood conditions have been seen to influence economic status differently across different population groups by age (Houston, 2005). Scholars have tended to focus on the implications of neighborhoods to youth. These studies argue that adolescences and young adult's future socioeconomic status are determined by various attributes, including both personal characteristics and external, environmental factors. Galster and Killen (1995), who suggested the "geography of opportunity", assumed that experiences in youth tend to shape people's socioeconomic status, and the decisions which they make for their future are related to personal characteristics and opportunity settings in their neighborhoods. The housing market, crime justice system, social service, education system, and labor market are localized in urban space, and they shape different opportunity sets across urban space. Given opportunity structures, adolescence and young adults choose opportunity sets with their personal characteristics which are also influenced by the opportunity sets (Galster and Killen, 1995).

For adults' socioeconomic status, the spatial mismatch hypothesis (SMH) has been used to explain neighborhood effects. The SMH was suggested by Kain in 1968 and is one of the leading theories regarding the shortcoming of the residential model in traditional urban economics. According to SMH, high-income and racially-advantaged group-friendly suburban zoning, racial discrimination, and industrial changes are the main factors that restrict socially disadvantaged people from choosing their residential locations. In general, SMH supporters argue that these factors force low-income and racially disadvantaged people to have a longer commute which causes a decrease in net income or giving up in job hunting. In his article, Kain (1968) suggested three hypotheses for the employment problems among blacks: 1) residential segregation affects the geographical distribution of black employment; 2) residential segregation increases black unemployment; and 3) the negative effect of housing segregation on black employment is magnified by the decentralization of jobs (Kain, 1968). In the first hypothesis, it is assumed that racial segregation largely results from involuntary segregation in the housing market and that commuting is more expensive for black Americans and that there are fewer chance to get job information when they are distant from job locations (Kain, 1968). Thus, they tend to work close to their residential locations. The second hypothesis suggests that since segregation places limitations on residential options for blacks in urban areas and blacks are dependent on employment near their residential locations, there are less employment opportunities for them if employment locations depend on several factors preferential for whites (Kain, 1968). In addition to the two hypotheses, if we consider that job locations are decentralized, the surplus of labor in black neighborhoods with fewer employments might be accelerated, and this worsens unemployment in black communities (Kain, 1968).

2.2.2 Behavioral Patterns Influence Physical and Social Environmental Contexts

Existing studies suggest environmental sources affecting human health could be physical and social. Factors such as ambient air quality, traffic, noise, toxic materials, foods, walkability have been used as a measurement of quality of physical environment (Brender et al., 2011; Brownson et al., 2009; Fruin et al., 2004). Crime/safety, social interaction, supportive community are considered as a measurement of social environmental quality (Acevedo-Garcia et al., 2004; Brownson et al., 2009). Existing spatial and health studies argue that exposure to these environmental sources are the main drivers of health outcomes.

Physical environmental quality is influenced by external factors and individuals' behavioral patterns (Figure 1.1). For instance, travel behaviors, determined by modal choice and travel time, affect air quality and risk of traffic injuries (Buliung and Kanaroglou, 2006; Sonmez and Graefe, 1998). As another example, urban sociologists and activists, including Jane Jacobs, argue that consistent flows of different people and activities on streets, through neighborhoods, and with open space are more likely to enhance self-government or self-management and encourage cohesiveness and safer communities (Jacobs, 1961). Although behavioral patterns affect both physical and social environmental quality, environmental quality also influences behavioral patterns and vise versa (Ceballo and McLoyd, 2002; Sonmez and Graefe, 1998). This is because people tend to alter their behavioral patterns by perceiving, adopting, and reacting to given environments. For instance, a person who used to commute by bike to commute might switch to automobiles after he/she moved and feels in greater danger of injuries from traffic or air pollution while cycling.

(1) *Exposure*

Regarding exposure to physical environments, many studies investigated variations of exposure to air pollution by built environments, policy, structural contexts and individual compositional factors (Buzzelli and Jerrett, 2007; Gunier et al., 2003; Hess et al., 2010; Houston et al., 2011; Perera et al., 2003; Wheeler and Ben-shlomo, 2005). Air pollution and exposure studies have mainly investigated the proximity of certain facilities, including houses, schools, and child care facilities, to sources of air pollutants, such as major traffic corridors and diesel truck routes (Green et al., 2004; Houston et al., 2006; Venn et al., 2000). Instead of measuring actual concentrations of pollutants, the studies tend to use proximity to sources as a proxy for exposure level. Although the studies have contributed to identifying strategies for regulating certain facility siting processes related to pollution sources, they have shown methodological limitations in understanding actual exposure based on human behaviors in time activity patterns (Steinle et al., 2013).

Some studies have attempted to examine the impacts of time use at certain environments at the micro level (Kousa et al., 2002; Levy et al., 2003; Riediker et al., 2003). In traffic-related air pollution, some studies measured exposure to air pollution at certain environments, such as in vehicles running on different road conditions and using different types of fuels at different time (Lipfert and Wyzga, 2008). Studies which examine air pollution exposure in different microenvironments (such as intersections of different traffic volumes, sidewalks, and transportation facilities) take measurements using either/both mobile tracking or/and fixed site monitoring methods (Hu et al., 2009; Kousa et al., 2002; Levy et al., 2001; Lipfert and Wyzga, 2008; Westerdahl et al., 2005). These studies provide useful insightful evidence on the relationship between built environments and air pollution exposure. Unfortunately, most measured exposure to pollution concentrations is not an individual person's exposure to overall environmental quality. This limitation is largely because studies tend to not have data on individual LAS patterns. Recently, with advances in remote sensing and positioning systems, studies have actively sought to understand temporal exposure of living subjects by adopting and applying spatial sciences identifying individuals' activity spaces to the exposure to environmental hazards (Kestens et al., 2010).

Compared to physical environmental quality, a few studies seek to measure exposure to social environmental quality and investigate their relation to LASs (Yen and Syme, 1999). Exposure to social environmental quality might include broader health impacts than physical environmental quality. Nonetheless, it can affect health in direct ways, especially mental health, and in indirect ways, by affecting health-related behaviors. In their literature review study, Yen and Syme (1999) suggested epidemiologic research on social environmental health are categorized into three concepts to explain health status with community socioeconomic status, social structures, and quality of environment (Yen and Syme, 1999). Traditionally, health studies have investigated community SES and health outcomes (including mortality, cardiovascular mortality, infant mortality, suicide, birth weight, and so on), and showed that lower community SES is associated with lower health outcomes (Anderson et al., 1997; Goodman, 1999; Lochner et al., 2003; Lynch et al., 1996; Winkleby and Cubbin, 2003; Yen and Syme, 1999). As social structural factors, traditional epidemiologic studies also suggest racial segregation, income inequalities and health outcomes, and show that there are associations between structural factors and health outcomes (Gee, 2002; Subramanian et al., 2005; Yen and Syme, 1999).

2.2.3 The Physical and Social Environment Influences Health-Related Behaviors and Health Status

(1) Traditional concepts of environmental exposure

Health conditions are the consequence of embodiment as a member of biological traits and as a social being (Krieger and Smith, 2004). Krieger and Smith (2004) suggested that physical embodiment of a human being is a joint process of "biological organisms and social beings" (Krieger and Smith, 2004). Thus, both biological mechanisms inside human bodies and external environmental characteristics jointly influence health status and physical traits, and external environments and physical traits are interrelated with each other. Traditional health studies define exposure as an interaction between external environmental sources and human bodies (Morello-Frosch and Lopez, 2006). With the involvement of such social-ecological aspects, scholars have shed light on how physical and social environmental settings play a role in the scope of an individual's exposure to certain environmental factors. Morello-Frosch and Lopez (2006) conceptualized the traditional discourse on exposure to external environments and suggested how it functions at an individual-level (Figure 1.2). At a community level, environmental sources determine environmental loads within the community. The concept of exposure implies the magnitude of environmental hazards transmitted to individual's body. According to

Morello-Forsch and Lopez, exposure links the external environmental burden to individual's internal, biological mechanisms. After exposure to environmental hazards and intake of an internal dose, the human body responds to the internal dose based its detoxification capacity, and it determines health effects (Morello-Frosch and Lopez, 2006). If the magnitude of the internal dose of environmental hazards exceeds the capability to detoxify, it could cause negative health effects on morbidity or mortality (Morello-Frosch and Lopez, 2006). Materials and the exposure, the interaction or dose, to the source of hazards is able to produce negative health outcomes, whereas the exposure to healthy resource can result in positive health outcomes (Figure 1.2).

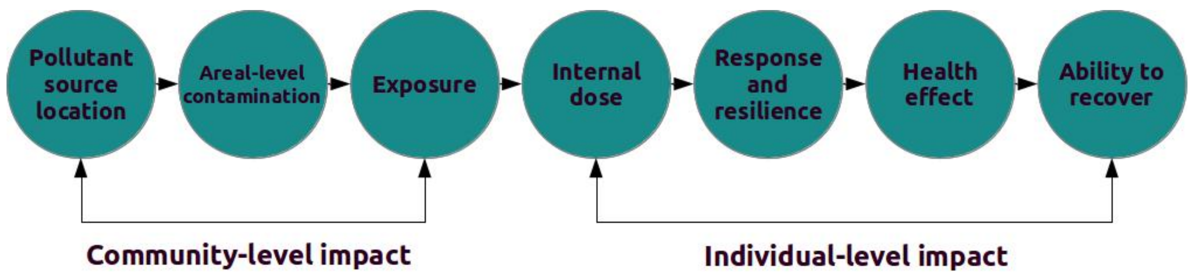

Figure 1.2 Traditional Concept of Exposure and Health Effects
Source: Morello-Frosch and Lopez (2006, 184)

The traditional concept of exposure and associated health effects provides insights for understanding the linkage between external environmental hazards and individuals' health outcomes. However, this conceptualization does not take account of the influence of broader, more inclusive environmental quality measures. This concept of exposure tends to be based on the health impacts of environmental hazards. Since an individual person's health status is influenced by different types of the environmental factors simultaneously and since environmental factors are interrelated to each other (for instance, the potential health benefit via physical activity while biking and the potential risk of air pollution), it is necessary to expand the conceptualization of exposure to more fully account for daily activity patterns.

Health outcomes, in general, can be simply understood by exposure to environmental quality in the theoretical framework (Figure 1.2). However, it is necessary to notice that mechanisms of exposure consist of a variety of components that influence and are influenced by each other, and that individual LASs are the centerpiece of exposure. Health science has demonstrated the physical health impact of the given amount of exposure to physical environmental quality.

3. Discussion: Using the LAEX Framework to Expand LAS Exposure Studies

With the technological advances in remote-sensing, recent environmental health studies increasingly have focused more on individual-level spatial and temporal patterns, which enable them to estimate individual people's behavioral patterns, activity spaces, and exposure. There have been attempts to measure exposure to environmental quality within both/either individual's diurnal activity space and/or temporal activity spaces (Chaix et al., 2013; Kestens et al., 2010; Zenk et al., 2011). Zenk et al. (2011) investigated the relationship between exposure to fast food outlets and parks and health-related behaviors, including dietary intakes and physical activity. The main concept of the study was to measure the density of fast food outlets and parks in individual people's daily activity spaces and daily activity paths. Activity spaces were estimated based upon individual-level GPS location monitoring rather than the conventional neighborhood boundary in aggregated levels, such as census block groups and tracts (Zenk et al., 2011). Density of facilities, which were regarded as either urban hazards or amenities within the individualized daily activity spaces, represented exposure to environmental quality, and the relationship between the density and dietary behaviors can be understood as the relation between exposure to environmental quality and health-related behaviors in the LAEX framework.

However, Zenk at al. (2000) paid less attention to exposures to environmental quality and connections to health-related behaviors and health status. In the LAEX framework, external factors, including built environmental factors, institutional factors, structural inequality, and individual, social, and cultural factors, are introduced to explain the variation of behavioral patterns, which influence the variation of exposure level.

4. Overview of Dissertation

This dissertation seeks to address and empirically assess the interrelations between the external social and built environment, behavioral patterns, and health-related behaviors and outcomes represented in the LAEX framework.

Chapter 2 develops computational methods to estimate activity spaces at an individual level. It uses travel behavior data driven from a GPS-tracking method for residents who lived near the EXPO Light Rail stations in Los Angeles, California. Unlike the traditional approaches using fixed residential zones to define exposure, Chapter 2 employs 1-sandard deviation ellipse (SDE1) and activity space path (ASP) methods, which weigh the amount of time an individual spent at certain locational points collected from the GPS devices which were carried by 126 participants during 3-7 days before/after the line opened in 2012. This chapter examines the relationship between the sizes of SDE1 and ASP and residents' socioeconomic background, including use of public-transit, car-ownership, gender, and household income. Using regression models, the chapter tests the relationship between given built environment around residential neighborhoods and individual resident's SES and the size of SED1 and ASP. It provides empirical evidence regarding the association between the given built environment, individual, social, and cultural factors and behavioral patterns based on the LAEX framework (Figure 1.1). This chapter also assesses the relationship between built environment quality, which is measured as environmental loads within an individual's activity space, and health-outcomes. This chapter sheds light on the connection between exposure and health-related behaviors/outcomes in the LAEX framework.

Chapter 3 characterizes the health-related built environment qualities of federally subsidized housing for low- and moderate-income households in Los Angeles and Orange Counties in Southern California. It examines variations in the built environment qualities of neighborhood across (1) existence of subsidized housing units, (2) subsidy types, such as housing voucher and the Low Income Housing Tax Credit, and (3) regions, such as Los Angeles and Orange Counties. Instead of using individual level activity spaces, this chapter uses the traditional zone-based method. It characterizes the built environment qualities in census block group level. Although it does not use activity space methods, the chapter provides some insights on the LAEX framework by providing empirical evidence regarding the relationship between institutional factors and the environmental qualities within the neighborhood level in the framework.

Chapter 4 sheds light on air pollution exposure, which was measured within an individual's activity space. This chapter employs SED1 and ASP methods to estimate activity spaces at an individual level. It seeks to relate built environmental features within activity spaces to air pollution exposure levels. The results show the relationship between built environmental settings that an individual is exposed to and associated air pollutant concentrations. This addresses the interrelation between built environment and environmental quality within an individual's activity space (Figure 1.1).

CHAPTER 2. The Location Activity Space and the Geography of Opportunity and Hazards

Overview

This chapter examines the micro-level location/activity patterns of 126 residents living near the Expo Light Rail line in Los Angeles using data from original GPS-based travel and activity monitoring, the implications of these patterns for understanding the geography of opportunity and hazards, and how and in what ways a new light rail transit service alters the activity spaces and associated exposure to opportunity/hazards of nearby residents. This chapter draws from spatial analytical techniques from the field of geography to examine the extent and character of participant activity spaces and to characterize and compare people's potential activity spaces with regards to the magnitude of exposure. In t-test and OLS regression analysis, I found that lower social status, smaller neighborhood blocks size, and lower transit accessibility in residential neighborhoods were associated with smaller geographic activity spaces. Although household income had a strong influence on the density of grocery stores and residential land use within participant.

1. Introduction

Environmental exposure can be defined as the environmental loads within the boundaries of places where people conduct their daily life. In order to estimate the environmental exposure, it is essential to understand where people conduct their daily activities. In traditional health environment studies, residential neighborhoods are considered as daily activity spaces (Buzzelli and Jerrett, 2007). Because people tend to spend about 80% of their time in residences, the methodological approach has been expected to estimate activity space (Jerrett and Finkelstein, 2005). However, recent studies show that such a residential, zone-based approach can cause over- or under-estimation of environment exposure (Jerrett and Finkelstein, 2005). This chapter seeks to develop methodologies to estimate activity spaces at an individual level. In addition, this chapter examines the relationship between the size of location activity space and characteristics (social and built environmental factors) for residents near a newly introduced public transit line in Los Angeles. It demonstrates how the LAEX framework described in chapter 1 provides an approach for understanding linkages between external factors and behavioral factors. This chapter also examines the relationship between social and built environment quality to which individual residents are exposed to within their daily activity spaces. This empirically tests the association between exposure to environmental quality and health-related behaviors and health outcomes within the LAEX framework.

2. Background

The concept of activity spaces emerged in the field of geography in the 1970's to understand and characterize where people travel and spend time over the course of the day (Hagerstrand, 1970; Lenntrop, 1976). Since that time, scholars in spatial science, geography, economics, and urban and transportation planning have developed, expanded and operationalized this construct to examine geographic accessibility to job, educational, shopping and recreational opportunities, and how accessibility differs across social categories, such as gender, age, income, and race/ethnicity (Carrasco and Miller, 2009; Church and Marston, 2003; McCray and Brais, 2007; Neutens et al., 2012). Activity spaces capture an individual's movements by constructing potential geographic boundaries circumscribing an individual's activities (Neutens et al., 2011). Figure 2.1 illustrates how Axhausen et al. (2001) used a two dimensional ellipse to depict the divergent activity spaces of a full time married employed adult versus a single adult student.

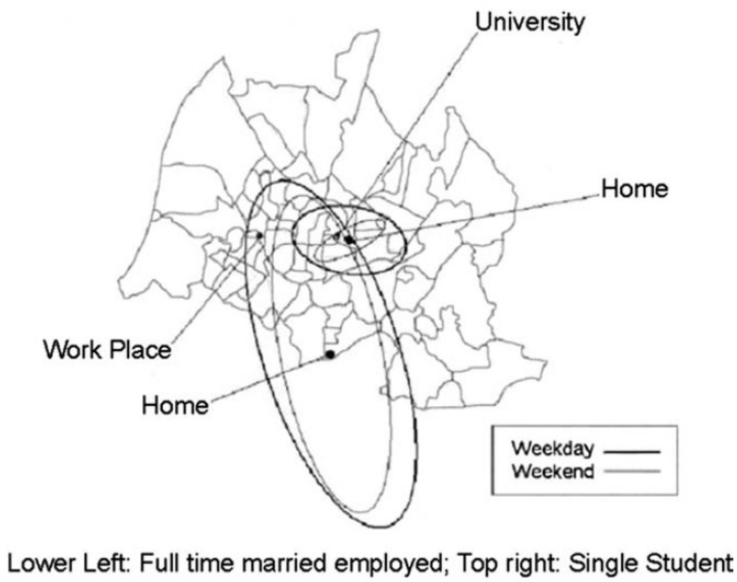

Figure 2.1 Activity spaces for two individuals in Germany (Axhausen et al., 2001 as cited in Jerrett 2006)

The construct of activity spaces has provided new insights not available using more traditional residence-based measures of accessibility common in transportation planning research. Traditional studies of accessibility to urban opportunity have focused on 1) how many amenities are within the census tract or transportation analysis zone (TAZ) in which an individual resides or 2) how distant amenities are from an individual's home location (Neutens et al., 2011). This zone-based accessibility measurement creates an ecological fallacy because individuals in the same zone are assumed to have the same accessibility level (Forer and Kivell, 1981; Miller, 1982; Neutens et al., 2011). Such place-based accessibility measures are increasingly problematic, as transportation, mobility activity patterns, and social structures are increasingly complicated. They also have substantial limitations in capturing variations of activity spaces by personal and household characteristics (Neutens et al., 2011).

Geographers have used the concept of activity spaces and time-space theories to develop person-based measures of accessibility which improve upon place-based measures common in transportation by computing available amenities or opportunities within or near the places where people travel or spend time over the course of the day, not just near their home location. In 1970, Hägerstrand developed conceptual frameworks of activity spaces which incorporate an individual's activities and time constraints. The main concept of his theory is that activity spaces are determined within a given time budget for every person, and that time constraints may limit the geographic extent of activity spaces. Hägerstrand suggested three constraints on activity spaces: capability, coupling, and authority constraints (Hagerstrand, 1970). Capability constraints are factors limiting activity spaces because of an individual's biological demands, such as sleeping and eating. Coupling constraints occur when a person should spend time, "to join to individuals, tools, and materials in order to produce, consume, and transact" (Hägerstrand, 1977, p.14). Authority constraints are related to time limitations on individuals or given groups for using resources (i.e. operating hours of sports centers and public transportation) (Hagerstrand, 1970). The degree of the integration of these three types of constraints varies by personal or household characteristics. Hägerstrand's conceptual framework of activity space enables consideration of more realistic factors, such as time sequence, in people's activity patterns.

The activity space analysis which incorporates both in time and space dimensions consists of three parts, such as space-time path, space-time prism, and potential path area.

The space-time path is a line tracing an individual's movement across space and time dimensions (Miller, 2005) (Figure 2.2a). The space-time prism is the extension of the space-time path, which provides three dimensional volumes implying the individual's ability to reach locations given the duration of other fixed activities (McCray and Brais, 2007) (Figure 2s.2b). This three dimensional space-time prism indicates the magnitude of possible activity spaces and provides substantial improvement over more traditional place-based approaches depicting accessibility. Despite this conceptual improvement and improvements in computational methodology, it is still difficult to implement the idea in computation with actual location data (Brownson et al., 2009).

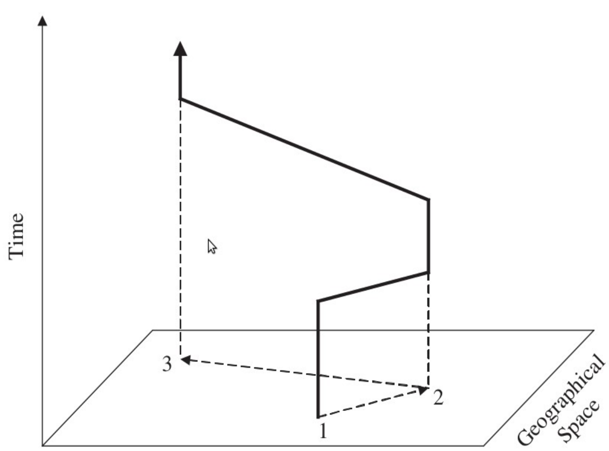

Figure 2.2a. Space-time path
Source: Miller, H. (2005) p.20 and p.21

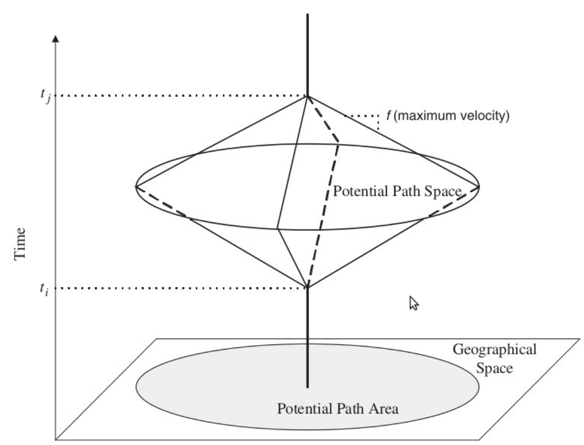

Figure 2.2b. Space-time prism and Potential Path Area

Some empirical studies have operationalized analysis of activity spaces using a two dimensional one standard ellipse (SDE1) based on locational points. SDE1 represents the directional distribution among a group of geographic points. SDE1 has been the most common method to represent individual's activity space with analogs to univariate analysis to represent the magnitude and direction of spread of two-dimensional locational points

(Newsome et al., 1998; Sherman et al., 2005; Zenk et al., 2011). Weighing time spent on certain location points, studies have considered time spent for certain activity locations to depict the size and direction of the ellipse (Newsome et al., 1998; Zenk et al., 2011). SDE1 is calculated based on three factors, including angle of rotation, dispersion of major axis, and dispersion of minor axis (Buliung and Kanaroglou, 2006; Sherman et al., 2005). The major axis goes through maximum dispersion among geographic points, whereas the minor axis goes through minimum dispersion among the points (Buliung and Kanaroglou, 2006; Sherman et al., 2005).

With advances in remote-sensing and data processing technology, it is easier to obtain geographic data with smaller time resolution, which enables consideration of time spent in a more accurate way. With smaller time resolution, it is possible to account for the amount of time spent in daily life in defining the size and direction of SDE1 by considering density of GIS point data in the calculation of mean and standard deviation.

3. Research Objectives

Objective 1: To select a methodology for representing activity spaces and analyzing the GIS-based geographic measures of opportunities and hazards

The first research objective is to evaluate methodologies to represent and analyze LAS's using GIS and spatial analysis software, and to select the most appropriate for addressing the research questions. Although it may not adequately take into consideration time and scheduling constraints, the first method I assess consists of drawing a 2-demensional ellipse and an activity space path around the GPS-based locations for a 24-hour period of time. Figure 2.3 provides an illustration of this approach for defining activity spaces for two study participants. The first study participant only walked or used transit on the given day, and the second study participant only rode in a private vehicle on the given day. Part of the research is to evaluate available methods and their assumptions with regards to the width and extent of a given activity space and how much time participants spend in given locations. Zenk et al. (2011) operationalized this approach using an SDE 1 method.

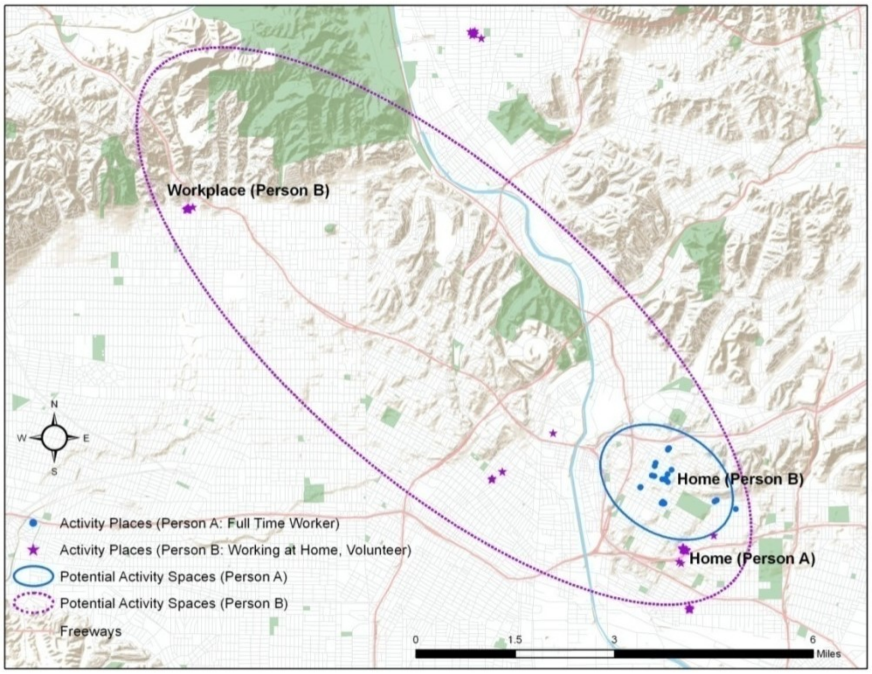

Figure 2.3 Comparison of the Extent of Potential Activity Spaces of Two Participants in the Boyle Heights Air Pollution Exposure Study (BHAES)

The second method I assess is an Activity Space Path (ASP). This method tracks an individual's location places and paths between the locations, and consider areas near the locations and paths as an LAS in two dimension. Zenk et al. (2011) operationalized the concept. Using GPS-tracking data, they created ½ mile buffers around the GPS points and measured environment quality within the buffers (Zenk et al., 2011).

Objective 2: To characterize and compare LASs of residents near a public transit line

This stage of the research seeks to examine, characterize, and compare LASs of residents by examining variations of activity spaces by travel patterns and mode. Mobility tends to differ by personal or household characteristics, and it has been shown that individuals with lower SES are less likely to use personal cars (Glaeser et al., 2008). Theoretically, the provision of more public transportation services, such as new transit line, should increase the frequency of operation of existing transit services, and could result in increased accessibility to opportunities for nearby residents.

Travel behavior, modes of transportation, and available transportation resources are major factors considered in previous studies analyzing the level of accessibility to opportunities (Kockelman, 1997). These studies stress the importance of mobility and the availability of amenities within a reasonable travel time and distance from residential locations. Thus, modes of transportation or modal choice plays a key role in the ability to overcome geographic barriers if all other conditions are equal. Automobile owners tend to have less difficulty overcoming distance to access opportunities compared to people using other modes of transportation, including public transportation (Hanson and Schwab, 1987). Given the same opportunity settings, activity spaces vary by the modes of transportation.

<u>Objective 3</u>: To assess how activity spaces relate to opportunity and hazards in residential neighborhoods

The third objective is to assess how an individual’s activity space is associated with environmental settings given in individual's residential neighborhood. In the LAEX framework, individuals' behavioral patterns and environment quality are interrelated. Residential environment might alter individual's behavioral patterns, whereas the residential environment can be the consequence of the individual's behavioral patterns.

Previous studies of environment exposure and LASs at individual level have not examined the relationship between given residential environment and characteristics of LASs. For opportunity settings, the research evaluates the relationship between size of LASs and the availability of opportunities within those spaces. The measurement of urban opportunities includes employment, retail/services, educational facilities, and health/recreational opportunities. In terms of urban hazards, this study assesses the relationship of an individual's activity space to the spatial distribution of traffic volume and transportation-related air pollution.

4. Methods and Data

4.1 Methodological Approach

I estimate the temporal and spatial boundaries representing urban residents' ability to utilize urban spaces. The geographic boundaries, which account for individuals' time budgets, could provide more realistic estimates of accessibility to urban amenities and exposure to hazards by integrating temporal and spatial aspects of time activity patterns. Accessibility and exposure to amenities and hazards can be measured by considering available amenities and hazards falling within individuals' LASs. The individuals' LASs are measured based on spatial and temporal location data, obtained from Global Positioning System (GPS) loggers tracking individual people's geographic location in 15 second intervals for 5 to 7 days. I use the same methods as the study of Zenk et al. (2011) to estimate individual people's location activity spaces, one-standard deviation ellipse (SDE1) and the activity space path area (ASP). These two methods are simpler than other three-dimensional representation of LASs, but since these techniques are focused on visualization they were not suitable for aggregating spatial patterns across participant subgroups.

The SDE1 method can be easily implemented using current computational systems. In addition to simplicity of calculation, this method can consider temporal factors in the calculation. In other words, density of GPS location points associated with the time a person spent in a certain location enabled me to weigh the temporal factors in the calculation of the size and direction of SDE1. ASPs are geographic boundaries to which an individual person can reach in walking distance from each geographic point where s/he was at certain time. The ASP traces a person's daily movements. I employed a ½ mile distance criteria to estimate areas reachable on foot from each GPS point, which Zenk et al. (2011) suggested in their study.

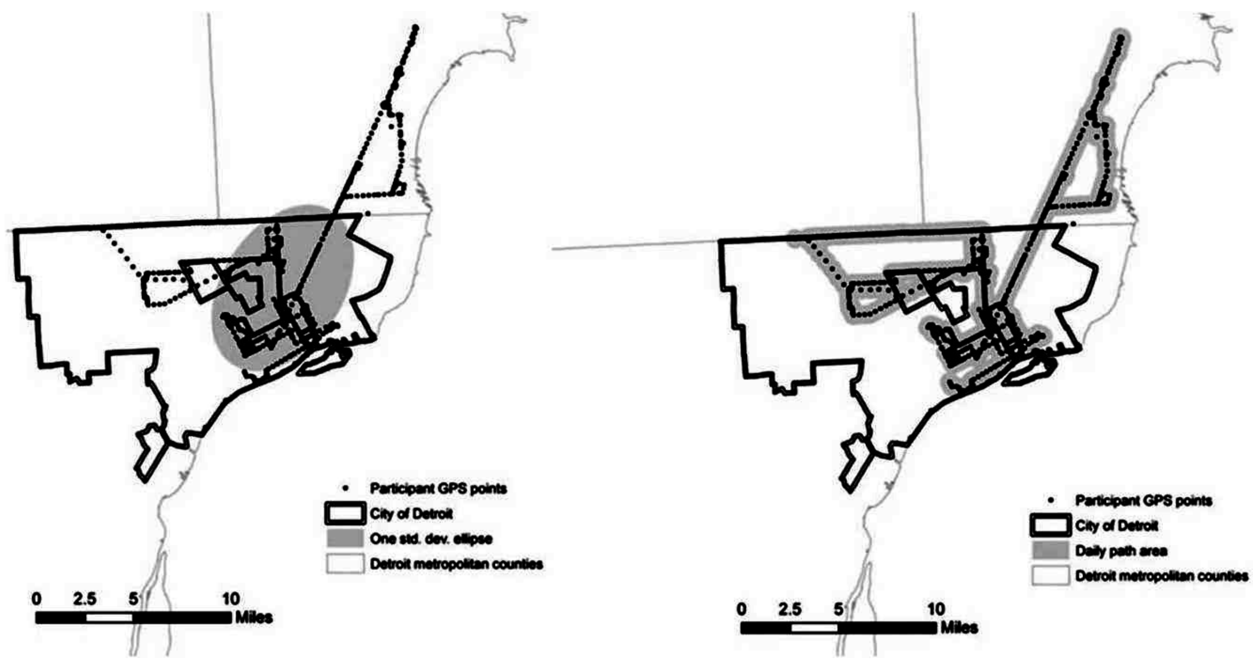

Figure 2.4 Comparison of Extent of LASs between SDE1 (Left) and ASP (Right) Methods
Source: Zenk et al. (2011) p. 1152

These estimated individuals' SDE1s and ASPs were considered the temporal and spatial boundaries of participant LASs, and I estimated how much their activity spaces were in proximity to or contained amenities and hazards. With spatial data management tools in ArcGIS 10, I overlaid individuals' LASs with the location of amenities and of hazards. I measured the quality of the physical environment within LASs which could promote quality of life based on employment, education, recreational and health-related facilities. I measured hazards with LASs based on air pollution, traffic, and other car-oriented physical settings. The amount of facilities, expressed as counts, density, or proportion to the entire area of individual's activity space, represented potential opportunities or amenities an individual could take advantage of, or potential hazards an individual could be exposed to.

I examined differences in the level of utilization of urban spaces by comparing the size of activity spaces and accessibility and exposure levels across physical environments and socioeconomic contexts. For descriptive analysis, I conduct t-test for the average size of activity spaces and the average accessibility level and exposure level between participant subgroups. In terms of socioeconomic status, I examined the differences in the activity space, accessibility level, and exposure to hazards across modes of transportation, household income, housing tenure, and gender and examined whether differences were statistically different using t-test analysis. In addition to the descriptive analysis, I estimate regression models to examine 1) the relationship between neighborhood built environments as external factors (within 1 mile from individuals' residences) and size of the individuals' LASs (SDE1 and ASP), and 2) the relationship between behavioral patterns (modal choice, residential choice, and occupational activities) observed at individual level and the health-related environmental exposure (NO_2 and grocery store density) within the individuals' LASs.

4.2 Data

4.2.1 Expo Data

The main source of travel and activity data was collected from a study for residents of the low-income communities in south Los Angeles near Los Angeles Metro Expo Line. Using GPS-based tracking methods, the study provided substantial insights into the geographic patterns of free living subjects during periods of everyday travel and activities.

The Expo study recruited people who lived with the Expo and Crenshaw corridors before and after the Expo line service began. A subset of survey participants carried one GPS logger and an accelerometer 24 hours and 7 days, which provided geographical location information and physical activity levels every 15 seconds and 60 seconds, respectively. In addition to the tracking devices, participants were asked to provide their household socioeconomic and demographic information, attitude towards to travel behaviors, neighborhood, and so forth through household baseline survey, and the number of trips by modes of transportation and total mileage per day through travel logs and vehicle travel logs in self-reporting format. Only one household member in every household carried the tracking devices, and all household members 12 years or older in every household were asked to fill out self-reporting travel surveys. The same survey participants carried the devices in each phase of surveys.

We conducted Wave I travel survey in fall 2011, approximately 6 months before the line started operation in April 2011. The Wave II survey took place in fall 2012 and 6 months after the line opened. We invited all 27,275 households in the study areas to participate in the survey, and 651 of them expressed interests in participating, 135 of which participated in the mobile tracking survey in Wave I. For the Wave II survey, 135 people from Wave I participated again in the GPS mobile tracking sample. Only participants with a minimum of 3 days of tracking were included in the analysis. The analysis was based on GPS-tracking for 126 participants and 96 participants were in the Wave I and Wave II mobile tracking surveys, respectively.

To identify periods of activity and travel in the GPS data, we conducted post-processing of the data to identify 15-second interval location data points which represented stationary and mobile periods using a classification procedure which has been previously validated (Ott and Siegmann, 2006; Wu et al., 2011; Zhu et al., 2002). Our initial classification of stationary periods included sequential GPS locations which were clustered within twenty meters of a location for longer than two minutes. Our initial classification of mobile periods and corresponding travel modes was based on the speed between sequential GPS points, which were not previously classified as stationary locations. We confirmed and corrected our initial classifications of stationary and travel periods by visually reviewing sequential GPS locations relative to roadways, sidewalks, and transit route/stops by overlaying GPS points with aerial photography using Geographic Information Systems (GIS). This procedure allowed us to confirm and make important corrections in our final classification. For instance, our visual inspection of GPS data in GIS helped confirm that a participant stopped longer than two minutes at a traffic light was classified as being in-vehicle and not at a stationary location.

4.2.2 Supplemental Data

Replicating methods of previous studies, I measured built environmental quality of individual participants' residential neighborhoods. I defined a residential neighborhood as an area covered in walking distance from the person's residence. Using Buffer Analysis tool in ArcMap 10.1, I created a 1 mile buffer around each participant's residence and regard it as the person's residential neighborhood. The environmental quality within activity spaces were measured based on walkability, land use composition, job availability, and public transportation resources. With respect to walkability, I assume that a higher walkability level encourages using alternative modes of transportation and contributes to a smaller size of activity space, because individuals might not feel the necessity to travel by automobile. The number of 4- or more-way intersections and the average block size in the residential neighborhood were used as indicators of walkability. More intersections and smaller block size imply the higher walkability level (Brownson et al., 2009; Frank et al., 2007, 2005; Lee and Moudon, 2006). With Network Analyst in ArcToolBox 10.1, I obtained intersection points with information about the number of directions at each intersection based on the 2010 Census TIGER roadway shapefiles. I intersected the point-based intersection information and the LAS areas for each participant. Regarding the average block size, I converted areas encompassed by TIGER street line segments into polygons using ArcMap 10.1. After intersecting the block polygons and each participant's residential neighborhood shapefile, I calculated average block size in acre.

For land use composition in the residential neighborhood, I assumed that more non-residential land use in the residential neighborhood discourages residents to drive out of the neighborhood often, so that the size of activity space of the person would be smaller than others. Using ArcGIS 10.1, I intersected the residential neighborhood shapefile of each participant and land use shapefiles, and calculated areas for each land use type and the percentage of each land use in the LAS areas for each participant. Existing land use shapefiles for 2008 were obtained from the Southern California Association of Governments (SCAG).

For job availability, I hypothesized that more job opportunities or potential destinations within a residential area would encourage residents to use alternative modes of transportation rather than to choose automobiles, so that their activity space would be smaller. I used the InfoUSA 2011 business location data obtained from SCAG including establishment location and the number of employees for each company. Using ArcGIS 10.1, I intersected the job location shapefiles and individual participants' LAS areas.

For public transportation infrastructure, I hypothesized people living in a neighborhood with more public transit lines and stops would have more opportunities to move within the city. Thus, I expect higher public the transit density would be associated with larger activity spaces. The public transit stop density measurement in participant LAS was obtained by intersecting the 2012 transit stop shapefiles obtained from SCAG and individual participants' LAS area shapefiles.

I generated comparable environmental variables for the LASs for the participants. For opportunity settings, the research evaluates the relationship between size of SDE1 and the availability of opportunities in urban space. The measurement of urban opportunities includes employment, retail/services, educational, and health/recreational facilities. The measurement of job accessibility is based on point-based job information available from InfoUSA in 2011. The data provided addresses of business establishments and the total number of employees. Information in the database about firm industry sector was used for measuring availability of retail/services and educational destinations. Since the database provides business types, it is possible to understand how many and where retail stores and educational facilities are located. In terms of recreational facilities, this study gathers location information of parks and open spaces from 2008 existing land use data from the Southern California Association of Governments (SCAG) and sports facilities from the 2011 InfoUSA data.

In addition, I estimated accessibility to healthy food stores. Information on business establishments from InfoUSA 2011 were used for the analysis. Using the North American Industry Classification System (NAICS) codes, I regard business establishments, supermarkets, and grocery stores (except convenient stores) as healthy food resources. The dataset provides geographic information, such as latitude and longitude of each business establishment. I geocoded supermarket and grocery store location, and calculated grocery store density by using the number of stores within individual activity spaces.

In terms of urban hazards, I assessed the relationship of an individual's LAS to the spatial distribution of traffic volume and transportation-related air pollution. Traffic information was obtained from the California Department of Transportation. The data included a street shapefile data with traffic volume in annual average daily traffic (AADT) units. For air pollution concentrations, the study used nitrogen dioxide (NO_2) concentration data developed by Dr. Julian Marshall of the University of Minnesota and his colleagues, which includes an estimated pollution surface which can be analyzed in GIS (Marshall, n.d.). Although its resolution is fairly coarse (census block group), it was used as a "proof of concept" which can be used in the future (Li et al., 2012).

Polluting industry density within an individual's activity space was also considered as a level of environmental hazard. From the InfoUSA 2011 dataset, firms categorized in manufacturing, oil extraction, mining, and other related industry were used. The firms regarded as polluting industry were geocoded using ArcGIS 10, and the density can be calculated by counting the number of polluting industry firms in a given individual's LAS.

4.2.3 Dataset and Analysis

I created the SDE1s based on each participant's GPS points, using a spatial analysis tool (Spatial Deviational Ellipse) in ArcGIS 10.0. The SDE1 for each participant was spatially joined to the accessibility/exposure measurements using ArcGIS 10.0. I obtained land use composition, density of each type of business and industry by calculating the proportion of the amenities to the size of SDE1. In addition, I merged each participant's socioeconomic and demographic information and additional travel behavior information collected from the self-report baseline household survey and travel logs to the built environment measurements within each participant's SDE1. Thus, the final participant-level dataset consists of built environment variables, including the size of SDE1 in square miles, the percentage of residential, commercial, industrial, public, and open space land use, the number of grocery stores per square mile, the number of hospitals per square mile, the percentage of mid-high traffic corridors, and the number of polluting industry per square mile.

I assemble comparable data based on the ASP LAS measure. The dataset includes the size of ASP rather than SDE1. The ASP LAS measure is based on buffer analysis. I estimated areas potentially reachable on foot from actual GPS points. I created ½ mile buffer from the all GPS points for each participants and dissolved them into one single shapefile in ArcGIS 10.0. I used ½ mile as a walking distance to be consistent with the Expo Line study and Zenk et al (2011)'s study. Since the size and shape of ASP are different from SDE1s, the accessibility/exposure measurements were different from those of dataset with SDE1s, whereas other socioeconomic, demographic information and additional travel behavioral information were the same.

The descriptive analysis compares accessibility to amenities and exposure across the LAS measures, non-residential land use density, grocery store density, polluting industry density, and examines differences by mode of transportation, gender, housing tenure and household income level. The t-test method is employed to test significant differences between two different levels for each key variables. Since modes of transportation and annual household income are not dichotomous, unlike gender and housing tenure, I used transformed variables with operational definitions. For the modes of transportation, I classified survey participants who reported they used any kind of public transportation into the transit rider group as transit riders. For household income, I classified participants, whose annual household income was below $55,909, the median household income in Los Angeles County (2009-2013 American Community Survey 5-Year Estimate), into the low-income group and the remainder into the higher-income group.

5. Findings

5.1 Descriptive Analysis

The first step of analysis was to characterize (1) activity spaces and (2) environmental qualities within the activity spaces by socioeconomic factors. Table 2.1 and 2.2 indicates characteristics of activity spaces and environmental qualities measured by 1-

standard deviation ellipse (SDE1) and activity space path (ASP), respectively. Columns of each table represent the socioeconomic factors, including (1) public transportation ridership, (2) availability of private transportation in households, (3) gender, (4) housing tenure, and (5) household income status. The rows of each table indicate characteristics of (1) activity space and (2) environmental qualities within the activity spaces.

As suggested in the LAEX framework, external factors are associated with individual residents' behavioral patterns (including travel behaviors) and individuals' location activity spaces and exposure to environmental qualities. Thus, the results of descriptive bivariate analysis in Tables 2.1 and 2.2 provide useful insights on the relationship between socioeconomic factors, activity spaces, and environmental qualities.

5.1.1 Size of Individuals' Activity Spaces

For the SDE1 method, public transit riders (who used public transportation for at least one trip over the period of their survey), people without a personal car in their household, females, and the low-income had smaller size of activity spaces than the remainder of participants in each category. However, only household income in the Wave II of the survey explained a significant difference in the size of activity spaces. In Wave II of the survey, the average size of activity space in low-income group (11.0 sq-mi) was about one quarter that of higher-income group (49.7 sq-mi) (Table 2.1).

I found similar results regarding the overall size of activity spaces using the second methodological approach based on measuring individuals' ASPs by calculating buffered areas around each GPS point (Table 2.2). The average size of activity spaces with the ASP buffer analysis differed across car-ownership and income level categories at 90% significant level. In terms of car-ownership, households with at least one automobile, tended to have a larger activity space than those without a car in their household (49.3 vs 33.3 sq-mi in Wave I; 52.3 vs 29.5 sq-mi in Wave II). The low-income group in Wave II had the smaller size of activity space on average (28.9 sq-mi) than the higher income group (49.2 sq-mi) (Table 2.2).

In summary, lower-income participants had relatively small activity spaces for both SDE1 and ASP in Wave II, compared to higher-income residents. This might result from the lower ability to utilize personal automobiles.

5.1.2 Environment Qualities within Location Activity Spaces (Amenities)

(1) Land Use Composition within Location Activity Spaces

I used land use data to measure accessible amenities within individual participants' location activity spaces. A higher percentage of commercial land use, public land use, and open space were regarded as an amenity. In contrast, a higher percentage of residential land use was considered to represent lower accessibility to non-residential amenities. Regarding residential land use within SDE1, people in the public-transit group had a higher percentage of residential land use within LASs in Wave II (Table 2.1). Participants in households without a household automobile had a higher percentage of residential land use for Wave I and Wave II. This suggests that the spatiotemporal boundaries of people without cars in their household were limited to more residential areas with lower amenities. The percentage of residential land use within LASs also differed by income level. For both Wave I and Wave II, low-income participants had a higher percentage of residential land use within their LASs (Table 2.1). This suggests that lower-income people had lower accessibility to non-residential amenities due to limited access to personal automobiles. These patterns in land use composition within SDE1 suggests that lower SES with respect to modes of transportation was related to limited accessibility to the non-residential amenities.

Regarding land use patterns within ASPs (Table 2.2), I found that participants in the non-public transit, car-owner, female, home-owner, and higher-income groups had a higher percentage of commercial land use within their activity spaces. The average percentage of commercial land use within activity space in non-public transit group in Wave was 10.7, which was significantly greater than transit group, 10.1 percent. The car-owner group in Wave I survey had a higher percentage of commercial land use (10.7 compared to 9.8 percent for the non-car owner group). Females in Wave II had a higher percentage of commercial land use (10.9 vs. 10.0 for males). The average percentage of commercial land use in home-owner group was 10.8 in Wave I, which is higher than renter group, 10.3. The average percentage of commercial land use in Wave I in the low-income group was lower than the higher-income group (10.2 vs 10.8 percent). Similarly, the percentage of land designated for open space varied across public transit, car-ownership, housing tenure, and income level. The public transit group in Wave II had a lower percentage of open space in their activity spaces than the non-public transit group (2.8 vs 3.7 percent). The average percentage of open space for the car-owner group in Wave I and Wave II were 3.7 and 3.6, respectively, which was higher than the percentage for the non-car-own group, 2.8 and 2.3. In Wave II, I also found that the home-owner group had a higher percentage of open space (3.9) compared to the renter group (3.0). The low-income group had a lower percentage of open space in their activity space in Wave I and II compared to the higher-income group (3.3 vs. 3.8 percent in Wave I; 3.1 vs 3.6 percent in Wave II) (Table 2.2).

In summary, the results for land use composition show common patterns for both the SDE1 and ASP methods. People in the socially disadvantaged groups tended to had a higher percentage of residential land use within their activity spaces, which implies they have lower chance to access to non-residential amenities.

(2) Grocery Store Density

I found that the grocery store density in individuals' LASs differed across car-ownership, housing tenure, and household income, but difference were not apparent for the transit use and gender categories. Based on the SDE1 method, the car-owner group had the higher grocery density than the non-car-owner group in Wave I (Table 2.1). In Wave II, the grocery density was higher in the homeowner group than the renter group (Table 2.1). These results imply that better mobility and higher SES was associated with potential access to more grocery stores within LASs. In contrast to the results showing positive relationships between higher mobility and homeownership and grocery density, lower household income were associated with higher grocery density within individuals' LASs in Wave I and II (Table 2.1).

Although the results based on the SDE1 method show the positive relationship between the higher SES (except for household income) and grocery store density, the ASP method suggests lower SES is associated with higher grocery density within LASs. For both Wave I and II, participants in the non-car-owner, renter, and lower-income groups had higher grocery store density than other groups (Table 2.2). Based on the ASP method, more factors were associated with differences in grocery store density than with the SDE1 method.

5.1.3 Environment Qualities within Activity Spaces (Hazards)

(1) NO_2 Concentration / Polluting Industry Density

Based on the SDE1 method, I found that household car ownership, housing tenure, and annual household income were associated with the concentration of NO_2 within individuals' activity spaces. In terms of car ownership in a household, the average NO_2 concentration level was higher in the non-car-owner group than the car-owner group in Wave II (Table 2.1). Participants in the homeowner group had the higher concentration of NO_2 than the renter group in Wave I (Table 2.1). Participants in the low-income group had a higher average concentration level of NO_2 than higher-income group (26.9 ng/m^3) in the low-income group vs. 26.4 ng/m^3 in the higher-income group in Wave I; 27.4 ng/m^3 of the low-income vs. 25.6 ng/m^3 of the higher-income group in Wave II) (Table 2.1).

The ASP method had the similar results of NO_2 exposure to the SDE1 method, regarding car ownership in households and household income. With the ASP method, I found that participants in the non-car-owner group and the low-income group had a higher average NO_2 concentration than other groups both in Wave I and II (Table 2.2). In addition to the car ownership in households and household income, the ASP method provides a result showing a positive relationship between public transit ridership and exposure to NO_2. In Wave II, participants in the public-transit rider group had a higher average NO_2 concentration than the non-public-transit rider group (Table 2.2).

In terms of polluting industry density in an individual's LAS, both the SDE1 and the ASP methods suggest that lower SES groups tended to have higher potential exposure to polluting firms. With the SDE1 method, I found that participants in the renter group in Wave I and the low-income group in Wave I and II had a higher average number of polluting firms than the home owner and the higher income groups (Table 2.1). Unlike my hypothesis, the car-owner group in Wave I had a higher polluting industry density than the non-car-owner group (Table 2.1).

The ASP method provided the similar results that participants in the renter and the low-income groups in Wave II had a higher polluting industry density (Table 2.2). However, the ASP method had different results in the relationship between car ownership and polluting industry density from the SDE1. In Wave I and II, participants in the non-car-owner group had higher polluting industry density than the car-owner group (Table 2.2).

5.2 Regression analysis

5.2.1 Built environmental characteristics of residential neighborhoods and location activity spaces

According to the framework of Location, Activity, and Environmental Exposure (LAEX) (Figure 1.1), an individual's behavioral patterns, which shape their own location activity spaces (LASs), are influenced by many external factors, such as built environmental characteristics surrounding their residences, institutional factors, individuals' demographic and socioeconomic status, and segregation. I assessed the relationship by examining associations between the size of individuals' LASs and built environmental quality of residential neighborhoods and their SES using ordinary least squares regression analysis. In this analysis, I used built environmental qualities of individuals' residential neighborhoods which were defined as areas covered within 1 mile from their home location. This measurement of the built environmental qualities is different from built environmental qualities to which individuals expose within their LASs. Given residential neighborhood walkability, neighborhood land use composition, neighborhood job availability, long length of residency (living in the same residence more than 10 years), and employment status were used as explanatory variables, and the size of LASs, including SDE1 and ASP, were used as dependent variables (Table 2.3).

In the model 1.A.1 (Table 2.3), I found that average block size of a residential neighborhood (within 1 mile from a residence), average percentage of residential land use in the neighborhood, public transit stop density of the residential neighborhood, and long length of residency were significantly associated with the size of SDE1 in Wave I survey. The average size of block in a residential neighborhood mile was positively associated with size of an individual person's SDE1 ($p = 0.008$) in Wave I. Regarding land use, increases in the percentage of residential land use by one percent were associated with increases in size of SDE1 ($p = 0.032$). Ten more public transit stops in a residential neighborhood were associated with an increase in the size of SDE1 ($p = 0.074$). In terms of length of residency, participants who have lived in his/her residential neighborhood ten years or longer were more likely to have SDE1s 37.2 acres smaller than those who lived in their neighborhood less than ten years ($p = 0.037$). In the Wave II Model 1.A.2 (Table 2.3), similar to Wave I, the percentage of residential land use in residential neighborhoods was positively and significantly associated with size of SDE1. The percentage of residential land use was positively associated with the size of SDE1 ($p = 0.065$). In addition, I found that the percentage of open space land use and job availability in residential neighborhoods were positively related to the size of SDE1. Low-income status was negatively associated with the size of SDE1 in Wave II. Participants in the lower-income group had the average SDE1 35.3 acres smaller than the higher-income group. In the Wave II model, the average block size and housing tenure were not statistically significant (Table 2.3). The variables included in the models are different, because I sought to find the best model in each wave and each LAS. Some variables were excluded and included for the purpose of goodness of fit.

In the Wave I model for the ASP type of LAS, such as activity space paths (Model 1.B.1), which cover ½ mile from each GPS point. I found that the percentage of commercial land use and open space in residential neighborhoods and working at home were the variables which were significantly associated with the size of ASP. The percentage of commercial land use and open space in residential neighborhood were negatively associated with in the size of ASP. If an individual person worked at home, s/he had an ASP smaller LAS than others. Only income status and employment status variables in the Wave II model (Model 1.B.2) were significantly related to the size of ASP. I found that participants in the lower-income group tend to have smaller ASPs than the higher-income group ($p = 0.009$). Employed percipients were more likely to have bigger ASPs than unemployed participants ($p = 0.025$).

In summary, I found that larger block size (lower walkability) and more residential land use (fewer amenities), better transit access (better mobility) in residential neighborhoods are associated with bigger LASs. In residential neighborhoods with lower walkability and fewer amenities, people might want to move out of their residential neighborhood to find more amenities. If they have better mobility in the neighborhood, they might move out of the neighborhood. In addition, I found commercial land use in residential neighborhood, low-income status, and working at home were associated with smaller LASs. Since more commercial land use around residences would imply that there are more amenities, it might help residents stay near their residences to keep their activity space limited around their residential neighborhood. Since income level is also related to mobility, low-income status would hinder people to move around. If an individual’s job is located in the individual’s home, his/her activity space should be smaller.

5.2.2 Individual Behavioral Factors, Built Environment of LAS, and Exposure to Health-Related Built Environments: Air Pollution and Grocery Access

The LAEX framework (Chapter 1) suggests that the location activity space at individual level is determined by the individual's behavioral patterns (e.g. modal choice, residential location choice, and occupational activity). The LAS provides the central linkage between behavioral patterns and environmental quality, and such linkages result in exposure to environmental quality. I examine the relationship between two exposure health-related built environments, NO_2 concentration level and grocery store density in individuals' LAS, and behavioral patterns and other built environmental qualities of LAS.

In terms of exposure to NO_2, I found that renters were associated with a lower level of exposure to NO_2 compared to home owners ($p = 0.003$) based on the SDE1 LAS estimation method (Table 2.3.A) and that the size of LAS was also associated with a lower level of NO_2 exposure level ($p < 0.0001$) (Model 2.A.3). Regarding built environments of LAS, the size of LAS, average block size within an LAS, and employment density within an LAS were associated with the lower NO_2 exposure, whereas commercial land use and transit access in an LAS were related with higher NO_2 exposure (Model 2.C.3). Similar results were shown in ASP methods (Model 2.B.4 and 2.D.3).

With regards to grocery store density, participants with cars in their households, renters, and the size of an LAS were associated with lower grocery store density in LAS (Model 2.A.3 and Model 2.A.4). In addition, the average block size within LAS and employment density in LAS were associated with lower grocery density (Model 2.C.3).

Greater transit access and public land use within an LAS and being lower income were related to higher grocery store density (Model 2.C.3).

In summary, the patterns of exposure to NO_2 and grocery stores were found to be similar, although these two built environmental qualities are hypothesized to represent a health hazard and a health amenity, respectively. Larger LAS, larger average block size, and employment density in LAS were related to lower exposure to NO_2 and grocery stores, while transit access in LAS and lower income status were associated with lower exposure to NO_2 and grocery stores. In other word, if an individual is more likely to be exposed to NO_2, s/he also tends to have greater exposure to grocery stores. This pattern could result if grocery stores tend to be located in non-residential areas where traffic and goods movements are more prevalent, and raises concerns of trade-off between urban amenities and air pollution exposure. From the results, built environments which encourage residents to walk or to use alternative transportation could increase accessibility to grocery stores but also increase exposure to air pollution as a trade-off.

6. Conclusion / Discussion

This study contributes to literature by providing a heuristic theoretical framework on environment health accounting for external socioeconomic, built environment, institutional factors and individuals' location activity space. Moreover, it employees more advanced methods to estimate individual's LASs which are more able to account for geographic and temporal aspects of environmental exposures. This approach estimated the temporal and spatial boundaries in which the person is more likely to occupy in urban space based on their observed spatial and temporal patterns. As suggested in the LAEX theoretical framework (Chapter 1), I expected given neighborhood built environment settings (block size, land use composition, and public transportation infrastructure), individuals' socioeconomic status as external factors, and individuals' behavioral patterns (modal choice and residential choice) to have meaningful effects on the extent of LASs. In the bivariate analysis, I found that participants in the transit-rider, non-car-owner, and the lower-income group had smaller size of LASs. I found significant effects on the size of LAS by neighborhood built environment variables. From regression analysis, I found larger block size, more residential land use, and higher transit density were related to larger size of LASs, whereas more commercial land use in residential neighborhoods, low-income status, and working at home were associated with smaller LASs.

In terms of accessibility/exposure to environmental quality, in general, the results of the descriptive analysis are consistent with the previous studies on inequality in environmental quality which found that socially disadvantaged groups tend to be exposed to urban hazards and have lower accessibility to urban amenities. The lower percentage of non-residential land use (commercial and open space), higher NO_2 concentration level and higher polluting industry density were associated with both the behavioral factor, such as public transit use, and the external factors, such as no automobile ownership, renting a house, and lower household income. Although the analysis shows lower SES was related to smaller activity spaces and lower accessibility to amenities in general, I found the lower SES group were exposure to higher grocery store density in their LASs. For lower-income households with smaller activity spaces, it would be the best way to be located in areas with more commercial land use. Since the grocery stores tend to be located in areas with better transportation access, public transit users had higher grocery store density.

In the regression analysis to assess the relationship between NO_2 exposure and behavioral patterns (modal choice, residential choice, size of LAS) and socioeconomic factors, transit user group, car-owner group, renter group, and the size of LAS were associated with lower exposure to NO_2. The low-income group was associated with higher exposure to NO_2. In terms of health-related amenities, I examined the relationship between grocery store exposure and behavioral patterns and socioeconomic factors. The transit group, the car-owner group, and the size of LAS were associated with lower grocery store density. The renter group and the low-income group were related to higher grocery store density.

I used two different methods to estimate location activity spaces, and found that accessibility and exposure levels varied somewhat depending on the method used. For instance, car owners tended to have a higher density of grocery based on the SDE1 activity space measure, whereas non-car owner group had higher density within based on the ASP measure. The same pattern can be shown with regards to exposure polluting industry density.

Results suggest that institutional factors can contribute to alleviating or exacerbating the inequality. Mixed-income and transit-oriented development could help people increase accessibility to amenities and reduce time to travel which can increase possibility to exposure to air pollution generated from automobiles. However, the smart growth strategies need to be implemented with more considerations on how to achieve some policy goals without conflicting in practical ways. Most mixed-use developments provide limited number of residential options to lower SES group, and some transit-oriented developments are adjacent to major traffic corridors. Since I don't examine the actual effect of institutional factors on location activity spaces and health-related behaviors, future research is needed to test the influence of institutional factors and activity space on environmental exposure and health.

In terms of the relationship between LAS and given built environmental settings in individuals' residential neighborhood, non-pedestrian friendly-environments around near an individual's residences (bigger block size and more residential land use) was associated with a larger LAS, which suggests that such near-residence built environments could influence residents to seek to engage in activities away from residential neighborhood. If an individual has better mobility, such residents will increase the size of their LASs. In the regression analysis, I also found that transit stop density in residential neighborhood and being employed were associated with larger LAS. These results support the hypothesis that occupational activity is related to characteristics of the LAS, as suggested by Zenk et al (2011). Commercial land use in residential neighborhood is a key factor associated with a smaller LAS. Pedestrian friendly physical configurations (smaller block size and more commercial-mixed land use) in a residential neighborhood contributed to a smaller LAS. Regarding socioeconomic factors, low-income status was related to smaller LAS. Because lower income status could limit to mobility, it would result in smaller LAS. In such cases, low-income participants may not be exposed to more amenities. From the descriptive analysis of built environment exposure within LAS, lower income participants had more residential and less commercial and open space within their LASs than higher-income participants.

In terms of the relationship between exposure to amenities and hazards and behavioral factors, I found that exposure to hazards (air pollution) and amenities (grocery stores) tended to mostly occur simultaneously. I found that exposure to built environments, which were not pedestrian-friendly (large block size and lower transit stop density), were associated with lower exposure to NO_2 and grocery stores. Transit- or pedestrian-friendly environments provided potential advantage of better access to amenities, whereas they make a trade-off with higher exposure to hazards. In terms of employment status, employed participants had lower grocery density than others, which was counter to the result often Zenk et al's study (2011).

This research has several limitations. First, this study does not analyze the influence of other external factors proposed in the LAEX framework (Chapter 1) because of the lack of operationalized definitions for them, such as built environment, institutional factors, and structural inequality (Figure 1.1). Although the LAS measures provide an estimate of exposure levels, these measures are unable to indicate the precise amenities or hazards a given individual was exposed to, including transportation networks, neighborhood design, housing, and distribution of amenities. This approach also does not assess the role of institutional factors, which play an important role in the LAEX framework.

In terms of measuring LASs, future research is needed to adapt and apply more advanced three-dimensional methods, such as those suggested by geographers, including Haggerstrand, Kwan, and Miller. Although SED1 and ASP are the best approaches to calculating LASs considering geographic locations and activity time in the two-dimensional because they account for time spent at certain locations, they are also limited in estimating temporal and spatial boundaries based on sequential movements over the course of the day.

CHAPTER 3. Walkability, Transit Access, and Traffic Exposure for Low-Income Residents with Subsidized Housing in Los Angeles and Orange Counties

Overview

This chapter assesses the spatial distribution of subsidized housing projects/units provided through low- income housing programs in Los Angeles County (LAC) and Orange Counties(OC) in relation to neighborhood walkability, transportation access, and traffic exposure. Results provide insights into implications of housing program design on the geographic distribution of subsidized units and their proximity to urban amenities and hazards. The objectives of the chapter are to characterize location patterns of neighborhood amenities and hazard across types of housing programs and to examine variations in the probability that subsidized housing is located near high traffic roadways by housing program types, nearby built environments and neighborhood socioeconomic status. This paper replicates analysis conducted for OC (Houston, et al., 2012) in order to provide comparative insights for LAC, which has historically experienced more entrenched residential segregation and economic inequality. Bivariate results suggest that overall residents of subsidized housing make a trade-off between having access to better amenities (walkability, transit access, and commercial land use)and experiencing exposure to higher levels of air pollution, and that subsidized housing neighborhoods in LAC had higher air pollution levels but better amenities than subsidized housing neighborhoods in OC. In terms of program types across both counties, LIHTC neighborhoods had higher air pollution exposure, lower transit access, lower walkability, but had more non-transportation amenities than HCV. Logistic regression results indicate the probability of a neighborhood having a subsidized unit in both counties was associated with greater public transit access, mixed-land use, and walkability, but contrary to bivariate results, subsidized units in LAC tended to be located in areas with lower air pollution, whereas subsidized units in OC tended to be located in areas with higher air pollution after controlling for other factors.

1. Introduction

Since the 1970's, subsidized housing policy for low- and moderate-income households has included a health-related goal: to de-concentrate poverty, crime, and other social illnesses, which had plagued the traditional project-based public housing program. Many studies have examined whether new housing programs, such as housing voucher programs, have de-concentrated poverty and addressed socioeconomic disparities, including in areas of employment and salary, poverty and welfare dependency (Buron et al., 2007; Clampet-lundquist, 2004; Devine et al., 2003; Fauth et al., 2004; Mendenhall et al., 2006; Rosenbaum and DeLuca, 2000), crime (Comey, 2007; DeLuca et al., 2010; Fauth et al., 2008; Keels et al., 2005; Rohe and Freeman, 2001), social disorder (Fauth et al., 2008; Popkin and Cove, 2007; Rosenbaum and Harris, 2001), educational achievement (Deng, 2007; Fauth et al., 2007; J Goering et al., 2002; Ludwig et al., 2001; Rosenbaum, 1998), and physical and mental health status (Buron et al., 2007; Fauth et al., 2008; Katz et al., 2001; Meyers et al., 2005; Newman et al., 1994).

Besides these affordable housing studies, a broad literature has addressed neighborhood conditions and their effects. Literature on community and public health has emphasized that neighborhood contexts directly or indirectly affect residents' health, and helps us understand ways that social and physical environment of neighborhoods influence health outcomes through pathways that alter individual physical and mental characteristics (Culhane and Elo, 2005). In terms of economic status, analysis of the Spatial Mismatch Hypothesis (SMH) shows that accessibility to jobs is associated with better employment status or earnings, and it is linked to accessibility to social environments which facilitate sharing of career information. Studies of affordable housing programs and neighborhood conditions commonly assess whether or not neighborhood conditions are linked to residents' living conditions and welfare. However, few studies have evaluated whether programs to de-concentrate poverty have resulted in greater proximity to built environment amenities, which could promote positive health and economic outcomes (neighborhood walkability, transit-access, amenities nearby, and air quality). Such amenities have been shown to be associated with positive health outcomes with regards to Body Mass Index, obesity, cardiopulmonary function, and respiratory diseases (MacDonald et al., 2010; Pope III et al., 2002; Sallis et al., 2009).

Although the policy goals of subsidized housing programs recently have been expanded to consider the quality of the surrounding built environment in the effort to better integrate affordable housing with smart growth, transit-orient development, and healthier cities (GAO, 2009), it is unclear whether current affordable housing programs have been successful in improving the built environment conditions of affordable housing neighborhoods. Furthermore, few studies have examined the spatial implications of housing program design and whether they are congruent with the goals of smart growth and other urban development policies making neighborhoods more walkable, safer, and with lower environmental hazards.

This chapter identifies health-related built environmental factors in affordable housing neighborhoods and examines the built environment qualities and location patterns of subsidized housing by institutional contexts and regional contexts, two factors which influence the provision of affordable housing. I examined spatial patterns of two low-income housing programs: the Section 8 Housing Choice Voucher (HCV) and the Low Income Housing Tax Credit (LIHTC) programs. The HCV subsidizes voucher holders the difference between fair market rent and what they are able to pay towards rent at an affordability level of 30 percent of their income. Since the HCV focuses more on housing mobility and gives renters more choices in location, it is more effective in dispersion of subsidized households than traditional project-based public housing programs (Goetz, 2003). The HCV may not, however, result in de-concentration of poverty if residents of segregated low-income areas use their subsidies to move to similar areas (Basolo and Nguyen, 2005).

Unlike subsidizing renters, LIHTC focuses on the supply side of housing provision through tax credits supporting proposed developments selected by state governments. Winners of LIHTC support develop housing projects with affordable component through either new construction or rehabilitation (McClure, 2000). LIHTC provides more flexibility and state governments consider built environment quality with a variety of market and housing needs (McClure, 2000) and have recently begun to consider neighborhood amenities in the selection process, including transit access, in the application process (Lockyer et al., 2012). The development and location of LIHTC units, however, may be more sensitive to the availability of land for new development or capital cost for rehabilitation than the HCV. Furthermore, they may be more likely to be located on a large land parcels that could prohibit pedestrian- or transit- friendly development. Few available studies has compared the spatial implications of the HCV and the LIHTC programs, and one of the studies found that HCV units are more likely to be located in high-traffic areas (Houston et al., 2012). This study, however, focused on Orange County, California, a largely suburban area. The state government has encouraged affordable housing developments to be built in high-opportunity areas with more non-residential or mixed land use and more amenities in supply-side through policies such as density bonuses and LIHTC support. Thus, I hypothesize that LIHTC housing units, are located in areas with more mixed-use patterns, more amenities, and more exposure to traffic exposure than HCV units.

In addition to program types, the distribution of subsidized units could vary by regional contexts. This chapter analyzes the difference in the built environment qualities of subsidized housing neighborhoods between Los Angeles County (LAC) and Orange County (OC). The two counties have different contexts in terms of development history, built environment, and socioeconomic background. LAC can be characterized as older, denser, more socially disadvantaged, having a higher level of accessibility to amenities, and having a higher chance of traffic exposure compared to OC. In terms of built environment density, areas with a denser built environment could have more mixed land use types and non-residential activity spaces. Subsidized housing units located in denser areas could expose residents to walkable and transit-friendly built environment. I hypothesize that because of the characteristics of LAC, subsidized housing in the county is located in more walkable and transit-oriented areas with higher exposure to traffic than OC. Regarding opportunities to provide more subsidized housing, dense and already built-up areas could be more inflexible for providing subsidized housing units. In addition, if neighborhood segregation increases, the chance of providing subsidized housing units in diverse neighborhoods would be lower. Despite the fact that subsidized housing units outnumber those in OC, it could be less likely that subsidized housing units would be located in an average neighborhood in LAC than OC, and that the locations of affordable housing in LA could be more clustered than OC.

In addition to potential county level differences, built environmental qualities and location patterns of federally subsidized housing could vary across municipalities. Besides the provision of subsidized housing through local Federal Housing Authorities (FHAs), which is in charge of the HCV and public housing, some cities governments make an effort to provide affordable housing options to low-income households in several ways, including density bonuses and zoning regulations, such as inclusionary zoning (IZ). The analysis assumes that the existence of non-federal programs of affordable housing provision could affect built environmental qualities and location patterns of federally subsidized housing units.

This chapter examines the location patterns of two different types of subsidized housing programs, including the Section 8 Housing Choice Voucher (HCV) and the Low Income Housing Tax Credit (LIHTC) in two major counties in Southern California. It examines differences in the built environment quality of neighborhood across types of housing programs (tenant-based and project-based) and regions, and factors associated with the probability that a neighborhood has subsidized housing projects/units.

2. Background: Subsidized Housing Programs and Neighborhood Conditions

2.1 Subsidized Housing Programs for Low- and Moderate-Income Renters

The approach of federal housing programs for providing subsidized housing for the poor has shifted substantially since the 1970's from the development of large-scale public housing projects which concentrated poverty, to the goal of de-concentrating poverty by geographically dispersing subsidized housing units and transforming the projects into mixed-income developments (Schwartz, 2006; Von Hoffman, 2000).

The first approach seeks to alleviate the concentration of poverty by demolishing and redeveloping traditional housing projects into mixed-income, new urbanist communities. The Housing Opportunities for People Everywhere (HOPE VI) program is the major federal rehabilitation program related to affordable housing and is designed to rehabilitate physical conditions of public housing and nearby neighborhoods by demolishing existing public housing and reconstructing new housing allowing higher income people to live in the same neighborhood with low income households (Schwartz, 2006; U.S. Department of Housing and Urban Development, 2015a). Since the program allows some proportion of housing units for higher income households, some of the original residents in subsidized units must move out(Schwartz, 2006; U.S. Department of Housing and Urban Development, 2015a). The HOPE VI program gives these former low-income residents the opportunity to move into neighborhoods by providing housing vouchers(Schwartz, 2006; U.S. Department of Housing and Urban Development, 2015a). This program is a mix of a project- and tenant-based housing program. The program seeks to alleviate poverty and increase access to opportunities through mixed-income development(Johnson and Talen, 2008; Schwartz, 2006). It is designed to improve physical conditions of existing deteriorated public housing projects and to give more options to public housing residents to reside in mixed-income neighborhoods or to move to other places with more opportunities(Johnson and Talen, 2008; Schwartz, 2006).

However, the HOPE IV program has been criticized because a low percentage of former public housing residents return to the revitalized housing; most move elsewhere, using housing vouchers and many former residents move into other poor neighborhoods. For this reason, many scholars have criticized the HOPE VI program because it forces public housing residents to relocate to other impoverished areas (Goetz, 2010, 2003; Levy and Woolley, 2007; Schwartz, 2006).

Introduced in 1998, the Section 8 Housing Choice Voucher (HCV) program, the latest revision of housing voucher programs since the Housing and Community Development Act of 1974, is the main tenant-based affordable housing program. Under this approach, local housing authorities set a rent payment standard ranging from 90 to 110 percent of fair market rents (Schwartz, 2006; U.S. Department of Housing and Urban Development, 2015b; Von Hoffman, 2000). The HVC allows low income households to spend their money for rent with more than 30 percent of their monthly adjusted income but does not allow more than 40 percent(Schwartz, 2006; U.S. Department of Housing and Urban Development, 2015b). The HCV aims to prevent poverty concentration by helping low income households lease in neighborhoods with more opportunities for employment(Basolo and Nguyen, 2005; Schwartz, 2006; Von Hoffman, 2000). Tenant-based housing programs tend to focus on dispersing low income households from their high-poverty areas in order to alleviate poverty and prevent the concentration of poverty(Basolo and Nguyen, 2005; Schwartz, 2006; Von Hoffman, 2000).

The third approach to providing affordable housing is to incentivize housing developers to provide low-rent units in new residential buildings through tax credits. The Low Income Housing Tax Credit (LIHTC) is the leading incentive program, encouraging private-sector developers to invest in the development of affordable housing. The program started as a part of the Tax Reform Act of 1986(U.S. Department of Housing and Urban Development, 2014a). Instead of providing benefits in tax deductions, which are subtracted from a taxpayer's total income based on the person's tax base, the LIHTC provides more amounts of monetary benefits by tax credits, which are subtracted directly from the developer's tax liability and reduce tax liability dollar-for-dollar(U.S. Department of Housing and Urban Development, 2014b). The federal tax credits are allocated to qualified developers through local housing and development agencies. Eligible developers must provide at least 20 and 40 percent of units as affordable units for households with an income below 50 and 60 percent of median income, respectively (U.S. Department of Housing and Urban Development, 2014b). The LIHTC program requires developers to retain units for low-income households for at least 15 years(U.S. Department of Housing and Urban Development, 2014b).

2.2 Implications of Housing Program Design on Health and Well-Being

2.2.1 Overview

Research regarding the geographic implications of housing programs suggests there is some evidence that housing programs provide differential impacts on well-being and health. Available studies have focused on outcomes of programs with respect to housing conditions, neighborhood conditions, economic status, child development, and health status. Most studies focused on economic status. Researchers have investigated how effective housing programs are in improving residents' economic status, measured by employment status, earnings, welfare dependency, and the percentage of households under the federal poverty line. These studies compare the economic status of residents living in subsidized housing units to that of low-income residents not living in subsidized housing. Some studies have also compared economic outcomes by program type, including tenant-based versus project-based housing programs. In terms of economic status, many studies have shown that tenant-based housing programs have better economic outcomes, such as higher employment rates, higher earnings, less welfare recipients, and fewer households under the poverty line (Clampet-lundquist, 2004; Hanratty et al., 1998; Ong, 1998; Rosenbaum and Harris, 2001; Rosenbaum and DeLuca, 2000; Rosenbaum, 1998, 1995). However, some scholars have argued that there are less significant impacts of tenant-based programs in the short run compared to project-based programs(Buron et al., 2007; Fauth et al., 2004; Mendenhall et al., 2006).

Available research also considers the programmatic implications on neighborhood conditions near subsidized units. Due to the suburbanization of residences and employment centers since the 1960s, historic inner cities have lost vitality(Holzer and Reaser, 2000; Holzer, 1991; Jackson, 1985; Wilson, 1999, 1990). As a result, suburbanization has increased the concentration of poverty, crime, and decreased the quality of public services. Since most traditional public housing projects were built in inner cities before the mid-1970s, when suburbanization was not the prevalent pattern, most existing public housing sites are located in neighborhoods with low quality neighborhood conditions(Rohe and Burby, 1988; Von Hoffman, 2000). Affordable housing studies on neighborhood conditions have investigated whether tenant-based programs helped public housing residents move to “better” neighborhoods(Von Hoffman, 2000). Most studies on neighborhood conditions have shown that tenant-based housing programs were helpful in relocating public housing residents to neighborhoods with lower crime rates, lower social disorder, and lower poverty rates in the short-run(Buron et al., 2007; Clampet-lundquist, 2004; Comey, 2007; DeLuca et al., 2010; Devine et al., 2003; Freedman and Owens, 2011; John Goering et al., 2002; Hanratty et al., 1998; Katz et al., 2001; Keels et al., 2005; Popkin and Cove, 2007; Turner, 1998).

While affordable housing studies focus mostly on affordability, economic outcomes, and neighborhood conditions, few studies have examined the implications of housing policy on health outcomes or health risk factors. Although the number of the health studies in housing and urban development is growing, there are still few studies on health implications for affordable housing residents. Most available studies examining the health outcomes of affordable housing residents have focused on self-reported health status (Fauth et al., 2008, 2004; Katz et al., 2001), accessibility to health services (Peroffi et al., 1979; Rosenbaum and Popkin, 1990; Rosenbaum, 1995), mental health (Buron et al., 2007; Fauth et al., 2008, 2004; Katz et al., 2001), physical activity (Buron et al., 2007), and obesity. Nonetheless, such studies have limitations to providing insights on relationship between built environment quality and health outcomes. Few studies of subsidized housing have examined environmental quality around subsidized housing.

2.2.2 HOPE VI

Since the main goal of the HOPE VI is to improve the physical conditions of distressed public housing through demolition and redevelopment, subsidized housing residents in HOPE VI developments tend to move to housing units with better housing conditions after redevelopment, compared to before the program(Buron et al., 2007; Comey, 2007). Project residents who were displaced during the HOPE VI redevelopment program used vouchers to relocate residents to units within the wider rental housing market and had better housing conditions on average than those who remained in traditional public housing projects(Buron et al., 2007; Comey, 2007). Another important outcome of the HOPE VI is improved neighborhood conditions, including decreased crime rates, social disorder, and poverty rates(Popkin and Cove, 2007). The central goal of the HOPE VI was to improve residents' neighborhood conditions. The program was designed to revitalize distressed neighborhoods, or to help public housing residents move to safer and more affluent neighborhoods. Many studies have shown that HOPE VI households tend to live in places with lower crime rates, lower social disorder reports, and lower poverty rates after the program was implemented (Fauth et al., 2008; Popkin and Cove, 2007). Of the residents who relocated to other locations, households using vouchers were more likely to move into safer and more affluent communities compared to those moving to other public housing projects(Buron et al., 2007; Comey, 2007; Popkin and Cove, 2007).

Although housing studies have paid less attention to residents' health status in general, some HOPE VI studies assessed health outcomes. Buron et al. (2007) examined depression levels and physical activity levels among HOPE VI recipients. Although the study showed that there was no significant effect on mental and physical health, it found that the program had effects on reducing anxiety levels(Popkin et al., 2009).

Research suggests the economic status of residents using housing vouchers through the HOPE VI redevelopment program was higher than that of residents who relocated to other public housing. The voucher group tended to have more employed residents, fewer welfare recipients, and fewer households below the poverty line (Clampet-lundquist, 2004). However, these insights are based on comparing outcomes between housing voucher holders and public housing residents after relocation. If the short-run economic outcomes of residents impacted by the HOPE VI program are compared to general low income renter groups, it is hard to find significant effects of the program on economic status (Clampet-lundquist, 2004; Levy and Woolley, 2007; Popkin et al., 2009).

In terms of children's development status and access to educational services, HOPE VI households generally experience more positive outcomes in children's social behavior than other low income renters (Gallagher and Bajaj, 2007). Out of the HOPE VI households relocating to other neighborhoods, households using housing vouchers also showed more positive outcomes in children's social behavior compared to public housing renters (Gallagher and Bajaj, 2007).

2.2.3 Experimental Housing Mobility Programs by Local Governments (Gautreaux/Yonkers)

Studies of the outcomes of the Gautreaux program have focused on comparing outcomes of the program between suburban movers and inner city movers or between residents before and after the Gautreaux "treatment". In terms of neighborhood conditions, households with the Gautreaux program tended to be located in neighborhoods with lower crime rates and poverty rates (DeLuca et al., 2010; Keels et al., 2005). In addition to neighborhood conditions, most studies of the Gautreaux program have focused on the effects of the program on economic outcomes and educational outcomes. In the early studies, scholars argued that the households in the treatment group were more likely to be hired than households in the control group (Rosenbaum, 1998, 1995, 1993, 1991). Among the treatment group, suburban movers were more likely to be hired and earn higher wages than inner city movers (Popkin et al., 1993; Rosenbaum and DeLuca, 2000; Rosenbaum, 1998, 1995, 1993, 1991). However, recent studies showed there was no significant difference in employment and earning status between suburb and city movers (Mendenhall et al., 2006). In terms of children's educational performance, Rosenbaum (1991, 1993, 1995, and 1998) and Keels (2008) showed that more children in the suburban treatment group had high grades and low drop-off rates compared to city movers (Keels, 2008; Rosenbaum, 1995). However, in terms of children's social behavioral outcomes, there was no significant difference between the suburb and city mover groups (Rosenbaum, 1995), and Keels (2008) argued that the children of the city mover group had better social behavioral outcomes compared to suburb movers.

Since the Yonkers program was implemented more recently and the size of the program was smaller than the Gautreaux program, there are fewer studies examining its impact. According to Fauth et al. (2004, 2008) and Briggs (1998), the Yonkers program had positive effects on neighborhood conditions, including lower crime rates, less social disorder, and lower poverty rates (Briggs et al., 2007; Fauth et al., 2008, 2007). The program had less significant effects on economic status in the short run (Fauth et al., 2004). However, Fauth et al. (2008) showed that there were significant positive effects of the program on employment in the long run (Fauth et al., 2008). Compared to other housing mobility programs, the Yonkers program had the opposite effect on children's educational and behavioral outcomes. Fauth et al. (2007) showed that children in the program treatment group had a worse educational performance and social behavioral outcomes compared to the control group (Fauth et al., 2007).

2.2.4 The Experimental Housing Mobility Program by Federal Government (Moving To Opportunity)

Most studies of the outcomes of the Moving to Opportunity (MTO) program compared the MTO voucher households' outcomes to those of households participating in the Section 8 Housing Choice Voucher program. Generally, scholars showed that the MTO voucher households generally received more housing market information and were able to find housing in better conditions. These resources helped the MTO voucher holders find better housing than the HCV holders (Rosenbaum and Harris, 2001).

Several studies have shown that the MTO households had more chances to live in safer neighborhoods with less social disorder, and more residents with a higher economic status than the general low income renter group, public housing, and regular the HCV groups (J Goering et al., 2002; Hanratty et al., 1998; Katz et al., 2001; Ludwig et al., 2001; Rosenbaum and Harris, 2001). Katz et al. (2001) found a higher general health status and a lower anxiety level among residents in the MTO treatment group, compared to the general renter group and public housing group (Katz et al., 2001).

In terms of economic status, Hanaratty et al (1998) showed that the MTO program was associated with increase in residents' earnings, compared to the general low income renter group (Hanratty et al., 1998). In contrast, some scholars have argued that the MTO program does not have significant effects on employment status, compared to the general low income renter group (Katz et al., 2001; Rosenbaum and Harris, 2001).

2.2.5 Regular Housing Voucher Choice (HCV) Program

Research indicates that the standard housing voucher program generally has no significant effect on voucher holders' housing conditions (Varady and Walker, 2000). Most studies on the impact of the standard HCV program have focused on economic outcomes rather than neighborhood conditions. There are few studies on neighborhood conditions of standard voucher holders, and they are generally focused on neighborhood economic status and poverty. In terms of poverty, some research indicates that voucher holders live in areas with lower poverty than other groups, including the general low income rental population and public housing residents (Devine et al., 2003; Turner, 1998). Other available research suggests that the program did not move residents into areas with lower poverty (Basolo and Nguyen, 2005; Pendall, 2000).

The effects of the housing voucher program on residents' economic status are not clear. Devine et al. (2003) showed that voucher holders were more likely to be employed than public housing renters and the general low income rental population (Devine et al., 2003). Ong (1998) also showed that voucher holders tend to earn higher wages than other low income renters (Ong, 1998). In contrast, many studies found no significant effects of housing voucher programs on employment and earning status and welfare usage (Newman et al., 2009; Varady and Walker, 2000). Newman et al. (1994) showed that there were more residents using housing vouchers that were suffering from anxiety compared to the general low income rental population (Newman et al., 1994). In terms of nutritional status, Meyer et al. (2005) found that housing voucher holders had higher nutritional status than the general low income rental population (Meyers et al., 2005).

2.2.6 The Low Income Housing Tax Credit (LIHTC)

Studies indicate that housing conditions of units constructed with Low Income Housing Tax Credit (LIHTC) support tend to be better than other types of low income housing (Cummings and Dipasquale, 1999). In general, these LIHTC units tend to be located in neighborhoods with lower crime and poverty rates than rental housing units for low income renters and voucher holders (Lens et al., 2011; McClure, 2006; Newman and Schnare, 1997; Rohe and Freeman, 2001; Williamson et al., 2009). Deng (2007) measured neighborhood educational outcomes of residents of LIHTC-supported units in the four metropolitan areas and found that in the Atlanta and Miami metropolitan areas the LIHTC projects on averaged tended to be located in areas with higher-ranked schools, than housing voucher units, but that housing voucher units in New York and Boston were located in areas with higher-ranked schools compared to LIHTC-supported units. Available studies do not provide insight into the implications of the LIHTC program on economic status and health outcomes (Deng, 2007).

2.3 Implications of Housing Program Design on Walkability, Transportation Access, Air Quality, and Traffic Exposure

Although available research of subsidized housing programs provides some insights into the economic, health, and family well-being, few studies have considered the implications of program design on neighborhood walkability, transportation access, and traffic exposure near subsidized units. My publication with Dr. Houston and Dr. Basolo provides some available insights into the geographic implications of affordable housing programs in Orange County, California in relation to these amenities and hazards (Houston et al., 2012). We found some evidence that housing program design influenced the geographic location of units, and that voucher units were more likely than tax credit projects to be located in high-traffic areas. Interestingly, subsidized units in walkable, poorer areas were associated with lower traffic exposure, and higher traffic exposure was associated with more transit service and mixed-use areas.

This chapter replicates and extends this previous research by examining location patterns of subsidized units in Los Angeles County (LAC) which has historically experienced more entrenched residential segregation and economic inequality. Similar to the Orange County (OC) study, this chapter considers the implications of voucher and tax credit programs. It compares the geographic implications of units provided through place-based approaches (tax credits) to those of non-place-based approaches (vouchers).

2.4 Smart Growth and Its Implication to Health Impact/Health Risk

With increased concerns over environmental quality, energy preservation, and healthy living, smart growth strategies have been adopted and applied to development projects in order to lower auto-dependency through high-density, and to promote mixed-use development. Smart growth principles could provide health benefits in that they may be associated with auto-independent lifestyles, which include more active transportation, such as walking and cycling. Some studies provide evidence of positive impacts of mixed-use, infill development on physical activity levels (Ewing et al., 2003; Frank et al., 2005; Handy et al., 2002).

In California, where greenhouse gas (GHG) emissions and other transportation-related air pollutants are a major policy concern, the state government has ambitiously adopted smart growth strategies to help reduce vehicle travel and associated GHG emissions through Senate Bill 375 (SB 375). Although smart growth development concepts could discourage vehicle travel and promote more physical activities, concerns have been raised about whether dense, mixed-use development will result in higher population exposure to vehicle-related air pollution from major roadways. In metropolitan areas like Los Angeles, where developable land is scarce, near-roadway areas may be targeted for new housing development. In addition, mixed-use developments are often placed near major transportation corridors and near major freeways, a pattern which could result in more air pollution exposure.

3. Research Objectives, Methodology, and Data

3.1 Research Objectives

Objective 1. To characterize locational patterns of neighborhood amenities and hazards by housing program type

The objective of the research is to characterize, examine, and compare spatial characteristics of amenities and hazards in neighborhoods in which affordable housing units are located and to examine differences in the distribution of units supported by (1) a place-based housing program (LIHTC) and (2) a non-place-based housing program (HCV). In order to characterize the amenities and hazards, the analysis includes descriptive analysis of walkability, transportation access, proximity to job opportunities, and traffic exposure around subsidized housing units.

Compared to tenant-based HCV housing programs, place-based affordable housing programs, such as the LIHTC and the rehabilitation of old public housing by the HOPE VI program, have flexibility in siting. Although HCV was designed to encourage low income households to relocate from poverty-concentrated areas to neighborhoods with better living conditions, many housing mobility studies have shown that housing voucher programs have had little impact on the dispersion of poverty concentration because of social networks, discrimination and segregation, and difficulties of using vouchers in other jurisdictions managed by different housing agencies (Varady and Walker, 2000). Our previous study on affordable housing siting near roadways for Orange County, California showed that HCV units are more likely to be located near traffic (Houston et al., 2012).

Objective 2. To characterize locational patterns of neighborhood amenities and hazards by region

I hypothesize that the spatial pattern by housing program types in Los Angeles County is different from Orange County due to different built environmental settings and regulations. Compared to Orange County, lands in Los Angeles County are largely already developed making it harder to find suitable land for new housing projects. As a result, there are more opportunities to reuse existing, urbanized areas for housing development. Subsidized affordable housing developments in Los Angeles County may be more likely to be located within inner cities in which more freeways and major arterials are located. Thus, I hypothesize that project-based housing is more likely to be located near roadways in Los Angeles County.

Objective 3. To examine how the built environmental characteristics of a neighborhood are related to the likelihood of affordable housing being in the neighborhood

Built environmental settings are important factors that affect affordable housing development. For place-based affordable housing units, some municipalities whose areas were already urbanized, like Los Angeles, suffer from the difficulties in finding feasible, developable land. In this context, higher-density development could be an alternative, but may not be preferred by residents. As a result, local governments may identify lower-density developable lands for affordable housing projects in areas with hazards, such as near freeways or high traffic corridors. Thus, I hypothesize that density and land use types are related to housing siting near roadways. In addition to density and land use types around the affordable housing sites, transportation-related resources, such as transit stops and the connectivity of streets, are also important factors in the housing siting process, especially tenant-based housing residents. These factors may affect voucher holders' residential location decision making.

Land use composition in a neighborhood might also affect the probability of the neighborhood having affordable housing units. Since the smart growth concept in housing development stresses lower automobile reliance for accessing jobs and amenities, mixed-use development can be an important objective. Moreover, housing developments close to existing amenities, such as commercial centers, business strips, and so forth, could help reduce car usage and encourage active transportation and physical activity. Mixed-use development may increase the risk of exposure to traffic-related air pollution. Regarding zoning regulations, sensitive types of development, such as mixed-use residential or multi-family residential uses, may be more likely to be designated in parcels near major roadways. Commercial use parcels may also be close to major streets, in order to help increase connectivity of commodities to people. Affordable housing in neighborhoods with a high proportion of mixed and commercial land use could also be located near major streets.

<u>Objective 4</u>. To assess how neighborhood demographic and socioeconomic characteristics relate to the location of subsidized housing and the built and social environment quality

The final objective of this chapter is to observe how neighborhood conditions are associated with the location of affordable housing. Environmental justice (EJ) research has shown that environmental risk tends to be spatially correlated with lower socioeconomic communities(Bevc et al., 2007; Evans and Marcynyszyn, 2004; Gilbert and Chakraborty, 2011). EJ studies also provide evidence that the location of freeways and heavy traffic roadways are close to low-income, minority neighborhoods within inner cities (Bae et al., 2007; Forkenbrock and Schweitzer, 1999; Houston et al., 2004). Historically, affordable housing units have been concentrated in socially disadvantaged neighborhoods, although the federal government has sought to decrease poverty concentration around public housing and other affordable housing projects. I hypothesize that affordable housing located in neighborhoods with low socioeconomic status has a greater chance of being located near major roadways. Few studies have focused on the relationship between the built environmental qualities and the socioeconomic status (SES) of neighborhoods in which affordable units are located.

3.2 Methodologies and Data

I examined the geographic location of subsidized housing in relation to (1) accessibility to built environment amenities, (2) exposure to built environment hazards, and (3) neighborhood demographic and socioeconomic characteristics. I compared the spatial patterns of the affordable housing units by program type, including project-based and tenant-based programs, and by region, including Los Angeles County (LAC) and Orange Counties (OC) in California.

The Section 8 Housing Choice Voucher data used in this study were obtained from the U.S. Department of Housing and Urban Development (HUD). The data included the number of households receiving the HCV in 2007, 2008, and 2009 aggregated at the 2010 census block group (BG) level. There were 81,646 households receiving HCV support in Los Angeles County in 2009, and 1,698 out of 6,353 block groups did not have a HCV household. There were 21,438 households receiving HCV support in Orange County in 2009, and 606 out of 1,826 BGs did not have a HCV household. I obtained data on the location of LIHTC-supported developments in Los Angeles and Orange Counties from HUD. The data include information of the location for 46,638 and 13,124 affordable units in 693 and 123 projects in LAC and OC, respectively. These units have been "placed-in-service" since 1987. I geocoded the location of the affordable units using ArcGIS 10.1 (ESRI, Redlands, CA) and used Google Maps to identify the location of units not geocoded in ArcGIS. I aggregated the location information of LIHTC units into the 2010 Census Block Groups to enable consistency with the HVC block group data. In the aggregated level, 468 out of 6,352 block groups in LAC and 102 out of 1,852 block groups in OC included at least one LIHTC-supported project. The number of HVC units and LIHTC projects were aggregated at the 2012 Census block group level.

I conducted descriptive analysis to understand general spatial patterns of subsidized housing units with respect to built environment amenities, hazards, and socioeconomic factors. In the descriptive analysis, I compared average environmental qualities between subsidized units provided through the two programs (LIHTC vs. HCV) and between LAC and OC, using t-test analysis to examine whether differences are statistically significant. The unit of analysis was census 2010 block group for the built environmental measures and 2010 census tract for the demographic and socioeconomic measures based on the 2005-20009 American Community Survey. The demographic and socioeconomic factors used in the analysis include percentages of White, Black, Non-Hispanic White, Hispanic, foreign-born residents, renters and poverty rates, average annual household income, and unemployment rates.

In addition to the demographic and socioeconomic factors, I characterized the built environment amenities in subsidized housing neighborhoods. Walkability, street connectivity, block size, availability of public transportation resources, land use composition, and firms as economic activity destinations were considered indicators of the built environment amenities. I characterized neighborhood walkability and street connectivity by estimating the density of street intersections with at least 4 roadway directions (Houston et al., 2012). Block size has been used as an indicator of walkability in the literature, and smaller block size has been found to promote positive health-behaviors, including walking and bicycling (Lee and Moudon, 2006; Moudon et al., 1997). I used a 2010 TIGER street line layer file obtained from the US Census Bureau to estimate block size. I converted enclosed areas by the street polylines into polygons using ArcGIS 10.1 then calculated average block size for each BG.

The availability of public transportation resources in a block group was estimated based on the percentage of coverage of areas accessible to transit stops (within 1/4 mile each block group). I estimated BG land use composition to understand how accessible housing locations were to commercial uses and employment opportunities. Existing land use information for 2008 was obtained from the Southern California Association of Government (SCAG). I measured areas of each land-use category in each block group and its ratio to the total areas of the block group. In terms of economic activities, I calculated the number of employees and the number of firms per acre in each BG based on 2011 InfoUSA data.

With respect to the built environmental hazards, I considered how much neighborhoods with affordable housing units were impacted by traffic and traffic-related air pollution, including nitrogen dioxide (NO_2). In order to measure exposure to high traffic, I estimated the percentage of BG area within 200 meters from high-medium traffic roadways (Houston et al., 2012) based on the 2005 Highway Performance and Monitoring System data obtained from the California Department of Transportation. Roadways with over 25,000 annual average daily traffic (AADT) were classified high-medium traffic roadways. I used a 200-meter distance as a criterion of exposure to air pollution, because it has been shown that vehicle-related air pollutants approximately reduce to background levels within the distance of a roadway(Houston et al., 2012).

Passenger and heavy duty vehicles are a major source of NO_2(Gehring et al., 2002; U.S. Environmental Protection Agency, 2012). NO_2 exposure has been associated with negative health outcomes, including respiratory diseases and malfunctions (Gehring et al., 2002; U.S. Environmental Protection Agency, 2012; Zemp et al., 1999; Zmirou et al., 2004). These data were obtained from Dr. Julian Marshall's research group website of the Department of Civil Engineering at the University of Minnesota(Marshall, n.d.). They estimated NO_2 concentration using land use regression analysis, which employed ground and satellite-based NO_2 measurement, land use type, and distance to major roadways (Novotny et al., 2011). These data contain estimated NO_2 concentration in parts per billion (ppb) at the census block level, which I average to the BG level. Since each BG contains several census blocks in which NO_2 level were estimated, I weighed the size of census blocks in the calculation of average NO_2 levels at the BG level.

In the descriptive analysis, I compared social and built environmental characteristics of BGs with subsidized housing by program type, including the HCV and the LIHTC, as well as by county. The following comparisons in built and social environment were conducted: 1) All BGs in the study area versus BGs with at least one subsidized housing units, 2) BGs with all subsidized housing units in LAC versus BGs with all subsidized housing units in OC, and 3) BGs with HCV units in the study area versus BGs with LIHTC units in the study area. T-test analysis was used for the comparisons of environmental qualities to assess whether difference in the mean values for the categories were statistically significant. In addition, I used logistic regression analysis to examine the associations of BG characteristics with the likelihood that a census block group would contain subsidized housing units. Logistic models were specified to examine the probability that any BG in the two county study areas had at least one subsidized unit, the probability that a BG had at least one voucher unit, and the probability that a BG had at least one LIHTC-supported unit. These models were also specified for each county separately.

4. Findings

4.1 Built Environmental Qualities in Subsidized Housing Neighborhoods

Subsidized housing units were distributed in areas with better access to public transportation, more commercial land use, and more walkable environments than the entire two-county study area as a whole (Table 3.1). Eighty-five percent of land in a subsidized housing BGs was accessible to transit stops in walking distance, which was significantly (6.5 percent points higher) than the study area average (78.5 percent). For land use composition, the average percentage of land designated as commercial use in subsidized housing BGs was 9.8%, which was higher than the average percentage of the entire study area (8.9%), and the difference was statistically significant. The average block size of a subsidized BG was 9.2 acres which was about one-third of the average block size of the entire study area, which implies that subsidized housing units were located in more walkable areas. Despite the better accessibility to non-residential amenities and a more pedestrian- and public-transit-friendly environment, subsidized housing units were located in areas with higher traffic and air pollution than the entire study area. For traffic exposure, the average percentage of BG area impacted by high/medium-traffic corridors for the entire study area was 38.7, while that of subsidized housing BGs was 42.3. In terms of air quality, the average NO_2 concentration in a subsidized housing BG was higher than the entire study area average (24.7 ng/$m_3$versus 23.7 ng/m_3).

In terms of demographic and socioeconomic characteristics, location patterns of subsidized housing units are consistent with the previous studies, which show that affordable housing units tend to be located in areas with more racial/ethnic minorities and lower economic status (Table 3.1). In terms of racial composition, the average percentage of White and Black population in a subsidized housing TR was 50.2 and 9.1, respectively, whereas the averages for the entire study area were 55.0 and 7.5. In addition, the average percentage of non-Hispanic White (27.1) and Hispanic residents (49.4) in a subsidized housing TR were lower and higher than they were for the entire study area (35.2 and 42.0, respectively). For neighborhood economic status, the poverty rate in subsidized housing TRs was 15.8 percent, which was higher than the average of the entire study area (13.6%). The average unemployment rate of subsidized housing TRs was 8.1 percent, which was higher than that of the entire study area (7.5%). The average annual household income in a subsidized housing TR was $24,337, which was lower than the average for the entire study area ($30,190).

Comparing at city level, there was no significant difference in the built and social environments between cities with subsidized housing units and the entire cities in the study area (Table 3.2).

4.2 Environmental Qualities of Subsidized Housing Neighborhoods by Program Types (HCV vs LIHTC)

HCV units were located in more walkable (smaller block size) and public-transit friendly areas compared to LIHTC units (Table 3.1). In addition, HCV units were located in areas with less environmental hazards than LIHTC. Ninety percent of the area in an average BG with HCV units was accessible to transit stops within walking distance, which was higher than that for LIHTC units (87.5 percent). The average block size of a HCV BG was 7.2 acres, which was about one-third of that of LIHTC units (22 acres). The average percentage of area impacted by high/medium-traffic in a HCV BG was 47, whereas this percentage was 51 for LIHTC BGs. Regarding air quality, the average NO_2 concentration in a HCV BG was 25.1 parts per billion (ppb) which was lower than the average for LIHTC BGs (25.6 ppb). Despite better nearby physical environmental qualities, which would promote positive physical health outcomes, areas with the HCV had less non-residential activities. In terms of land use, HCV BGs had a lower percentage of land designated as commercial, public, industrial, and open space than LIHTC BGs. In addition, HCV BGs had a lower number of employees per acre compared to LIHTC BGs.

Consistent with conventional housing studies, I found that HCV units were located in areas with higher SES than the LIHTC supply-side housing program. HCV BGs had a lower percentage of Black and Hispanic populations and higher economic status, including lower poverty rates, higher average income, and lower unemployment rates than LIHTC BGs.

Unlike the comparison between the HCV and the LIHTC at BG level, I could not find any difference in the built and social environments between cities with HCV units and cities with LIHTC units (Table 3.2).

4.3 Environmental Qualities of Subsidized Housing Neighborhoods by Region (LAC vs. OC)

There were significant differences in built environment quality and SES between subsidized units in LAC and OC. In general, subsidized units in LAC were located in areas with higher accessibility to public transportation and more walkable environments (intersection density), but higher exposure to traffic, lower non-residential land uses, and worse air quality than BGs with subsidized units in OC. The average percentage of areas accessible to transit stops in BGs with subsidized units in LAC was 92.1, which was 14.7 percent points higher than the average for BGs with subsidized units in OC. Regarding walkability measures, the average number of intersections per 10 acres in subsidized housing BGs in LAC was 5, slightly but significantly higher than subsidized housing BGs in OC (4 intersections per 10 acres). The average block size in subsidized housing BGs in LAC was 9.9 acres, which was smaller than that of subsidized housing BGs in OC (22.7 acres). The average employment density of subsidized housing BGs in LAC was higher than OC (11.1 vs. 6.1 employees per acre). In spite of the better quality of the built environment for pedestrians and public transit riders, subsidized housing BGs in LAC had worse environmental quality as measured by traffic and air pollution. The average percentage of areas impacted by high/medium-traffic corridors in subsidized housing BGs in LAC was 50, whereas that in subsidized housing BGs in OC was 42.8. The average NO_2 concentration in subsidized housing BGs in LAC was 26.1, whereas that in subsidized housing BGs in OC was 22.2.

With regards to the social environment, subsidized housing BGs in LAC were located in more disadvantaged areas than subsidized housing BGs in OC. The average percentage of white residents in subsidized housing BGs in LAC was lower than subsidized housing BGs in OC. The average percentage of black residents of subsidized housing BGs in LAC was higher than that of subsidized housing BGs in OC. An average subsidized BG in LAC had a higher average percentage of Hispanic residents than subsidized housing BGs in OC. The average poverty rates in TRs with subsidized units in LAC was24.7 percent which was lower than that for subsidized housing BGs in OC (13.5 percent). The average annual household income in a TR with subsidized units in LAC was $18,944, lower than that of subsidized units in OC ($24,695).

In the descriptive analysis at city level, there were significant differences in the several built and social environments (Table 3.2). Similar to the BG level analysis, I found that subsidized housing cities in OC had higher percentages of commercial and public land uses than those in LAC (11.3% vs. 8.3% for commercial land use; 6.8% vs. 5.2% for public land use). In terms of walkability, subsidized housing cities in OC had a larger average block size (lower walkability) than those in LAC (14.1 acres vs. 8.2 acres). Unlike the analysis at BG level, I found that subsidized housing cities in OC had a higher intersection density than those in LAC (0.3 vs. 0.2 intersections per acre).

In terms of racial composition, subsidized housing cities in OC had a higher percentage of White residents and a lower percentage of Black residents than those in LAC (56.1% vs. 49.7% for White; 2.0% vs. 10.7% for Black residents). Regarding ethnicity, subsidized housing cities in OC had a higher percentage of Non-Hispanic White residents than those in LA (36.6% vs. 28.3%).

4.4 Likelihood of a BG or City Having Subsidized Units

Logistic regression modeling was used to assess the likelihood of the BG having federally subsidized units (Table 3.3, Model 1). In the logistic regression analysis, not all variables used in the descriptive analysis were included. Variables that were strongly correlated to others were excluded from the analysis. For air quality measure, average NO_2 concentration was used instead of the traffic variable. Coverage of areas accessible to transit stop in a BG was included as a public transit access measure. In terms of land use, I included mixed-land use measure to find the effect of non-residential activity. For a walkability measure, I chose average block size over number of intersections. Percentage of Black residents, Non-Hispanic White, and poverty rates in a BG were used to assess the effects of demographic and socioeconomic status.

While controlling for other factors, the percentage of areas accessible to transit stops in a BG was positively associated with the probability that a BG would have a subsidized housing unit (Table 3.3, Model 1). Subsidized housing units were more likely to be located in mixed land use. Regarding neighborhood walkability, the average block size in a BG was positively associated with the probability of BG having a subsidized housing unit. The probability of a BG having a subsidized unit was negatively associated with NO_2 concentration. The percentage of Black residents was positively associated with the likelihood of a BG having subsidized units, while the percentage of non-Hispanic Whites in a BG was negatively related to the probability of a BG having subsidized units. In addition, existence of subsidized housing in a BG was positively related to poverty rates in the area. Model 1 confirmed that subsidized housing units were more likely to be located in areas with more diverse land use types that provide more services and encourage health-related behaviors, but also units were more likely to be located in poor and low-income neighborhoods.

Regarding the city level method, only the walkability factor as a built environment factor was statistically associated with the probability of a city in the entire study area to have a subsidized unit (Table 3.4, Model 1). I found that the average block size in a city was negatively associated with the probability that a city had a subsidized unit.

In terms of demographic and socioeconomic status, a higher percentage of Black residents and higher poverty rates in a city were associated with a higher probability of the city to have a subsidized unit.

4.5 Likelihood of a BG or City Having Subsidized Housing by Program Types

Similar to the location patterns of all subsidized housing units shown in Model 1, the likelihood of a BG having a HCV unit was associated with better built environmental factors (Table 3.3, Model 2 and 3). An increase in the percentage of BG area accessible to transit stops was associated with an increased probability that a BG would have a HCV unit. Mixed use land use was positively related to the presence of a HCV unit. The average block size in a BG was positively associated with the likelihood of having a HCV unit. In terms of air quality, lower NO_2 concentrations were associated with a higher probability that a BG would have a HCV unit. Regarding racial/ethnic composition of a neighborhood, the probability of presence of a HCV unit was associated with a higher percentage of Black population and lower percentage of non-Hispanic White population in a BG. There was no significant relationship between poverty rates and the presence of a HCV unit. This implies that location patterns of a HCV unit are driven by neighborhood poverty, which is different from traditional public housing projects which tend to concentrated in poor areas.

Similar to HCV units, the likelihood of presence of a LIHTC unit in a BG was associated with a higher public transit access, higher percentage of mixed land use, larger block size (lower walkability), and lower NO_2 concentration. The location pattern of the LIHTC was also related to a higher percentage of racial minorities and higher poverty rates.

In term of city level analysis, most factors, except for poverty rates, were not associated with the probability of a city to have a subsidized unit (Table 3.4, Models 2 and 3). For HCV units, an increase in average NO_2 concentration in a city in the entire study area was associated with the likelihood of the city having a subsidized unit. The probability of a city to have an HCV unit was also positively associated with a higher percentage of Black residents in the city. An increase in poverty rates in a city was commonly associated with a likelihood of the city having HCV units and LIHTC projects (Model 2 and Model 3).

4.6 Likelihood by Counties

I examined differences in environmental qualities of neighborhoods of HCV and LIHTC units for the two study area counties, LAC and OC. Models 4 and 5 (Table 3.3) represent results of logistic analysis of the probability that a BG will have a HCV unit in LA and OC, respectively. These models show some similarities to the results in Model 1. The possibility of a BG having a HCV unit was associated with higher percentage of areas accessible to transit stops and a higher percentage of mixed land use for both LAC and OC. In terms of air quality, I found a difference in location pattern between two programs. HCV units in LAC and a lower possibility of being located in a BG with higher NO_2, while this probability in OC was positively associated with NO_2 concentration. HCV units both in LAC and OC were more likely to be located in a BG with a lower percentage of non-Hispanic Whites. A higher percentage of Black population was significantly associated with a higher possibility of having a HCV unit in the LAC model, while it is not related to that in OC.

Regarding built and social environments in BGs with LIHTC units by the two counties, the LIHTC models for LAC and OC (Model 6 and 7) also have somewhat similar results to the LIHTC model for the study area (Model 3). In LAC, higher public transit access in a BG is associated with higher possibility of existence of LIHTC units in the BG, whereas the public access was not associated with existence of LIHTC units in OC. In both counties, the possibility of existence of LIHTC units was related to mixed use land. In terms of walkability, larger block size in a BG is associated with existence of LIHTC units in LAC and OC, which implies that LIHTC units tend to be located in less walkable areas in the two counties. In terms of air quality, LIHTC units in LAC tend to be located in BGs with lower NO_2 concentration, whereas those in OC tend to be located in worse air quality. In terms of demographic and socioeconomic status, the LIHTC models for both LAC and OC indicated that larger Black population and a higher poverty rates were associated with a higher likelihood that a BG contained LIHTC units.

The logistic regression models for LIHTC units in LAC and OC did not provide significant relationship between the probability of a city to have an LIHITC unit and built and social environmental factors (Models 6 and 7, Table 3.4).

5. Summary, Discussion, and Future Research

I examined the qualities of physical and social environment of neighborhoods of federally subsidized housing for low- and moderate-income households in the Southern California Area, including Los Angeles County (LAC) and Orange County (OC). Despite concerns raised regarding the health effects of built environments in urban spaces and consideration of environmental health in urban design, housing development, and transportation planning, the environmental quality of subsidized housing for low-income households has not been previously sufficiently studied. Although affordable housing programs mainly aim to improve neighborhood conditions that are somehow associated with residents' health outcomes, their goals are to focus more socioeconomic conditions of neighborhoods with subsidized housing. In addition to socioeconomic environments which are more concerned in affordable housing studies, my dissertation research considers walkability, accessibility to urban amenities and exposure to urban hazards as health-related factors. I measured intersection density, average block size, land use composition, and areas impacted by higher/medium-traffic in a census block group where subsidized housing units are located, and then I compared the measurements to the study area and by program types and counties. In addition, this study examines the health-related built environment qualities of the federally subsidized housing neighborhoods by 1) housing program types and 2) regions.

With respect to program types, differences in built environmental qualities between place-based subsidized housing and tenant-based subsidized housing neighborhoods were characterized. The Section 8 Housing Choice Voucher (HCV) and the Low Income Housing Tax Credit (LIHTC) units were used in analysis to examine the difference by program types. In terms of regions, built environmental characteristics of subsidized housing units would vary across regions with different physical and institutional contexts. This study also examines difference in built environmental qualities of subsidized housing neighborhoods by LAC and OC have different development history, physical settings and regulations.

Regardless of program types, neighborhoods with federally subsidized housing units have better transit access, more mixed land use, and better walkability than the study area as a whole, whereas these neighborhoods have higher traffic and traffic-related air pollution exposure (Table 3.1). This indicates that residents of subsidize housing possibly have alternative transportation options promoting physical activities and accessibility to amenities. However, the results also imply that location of subsidized housing units shows contradiction between transit and non-motorized transportation-friendly environments and exposure to transportation-related urban hazards, such as traffic-related accidents and air pollution exposure. Despite an increase in share of public transportation, most people in the Greater Los Angeles area still rely on private cars for commuting to inner cities where subsidized housing units are located. However, locational patterns in logistic regression analysis showed different the general location patterns in the descriptive analysis. Regarding estimated possibility for a neighborhood to have subsidized units, subsidized housing units are more likely to be located in areas with lower NO_2 concentration, bigger average land block size, better transit access, and more mixed land use composition (Table 3.3, Model 1). However, affordable housing units tend to be located in lower employment density and lower SES areas. Unlike the descriptive analysis in Table 3.1, possibility to have subsidized units is associated with better air quality and lower walkability, while considering all possible factors. Since new affordable housing development projects need more land consumption and developable land tend to be available outskirt of old towns, the possibility of a BG to have a subsidized unit are associated with bigger land block size and lower NO_2 concentration. Scarcity in developable lands for affordable housing projects within old towns would push housing demands outward, and this might cause the positive association of possibility to have subsidized units in a BG with block size.

In comparison in built environmental qualities between BGs with the HCV and the LIHTC, LIHTC units were located in BGs with more employment opportunities and non-residential activity locations than HCV units from the descriptive analysis. The average employed population density of LIHTC neighborhoods were as about twice as HCV neighborhoods. LIHTC neighborhoods showed a lower average percentage of residential land and a higher percentage of non-residential land than HCV neighborhoods (Table 3.1). Despite more non-residential activities, LIHTC neighborhoods exposure to more environmental hazards and have worse pedestrian environments than HCV neighborhoods. The average percentage of areas impacted by high- and medium-traffic and average NO_2 concentration in LIHTC neighborhood were highers than HCV neighborhoods. LIHTC neighborhoods were less served by public transit, and land bock size of them are larger than HCV neighborhoods (Table 3.1). Higher accessibility to non-residential amenities but lower walkability and higher exposure to traffic and traffic-related air pollution in LIHTC neighborhoods than the HCV could be explained by several things. Project-based affordable housing developments tend to require land consumption in larger scale than tenant-based housing programs. Since major cities in Southern California are so built up that it is harder to find developable land for provision of affordable housing than outskirt of inner cities. In contrast, tenant-based housing programs subsidize difference in rents and allow individual households to choose their housing in wider rental market including inner cities. This might result in larger land block size in LIHTC neighborhoods. In addition, voucher holders have more rental options including more affluent areas with more residential land use and less traffic and traffic-related hazards. This might cause lower traffic, lower NO_2 concentration, and higher residential land use in HCV neighborhoods than the LIHTC.

In terms of possibility of a BG having subsidized units while considering all possible built and social environmental factors, I found little difference in location patterns between two program types, the HCV and LIHTC units. Regarding sign of coefficients of independent variables, the possibility of a BG having HCV or LIHC units are associated with lower air pollution, better public transit access, more mixed land use, and higher walkability in the BG (Table 3.3, Model 2 and Model 3). The results from the two models based on program types are also similar to those of Model 1 considering all subsidized housing units..

Regarding regions, built-environments of subsidized housing neighborhoods in LAC were more pedestrian- and public transit-friendly than OC, while subsidized housing neighborhoods in OC were safer and cleaner from traffic and traffic-related air pollution (Table 3.1). Street intersection density in LAC was higher than OC, and the average land block size of subsidized housing neighborhoods in LAC was about half of that of OC. Regarding transit access, the average percentage of areas accessible to transit stops in subsidized housing neighborhoods in LAC was higher than OC. More walkable and transit-friendly environments in the subsidized housing neighborhoods in LAC might result from unique physical settings in LAC from OC. In general, built-up areas in LAC have had longer history in urban development than OC, and the older areas tend to have smaller land development than recently developed areas. The longer history of urban development in LAC accompanied smaller size of land development patterns might reflect on the smaller size of block and higher street intersection density than OC. The average percentage of areas impacted by high/medium-traffic corridors in subsidized housing neighborhoods in LAC was higher than in OC. The average NO_2 concentration in subsidized housing neighborhood in LAC was also higher than OC. In addition to smaller land size, denser built-environment in LAC would contributes to a worse air quality and a higher traffic-exposure in subsidized housing neighborhoods than OC. In terms of land use composition, subsidized housing units in OC were located in BGs with a higher percentage of non-residential land use than LA. Because OC has more available land to develop multi-family housing than LAC with restricted options, subsidized housing might be located in land for multi-family housing with a higher possibility to have non-residential land use nearby than residential land for single family housing. Since LIHTC units are subsidized for new construction or rehabilitation, units subsided by the LIHTC tend to be located in a bigger size complex development. In the situation of lower availability of developable land inner city areas in metropolitan area, density bonus incentives would not be effective to encourage developers to provide subsidized units in areas with more job opportunities in which mostly are located in denser areas, such as downtown Los Angeles. In general, I found that possibility of a BG having LIHTC units is indistinguishable from HCV units. Since the HCV holders use their vouchers for housing subsidized by the LIHTC and I could not exclude HCV units duplicated with LIHTC units, I could not see clearer differences in location patterns between the two programs.

In terms of likelihood of a BG having subsidized housing units, I could not find meaningful difference between LAC and OC, except for air quality. While considering all built- and social-environmental factors, possibility of a BG having voucher units is associated with better public transit access and more mixed land use in both LAC and OC models (Table 3.3, model 4 and 5). Average NO_2 concentration was negatively associated with possibility of having voucher units in a BG in LAC but positively associated in OC. The similar patterns occur in models for LIHTC units (Table 3.3, model 6 and 7). Because, as discussed in the descriptive analysis (Table 3.1), subsidized housing units in OC were located in areas with more non-residential land use which cause more traffic and goods movement, subsidized housing units in OC tend to be located in areas with more air pollution than LAC. The location pattern of subsidized housing units in OC would show the smart growth paradox. This contradicts my initial assumption on the difference in traffic exposure level between two counties. Since LAC is denser and more goods movements are involved in the county, I assumed that subsidized housing in the area is also more exposed to high traffic. Another interesting finding is that the likelihood of a BG having subsidized housing units is positively associated with the fact that the BG is located in OC, not LAC, although LAC has more subsidized housing unit than OC. This might occur, because the proportion of subsidized housing BGs to the all BGs in LAC is lower than OC. This might imply that subsidized housing units in LAC are more concentrated in limited number of areas than OC and the segregation of subsidized housing BGs in LAC is worse.

Although this study provides insights into federally subsidized housing regarding health-related built environment in neighborhood, there are several limits to the study which need to be addressed in the future research. Some health-related built environment measures could be replaced with measures which indicate more direct health impact. For walkability measure, this study uses street intersections and size of land block. These two measures are now broadly employed in many studies as walkability measures and provide more insights related to urban development. Since walking patterns are more sensitively related to micro-environment, better walkability measures need to consider micro-level urban designs, such as existence of sidewalks, street furniture, vegetation, safety facilities, pedestrian paths, and so forth. For non-residential activity opportunity, only number of business establishment were counted and used for the measurement. This would be useful to understand opportunity sets in general, whereas it is difficult to understand difference in occupational and non-occupational activities. Even for non-occupational activity locations, it is difficult to account for people's actual level of accessibility to opportunities because individual people have different behavioral patterns and time allocation for their daily life. In the future research, it is necessary to understand individual residents' behavioral patterns. Another caveat is that this research couldn't consider the location of other major federal subsidized housing programs. HOPE VI and traditional public housing are still major avenues to provide affordable housing by federal government. Because of limitation to data obtaining, this dissertation research could not include the two program housing units. Including HOPE VI and public housing units could give more meaningful policy implication in the future research. HOPE VI data might enable to look at impact of mixed income housing development on built environmental qualities. For public housing units, it would be give clearer difference in built environmental qualities between project-based and tenant-based housing units.

CHAPTER 4. Particle-Bound Polycyclic Aromatic Hydrocarbon (pPAH) Concentrations in Transportation Microenvironments for Residents of a Major Goods Movement Corridor

Overview

This chapter characterizes the land use and infrastructure factors associated with the diurnal exposure to vehicle-related pollution of free-living subjects during everyday activity and travel. Previous studies have used location-specific assessment methods to characterize the potential magnitude of near-roadway pollution impacts and their environmental justice implications for populations, but fail to evaluate the impact of individual time activity on diurnal exposure. This essay examines the travel, activity and air pollution exposure patterns of 24 residents of the Boyle Heights neighborhood near downtown Los Angeles, and demonstrates techniques to measure and characterize exposure in microenvironments that people occupy over the course of the day. The analysis extends a previous publication (Houston et al., 2012), which characterized the exposure of urban residents to localized traffic-related air pollution across different locations and transportation microenvironments by examining the size of participants' LASs across key socio-demographic and household characteristics and by characterizing the magnitude of associated exposure to amenities/hazards. In the momentary analysis, I found that walking outdoors and travel in-vehicle was associated with higher exposure to pPAH compared to other in-transit periods and non-travel periods. Intersection density and distance to high traffic roadways were associated with lower exposure to pPAH. In terms of LAS-based analysis, I found intersection density within activity spaces was negatively associated with exposure to pPAH.

1 Introduction

Government officials, urban planners, grass roots groups, and public health experts have focused more attention over the last two decades on altering urban built environment into more pedestrian-friendly, open space, public transportation, and alternative non-motorized mode of transportation to promote physical activity and positive health outcomes (Steg and Gifford, 2005). However, such health promotional activities could potentially expose urban residents to air pollution (Marshall et al., 2009). Outdoor air quality is still a major concern in the most metropolitan areas in the US, despite the dramatic deduction since the 1980s achieved through regulations and improvements in technologies using fossil energy efficiently (Bae, 2004). Transportation-related source makes up the significant portion of urban air pollutants, including nitrogen oxides (NOx), carbon oxide/dioxide (CO, CO2), ozone (O3), and particle matters (PM_{10}, $PM_{2.5}$) (Bae, 2004). Air pollutants cause negative health outcomes, including asthma, malfunction of lungs, pulmonary disease, allege, low birth weight, perinatal mortality (Morello-Frosch and Lopez, 2006). Although smart growth and related urban development concepts aim to promote physical activity in urban space by providing alternative modes of transportation and related infrastructure, such as bike path and pedestrian-friendly sidewalks, these improvement could cause more traffic related air pollution especially in big metropolitan areas where residents are still dependent on automobiles to commute from outskirts of cities to inner cities. Although potential contradictions exist between promoting smart growth in urban developments and the potential exposure to traffic-related pollution, few studies have assessed the built environment qualities, which are assumed to affect health-related behaviors or outcomes, with respect to exposure to air pollution.

This chapter provides a case study to characterize the exposure of residents in major goods movement corridors to air pollution and to assess the extent to which exposures are associated with nearby land use and built environment factors, and individual demographic and socioeconomic characteristics. The characterization of air pollution exposure is based on the physical and social environmental characteristics of an activity place where an individual person usually spends his/her time in daily life. Unlike conventional air pollution studies, which examine the relationship between air pollution exposure and people's activity spaces based on zonal analysis which raises concerns over ecological fallacies, this essay estimates environmental quality and its relation to individual exposure.

Two types of activity space measurements were used in this essay. The first method measured built environment qualities and momentary exposure to air pollution every 15 seconds. The second method measured environmental qualities and air pollution at a daily level. For the first method, I measured built environmental qualities in areas in walking distance from an individual's geographic location every 15 seconds. For the daily activity space, I estimated a directional distribution of an individual's geographic locations with 1-standardized deviation ellipse (SDE1) and activity space path (ASP). This study is one of the first case studies to characterize the exposure of urban residents to localized traffic-related air pollution across locations and transportation microenvironments for free-living subjects during everyday activities.

2 Literature on Air Pollution Exposure and Built Environment Qualities

2.1 Air Pollution Exposure Studies

Understanding air pollution exposure during travel is particularly important since vehicle-related pollution is highly concentrated on and along high-traffic roadway corridors and time spent in transportation microenvironments could represent a significant portion of overall daily air pollution exposure (Fruin et al., 2008; Hu et al., 2009; Kaur et al., 2007; Westerdahl et al., 2005; Wu et al., 2012; Zhu et al., 2002). Fruin et al. (2008) characterize concentrations of traffic-related air pollutants, including NOx, PM, UFP, and PAH sampled from an air pollution monitor installed in a zero-emission electrical vehicle running different environmental settings. They found that 33-45 percent of total exposure to UFP in Los Angeles was associated with the time people spend in vehicle (Fruin et al., 2008). In their literature review study of air pollution exposure in urban microenvironment by Kaur et al. (2007), Kaur et al. (2007) showed that traffic was a significant factor of the concentration of CO and UFP, and that the traffic factor explained 35% and 32% of a variability of concentrations, respectively (Kaur et al., 2007). In the same literature study, Zagury et al. (2000) showed that higher concentration of air pollution was associated with traffic volume (Zagury et al., 2000). Westeralhl et al. (2005) sampled air pollutants using air pollution monitors installed in electrical vehicles. They tested the relationship between the average concentration of UFP and PAH and microbuilt environments, and showed higher correlation between UFP and truck traffic density. Wu et al. (2012), Hu et al. (2009), and Zhu et al. (2002) provide evidence that concentration of air pollutants, such as black carbon (BC), CO, and UFP, are negatively correlated to the distance to the major highways and arterials. Concentrations of vehicle-related air pollution in indoor, in-vehicle, and outdoor microenvironments can vary substantially (Fruin et al., 2008, 2004; Hu et al., 2009; Kozawa et al., 2009; Zhu et al., 2005, 2002; Zuurbier et al., 2010), and linking time-location information with measured pollution concentrations and proximity provides a valuable tool for estimating personal exposure and identifying where exposure to vehicle-related air pollution occurs over the course of the day (Ott, 1985).

A growing number of studies has examined the concentration of vehicle-related air pollution in near-roadway and transportation microenvironments and its association with traffic, nearby land use, and built-environment qualities. With sampling campaigns, studies provide insights into vehicle-related pollution concentrations at traffic intersections, sidewalks, and transit stops/platforms. They identify microenvironmental factors associated with concentrations, including roadway configuration and traffic volume, near-roadway building placement and height, and sidewalk design (Adams et al., 2001; Boarnet et al., 2011; Hess et al., 2010; Kam et al., 2011; Kaur et al., 2007; Kinney et al., 2000; Lena et al., 2002). Adams et al. (2001) conducted the first study of exposure to $PM_{2.5}$ in a variety of transportation microenvironments, including bicycle, bus, personal car, and subway in London, the United Kingdom. Air pollution sampling campaigns were carried out on the three different fixed routes with different level of traffic density (low-, medium-, and high-traffic). Along the routes, the sampling campaigns were conducted by different transportation modes and microenvironments (bicycle, bus, personal car, and subway). Based on regression analysis, they found that traffic density was significantly associated with $PM_{2.5}$ exposure level, while mode of transportation was not a significant determinant of the exposure level (Adams et al., 2001). Boarnet et al. (2011) provide some insights on microenvironment factors in relation to $PM_{2.5}$ concentration. They monitored the PM concentration in “low-density, auto-oriented development, and dense urban areas with mid- and high-rise buildings” (Boarnet et al., 2011). The sampling campaign was conducted during morning, midday, and evening periods at fixed sites as well as during walking periods. The study sought to find an association of the PM concentration level with meteorological and microenvironmental factors. Using regression models, they showed that lower wind speeds, higher temperatures, higher adjacent passenger vehicle traffic, higher ambient concentration, and street canyons with high rise building were associated with higher PM concentration (Boarnet et al., 2011). Hess et al. (2010) investigated the $PM_{2.5}$ exposure level outside and inside bus shelters, and the impact of land use configurations around bus shelters (building, no-building and paved, and no-building and unpaved). With the multiple regression models, they showed that the PM concentration was higher inside shelters than outside shelters, after accounting for meteorology and time of day (Hess et al., 2010). Kam et al. (2011) examined differences in the PM concentration level between underground and on-ground rail systems and compared levels on platforms and inside trains in Los Angeles. They conducted a pollution sampling campaign on train platforms and in trains of the above-ground light rail line (Gold Line) and under-ground subway rail line (Red Line). They observed higher PM concentration in the subway line than the on-ground light rail train. In regression models, higher ambient PM concentration was more strongly associated with the light-rail train than the subway, because of more sources of PM existed above-ground, and additional source of PM from the daily operation of train (Kam et al., 2011).

Previous air pollution studies mainly assessed air pollution impacts based on concentration measurements derived from fixed site monitoring stations (Buonocore et al., 2009; Chetwittayachan et al., 2002; Hoshiko et al., 2012; Levy et al., 2003, 2001; Noth et al., 2011; Thornhill et al., 2008; Velasco et al., 2004; Zwack et al., 2011). Unfortunately, these stations are dispersed within regions, and are largely insufficient to assess potential heightened exposures at near-roadway and transportation microenvironment concentrations. The previous studies have used the location-specific assessment methods to estimate the potential magnitude of near-roadway pollution impacts and their environmental justice implications for populations in residents (Gunier et al., 2003; Houston et al., 2004), schools (Appatova et al., 2008; Green et al., 2004), and childcare locations (Houston et al., 2006), but fail to evaluate the impact of individual time activity on diurnal exposure. To my knowledge, however, only two available studies measures the exposure of free-living subjects to vehicle-related pollution during everyday activity and travel periods (Houston et al., 2013; Wu et al., 2012).

2.2 PAH Concentrations in Near-roadway and Transportation Microenvironments

Polycyclic aromatic hydrocarbons (PAHs) are typically produced from incomplete combustion of fossil fuels (Polidori et al., 2007). Motor vehicles are the primary source of PAHs in California (Air Resources Board, 2006). On-roadway and near-roadway concentrations of pPAH have been associated with passenger vehicle and heavy duty diesel truck traffic. With a regression analysis, Fruin et al. (2008) found that truck density on streets and the number of motor vehicles followed were significantly associated with PAH concentration in-vehicle environment (Fruin et al., 2008; Levy et al., 2003). Levy et al. (2003) carried out PAH sampling campaigns at many sites in Roxbury, Massachusetts. They showed that the concentration of PAH was lower at places farther from the road (Levy et al., 2003). Based on regression analysis, they found that PAH concentrations were associated with engaged in diesel truck counts while accounting for other factors (Levy et al., 2003). Other sources of PAH in urban environments include industrial facilities associated with diesel combustion, aluminum/iron smelting, and cigarette/tobacco smoke (Ott and Siegmann, 2006). PAH has been associated with health impacts, including adverse respiratory health outcomes and birth outcomes (Delfino, 2002; Perera et al., 2003). Since the production of PAH is dynamic in urban environments on a scale of minutes or hours, it is important to monitor its variation using shorter time intervals (Polidori et al., 2007).

Previous location-specific studies have used the same portable PAS 2000CE monitor model as the current study examining pPAH concentrations in transportation microenvironments. Levy's studies (2001, 2003) suggest that proximity to bus routes, types of streets, distance to bus stops, and traffic volume were major factors associated with PAH concentrations (Levy et al., 2003, 2001). The studies show that distance from a bus station and distance to the source of pollutants were major contributing factors to higher concentration of PAH. Since air pollution concentrations vary by many factors, further study is needed to assess the built environment factors which are significantly related to PAH concentration (Noth et al., 2011).

Table 4.1 provides an overview of studies of pPAHs in transportation and roadway microenvironments.

2.3 Exposure to Air Pollution by Socioeconomic Status

Some recent research sheds light on the relationship between proximity to major roadways and socioeconomic status, and suggests that populations of a low income classes or minority populations are more likely to reside near major roadways and tend to experience higher exposure to air pollution (Air Resources Board, 2006; Houston et al., 2008, 2006). Houston et al. (2008) characterize diesel truck traffic in a low-income minority community near the Ports of Los Angeles and Long Beach. By videotaping traffic at 11 intersections and street segments, the study measured the number of diesel trucks traveling on arterial roadways. The study shows that "the volumes of heavy-duty-truck traffic reached 400 to 600 per hour" (Houston et al., 2008). The results suggested these were raised health concerns at residential, school, and recreational facilities nearby roadways in this low-income minority neighborhood (Houston et al., 2008). Environmental inequality in location patterns of childcare facilities was discussed in a study by Houston et al. (2006). In their study, Houston et al. (2006) characterized the proximity of childcare facilities in California to the high- or medium-traffic arterials by built environment characteristics and socioeconomic status in the neighborhoods where the facilities are located. Based on logistic regression analysis, they showed that facilities located close to high-traffic roadways were more likely to be in socially disadvantaged areas (Houston et al., 2008). Appatova et al. (2008) also used the proximal method as a proxy of air pollution exposure to examine the exposure level of public school facilities to major roadways. The study showed no significant relationship between race/ethnicity and proximity of public schools to high-traffic roadways (Appatova et al., 2008).

In addition to studies of the location patterns of residential, school, and childcare facilities relating to air pollution sources, it has been shown that the level of exposure to air pollution varies by socioeconomic status (Appatova et al., 2008; Gunier et al., 2003; Houston et al., 2004). People in lower SES tend to live in environmentally distressed places, compared to people with higher social status (Appatova et al., 2008; Gunier et al., 2003; Houston et al., 2004). Lower income households tend to reside in neighborhoods closer to major roadways or closer to commercial or industrial areas. These areas tend to have more vehicle trips or activities which could be a possible source of air pollution (Appatova et al., 2008; Gunier et al., 2003; Houston et al., 2004). Moreover, residential location among the disadvantaged tend to be close to air pollution sources (Appatova et al., 2008; Gunier et al., 2003; Houston et al., 2004). In addition, transportation-related air pollutants tend to be concentrated in outdoor rather than indoor environments, making it critical to consider how much time people spend time outdoors and the type of built environments in which people spend their time in outdoor settings (Boarnet et al., 2011). Research shows that people spend about 90% of their time indoors and about 10% of their time in outdoor settings (United States Environmental Protection Agency, 2012).

2.4 Exposures of Free Living Subjects During Everyday Activities

Although previous studies examined the relationship of built environment and socioeconomic factors to air pollution concentration, these studies were limited in that they examined exposure at specific locations and do not provide insights into exposure over the course of the day (Buonocore et al., 2009; Levy et al., 2003; Noth et al., 2011; Thornhill et al., 2008; Zwack et al., 2011). Also, studies which estimated exposures based on data from monitors at fixed locations cannot characterize the dynamic exposure patterns which individual people experience while traveling.

To my knowledge, only two available study has measured exposure of free-living subjects to vehicle-related pollution during everyday activity and travel periods (Houston et al., 2013; Wu et al., 2012). Monitoring free living subjects is an alternative approach which overcomes the measurement errors in the previous air pollution exposure studies. Most previous exposure monitoring studies measured concentrations of air pollutants in motorized vehicles (car, train, bus, etc.) under various conditions, including driving on high traffic corridors (Riediker et al., 2003), driving with open windows (Sabin et al., 2005), driving behind diesel cars (Houston et al., 2008), driving vehicles with different fuel types (Leutwyler et al., 2002; Liu et al., 2010), and riding transit in smoking sections (Leutwyler et al., 2002; Ott and Siegmann, 2006).

3 Research Objectives

Objective 1: To characterize the magnitude and variation of vehicle-related air pollution within transportation and locational microenvironments

The first objective of the study is to characterize the pPAH exposure levels in transportation and locational micro-environments. Based on the previous location-specific monitoring studies, I hypothesize that pPAH concentrations will vary across various places and situations and by whether an individual person is indoors/outdoors, travels in transit, in a passenger vehicle, or walking to the microenvironments.

Since transportation-related air pollution is prevalent outdoors, I hypothesize that spending time in an outdoor setting is associated with higher exposure to air pollution. Compared to the exposure to air pollution during non-travel periods, I hypothesize that time in residential places will be associated with lower exposure to pPAH than non-residential places. I hypothesize that traveling in public transit will be associated with lower exposure than traveling in a personal automobile, because public transit buses and light rail vehicles tend to use environmentally friendly fuels, such as natural gas or electricity. I hypothesize that periods of outdoor walking along a mayor roadway will be associated with higher exposure to air pollution than waiting at a transit stop.

Objective 2: To examine the association of nearby land use and built environment factors with pPAH exposure

The next objective of the study is to investigate how and whether land use compositions are associated with pPAH exposure. I hypothesize that nearby land use which is associated with more traffic-generation will on average be associated with greater exposure, and that nearby residential land uses will be associated with lower traffic generation and therefore lower exposure. It is less clear whether periods in mixed-use areas will be associated with higher or lower exposure. A main goal of mixed-used land use development is to promote more walkable environments, and to discourage usage of automobiles by mixing residential use and other uses, typically commercial uses. Thus, if a location is surround by more land designated as mixed use, the location is expected to have fewer number of people who use personal automobiles to get there (Chatman, 2003; Potoglou and Kanaroglou, 2008). Instead, it is expected that more people visiting the location live close by, so that the location is associated with lower air pollutants (Frank et al., 2006). Conversely, mixed land use, in some cases, could represent an important destination in the region which generates substantial traffic from outside areas. In such cases, walking in mixed-use areas could result in greater proximity to stop and go traffic and higher pollution exposure.

Given the number of studies that indicate proximity to the heavy traffics is associated with exposure to transport-related air pollution, I hypothesize that driving on freeways will be associated with higher risk of exposure, because there are more traffic (and diesel trucks) on these facilities. Street connectivity could be a key factor associated with the level of exposure, because greater connectivity can be associated with greater volume of traffic. I will also assess the role of distance from high traffic roadways in an individual's exposure.

Objective 3: To characterize the exposure to air pollution by personal/household characteristics

The last objective of the study is to examine variations in exposure across personal characteristics given environmental justice studies indicate that low-income and minority communities tend to have higher air pollution exposure. Also, because travel behavior varies across personal/household characteristics, it is important to examine the relationship between personal characters and exposure to air pollution (Bae et al., 2007; Forkenbrock and Schweitzer, 1999).

4 Methods and Data

4.1 Analytical Approach

Because this study investigates the relationship between air pollution exposure, microenvironment characteristics, nearby land use, transportation infrastructure, and SES during one time period, it is a cross-sectional study. There are two stages of analysis. For the first stage of analysis, I identified momentary exposure to pPAH and its relation to nearby land use and built environment qualities based on a distance of 100 m of all locations during stationary and travel periods. The distance of 100 m corresponds to the distance downwind of freeways in which vehicle-related pollutants such as ultrafine particles and black carbon are generally at their highest concentrations (Leutwyler et al., 2002; Zhu et al., 2002).

In addition to the momentary exposure, I identified pPAH exposure, land use and built environmental characteristics within an individual person's location activity spaces

(LASs). LAS is an aggregated geographic boundary in which a person is expected to spend his/her time dominantly in daily life, and 1-statndard deviation ellipse (SDE1) and activity space path (ASP) were used to estimate LASs. In the second stage of analysis, I examined individuals' potential exposure to pPAH based on the location activity spaces (LASs).

The difference between two stages of analysis is the extent of geographic boundary of measurement of environmental qualities. The first stage of analysis focuses on exposure to pPAH at a certain locational point and time and built- and social-environments surrounding the locational point. Unlike the momentary analysis, the second stage of analysis is based on aggregated geographic boundary which is expected where an individual visits and spends their time in daily life.

4.1.1 Analysis Stage 1: Momentary Analysis of Matched GPS-Air Pollution Monitor Data

For the first stage of analysis, I used descriptive statistics, t-tests, and multiple regression techniques in order to assess the magnitude of association between exposure level of pPAH and the factors which are hypothesized to influence exposure level. In the OLS models, the dependent variable is pPAH concentration. Nearby land use composition, the number of intersections, and the distance to high- traffic roadways, location type, and number of employments near the place of residence were considered as independent variables in the models. Dispersion or concentration of ambient air pollutants is affected by aerodynamics, so that meteorological features will also be considered as important factors of exposure to air pollution. Moreover, demographic and socioeconomic characteristics affecting travel behaviors are the plausible rival hypothesis. I use the regression models to assess associations between exposure and socioeconomic variables after controlling for confounding variables, not to infer causality.

4.1.2 Analysis Stage 2: LAS Analysis

For the second stage of analysis, I analyzed the potential exposure to the air pollutant by measuring air pollutant within individual participants' Location Activity Spaces (LASs). Similar to the previous model, the activity space based exposure model takes the following forms. The unit of analysis is an individual participant. I used 35 participants' GPS point data to create LASs by calculating 1-standardarized deviation ellipse (SDE1) and Activity Space Path areas (ASP) using ½ mile buffer around the GPS points in ArcMap 10.1. Since 9 participants did not provide air pollution data, I used 25 participants' SDE1 and ASP for analysis. I averaged individual participants' pPAH level in one minute.

Results of this study are not readily generalizable since this study was not based on a randomized sample. Instead, this study provides an important case study which provides insights into the travel and activity patterns which are associated with exposure in a neighborhood impacted by major goods movement corridors.

I tested the relationship between built environment qualities within individual participants' LAS and the actual amount of air pollutants to which they were exposed to using the ordinary least squares (OLS) methods. The parameters of built environment variables in the model would explain how much the given built environment quality, which an individual is expected to expose to in his/her daily life, are significantly related to the exposure to pPAH. I had two different OLS regression models for the different types of LASs calculated by SDE1 and ASP. Both methods regard spatial and temporal level of geographic points, whereas they have the different approaches in calculation. On one hand, the SDE1 presents the directional distribution of a group of geographic points and the density of points could represent of time spent in the location, so that the method estimates activity space better in terms of time spent. On the other hand, the ASP is the method to estimate possibly approachable areas by an individual person on foot from the person's actual geographic points.

4.2 Overview of the Boyle Heights Activity Exposure Study (BHAES)

The Boyle Heights neighborhood is a community located east of downtown Los Angeles and adjacent to East Los Angeles. The area is heavily impacted by roadways with high traffic and goods movement. The Interstate 5, the Interstate 10, and California State Route 60 are surrounding the neighborhood. In 2009, there were 91,481 people estimated to live in the area, and the population density was 13,708 people per square mile which was much denser than that of the city (City of Los Angeles Department of City Planning, 2015a). Hispanic/Latino is the dominant population in the area: 93.7 percent of residents in the area were Hispanic or Latino in 2009 (City of Los Angeles Department of City Planning, 2015b). The area is economically disadvantaged, compared to the city and the county. The median income of the neighborhood was $33,235, which was lower than the city and the county (The Los Angeles Times, 2015). In terms of housing, 75.2 percent of all occupied housing units were occupied by renters (City of Los Angeles Department of City Planning, 2015b), which is a higher rate compared to the city (61.4%) (Housing Characteristics: 2000, Census Bureau, 2000). Since the area is encompassed by high traffic roadways and diesel trucks pass through the middle of the neighborhood, there have been raised concerns about air pollution and its negative impact. The area has had the higher hospitalization rates for asthma (137.7 per 100,000 people) than the state of California (86.2 per 100,000 people) in 2009 (Bravo and Lujan, 2012). From school monitoring sites in Boyle Heights, the California Air Resource Board sampled six key pollutants emitted from motorized vehicles and found that some monitoring sites recorded higher concentration levels of air pollutants than other locations in the city (California Environmental Protection Agency Air Resources Board, 2003).

This study uses real-time activity and air pollution data from a research project, the Boyle Heights Activity Exposure Study (BHAES), which was funded by the University of California Transportation Center. BHAES conducted a mobile-tracking survey for thirty adult residents of the Boyle Heights neighborhood near downtown Los Angeles from February 10, 2011 to May 17, 2011 (Figure 4.1). Each survey participant carried a Global Positioning System (GPS) device and a Photoelectric Aerosol Sensor (PAS) air pollution monitoring device during the day while they were away from home for seven days. The GPS recorded the participants' geographic position, including latitude and longitude, every fifteen seconds and the PAS measured pPAH in nano-grams per cubic meter (ng/m3) every minute. Besides the mobile tracking survey, participants also completed a baseline survey to report their socioeconomic status and travel behaviors, including demographics, immigration status, household income and transportation resources, and supplemental information about locations they visit frequently.

About 40 percent of participants were female, about 66 percent were foreign-born, and about 46 percent preferred to speak Spanish. About 70 percent reported a household income below $25,000/year while the remainder reported $25,000-$50,000/year. Participants were about equally divided among the different age groups (20-29, 30-39, and 40-49 years old) and educational attainment categories (less than high school, high school or equivalent, more than high school). Participants received grocery gift cards totaling $75 for their participation.

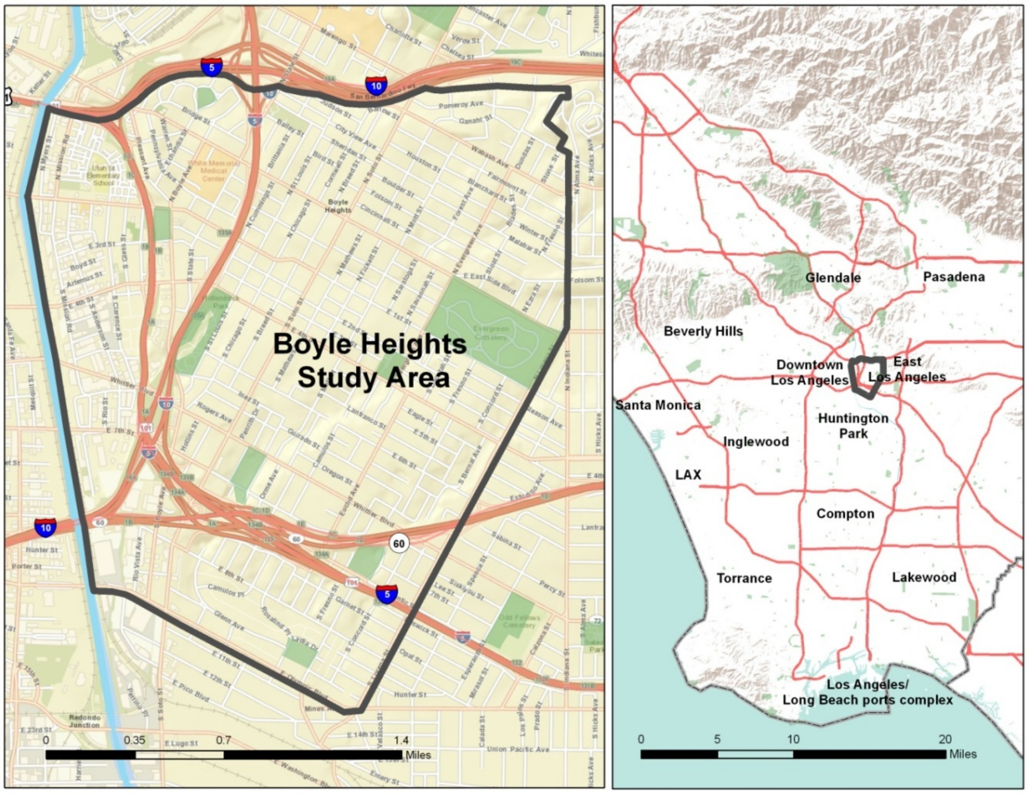

Figure 4.1 The Boyle Heights Activity Exposure Study Recruitment Area

4.3 Post-processing GPS Data to Determine Microenvironment/Location Types

The raw data collected from the GPS devices included only time, date, and latitude/longitude, and post-processing, and location classification was required to identify periods of travel and periods at a location. First, I reviewed the data for completeness. Although the GPS devices participants carried were programmed to log their location every 15 seconds, the data had periods with no records for several minutes or, in some cases, a few hours. Our classification procedures described below reviewed data quality and completeness. This procedure identified whether gaps in the GPS location sequence represented valid periods of signal loss over the course of normal activities (during periods of bad satellite signal reception while in a concrete building or in a subway tunnel) or invalid periods which did not represent a participant's everyday activities (such as the GPS device running out of battery). For the analysis, we eliminated days with large gaps in the GPS data since the data did not fully represent the given participant's daily travel and activities.

The first step was to identify static locations in the GPS point data. We generated a point shapefile representing the locations which participants indicated they frequented during the baseline interview. This point file included information about locations, including location types, such as residential, commercial, industrial, retail, and recreational. Next, we performed a cluster analysis on all GPS locations in a given participant's GPS data to identify clusters of points which might represent static periods spent at a given location. We identified the location type of many clusters based on the participant-reported location information provided during the baseline survey, and we gathered information about other non-reported cluster locations from participants during the follow-up interview.

The second step was to use an algorithm to classify points (which were not previously identified as a static location) as periods of travel and the mode of travel for points not identified as a static location. We developed and used an algorithm to classify GPS points into four categories: staying in a place, being in an automobile, riding public transit, being engaged in non-motorized trips. To identify periods in a stationary location, the distance from each GPS point to the nearest location point was calculated using Spatial Join function in ArcMap 10. If the distance from the GPS point to the nearest place was less than 20 meters, the record was defined as being at the location. In cases in which a person passed a given location, the automated classification process could classify the records of the person were marked as being in a location because the person passed the 20-meter-boundary of the location. In order to avoid such miss-classification, we re-coded them as a traveling period after visual review in mapping software. If the distance from any given point was greater than 20 meters, the point was regarded as not being associated with a location. The remaining non-location points were assessed based on their speed (distance/time) compared to the previous sequential point. If a point's speed from the previous point was faster than 6 miles per hour, the record was defined as traveling in a passenger vehicle. Since periods of movement below 6 mph may be periods in slow traffic or stopping at a traffic light we examined all non-location points slower than 6 mph to determine if any sequential point two minutes before or two minutes after the given point was faster than 6 mph. If this was the case, the point was classified as being a period of traveling in a passenger vehicle. For non-locations points slower than 6 mph were classified as being non-motorized or walking periods.

We confirmed and corrected our initial classifications of stationary and travel periods by visually reviewing sequential GPS locations relative to roadways, sidewalks, and transit route/stops by overlaying GPS points with aerial photography using Geographic Information Systems (GIS). This procedure allowed us to confirm and make important corrections in our final classification. For instance, our visual inspection of GPS data in GIS helped confirm that a participant stopped longer than two minutes at a traffic light was classified as being in-vehicle and not at a stationary location. This process also helped us identify which in-vehicle periods were on public transportation based on whether they followed established transit routes and started or ended at established transit stations.

We combined the GPS data with additional location or movement information with the PAH data from the PAS device. The two datasets share participants ID and time and date, so I was able to join them with the two common factors. Since PAH level was measured per minute, unlike GPS data per 15 seconds, each GPS record was associated with 1-minute average PAH level. Since pPAH concentrations were collected at a 1-minute interval and GPS location data were collected at a 15-second interval, we used several criteria to convert 15-second interval GPS location attributes to 1-minute interval factors. The majority of 1-minute intervals contained 15-second interval GPS location attributes with the same microenvironment classification and in such cases we assigned this classification as the minute's microenvironment classification. In minutes of transition between microenvironments, we classified any minute with at least one 15-second GPS in-vehicle travel location as an in-vehicle travel minute. We classified remaining minutes with at least one 15-second interval in an outdoor travel period as an outdoor travel minute. All remaining minutes were classified as a non-travel period.

4.4 Built/Natural Environment Data

4.4.1 Land Use

The land use database includes information on land use composition and transportation infrastructure within 100 m of all locations during stationary and travel periods, a distance threshold which corresponds to the distance downwind of freeways in which vehicle-related pollutants such as ultrafine particles and black carbon are generally at their highest concentrations (Lipfert and Wyzga, 2008; Zhu et al., 2002). In addition, I try to examine the association of pPAH exposure level with built environment qualities within individual people's location activity spaces (LASs). Instead relating air pollution exposure level to built environment qualities within 100 m of all locations of GPS points, I measure the environmental qualities in broader and widely aggregated geographic boundary, LAS, which represent a daily geographic boundary where a person is expected to stay.

The Southern California Association of Governments (SCAG) 2008 existing land use GIS data at the parcel level was used to identify the nearby land use composition around participant locations. Information about land use designation in 2008 for each parcel in Los Angeles County were included in the shapefile. I created a 100-meter buffer around every GPS location and travel point that participants occupied, then intersected the buffer with land use shapefile. From the intersected data, I obtained the percentage of the buffer area which was designated as each type of land use (e.g., commercial, residential, and transportation land use).

In addition, I estimated land use composition within the individuals' LAS. Using the intersect function in ArcGIS 10.1, I merged land parcel data with land use information in Southern California in 2008 to each individual's activity space. Using R software, I calculated percent of each type of land use with each individual's activity space.

4.4.2 Street Connectivity, Walkability, and Traffic

I used 4- or more-way intersection density and block size as a street connectivity measure, which is related to walkability level. Using intersect function in ArcGIS 10.1, I merged street intersection and block size data to individuals' LASs and ASPs.

I used 2010 TIGER/Line street shapefile from the US Census Bureau to calculate the number of intersections within 100 meters from each GPS point. I developed an original procedure to use the ArcGIS program to generate point-level data representing intersection or node or streets. In order to calculate the number of intersections around GPS points, I created a 100 meter buffer from every GPS location and travel point and then intersected location buffers with the point-based intersection shapefile. This information provided a measure of street connectivity.

This study used the 2005 Caltrans Highway Performance Monitoring System (HMPS) data with annual amount daily traffic (AADT) information to calculate the proximity of GPS location points to traffic within 100 m.

4.4.3 Meteorological Factors

Data for meteorological factors, including wind speed (mph), mean temperature (F), and relative humidity (%), were obtained from the California Air Resources Board based on measurement obtained at University of Southern California main campus about 3.75 miles from Boyle Heights area. Noh et al. (2011) and Boarnet et al. (2011) have demonstrated the importance of using meteorological factors as control variables for understanding the air pollution concentration in near-roadway and transportation microenvironments. These studies indicated that meteorology was significantly related to concentration of air pollution (Boarnet et al., 2011).

4.4.4 Employment

Employment data, including number of firms and number of employees for each business establishment, was obtained from InfoUSA 2008 provided by the Southern California Association of Governments. By intersecting the employment data to individual's activity space in ArcGIS 10.1, I merge employment information to participant activity spaces.

4.4.5 Public Transit Accessibility

Using the intersect function in ArcGIS 10.1, I merged transit areas, accessible to public transit stops in ¼ mile, to individuals' LASs. I calculated the percent of transit areas in each participant's LAS.

5. Findings

5.1 Time Use and Travel Patterns

Participants spent about 94.3% of their day (22.6 hours per day) in non-travel activities, and 77.4% of their day residences (18.6 hours per day) (Table 4.2). On average, participants spent approximately 1.4 hours traveling per day (5.7% of times per day). With respect to gender, female participants spent more time in retail locations than males, while males spent more time in recreational locations. There was no significant difference in time use in travel across modes between men and women. In terms of car ownership, car owners tended to spent more time in services and retail locations, and participants without a car spent more time in school, food, and other locations. As excepted, participants without a household car spent more time traveling by or waiting on public transportation, but they were not different from car owners in terms of the amount of time spent walking. Foreign born participants spent more time in non-residential places, such as school, recreation, and food, while non-foreign born participants spent more time in residential places. There was no significant difference in time spent in travel by foreign born status. For income level, participants earning $24,000-50,000 per year spent more time at retail locations than households earning $24,000 per year; low income earners spent more time in service locations than the higher income group.

5.2 Exposure to pPAH

The average exposure level of pPAH varied by time of day (Figure 4.2). The level of pPAH level was low between 9 pm and 6 am during periods of lower traffic and activity. Concentrations rose between 7 am and 8 pm. In terms of exposure to PAH by location and activity types, people had higher exposure to PAH when they were traveling in a car, public transit, staying at a bus stop, and walking than place-based activities. Among the trip-based activities, people were exposed to the highest level of PAH when they were walking (Figure 4.3).

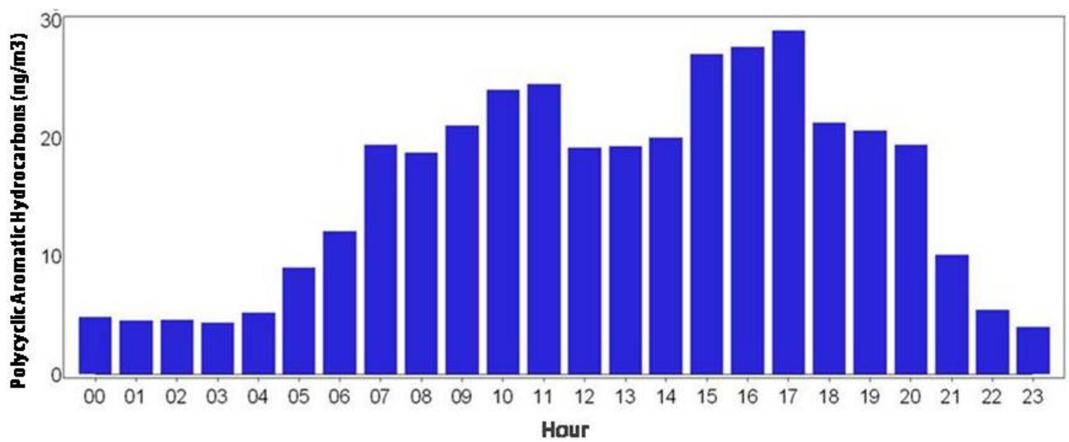

Figure 4.2. Average Exposure to pPAH by Time of Day

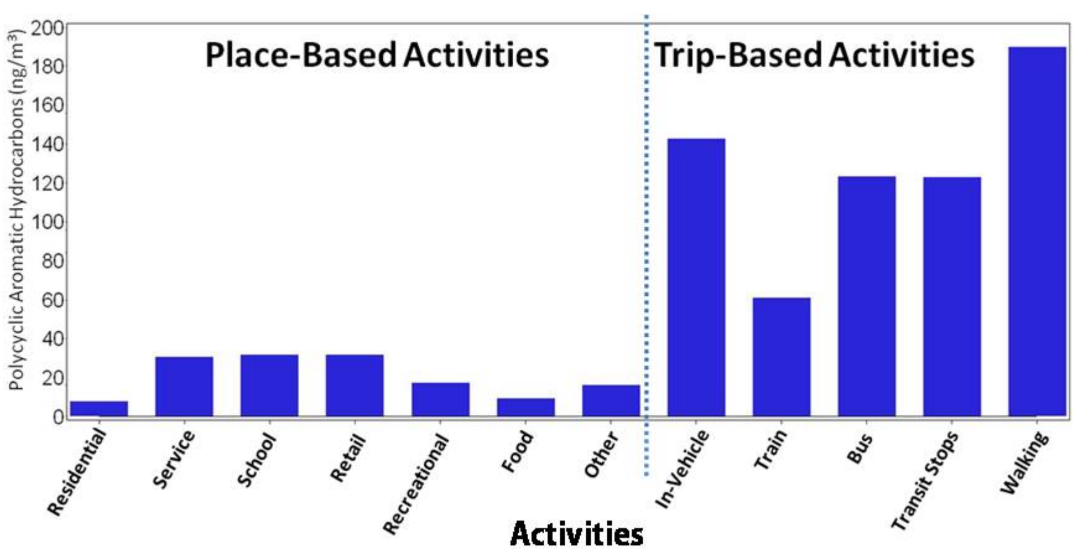

Figure 4.3. Average Exposure to pPAH by Location Types

5.3 Stage 1 Analysis: Descriptive Statistics of Key Variables Used in Regression Analysis

The total minutes of available GPS and pPAH data were 132,654. About 94% of these minutes were spent in non-travel periods, 4% were spent traveling in-vehicle, and 2% were spent traveling outdoors. The average pPAH concentration was highest during outdoor travel periods than others. The mean pPAH concentration in outdoor travel periods was 179.86 ng/m3, whereas the average pPAH concentration for non-travel periods was 10.36 ng/m3.

In terms of microenvironment categories, 78% of total minutes were spent in residential places and 16% were spent in non-residential locations. Only 6% of total minutes were spent in travel periods. In terms of non-travel periods, 83% of total minutes were spent in residential locations. Of all minutes in-vehicle periods, 16% of total minutes were spent traveling on public transit, whereas 84% of total minutes were spent traveling in a personal vehicle. When people traveled outdoors, they spent 15% of their total minutes waiting for public transit stops.

On average, about 12% and 16% of areas within 100 meters from a person's location was designated as commercial use and residential use, respectively. About 32% was designated as not being within a parcel, which generally represents the area dedicated to roadways, parking and sidewalks. In terms of transportation infrastructure, about 1% of total minutes were spent on a freeway during vehicle or transit travel. However, when considering only in-vehicle periods, 28% of the total times were spent on freeway travel. The average number of intersections within 100 meters was 2.88, and the average distance to high traffic roadways was 621 meters.

5.4 Stage1 Analysis: OLS Results

I specified four different multiple regression models to assess factors associated with concentrations for all periods, non-travel periods, in-vehicle periods, and outdoor travel periods (Table 4.4). The dependent variable was the log of pPAH exposure in 1-minute interval.

In terms of microenvironments (Model 1), all location and travel microenvironments were associated with higher exposure to pPAH than residential locations, the excluded category. Walking outdoors was associated with relatively high exposure to pPAH compared to periods in other travel modes. For in-vehicle travel periods, periods riding public transit were associated with lower exposure than periods traveling in a personal vehicle or truck. For outdoor travel periods, periods waiting at transit stations were associated with lower exposure than periods riding transit.

With respect to nearby land use within 100 meters, the percent of commercial land use was negatively associated with pPAH exposure. More non-residential amenities around individual's location may help to lessen exposure to air pollution. In terms of non-travel periods, the percent of residential land use around a participant's location was positively associated with exposure to pPAH. During travel periods, the percent of nearby residential land use was negatively associated with pPAH. However, periods in mixed-use areas were not significantly associated with exposure. Interestingly, the percent of non-parcel area during travel periods near individuals' location was associated with higher exposure. This could imply that more land for streets can be related to higher exposure. Distance to heavy-traffic roadways was also consistent with the hypothesis that being distant from roadways is associated with lower exposure to pPAH. However, contrary to expectations, the number of intersections and high traffic roadways within 100m are consistently associated with lower exposure to pPAH. In terms of meteorology, the analysis shows that wind speed and temperature were negatively associated with exposure to pPAH, whereas relative humidity was associated with higher exposure.

5.5 Stage 2 Analysis: Location Activity Space (LASs) OLS Results

In the second stage of analysis, all environmental measurements were aggregated at individuals' Location Activity Spaces (LASs). I used two types of LASs: one-standard deviation ellipse (SDE1) and activity space path (ASP). SDE1 represents two-dimensional directions and spread of a group of location points. With the ASP method, I estimate an individual's LAS by creating a ½ mile buffer around each GPS point provided by the individual. Using an individual's GPS location points, I could estimate an SDE1 and an ASP. GPS data from BHAES study were used to estimate SDE1 and ASP. 26 participants provided valid GPS data. Since I created SDE1 and ASP for each participant, the number of SDE1 and ASP are the same as 26. The unit of analysis is an individual. I ran the OLS regression models of relationship between the average pPAH, to which an individual exposed, and built- and social-environmental measures aggregated within the individual's SDE1 and ASP.

In the OLS regression model of factors associated with the SDE1-based LAS (Table 4.5), the percent of areas impacted by high/medium traffic corridors, percent of areas accessible to transit stops, block size, and percent of commercial land use were positively associated with pPAH concentration, whereas employment density, intersection density, and percent of residential land use are negatively associated with pPAH. However, only the traffic and intersection density variables were statistically significant. In terms of high/medium traffic corridor, if there were more nearby area with high/medium traffic in the LAS, the person was more likely to be exposed to higher pPAH. Regarding intersection density, more intersections in an individual's activity boundary resulted in lower exposure to pPAH. This implies that areas with better walkability settings contribute to lower exposure to air pollution, perhaps because the possibility of traveling by automobile in the area was lower.

In the OLS regression model of factors associated with the ASP-based LAS (Table 4.6), traffic, transit stop density, average block size, and commercial land use within the LAS were positively associated with exposure to pPAH. In contrast, the number of 4- or more-way intersections per acre and percent of residential land use in an ASP were negatively related to pPAH concentration level. However, only transit stop density and intersection density were statistically significant in the model.

The results of the two regression models were similar. Both models shows that higher 4- or more-way intersection density was associated with lower pPAH exposure and the results were statistically significant. Unlike intersection density, which is significant in the two models, high traffic and transit measure were significant in the two models, respectively. This implies that the percent of areas impacted by high-traffic corridors within an activity space estimated by SDE1 was better explanatory variable for estimating air pollution exposure and that transit stop density within an activity space estimated by ASP was the better explanatory variable for estimating the exposure to air pollution. In general, the LAS-based models explain a substantial amount of variation. The SDE1- and ASP-based models explain 50.4 and 47.9 percent of variation of the average daily exposure to pPAH (Table 4.5 and 4.6), which are higher than R-square of models of momentary exposure to pPAH (Table 4.4).

6. Discussion and Implications

This study contributes to the growing body of literature characterizing exposure to urban air pollution hazards with regards to the microenvironments people occupy during everyday activities. Most available studies have been limited in that they classified exposure by assigning the air pollution concentrations for larger areas to given subjects. This approaches could result in exposure misclassification given vehicle-related pollution can vary substantially in urban environments. This case study contributes to the literature by demonstrating techniques to measure and characterize exposure in the microenvironments that people occupy over the course of the day under everyday activities and travel.

This study provides an important case study given the neighborhood is surrounded by major freeways with significant amounts of heavy duty diesel truck traffic. Local streets in the neighborhood are also impacted by heavy traffic. In addition, redevelopment efforts in the area have embraced sustainable planning approaches for community improvements, including opening of Gold Line light rail line and nearby projects and transit oriented developments. Results will inform these planning efforts by helping to assess land use and built environmental factors associated with exposure and may provide insights into current efforts by the South Coast Air Quality District and the Los Angeles Metro to develop neighborhood design principles to help mitigate exposure to vehicle-related pollution. Such efforts will be particularly important given current land use planning, policy, and development initiatives which are increasingly seeking to build more pedestrian, mixed used, and public transit-oriented development. These programs are designed to reduce the reliance on automobiles and to encourage the use of non-motorized modes of transportation to reduce vehicle travel and associated greenhouse gas emissions and to build more pedestrian friendly environments. This chapter provides a framework for assessing the implications of such programs on exposures of community residents to vehicle-related air pollution.

Results presented in this chapter indicate that Boyle Heights participants experienced less air pollution while riding public transportation compared to traveling by personal vehicles. This pattern could be related to the vehicle characteristics, window status (open/closed) and fuel type. Moreover, public transit riders might tend to experience less exposure to air pollution because public transportation tends to travel on local roads rather than freeways with higher risk of exposure to air pollution. In terms of nearby land use, nearby commercial and mixed land use areas were at times associated with lower levels of exposure level, which could suggest the need to promote the location more non-residential amenities within walking distance of residences. This case study raises concerns that periods of walking could be associated with relatively high levels of exposure. Further research is needed to better understand whether and to what extent urban design strategies can be used to mitigate air pollution exposures in pedestrian environments. Governments and community organizations should prepare mitigation programs, which could include vegetation barriers or indoor filtration systems.

Summary, Conclusion, and Implication of the Dissertation

This dissertation provides a heuristic theoretical framework for understanding dynamics that impact environmental health including social/built environmental settings, individual residents' behavioral patterns, location activity spaces (LAS), environmental quality, exposure, and health outcomes. It examines the relationships between the factors identified in the Location, Activity, and Environmental Exposure (LAEX) framework based on individuals' LASs, which represents a hypothetical geographic boundary in which an individual is expected to spend his/her time in daily life. Through empirical tests, I sought to understand the relationship between social and built environmental settings of residential neighborhood, and the size of LAS, and health-related environmental exposure to amenities and hazards. In addition to the individual level exposure, I characterized built environmental quality for subsidized housing neighborhoods in Los Angeles and Orange Counties, which have not been the focus of previous affordable housing studies.

In Chapter 1, I proposed the Location, Activity, and Environmental Exposure (LAEX) framework. The framework explains the interrelationship between individuals' environmental health outcomes and environmental factors. The framework consists of four factors: 1) External Factors, 2) Behavior Patterns, 3) Environmental Factors/Context, and 4) Behavior/Outcomes. Individuals' LASs play an important role in connecting the external environmental factors and individuals' exposure patterns. The external factors represent all possible attributes shaping urban spaces, including social environments, built environments, institutional interventions, and structural inequality. Urban space is shaped by external factors, and these factors influence how individuals make decisions regarding modal choice, travel time, residential choice, and types of daily activity. For instance, in the context of transportation networks or housing markets, an individual or a household decides where to live and their mode of transportation to reach certain activity places (occupational and non-occupational). The selected mode of transportation influences the size of an individual's daily activity spaces. If a person spends more time out of his/her residential neighborhood, his/her LAS will be constructed mainly around the non-residential activity space. If a person travels by car, he/she would likely have a bigger LAS compared those who use public transportation. In collective ways, individuals' behavioral patterns also influence environmental quality. For instance, individuals' travel behaviors could influence energy consumption and vehicle-related green house gases or traffic risk. Exposure to environmental quality could also be understood as the environmental quality within individuals' LASs. The concept of exposure proposed in the LAEX framework can potentially overcome methodological limitations (ecological fallacy, etc) caused by zone- or place-based constructs of location activity spaces (census block, block groups, etc.).

In Chapter 2 and Chapter 4, I empirically tested the LAEX framework for residents in neighborhoods near the Metro Expo Right Rail Transit line and the Boyle Heights community in Los Angeles. In Chapter 2, I assessed the relationship between the built environmental quality in residents' neighborhoods (areas within 1 mile buffer around each residence) and the size of individuals' LASs and NO2 exposure and grocery density within LASs. Based on t-test analysis, I found that socially disadvantaged groups (low-income and non-car owner) had smaller LASs. Because of lower mobility, they tended to utilize less urban spaces than other groups. Based on OLS regression analysis, I found that bigger LASs were associated with lower walkability in residential neighborhood, more residential and lower commercial land use in residential neighborhood, higher transit stop density in residential neighborhood, shorter length of residency, employed/working out of home, and higher income. Individuals for whom it is hard to get around his/her residential neighborhood (because of lower walkability and fewer amenities) may essentially be forced to spend more time outside of the residential neighborhood. Since higher transit stop density was associated with larger LASs, it appears that for low-income households, who have lower mobility, better transit access in their neighborhood could be important. In terms of exposure to NO2 and grocery stores within LASs: smaller LASs, smaller block size in LASs, better transit access in LASs, and low-income status were associated with both higher NO2 exposure and higher grocery density. This represents a paradox in locations of amenities and hazards.

In Chapter 4, I tested how built environmental qualities within individuals' LASs influence momentary and diurnal exposure to an air pollutant, particle-bound polycyclic aromatic hydrocarbon (pPAH), for residents in the Boyle Heights community which is heavily impacted by high traffic and goods movement. I constructed individuals' LASs based on the GPS driven location data linked with pPAH level monitored by portable air pollution monitors every minute for several days. Similar to Chapter 2, I tested the relationship between the built environment within individuals' LASs and the average exposure to pPAH. In terms of momentary exposure, I found that time spent for walking outdoor was associated with the highest exposure to pPAH, followed by time spent in-vehicle, in-bus, transit stops, and in-train. Based on the OLS regression model, I found higher momentary exposure to pPAH was associated with lower commercial land use, higher non-parcel area, proximity to high traffic roadways, and intersection density. In terms of diurnal exposure, I found that higher percentages of areas impacted by high-traffics within LAS, lower walkability in LAS, and a higher percentage of areas accessible to transit stops were related to the higher diurnal exposure to pPAH. These results imply that public transit travel could be associated with a health benefit, compared to travel by private automobile. However, walking outdoors was associated with higher exposure to air pollution compared to all other microenvironments assessed. Thus, in order to increase health benefit from transit ride, it is necessary to mitigate outdoor air pollution with through variety of planning and policy efforts, including re-routing diesel truck movement, and providing more pedestrian-friendly environments.

Although it uses zone-based analysis, Chapter 3 provides meaningful insights into the health-related built environmental qualities of federally subsidized low-income housing neighborhoods in Los Angeles and Orange Counties. I characterized built environmental qualities (including public transit access, walkability, non-residential land use, and NO2 concentration) for the subsidized housing neighborhood by housing program type (Section 8 Housing Choice Voucher versus Low Income Housing Tax Credit) and by region (Los Angeles County versus Orange County). I examined the relationship between the probability of a census block group (BG) having at least one subsidized unit and BG built environmental qualities. Based on logistic regression models, I found that subsidized housing units/projects tended to be located in BGs with better transit access, lower walkability, more mixed-use, and lower NO2 concentration. Similar location patterns occurred both for HCV and LIHTC units, and I did not find any difference between two housing programs. In terms of region, subsidized units in Orange County tended to be located in BGs with higher NO2 concentrations than those in Los Angeles County.

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Table 2.1 Size of Location Activity Spaces, Accessibility Level, Exposure Level (SDE1)

Wave1	ALL	PUBLIC TRANSIT			HH VEH			GENDER			HOUSING TENURE			LOW INCOME		
		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=126)	(n=88)	(n=38)	Pr > t	(n=19)	(n=107)	Pr > t	(n=38)	(n=86)	Pr > t	(n=54)	(n=69)	Pr > t	(n=62)	(n=64)	Pr > t
Land Use (Avg. % of LAS)																
RES	47.8	47.3	48.9	0.327	52.0	47.0	0.021**	46.9	48.2	0.433	46.9	48.1	0.462	46.1	49.3	0.038*
COM	8.9	8.5	9.9	0.079.	8.5	9.0	0.610	10.0	8.4	0.053.	8.7	9.2	0.500	8.9	8.9	0.990
PUB	4.8	4.9	4.5	0.282	4.4	4.8	0.331	5.1	4.6	0.178	5.1	4.5	0.065.	5.0	4.6	0.193
OPEN	3.2	3.1	3.4	0.459	2.0	3.4	0.033*	2.9	3.3	0.480	3.2	3.2	0.975	3.4	3.0	0.448
IND	5.0	5.3	4.4	0.241	2.6	5.5	0.007**	5.3	4.9	0.566	5.1	5.2	0.948	5.4	4.7	0.327
NON DESIGNATED	28.2	28.6	27.2	0.312	28.9	28.1	0.640	27.2	28.6	0.330	28.7	27.8	0.484	28.9	27.5	0.319
Polluting Industry in LAS	16.7	15.9	18.9	0.362	13.6	17.4	0.003**	16.6	17.0	0.898	15.9	17.4	0.079.	14.3	18.6	0.0008**
Grocery Store in LAS	5.7	5.7	5.7	0.996	4.9	5.9	0.066.	5.4	6.0	0.148	6.0	6.7	0.215	5.2	6.3	0.005**
Healthcare Facility in LAS	49.1	46.2	57.8	0.019**	26.6	52.6	<.0001 **	48.9	49.7	0.865	45.7	52.2	0.142	48.3	50.2	0.670
NO2in LAS	26.7	26.7	26.7	0.880	27.0	26.6	0.358	26.5	26.8	0.361	26.9	26.4	0.083.	26.4	26.9	0.048*
	ALL	**PUBLIC TRANSIT**			**HH VEH**			**GENDER**			**HOUSING TENURE**			**LOW INCOME**		
Wave2		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=94)	(n=64)	(n=30)	Pr > t	(n=14)	(n=80)	Pr > t	(n=30)	(n=64)	Pr > t	(n=42)	(n=50)	Pr > t	(n=48)	(n=46)	Pr > t
Land Use (Avg. % of LAS)																
RES	48.4	47.1	51.0	0.080.	53.3	47.5	0.042*	49.4	47.8	0.488	47.1	49.4	0.283	44.8	51.9	0.0004**
COM	8.1	8.2	7.9	0.593	7.1	8.3	0.128	8.3	8.0	0.530	8.3	8.0	0.514	8.3	7.9	0.494
PUB	4.4	4.3	4.6	0.516	4.2	4.5	0.658	4.0	4.6	0.180	4.4	4.5	0.918	4.2	4.6	0.351
OPEN	4.0	4.4	3.3	0.202	3.0	4.2	0.313	3.8	4.1	0.718	4.3	3.7	0.512	4.6	3.4	0.150
IND	5.2	6.0	3.6	0.031*	2.9	5.6	0.058.	3.9	5.9	0.076.	7.1	3.6	0.0006**	7.3	3.2	<.0001 ***
NON DESIGNATED	28.0	27.9	28.1	0.876	28.2	27.9	0.862	28.6	27.7	0.496	26.7	29.2	0.048*	28.4	27.5	0.458
Polluting Industry in LAS	20.7	19.3	25.0	0.158	26.4	20.3	0.414	20.7	20.6	0.984	22.1	18.6	0.320	17.2	31.8	<.0001 ***
Grocery Store in LAS	5.9	5.8	6.3	0.349	7.1	5.9	0.383	6.0	5.8	0.760	6.4	5.4	0.052.	5.6	7.1	0.012**
Healthcare Facility in LAS	50.1	47.9	57.0	0.046*	38.0	50.5	0.271	53.9	47.9	0.142	51.4	49.1	0.558	48.7	55.3	0.168
NO2in LAS	26.5	26.2	27.0	0.235	27.7	26.3	0.091.	26.1	26.7	0.336	26.6	26.3	0.619	25.6	27.4	0.001**

Wave1& Wave2 Combined	ALL	PUBLIC TRANSIT			HH VEH			GENDER			HOUSING TENURE			LOW INCOME		
		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=220)	(n=152)	(n=68)	Pr > t	(n=33)	(n=187)	Pr > t	(n=68)	(n=150)	Pr > t	(n=96)	(n=119)	Pr > t	(n=110)	(n=110)	Pr > t
Land Use (Avg. % of LAS)																
RES	48.0	47.2	49.8	0.051.	52.6	47.2	0.002**	48.0	48.1	0.960	47.0	48.6	0.203	45.6	50.4	<.0001***
COM	8.6	8.4	9.0	0.215	7.9	8.7	0.246	9.3	8.2	0.050.	8.5	8.7	0.747	8.6	8.5	0.757
PUB	4.6	4.7	4.6	0.754	4.3	4.7	0.317	4.6	4.6	0.972	4.8	4.5	0.234	4.7	4.6	0.812
OPEN	3.5	3.6	3.4	0.575	2.5	3.7	0.039*	3.3	3.7	0.501	3.7	3.4	0.581	3.9	3.2	0.103
IND	5.1	5.6	4.0	0.018**	2.7	5.5	0.001**	4.7	5.3	0.382	6.0	4.5	0.017**	6.2	4.0	0.000**
NON DESIGNATED	28.1	28.3	27.6	0.460	28.6	28.0	0.627	27.8	28.2	0.686	27.8	28.4	0.577	28.7	27.5	0.213
Polluting Industry in LAS	18.0	17.1	20.8	0.033*	15.3	18.5	0.139	17.8	18.4	0.711	18.4	17.7	0.654	15.7	21.0	0.000**
Grocery Store in LAS	5.8	5.7	6.0	0.545	5.2	5.9	0.174	5.6	5.9	0.367	6.1	5.4	0.026*	5.4	6.5	0.001**
Healthcare Facility in LAS	49.5	46.9	57.5	0.002**	28.1	51.7	<.0001***	50.8	49.0	0.561	48.0	51.0	0.330	48.5	51.5	0.354
NO2in LAS	26.6	26.5	26.8	0.276	27.3	26.5	0.054.	26.3	26.7	0.188	26.8	26.4	0.185	26.0	27.1	0.000**

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

Table 2.2 Size of Location Activity Spaces, Accessibility Level, Exposure Level (Activity Space Path)

Wave1	ALL	PUBLIC TRANSIT			HH VEH			GENDER			HOUSING TENURE			LOW INCOME		
		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=126)	(n=88)	(n=38)	Pr > t	(n=19)	(n=107)	Pr > t	(n=38)	(n=86)	Pr > t	(n=54)	(n=69)	Pr > t	(n=62)	(n=64)	Pr > t
Land Use (Avg. % of LAS)																
RES	41.8	41.0	43.8	0.013**	43.8	41.5	0.126	42.5	41.5	0.419	41.3	42.1	0.505	40.8	42.8	0.058.
COM	10.5	10.7	10.1	0.045*	9.8	10.7	0.022**	10.4	10.6	0.522	10.8	10.3	0.089.	10.8	10.2	0.025*
PUB	5.8	5.8	5.7	0.765	5.6	5.8	0.406	5.6	5.8	0.389	5.8	5.8	0.988	5.9	5.7	0.481
OPEN	3.6	3.6	3.5	0.792	2.8	3.7	0.002**	3.6	3.5	0.701	3.7	3.5	0.295	3.8	3.3	0.016**
IND	6.4	6.8	5.7	0.048*	6.2	6.5	0.669	6.3	6.5	0.675	6.9	6.1	0.112	6.7	6.2	0.367
NON DESIGNATED	28.1	28.2	27.8	0.407	28.3	28.1	0.714	27.8	28.3	0.463	27.8	28.4	0.248	28.1	28.1	0.889
Polluting Industry in LAS	23.4	23.5	22.9	0.839	29.1	22.5	0.070.	22.8	23.8	0.724	21.7	24.1	0.343	21.9	24.7	0.268
Grocery Store in LAS	5.8	5.7	6.2	0.178	7.6	5.6	0.002**	5.8	5.9	0.798	5.3	6.0	0.052.	5.2	6.5	0.001**
Healthcare Facility in LAS	211.6	178.3	284.6	0.005**	119.9	219.0	0.144	213.3	210.2	0.937	154.5	251.7	0.008**	233.7	181.9	0.149
NO2in LAS	26.3	26.3	26.4	0.768	27.1	26.2	0.053.	26.6	26.2	0.299	26.5	26.1	0.235	25.9	26.7	0.056.

Wave2	ALL	PUBLIC TRANSIT			HH VEH			GENDER			HOUSING TENURE			LOW INCOME		
		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=94)	(n=64)	(n=30)	Pr > t	(n=14)	(n=80)	Pr > t	(n=30)	(n=64)	Pr > t	(n=42)	(n=50)	Pr > t	(n=48)	(n=46)	Pr > t
Land Use (Avg. % of LAS)																
RES	41.3	40.0	44.1	0.006**	45.8	40.5	0.006**	41.5	41.2	0.828	40.1	42.3	0.139	38.6	44.0	<.0001
COM	10.6	10.7	10.4	0.446	10.9	10.6	0.449	10.0	10.9	0.029*	10.4	10.7	0.384	10.5	10.7	0.561
PUB	5.9	5.8	6.0	0.420	5.9	5.8	0.800	5.9	5.8	0.932	5.6	6.1	0.103	5.8	5.9	0.607
OPEN	3.4	3.7	2.8	0.027*	2.3	3.6	0.006**	3.4	3.4	0.894	3.9	3.0	0.026*	3.6	3.1	0.058.
IND	6.1	6.6	5.1	0.021**	4.8	6.3	0.073.	5.4	6.4	0.103	7.1	5.2	0.002**	6.9	5.3	0.012**
NON DESIGNATED	29.1	29.3	28.8	0.730	28.1	29.3	0.491	29.8	28.8	0.404	5.2	6.4	0.561	30.0	28.2	0.126
Polluting Industry in LAS	24.3	23.0	27.3	0.240	33.1	23.2	0.057.	25.5	23.7	0.619	18.1	29.1	0.001**	21.3	28.3	0.036*
Grocery Store in LAS	5.9	5.5	7.0	0.017**	8.8	5.6	0.000**	5.7	6.0	0.616	5.0	6.6	0.003**	4.9	7.2	<.0001***
Healthcare Facility in LAS	55.7	53.4	61.3	0.170	64.4	54.7	0.269	59.7	53.8	0.288	50.9	58.9	0.134	53.9	58.1	0.423
NO2in LAS	26.2	25.8	27.0	0.064.	27.7	25.9	0.039*	25.7	26.4	0.299	25.9	26.4	0.419	25.0	27.4	0.0002**

Wave1& Wave 2 Combined	ALL	PUBLIC TRANSIT			HH VEH			GENDER			HOUSING TENURE			LOW INCOME		
		NO	YES		NO	YES		MALE	FEMALE		Own	Rent		NO	YES	
	(n=220)	(n=152)	(n=68)	Pr > t	(n=33)	(n=187)	Pr > t	(n=68)	(n=150)	Pr > t	(n=96)	(n=119)	Pr > t	(n=110)	(n=110)	Pr > t
Land Use (Avg. % of LAS)																
RES	41.6	40.6	43.9	0.000**	44.7	41.1	0.003**	42.1	41.4	0.471	40.8	42.2	0.125	39.9	43.3	<.0001***
COM	10.6	10.7	10.2	0.048*	10.3	10.6	0.247	10.2	10.7	0.042*	10.6	10.5	0.506	10.7	10.4	0.213
PUB	5.8	5.8	5.9	0.676	5.7	5.8	0.711	5.7	5.8	0.614	5.7	5.9	0.231	5.8	5.8	0.925
OPEN	3.5	3.6	3.2	0.057.	2.6	3.7	<.0001 ***	3.5	3.5	0.900	3.8	3.3	0.018**	3.8	3.2	0.003**
IND	6.3	6.7	5.4	0.002**	5.6	6.4	0.131	5.9	2.9	0.156	7.0	5.7	0.001**	6.8	5.8	0.020**
NON DESIGNATED	28.5	28.7	28.2	0.496	28.2	28.6	0.683	28.7	28.5	0.701	28.2	28.8	0.294	28.9	28.2	0.206
Polluting Industry in LAS	23.8	23.3	25.0	0.468	30.6	22.8	0.009**	24.0	23.8	0.912	20.2	26.1	0.004**	21.6	26.0	0.028*
Grocery Store in LAS	5.9	5.6	6.5	0.007**	8.2	5.6	<.0001 ***	5.7	5.9	0.584	5.2	6.3	0.001**	5.1	6.7	<.0001***
Healthcare Facility in LAS	179.1	151.4	241.5	0.001**	105.8	185.4	0.091.	180.1	177.2	0.917	131.1	215.1	0.001**	195.8	156.5	0.126
NO2in LAS	26.3	26.1	26.7	0.098.	27.4	26.0	0.005**	26.2	26.3	0.832	26.2	26.2	0.943	25.6	26.9	<.0001***

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

Table 2.3 Regression analysis results (BE qualities of residential neighborhood and size of location activity spaces)

Dependent Variable:	Model 1.A.1 Wave 1			Model 1.A.2 Wave2		
Size of SDE1	Est.	Pr > |t|		Est.	Pr > |t|	
Intercept	-518.3	0.024	**	-618.9	0.089	.
Ave. Block Size in RN	20.1	0.008	**	-2.9	0.585	
ln(RES in RN)	95.1	0.032	*	157.7	0.065	.
ln(COM in RN)						
ln(PUB in RN)	-19.8	0.194				
ln(OPN in RN)				17.3	0.021	**
Employment Density in RN				0.02	0.007	**
ln(transit stop density in RN)	35.1	0.074	.			
Low Income (1/0)	-15.2	0.344		-35.3	0.033	*
Age						
Living in the same location 10 years or longer (1/0)	-37.2	0.037	*	-4.8	0.749	
Employed (1/0)						
Working at home (1/0)	-12.8	0.457				
N	126			94		
R-sq.	0.1796			0.2377		
Adj. R-sq.	0.0998			0.1705		

Dependent Variable:	Model 1.B.1 Wave1			Model 1.B.2 Wave2		
Ln(Size of ASP)	Est.	Pr > |t|		Est.	Pr > |t|	
Intercept	8.42	0.003	**	3.08	0.301	
Ave. Block Size in RN	0.08	0.471		-0.05	0.465	
ln(RES in RN)	-0.77	0.181		0.32	0.633	
ln(COM in RN)	-0.69	0.044	*	-0.17	0.500	
ln(PUB in RN)	-0.23	0.200		-0.16	0.429	
ln(OPN in RN)	-0.18	0.046	*			
Employment Density in RN						
ln(transit stop density in RN)	0.14	0.612				
Low Income (1/0)	-0.18	0.329		-0.55	0.009	**
Age	-0.01	0.157				
Living in the same location 10 years or longer (1/0)	-0.24	0.289		-0.17	0.409	
Employed (1/0)				0.52	0.025	**
Working at home (1/0)	-0.39	0.054	.			
N	126			94		
R-sq.	0.2904			0.1863		
Adj. R-sq.	0.1394			0.1185		

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

1) RN: Residential Neighborhood (1 mile buffer from individuals' home location)

Table 2.3.A Regression analysis results (NO_2 Exposure)

a) Influence of SES Factors

SDE1

Dependent Variable:	Model 2.A.1		Model 2.A.2		Model 2.A.3	
	Wave 1		Wave2		Wave1 & Wave2	
NO2	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	28.10	<.0001***	27.55	<.0001***	27.88	<.0001***
Transit (1/0)	-0.521	0.056.	-0.095	0.871	-0.311	0.327
HHVEH (1/0)	-0.886	0.018**	-0.366	0.651	-0.716	0.100
Gender (F=1; M=0)						
Renter (1/0)	-0.799	0.002**	-0.486	0.339	-0.852	0.003**
Low Income (1/0)	0.799	0.002**	0.806	0.127	1.036	0.000**
Size of LAS	-0.009	<.0001***	-0.030	<.0001***	-0.016	<.0001***
Work at Home (1/0)						
Employed (1/0)	-0.283	0.212	0.053	0.914	-0.230	0.3841
N	126		94		220	
R-sq.	0.393		0.539		0.401	
Adj. R-sq.	0.361		0.506		0.383	

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

ASP

Dependent Variable:	Model 2.B.1		Model 2.B.2		Model 2.B.3		Model 2.B.4	
	Wave1		Wave2		Wave1 & Wave2		Wave1 & Wave2	
NO2	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	28.15	<.0001***	26.51	<.0001***	27.54	<.0001***	28.03	<.0001***
Transit (1/0)	-0.516	0.383	0.491	0.531	-0.086	0.881	-0.315	0.449
HHVEH (1/0)	-0.716	0.440	0.266	0.805	-0.654	0.451	-0.562	0.325
Gender (F=1; M=0	-0.544	0.302	0.646	0.296	0.034	0.945	0.005	0.989
Renter (1/0)	-1.054	0.046*	-0.213	0.748	-0.742	0.134	-0.546	0.137
Low Income (1/0)	1.329	0.017**	1.496	0.031*	1.492	0.006**	1.179	0.002**
Size of LAS	-0.020	0.002***	-0.027	0.000**	-0.030	<.0001***	-0.023	<.0001***
Work at Home (1/0)	0.249	0.620			0.471	0.344		
Employed (1/0)			-0.924	0.164			-0.759	0.029*
N	126		94		220		220	
R-sq.	0.250		0.320		0.297		0.2621	
Adj. R-sq.	0.173		0.262		0.257		0.2364	

b) Influence of BE Factors within the LAS

SDE1

Dependent Variable:	Model 2.C.1		Model 2.C.2		Model 2.C.3	
	Wave 1		Wave2		Wave1 & Wave2	
NO2	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	39.183	<.0001 ***	17.92	0.005 **	27.957	<.0001 ***
Size of LAS	-0.006	<.0001 ***	-0.02	0.0004 **	-0.007	<.0001 ***
Avg. Block Size of LAS	-0.915	<.0001 ***	-0.33	0.005 **	-0.600	<.0001 ***
Ln(RES in LAS)	-2.918	0.009 **	1.453	0.291	-0.435	0.617
Ln(COM in LAS)	0.959	0.053 .	1.969	0.018 **	1.009	0.016 **
Ln(PUB in LAS)	-0.282	0.262	-0.46	0.276	-0.364	0.099 .
Ln(OPN in LAS)	0.062	0.480	-0.05	0.765	0.068	0.387
EMP Density in LAS	0.000	<.0001 ***	-0	0.127	0.000	<.0001 ***
Transit Access in LAS	0.008	0.0001	0.009	<.0001 ***	0.009	<.0001 ***
Low Income (1/0)	0.322	0.067 .	0.165	0.584	0.269	0.090 .
N	126		94		220	
R-sq.	0.680		0.860		0.784	
Adj. R-sq.	0.654		0.842		0.773	

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

1) LAS: Location Activity Space (Constructed by SDE1 or ASP Method)

ASP

Dependent Variable:	Model 2.D.1		Model 2.D.2		Model 2.D.3	
	Wave1		Wave2		Wave1 & Wave2	
NO2	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	11.739	0.095 .	-20.932	0.019 **	-6.879	0.210
Size of LAS	-0.007	0.123	-0.001	0.905	-0.004	0.319
Avg. Block Size of LAS	-0.647	0.034 *	0.544	0.124	0.082	0.713
Ln(RES in LAS)	2.622	0.071 .	10.240	<.0001 ***	6.820	<.0001
Ln(COM in LAS)	1.514	0.196	0.502	0.766	1.261	0.183
Ln(PUB in LAS)	1.086	0.172	1.405	0.160	1.082	0.080 .
Ln(OPN in LAS)	0.757	0.026 *	0.625	0.169	0.567	0.032 *
EMP Density in LAS	0.000	<.0001 ***	0.000	0.036 *	0.000	<.0001 ***
Transit Access in LAS	0.016	<.0001 ***	0.021	<.0001 ***	0.019	<.0001 ***
Low Income (1/0)	0.014	0.957	0.261	0.572	0.172	0.480
N	126		94		220	
R-sq.	0.573		0.627		0.5817	
Adj. R-sq.	0.539		0.587		0.5636	

Table 2.3.B Regression analysis results (Grocery Store Exposure)

a) Influence of SES Factors

SDE1

	Model 2.A.1		Model 2.A.2		Model 2.A.3		Model 2.A.4	
	Wave1		Wave2		Wave1 & Wave2		Wave1 & Wave2	
	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	2.161	<.0001***	1.892	<.0001***	2.06	<.0001***	1.965	<.0001***
Transit (1/0)	-0.211	0.063.			-0.12	0.257		
HHVEH (1/0)	-0.484	0.002**	-0.156	0.530	-0.36	0.014**	-0.285	0.029*
Gender (F=1; M=0)								
Renter (1/0)	-0.137	0.177	-0.109	0.507	-0.16	0.076.	-0.182	0.045*
Low Income (1/0)	0.211	0.040*	0.290	0.094.	0.28	0.003**	0.277	0.003**
Size of LAS	0.000	0.850	-0.004	0.003**	0.00	0.017**	-0.001	0.018**
Work at Home (1/0)								
Employed (1/0)	-0.007	0.936	-0.031	0.852	-0.03	0.764	-0.020	0.821
N	126		94		220		220	
R-sq.	0.150		0.218		0.1422		0.1363	
Adj. R-sq.	0.104		0.168		0.1156		0.1142	

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

ASP

Dependent Variable:	Model 2.B.1		Model 2.B.2		Model 2.B.3	
	Wave1		Wave2		Wave1 & Wave2	
Grocery Density	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	7.864	<.0001***	7.417	<.0001***	7.682	<.0001***
Transit (1/0)						
HHVEH (1/0)	-1.608	0.0109**	-1.124	0.204	-1.387	0.007**
Gender (F=1; M=0						
Renter (1/0)	0.692	0.090.	1.395	0.019**	0.994	0.004**
Low Income (1/0)						
Size of LAS	-0.012	0.038*	-0.017	0.017**	-0.014	0.001**
Work at Home (1/0)						
Employed (1/0)	-0.585	0.161	-0.759	0.228	-0.662	0.059.
N	126		94		220	
R-sq.	0.195		0.216		0.200	
Adj. R-sq.	0.166		0.179		0.185	

b) Influence of BE Factors within the LAS

SDE1

Dependent Variable:	Model 2.C.1		Model 2.C.2		Model 2.C.3	
	Wave1		Wave2		Wave1 & Wave2	
Log(Grocery)	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	4.745	0.015 **	-1.423	0.431	0.960	0.466
Size of LAS	0.002	0.004 **	0.003	0.046 *	0.001	0.002 **
Avg. Block Size of LAS	-0.289	<.0001 ***	-0.096	0.005 **	-0.130	<.0001 ***
Ln(RES in LAS)	-0.689	0.100	0.408	0.317	0.001	0.997
Ln(COM in LAS)	0.003	0.989	0.462	0.061 .	0.178	0.212
Ln(PUB in LAS)	0.080	0.519	0.317	0.036 *	0.181	0.050 *
Ln(OPN in LAS)	0.025	0.466	-0.010	0.822	0.011	0.677
EMP Density in LAS	-0.0001	0.015 **	- 0.0001	0.012 **	- 0.0001	0.001 **
Transit Access in LAS	0.003	0.003 **	0.003	<.0001 ***	0.003	<.0001 ***
Low Income (1/0)	0.156	0.020 **	0.091	0.298	0.115	0.029 *
N	126		94		220	
R-sq.	0.4709		0.792		0.6389	
Adj. R-sq.	0.4272		0.7644		0.6215	

. p< 0.100 *p< 0.050; ** p < 0.025; *** p < 0.0001

ASP

Dependent Variable:	Model 2.D.1		Model 2.D.2		Model 2.D.3	
	Wave1		Wave2		Wave1 & Wave2	
Grocery Density	Est.	Pr > |t|	Est.	Pr > |t|	Est.	Pr > |t|
Intercept	10.353	0.087 .	0.649	0.922	4.4670	0.306
Size of LAS	0.002	0.519	0.002	0.675	0.0020	0.521
Avg. Block Size of LAS	-0.841	0.002 **	-0.520	0.053 .	-0.6781	0.0002 **
Ln(RES in LAS)	0.480	0.699	0.500	0.731	0.7920	0.391
Ln(COM in LAS)	-3.608	0.001 **	-0.135	0.915	-2.0139	0.008 **
Ln(PUB in LAS)	1.126	0.101	1.336	0.078 .	1.2791	0.010 **
Ln(OPN in LAS)	0.057	0.844	0.067	0.845	0.1872	0.370
EMP Density in LAS	- 0.0002	0.018 **	- 0.0002	0.044 *	-0.0002	0.0004 **
Transit Access in LAS	0.018	<.0001 ***	0.019	<.0001 ***	0.0194	<.0001 ***
Low Income (1/0)	0.662	0.005 **	0.612	0.083 .	0.6721	0.001 **
N	126		94		220	
R-sq.	0.7459		0.7584		0.7408	
Adj. R-sq.	0.7261		0.7322		0.7925	

1) LAS: Location Activity Space (Constructed by SDE1 or ASP Method)

Table 3.1 Built Environment and SES Characteristics (t-test; block group level)

	All BGs (n = 8179)	BGs w/ Subsidized (n = 5897)	p> |t|		BGs w/ Subsidized in LA (n = 4673)	BGs w/ Subsidized in OC (n = 1224)	p> |t|		BGs w/ HCV (n = 5875)	BGs w/ LIHTC (n = 570)	p> |t|	
Traffic												
Areas impacted by high/medium-traffic in a BG, %	38.7	42.3	<.0001	***	50	42.8	<.0001	***	47	51	<.0001	***
Air Quality												
Average NO_2 concentration (ppb)	23.7	24.7	<.0001	***	26.1	22.2	<.0001	***	25.1	25.6	<.0001	***
Economic activities												
Employees/acre in a BG	6.1	6.3	0.410		11.1	6.1	<.0001	***	7.6	14.3	<.0001	***
Walkability / Intersections												
Intersection Density (per acre)	0.4	0.5	0.147		0.5	0.4	<.0001	***	0.4	0.4	0.066	
Public transportation												
Coverage of areas accessible to transit stops in a BG, %	78.5	85	<.0001	***	92.1	77.4	<.0001	***	89.8	87.5	<.0001	***
Land use composition												
Residential in a BG, %	47.9	48.4	0.135		43.6	41.8	0.005	**	47.7	35.5	<.0001	***
Commercial in a BG, %	8.9	9.8	<.0001	***	13.3	14.4	0.003	**	11.6	16.8	<.0001	***
Public in a BG, %	5.7	5.9	0.334		7	8.9	<.0001	***	6.4	9.2	<.0001	***
Industrial in a BG, %	3.4	3.6	0.250		3.6	4.4	0.004	**	3.3	4.6	<.0001	***
Open space in a BG, %	2.9	2.3	<.0001	***	1.3	4	<.0001	***	1.8	2.1	0.017	*
Non-parcel in a BG, %	24.3	25	<.0001	***	25.9	20.6	<.0001	***	24.9	24.6	0.092	
Block Size												
Average bock size in a BG, acre	29.1	9.2	0.009	**	9.9	22.7	0.001	***	7.2	22	<.0001	***
Racial composition												
White in a TR, %	55	50.2	<.0001	***	41.4	52.9	<.0001	***	43.8	43.9	0.977	
Black in a TR, %	7.5	9.1	<.0001	***	17.2	2.2	<.0001	***	15.3	11.9	<.0001	***
Ethnicity												
Non-Hispanic white in a TR, 2005-2009	35.2	27.1	<.0001	***	18.5	32.3	<.0001	***	21.8	20.8	0.082	
Hispanic in a TR, 2005-2009	42	49.4	<.0001	***	52.4	42.6	<.0001	***	49.5	51.6	0.001	**
Immigration												
Foreign-born in a TR, %	32.5	35.8	<.0001	***	39.2	38.4	0.078		38.4	40.1	<.0001	***
Economic status												
Poverty rates in a TR, 2005-2009, %	13.6	15.8	<.0001	***	24.7	13.5	<.0001	***	20.5	25.4	<.0001	***
Average income in a TR, 2005-2009, USD	30189.5	24336.7	<.0001	***	18944.1	24695.1	<.0001	***	20287.5	19952.4	0.226	
Unemployment rates in a TR, 2005-2009, %	7.5	8.1	<.0001	***	10.1	7.6	<.0001	***	9.3	10.1	<.0001	***
Renters in a TR, %	46.3	52.1	<.0001	***	69.3	54.2	<.0001	***	63.6	70.3	<.0001	***

*p< 0.01; ** p < 0.001; *** p < 0.0001

Table 3.2 Built Environment and SES Characteristics (t-test; city level)

	All Cities (n = 170)	Cities w/ Subsidized (n = 155)	p> |t|	Cities w/ Subsidized in LA (n = 117)	Cities w/ Subsidized in OC (n = 38)	p> |t|		Cities w/ HCV (n = 154)	Cities w/ LIHTC (n = 91)	p> |t|
Traffic										
Areas impacted by high/medium-traffic in a City, %	28.6	30.6	0.319	31.8	36.2	0.062		33.7	31.1	0.090
Air Quality										
Average NO_2 concentration (ppb)	21.8	21.5	0.352	21.5	21.6	0.924		21.7	21.1	0.280
Economic activities										
Employees/acre in a City	4.2	5.3	0.833	5.3	5.5	0.629		5.4	5.3	0.785
Walkability / Intersections										
Intersection Density (per acre)	0.3	0.2	0.519	0.2	0.3	0.003	**	0.3	0.2	0.228
Public transportation										
Coverage of areas accessible to transit stops in a City, %	59.4	62.4	0.263	61.7	65.1	0.325		63.8	59.9	0.096
Land use composition										
Residential in a City, %	40.8	36.3	0.777	35.6	38.9	0.055		36.9	35.3	0.169
Commercial in a City, %	7	8.9	0.305	8.3	11.3	<.0001	***	8.9	8.9	0.971
Public in a City, %	5.8	5.5	0.668	5.2	6.8	0.000	***	5.5	5.5	0.941
Industrial in a City, %	6.2	5.1	0.685	4.8	6.4	0.089		5.1	5.2	0.810
Open space in a City, %	4.7	3.7	0.685	3	6.1	<.0001	***	3.6	3.8	0.720
Non-parcel in a City, %	21.4	22.9	0.616	23.5	20.5	0.028	*	23.3	22.3	0.322
Block Size										
Average bock size in a City, acre	26.5	9.5	0.199	8.2	14.1	0.004	**	8.8	10.6	0.196
Racial composition										
White in a city, %	55.2	51	0.762	49.7	56.1	0.006	**	50.7	51.5	0.615
Black in a city, %	6.2	8.9	0.731	10.7	2	<.0001	***	9.3	8.1	0.302
Ethnicity										
Non-Hispanic White in a city, 2005-2009	35.7	30	0.553	28.3	36.6	0.007	**	29.8	30.3	0.807
Hispanic in a city, 2005-2009	38.9	46	0.482	47.9	38.7	0.006	**	45.8	46.5	0.764
Immigration										
Foreign-born in a city, %	28.7	36.2	0.429	36.4	35.5	0.594		36.4	35.9	0.696
Economic status										
Poverty rates in a city, 2005-2009, %	10.4	16.2	0.320	17.6	11.1	<.0001	***	16.3	16.1	0.754
Average income in a city, 2005-2009, USD	32374.3	26294.5	0.210	25928.2	27707.2	0.251		26067.4	26686.3	0.549
Unemployment rates in a city, 2005-2009, %	6.8	8	0.487	8.3	7.1	<.0001	***	8.1	7.9	0.387
Renters in a city, %	37	53.5	0.192	56.2	43	<.0001	***	54.1	52.5	0.314

*p< 0.01; ** p < 0.001; *** p < 0.0001

Table 3.3 Logistic Regression on Probability of a BG had Subsidized Units

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	All Subsidized in LA/OC	**HCV in LA/OC**	**LIHTC in LA/OC**	**HCV in LA**	**HCV in OC**	**LIHTC in LA**	**LIHTC in OC**
Air quality							
Average NO_2 concentration (ppb)	-0.016 **	-0.038 ***	-0.006 *	-0.038 ***	0.079 ***	-0.019 ***	0.022 **
Public transit access							
Coverage of areas accessible to transit stops in a BG, %	0.016 ***	0.021 ***	0.003 ***	0.022 ***	0.013 ***	0.004 ***	0.001
Land use composition							
Mixed use (BG|Mixed Use = Yes) [1]	1.675 ***	1.299 ***	1.770 ***	1.606 ***	0.878 ***	1.643 ***	1.866 ***
Walkability measure							
Average block size in a BG / 100, Acres	0.020 ***	0.027 ***	0.057 ***	-0.008	0.000	0.045 ***	0.132 ***
Demographic/Socioeconomic status							
Black in BG, %	0.059 ***	0.025 ***	0.007 ***	0.058 ***	0.022	0.005 ***	0.097 ***
Non-Hispanic White in BG, 2005-2009	-0.034 ***	-0.035 ***	-0.001	-0.034 ***	-0.035 ***	0.000	-0.011 ***
Poverty rates in BG, 2005-2009, %	0.113 ***	-0.002	0.087 ***	0.103 ***	0.111 ***	0.090 ***	0.045 ***
County Flag							
(BG|LA=Yes)	-1.455 ***	-0.906 ***	-0.818 ***				
# of Subsidized BGs	5,897	5,875	570	4,655	1,220	468	102
Total BGs in Study Area	8,179	8,179	8,179	6,353	1,826	6,353	1,826

*p< 0.05; ** p < 0.025; *** p < 0.0001
Note 1: Residential Land Use > 33.3% and Commercial Land Use > 33.3%

Table 3.4 Logistic Regression on Probability of a city had Subsidized Units (city level)

	Model 1	Model 2	Model3	Model 4	Model 5	Model 6	Model 7
	All Subsidized in LA/OC	**HCV in LA/OC**	**LIHTC in LA/OC**	**HCV in LA**	**HCV in OC**	**LIHTC in LA**	**LIHTC in OC**
Air quality							
Average NO_2 concentration (ppb)	0.05	0.13 *	0.01	0.26 ***	69.0	0.0	0.0
Public transit access							
Coverage of areas accessible to transit stops in a City, %	0.01	0.03	0.00	0.04 ***	-17.6	0.0	0.0
Land use composition							
Mixed use (City|Mixed Use = Yes) [1]	0.39	1.94	0.96	11.62 ***	-249.9	16.4	-21.1
Walkability measure							
Average block size in a City / 100 (Acres)	-0.69 *	-0.58	-1.99	-7.19 ***	-110.2	-1.8	-4.4
Demographic/Socioeconomic status							
Black in BG, %	1.03 **	0.81 *	-0.01	1.37 ***	1021.3	0.0	0.8
Non-Hispanic White in BG, 2005-2009	-0.01	0.01	-0.01	0.09 ***	-7.2	0.0	0.0
Poverty rates in BG, 2005-2009, %	1.24 ***	0.67 ***	0.09 **	1.11 ***	238.4	0.1	0.4 *
County Flag							
(City|LA=Yes)	-5.80 ***	-5.11 ***	-1.42 ***				
# of Subsidized Cities	155	154	91	116	38	65	26
Total Cities in Study Area	170	170	170	128	42	128	42

*p< 0.05; ** p < 0.025; *** p < 0.001
Note 1: Residential Land Use > 33.3% and Commercial Land Use > 33.3%

Table 4.1 Previous studies of pPAH concentrations (ng/m^3) in transportation and roadway microenvironments

Microenvironment	Location / Time / Citation	Description	PAH level (ng/m^3)	Important Factors
walking	Brooklyn, NY June, 2007 (Zwack et al., 2011)	Walking outdoors within Williamsburg neighborhood with major bridge and highway	• Mean: 76 (SD: 55)	• None identified
in-vehicle	California highways January, 2002 (Ott and Siegmann, 2006)	In-cabin measurements in passenger vehicles on residential arterials and interstate highways	• Two 11.8 mi trips on arterial highway in CA: 26-28 (Max:~140) • Two 300-400 mi trips on CA Interstate 5: 44-50 (SD:48-64)	• Following trucks and diesel vehicles
	Los Angeles, CA May-June, 2002 (Sabin et al., 2005)	In-cabin measurements inside school buses of different fuel types	• Following a diesel vehicle: Avgs of 110-550, Max of 1,000-2,000 • Not following a diesel vehicle: Avg.of 42-290, Max of 160-1,600	• Following a diesel bus or vehicle • Window configuration (open/closed) • Vehicle self-pollution
	Seattle, WA summer 2005 (Liu et al., 2010)	In-cabin measurements in two diesel school buses during operation on residential route(little truck traffic)	• Mean: 54 (SD: 42, Range: 0-259)	• Vehicle self-pollution • Window configuration (open/closed)
	Wake County, NC August-October, 2001 (Riediker et al., 2003)	In-cabin measurements in two police patrol cars	• Mean: 21.5 (SD: 10.3-33.1)	• Traffic volumes
	Zurich-Berne, Switzerland June-July 2000 (Leutwyler et al., 2002)	In-cabin measurements in passenger electrified train coaches on 75 minute route	• Non-smoking cabin: 30-48 (SD: 30-70) • Smoking cabin: 253-275 (SD: 277-306)	• Smoking
on-roadway	Los Angeles, CA February-April, 2003 (Westerdahl et al., 2005) (Fruin et al., 2008)	On-roadway concentration measurements using zero-emission vehicle	• On freeways: Range ~100-300 • On arterials: Range ~10-50	• Roadway type (arterial vs. interstate) • Diesel truck density • Time of day • Vehicle accelerations
roadside	Bangkok, Thailand August-September 2000 (Hoshiko et al., 2012)	Fixed-site measurements at roadside (74,000-92,000 average vehicles/day)	• Range at Roadside: about 0-350	• Traffic Flow • Time of Day • Atmospheric dilution and inversion
	Fresno, CA February 2002 to 2003 (Noth et al., 2011)	Fixed-site measurement outdoor homes	• Mean: 6 (Range: 0.7-57.1)	• Winter, Wind direction, Humidity • Road types • Total Length of Highway
	Roxbury, MA July-August 2001 (Levy et al., 2003)	Fixed-site outdoor measurements at roadside and 25, 50, 75m from roadway	• Mean: 18 (Range: 4 – 57)	• Distance to source of pollutants • Wind direction • Total traffic, diesel vehicles
	Tokyo, Japan August-September 2000 (Chetwittayachan et al., 2002)	Fixed-site measurements at roadside and 100, 250, 520 m from roadway	• Range at Roadside: about 0-150 • Range away from roadside: about 0-50	• Traffic Flow • Time of Day • Distance from roadway • Wind speed and direction
mixed	Mexico City, Mexico December, 2001 (Velasco et al., 2004)	Outdoor, indoor, near-roadway and in-vehicle measurements	• Outdoor Sites Range incl. subway/bus stations: 17-582 • Underground Subway Stations Range ~10-250 • Roadway Sites: 173 • 2-hour car trip: Average 180	• Proximity to traffic sources • Diesel truck and bus traffic • Gross-emitting vehicles • Rapid acceleration
	Roxbury, MA July-August 1999 (Levy et al., 2001)	Walking outdoors within 1 mile of large bus terminal / Fixed-site outdoor rooftop measurements near terminal	• Walking: 29 (SD: 54) • Fixed: 9 (SD: 26)	• On bus routes • Road class • Distance from bus station • Temperature • Relative humidity

Table 4.2. Average percent of time spent by location types (Stay-Home days excluded)

		Gender			Car Ownership			Foreign Born Status			Income Level		
	Mean	Female (n=45)	Male (n=55)	P>|t|	Car (n=70)	No Car (n=30)	P>|t|*	FB (n=70)	NFB (n=30)	P>|t|*	<24k (n=72)	24-50k (n=28)	P>|t|*
Non-Travel Periods													
Residential	77.36	78.36	76.54	0.599	77.35	77.39	0.991	79.73	71.82	0.034 *	76.24	80.25	0.296
Service	3.06	2.38	3.62	0.441	4.17	0.47	0.033 *	3.89	1.13	0.114	1.78	6.35	0.010 **
School	2.51	2.31	2.67	0.805	1.16	5.66	0.004 **	1.38	5.15	0.016 **	2.29	3.07	0.63
Retail	5.26	8.91	2.28	0.000 ***	6.83	1.6	0.009 **	6.11	3.28	0.163	6.56	1.93	0.025 **
Recreational	3.13	0.89	4.97	0.015 **	3.84	1.48	0.198	1.08	7.92	0.000 ***	3.87	1.23	0.158
Food	1.37	0.67	1.94	0.196	0.72	2.9	0.039 *	0.53	3.34	0.007 **	1.58	0.83	0.488
Ind/Off/Other	1.63	1.6	1.67	0.959	0.76	3.68	0.044 *	1.88	1.07	0.581	1.98	0.73	0.402
Travel Periods													
Vehicle	3.04	2.58	3.42	0.232	3.26	2.53	0.334	2.74	3.73	0.189	2.71	3.89	0.124
Train	0.1	0.08	0.11	0.724	0.02	0.26	0.033 *	0.06	0.17	0.341	0.13	0	0.246
Bus	0.51	0.48	0.53	0.896	0.09	1.49	0.002 **	0.46	0.63	0.707	0.48	0.58	0.841
Bus Stop	0.46	0.38	0.52	0.560	0.24	0.98	0.005 **	0.43	0.54	0.682	0.54	0.24	0.272
Pedestrian	1.54	1.34	1.71	0.531	1.54	1.55	0.989	1.69	1.2	0.441	1.8	0.88	0.152
Total	100	100	100		100	100		100	100		100	100	

*p< 0.05; ** p < 0.025; *** p < 0.001

Table 4.3 Means of Key Variables Used in Regression Analysis

Variables	All Periods	Non-Travel Periods	In-Vehicle Periods	Outdoor Travel Periods
Total Minutes	132,654	125,328	4,949	2,377
Total Days				
Participants				
pPAH (ng/m3): 1-min interval	18.13	10.36	137.21	179.86
Log of pPAH (ng/m3): 1-min interval	1.40	1.22	4.45	4.69
Periods in Boyle Heights	0.82	0.85	0.27	0.69
Microenvironment				
Non-Travel Place, Residential (1/0)	0.78	0.83		
Non-Travel Place, Non-Residential (1/0)	0.16	0.17		
Travel Outdoors, Transit Stations (1/0)	0.00			0.15
Travel Outdoors, Walking (1/0)	0.02			0.85
Travel In-Transit, Bus/LRT (1/0)	0.01		0.16	
Travel In-Vehicle, Passenger in Vehicle or Truck (1/0)	0.03		0.84	
Nearby Land Use within 100m				
Total Employment	0.06	0.06	0.14	0.18
% of Commercial Land Use	0.12	0.11	0.16	0.23
% of Residential Land Use	0.16	0.16	0.11	0.07
Mixed Use Area (25% of Com. And 25% of Res.) (0/1)	0.13	0.13	0.12	0.15
% of Non-Parcel Area	0.32	0.31	0.44	0.31
Transportation Infrastructure				
On-Freeway Travel (0/1)	0.01	0.00	0.28	0.00
Total Number of Intersections Within 100m	2.88	2.83	3.93	3.03
100 Meters to High Traffic Roadways	6.21	6.23	4.77	7.95
Meteorology (Hourly Average)				
Wind Speed (mph)	0.84	0.81	1.29	1.12
Temperature (F)	60.36	60.22	62.32	63.18
Relative Humidity (%)	61.88	62.29	55.72	52.26
Time of Day (0/1)				
Morning (7 - 11am)	0.17	0.17	0.26	0.23
Midday (11am - 3pm)	0.17	0.17	0.27	0.25
Early Evening (3 - 7pm)	0.16	0.15	0.29	0.38
Personal Characteristics (0/1)				
female	0.45	0.46	0.39	0.41
young	0.29	0.29	0.37	0.24

Table 4.4 Results of Regression: Log of pPAH(ng/m³) concentration (1-minute interval)

Explanatory Variables	Model 1 All Periods		Model 2 Non-Travel Periods		Model 3 In-Vehicle Travel Periods		Model 4 Outdoor Travel Periods	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Intercept	1.97	***	1.92	***	5.64	***	3.50	***
Boyle Heights Area (0/1)	0.13	***	0.17	***	-0.17	**	-0.04	
Microenvironment								
Non-Travel Place, Residential (the excluded category)								
Non-Travel Place, Non-Residential (1/0)	0.69	***	0.75	***				
Travel Outdoors, Transit Stations (1/0)	2.80	***					-1.21	***
Travel Outdoors, Walking (1/0)	3.84	***						
Travel In-Transit, Bus/LRT (1/0)	2.99	***			-0.27	***		
Travel In-Vehicle, Passenger in Vehicle or Truck (1/0)	3.40	***						
Nearby Land Use within 100m								
Total Employment	0.01		-0.06	**	0.11	*	0.09	*
% of Commercial Land Use	-0.37	***	-0.41	***	-0.09		-0.46	**
% of Residential Land Use	0.03		0.07	***	-0.41	**	-0.76	**
Mixed Use Area (25% of Com. And 25% of Res.) (0/1)	-0.01		0.01		-0.04		-0.16	*
% of Non-Parcel Area	1.58	***	1.78	***	0.22		2.12	***
Transportation Infrastructure								
On-Freeway Travel (0/1)	0.03				0.13			
Total Number of Intersections Within 100m	-0.08	***	-0.09	***	-0.01		-0.18	***
100 Meters to High Traffic Roadways	-0.01	***	-0.01	***	-0.02	***	-0.06	***
Meteorology (Hourly Average)								
Wind Speed (mph)	-0.14	***	-0.14	***	-0.11	***	-0.05	*
Temperature (F)	-0.01	***	-0.01	***	-0.01	**	0.01	
Relative Humidity (%)	0.00	***	0.00	***	0.00		0.01	**
Time of Day (0/1)								
Morning (7 - 11am)	0.25	***	0.25	***	0.19	**	0.44	***
Midday (11am - 3pm)	0.10	***	0.09	***	0.31	***	0.43	***
Early Evening (3 - 7pm)	0.11	***	0.11	***	0.17	**	0.36	***
Personal Characteristics (0/1)								
female	0.15	***	0.14	***	-0.20	***	0.61	***
young	-0.32	***	-0.32	***	-0.64	***	0.28	**
Adj. R-Square	0.36		0.09		0.10		0.31	
N	122,461		115,836		4,583		2,042	

Table 4.5. Regression results: Log of pPAH (ng/m^3) concentrations (SDE1 level)

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	6.229	2.356	2.644	0.017	*
Traffic					
Areas impacted by high/medium-traffic (%)	0.019	0.006	3.332	0.004	**
Economic activity					
Employees / 100 acres	-0.005	0.005	-0.909	0.375	
Transit					
Log, Areas accessible to transit stops (%)	2.556	1.809	1.413	0.175	
Walkability					
Log, Average block size (acre)	0.595	0.476	1.249	0.228	
4-or more-way intersection / acre	-0.013	0.006	-2.379	0.029	*
Land use					
Percent of residential land use	-0.016	0.014	-1.181	0.253	
Percent of commercial land use	0.089	0.052	1.717	0.103	
Adjusted R-Square	0.504				
N	26				

Significance: * p < .05. ** p < .01. *** p < .001.

Table 4.6. Regression results: Log of pPAH (ng/m^3) concentrations (ASP level)

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.405	2.492	-0.163	0.8726	
Traffic					
Areas impacted by high/medium-traffic (%)	0.033	0.028	1.189	0.25	
Economic activity					
Employees / 100 acres	0.003	0.005	0.533	0.6006	
Transit					
Areas accessible to transit stops (%)	6.777	2.737	2.476	0.0235	*
Walkability					
Average block size (Acre)	71.885	155.751	0.462	0.6499	
4- or more-way intersection / acre	-0.057	0.021	-2.753	0.0131	*
Land use					
Residential (%)	-0.027	0.020	-1.334	0.1987	
Commercial (%)	0.055	0.065	0.853	0.4047	
Adjusted R-Square	0.479				
N	26				