FINAL REPORT

Effects of Complete Streets on Travel Behavior and Exposure to Vehicular Emissions

Contract Number 11-312

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I. DISCLAIMER

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VI. ABSTRACT

In this study, we aimed to answer how complete streets as compared to incomplete streets impact travel behavior and street users' exposure to traffic-related air pollutants. We employed two empirical study designs: a natural experimental design using before-after comparisons and a quasi-experimental design using a spatial difference-in-difference (DID) approach.

In the before-after study, we investigated volume of motorized vehicles, cyclists, and pedestrians as well as exposures to fine (PM2.5) and ultrafine particles (UFP) among drivers, cyclists, and pedestrians before and after two complete street retrofit projects. We also conducted a neighborhood survey in an area adjacent to one of the study sites before and after the retrofit. In the DID study, we selected six pairs of streets to represent the diversity in road types and land use contexts. Each pair comprised of one complete street and one parallel incomplete street. We measured PM2.5 and UFP concentrations as well as traffic, pedestrian, and cyclist volume on each pair of streets to investigate the difference between complete and incomplete streets. We also conducted road-side intercept surveys at these six sites to assess street users' perceptions of the streets.

Results from the before-after study showed that the emission-weighted traffic volume decreased 26% at one of the study sites, but it is not determined whether the decrease were caused by natural fleet turnover or the complete street retrofit (or both). Even so, this change may explain the observed significant decrease of UFP concentrations after street retrofit. At the other site, the total traffic volume decreased 16% after the retrofit but no significant difference was observed in the background-subtracted UFP and PM2.5 concentrations. The neighborhood survey results showed that the complete street retrofit project has resulted in an increase of recreational biking and some increase in using biking and walking to access public transit. In addition, the survey results revealed that important barriers keeping people from biking, walking, and taking transit more. The DID study results showed that for three out of the six pairs, the complete streets had significantly lower UFP concentrations than the incomplete streets, while all six pairs showed similar PM2.5 concentrations. Three out of six sites had lower total traffic volume on the complete streets compared with the incomplete streets, while two other sites showed just the opposite, and one site showed no significant difference. Higher pedestrian and cyclist volumes were found on complete street at some but not all sites. The road-side intercept survey at the six sites showed that the street users believed that compared with the incomplete street, the complete street: (1) had more shade, (2) had more interesting things to do, (3) was more secure to walk on, (4) was easier to cross. However, the retail establishments on the streets also likely to affect the pedestrian and cyclist volume, as found at one of the study sites. Overall, the findings of this study, although preliminary and difficult to generalize, suggest that the complete streets have favorably impacted some, but not all, tested parameters and the differences between complete and incomplete streets are site-specific and vary greatly depending on the location and function of the complete streets.

VII. EXECUTIVE SUMMARY

BACKGROUND

Increasing numbers of communities have adopted complete streets. However, there is surprisingly little evidence on whether and how complete streets result in travel behavior changes, which generate claimed benefits. Do complete streets actually reduce driving or do they add more walking and bicycling trips? Are complete streets equally effective in different land use contexts? What are the important barriers that keep people from driving less and taking more walking, biking, and/or transit trips? This study aimed to address above research questions by collecting questionnaire data, traffic data, and on-road air quality data in the Greater Los Angeles Area. It helps to fill the knowledge gap of the impacts of complete streets provisions on travel behavioral response and on personal exposure to traffic-related air pollutants.

METHODS

This study employed two empirical designs: a natural experimental design using before-after comparisons and a spatial difference-in-difference (DID) approach. For the before-after comparison design, travel behavior data and air pollutant exposure data were collected on a section of an incomplete street before and after it had been converted into a complete street. This part included two complete streets retrofit projects, one on the Ocean Park Boulevard and the other on Michigan Avenue, both in Santa Monica, California. A neighborhood survey was conducted in the most adjacent area of the Michigan Avenue site. We contacted 600 addresses before the project and received valid responses from 165 addresses. We contacted the same 600 addresses after the project and got valid responses from 188 addresses. Researchers collected on-road air quality data on the Ocean Park Boulevard site for nine test days before the retrofit in 2011 and five test days after the retrofit in 2013. Researchers also collected on-road air quality data on the Michigan Avenue for two test days in 2014 before the retrofit and again in 2015 after the retrofit. For the DID study, we collected road-side intercept survey data and air pollutants exposure data on twin-streets, each comprised of a complete street and a parallel incomplete street. A pair of twin-streets was identified at each of the six study sites: Downtown LA, Santa Monica, Long Beach, Willowbrook, Glendale, and Northridge, which include three different types of locations (downtown, urban, and suburban) and three different functions (business, mixed, and residential). We conducted measurements for a total of 24 test days, ranging from October 2013 to March 2015, on these six pairs of twin-streets. On each test day, a survey on travel behaviors and street users' perceptions was conducted by intercepting and surveying street users on both streets. In addition, researchers concurrently measured on-road UFP and PM2.5 concentrations on the twin-streets by using two sets of portable instruments. On each test day, we conducted three two-hour sessions, including a morning session, a noon session, and an afternoon session, in order to capture the differences in traffic and street users' activities throughout the day.

RESULTS AND DISCUSSION

The before-after study conducted on Ocean Park Boulevard showed that, background-subtracted UFP concentrations significantly decreased by 4200 particles per cm^3 after the complete street retrofit, but PM2.5 did not change significantly. This change in UFP concentrations may be explained by the observed fact that, the emission-weighted traffic volume (which reflected the composition of light-duty and heavy-duty vehicles) dropped 26%, which is statistically significant. The before-after study conducted on Michigan Avenue showed that the total traffic volume was reduced by 16% after the retrofit but the background-subtracted on-road UFP and PM2.5 concentrations were similar before- and after-retrofit. The results of a neighborhood survey conducted in the areas adjacent to Michigan Avenue suggested that the Michigan Avenue Neighborhood Greenway (MANGo) project has resulted in an increase in recreational biking and some increase in using biking and walking to access public transit. We found recreational biking increased from an average of 0.6 day before the MANGo project to an average of 0.8 day after the MANGo project. But it does not seem that the MANGo project has meaningfully changed the main mode of commuters. In addition, the survey results revealed that the important barriers keeping people from biking more include “too busy”, “too many things to carry”, “too many cars in traffic”, “fast traffic”, “not enough bike lanes or wide curb lanes”, and “unsafe street crossings”. Major barriers keeping people from walking more include “too busy” and “I simply do not like walking”. Major barriers to taking transit include “(transit) does not accommodate my schedule”, “(transit) does not get me to where I want to go”, and “transit vehicles are too slow”.

The DID study results showed that, three out of the six sites had overall significantly higher average UFP concentrations on the incomplete streets. When we pooled data from all six sites together, the average UFP concentrations and PM2.5 on complete streets were 1300 particles per cm^3 and 0.3 µg per m^3 lower than those on incomplete streets, respectively, and both differences were statistically significant. The traffic volume data were more complicated: three sites showed that incomplete streets had significantly higher traffic volume than its twin complete streets, two other sites showed the opposite, and one site showed similar traffic volume. For street users, the Downtown LA complete street had 500 per hour more pedestrians when compared with those on the incomplete street. This difference was one to two orders of magnitude higher than the differences observed at the other five sites. With a total of 714 refusals, the total 774 completed surveys collected from these six sites showed that street users believed that complete streets provided more shade, were more interesting, easier to cross , and made the pedestrians feel safer than incomplete streets.

CONCLUSIONS

Overall, the preliminary findings of this study suggest that the complete streets have favorably impacted some, but not all, tested parameters. This study provides CARB a first set of information on the impact of complete streets on travel behavior and street users’ exposure. It should be noted that the results of this project are preliminary and more research is needed to explain the potential impacts of complete street designs on the travel behavior and street users’ exposure. The results of this project suggest that there are many other factors, such as time from street retrofit, need to be included in future research, to provide a set of comprehensive evidence for decision making.

1 INTRODUCTION

1.1 Complete Streets Movement

With growing interests in travel demand management, smart growth, climate change mitigation, and transportation safety and equity, increasing numbers of communities have adopted complete streets policies to make streets accessible for all users – drivers, transit users, pedestrians, cyclists, seniors, children, and people with disabilities. During the past few years, the number of state and local jurisdictions adopting complete streets policies increased rapidly in the U.S.

California is the second state to adopt a state-wide complete streets policy. In September 2008, Governor Schwarzenegger signed into law Assembly Bill (AB) 1358, the Complete Streets Act, which requires "commencing January 1, 2011, that the legislative body of a city or county, upon any substantive revision of the circulation element (transportation section) of the general plan, modify the circulation element to plan for a balanced, multimodal transportation network that meets the needs of all users of streets, roads, and highways, defined to include motorists, pedestrians, bicyclists, children, persons with disabilities, seniors, movers of commercial goods, and users of public transportation, in a manner that is suitable to the rural, suburban, or urban context of the general plan." AB 1358 was quickly followed by an update of Caltrans' internal policy to adopt complete streets and a Complete Streets Implementation Action Plan issued by the Governor's Office of Planning & Research. According to the State's Annual Planning Survey, by 2010, at least 219 out of the 539 cities and counties (based on survey responses from 462 of the 539 cities and counties) had adopted complete streets policies and/or programs through their general plan, transportation plan, bicycle/pedestrian plan, and/or street design standards.

The Complete Streets Act also demonstrates a parallel effort to the Sustainable Communities and Climate Protection Act (SB 375), a State law targeting greenhouse gas emissions from passenger vehicles. SB 375 was the first attempt among states to connect land use and AB 32 ("The Global Warming Solutions Act"), which requires the State of California to reduce greenhouse gas emissions to 1990 level by the year 2020. SB 375 promotes smart growth by advocating compact, transit-oriented, walkable, bicycle friendly land use, including complete streets and mixed-use development. Both Complete Street Act and SB 375 encourage people to decrease their dependence on driving passenger vehicles, thus reducing vehicle miles traveled (VMT) and associated emissions, enhancing active travel, and reducing transportation costs.

However, there is surprisingly little evidence on whether and how complete streets result in travel behavior changes (e.g., the frequency and mode choice of travelers), which generate the above claimed benefits. Do complete streets actually reduce driving or do they simply add more walking and bicycling trips? Which sub-group of the population benefits the most from complete streets? Are complete streets equally effective in different land use contexts? What are the important barriers that keep people from driving less and taking more walking, biking, and/or transit trips? Although the relationship between the built environment and travel behavior has been an active research field by transportation, planning, and health scholars for some time, most studies focus on the land use density, diversity, and/or network pattern (e.g., street connectivity) of the built environment. There exists little evidence on how street design impacts travel behavior based on rigorous research design and real-world data.

It is important to note that although the term "complete streets" is becoming a well-known concept, there is no widely- agreed upon engineering definition of a complete street besides various best practice recommendations. As stated in AB 1358, the exact form of a complete street is context-based. For example, sidewalks may be a necessary element for all complete arterial and residential streets, whereas marked bicycle lanes may not be necessary and can be substituted with wide shoulders or sidewalks in lower-density areas. Similarly, transit stops/lanes are needed only when transit route(s) exist. However, no matter what the design details are, all complete streets are designed to support multiple forms of transportation, not just motor vehicles. In this study, we define complete streets by adopting the minimum standards based on the most updated design manuals published by the Institute of Transportation Engineers (2010) and Los Angeles County (2011).

1.2 Relevant Literatures

The relationship between the built environment and travel behavior has been an active research field by transportation and planning scholars primarily due to the interest in using a better planned built environment to reduce dependence on driving, traffic congestion, and related environmental and health impacts (e.g., climate change, energy shortage, air pollution, and lack of physical activity). There have been several reviews of this literature, such as Crane (2000), Handy (2005), Guo and Chen (2007), Mokhtarian and Cao (2008), and Ewing and Cervero (2010). Most studies have shown that features of the built environment, such as the "three Ds" (density, diversity or land use mix, and design related to comfort and safety of travelers) and street pattern (especially connectivity), were often associated with travel behaviors including trip frequency, trip distance, mode choice, etc. For example, both increased intersection density and additional street connectivity were associated with more walking, biking, and transit use among census population groups in 24 California cities (Marshall and Garrick 2010).

Most of the previous studies on the impacts of complete streets focused on the aspects of urban development (LaPlante 2007; Walljasper 2008; Lynott, Haase et al. 2009; Holzer and Lockrem 2011), transportation planning (Carter, Martin et al. 2013), and policy making (LaPlante and McCann 2008; Heinrich, Aki et al. 2011; Dodson, Langston et al. 2014; Tolford, Renne et al. 2014). Complete streets have been shown to increase public and agency awareness of pedestrian and bicycle safety issues (Geraghty, Seifert et al. 2009), improve the pedestrian and cyclist experience (Elias 2011), and result in only a small percentage cost increase in project budgets (Shapard and Cole 2013). In a recent report (Perk, Catalá et al. 2015), the complete streets were found to have a strong association with increased economic activity, in addition to their safety benefits. In another recent report compiled by Smart Growth America and National Complete Street Coalition (2015), the complete streets were found to have many positive impacts on the street safety and local economy. This report examined a total of 37 complete street projects across the U.S. and found that the construction of complete streets led to a decrease in collisions, more walking, biking, and public transit trips. Researchers believed that the complete street was a potential solution which could begin to address the air quality and transportation problems, as suggested by Geraphyty et al. (2009). Lester et al. (2016) studied the extent of changes in pedestrian and bicyclist attitudes and behaviors after a complete street project in Florida by field observations and intercept survey. They found that dangerous behaviors continued to exist and the survey participants had same perception of the street safety as they did before the complete street construction. Based on this case study, however, it is not clear if other complete street projects would have no obvious impacts either.

These existing literatures suggest that the construction of complete streets may potentially change people's travel behavior and thus influence their exposure to traffic-related air pollutants, by changing both on-road concentrations and exposure time. The health impacts of traffic-related air pollutants have been well-documented. Many studies have shown that exposures to particulate matter (PM) are associated with cardiovascular and respiratory diseases (Künzli, Jerrett et al. 2005; Dominici, Peng et al. 2006; USEPA 2009; Brook, Rajagopalan et al. 2010). PM2.5 (particles with aerodynamic diameter equal to or less than 2.5 micrometer) has been listed as one of the six 'criteria air pollutants' by USEPA National Ambient Air Quality Standards. Although ultrafine particle (UFP) is not a regulated air pollutant, animal studies have shown that UFP is also associated with cardiovascular and pulmonary risk (Delfino, Sioutas et al. 2005; Elder, Gelein et al. 2006; Warheit, Webb et al. 2007). In an urban environment, PM2.5 concentrations are usually more influenced by its regional background while UFP concentrations have much more spatial variations caused by local sources such as motor vehicles and restaurants (Kinney, Aggarwal et al. 2000; Zhu, Hinds et al. 2002a; Zhu, Hinds et al. 2002b). Therefore, exposures to UFPs among street users – drivers, pedestrians, and cyclists are often affected by factors including but not limited to: proximity to vehicles, traffic volume and speed, types of vehicles on the street, and meteorological conditions (de Nazelle, Fruin et al. 2012; Bigazzi and Figliozzi 2014).

Based on theoretical calculations instead of actual measurements, recent studies have shown that the health benefits incurred from active transportation such as cycling and walking may exceed the deleterious effects of traffic-related pollutant exposure at individual levels (De Hartog, Boogaard et al. 2010; Panis, Willems et al. 2012). However, these studies assumed that all the other conditions remained the same and the only difference was in each person's choice of transportation mode. This is not the case for a complete street retrofit, which can possibly change many aspects of a street; including but not limited to street users' activity patterns, street usage by different transportation modes, concentrations of various traffic-related pollutants, and street users' exposure to those pollutants. All of these factors impact street users' exposure to traffic-related air pollutants. Therefore, the interactions among the changes brought by complete street construction and their cumulative effects on public health remain largely unknown. Many conditions, such as the on-road air quality, time needed to travel through the street, and street user volume, are subject to change after a complete street construction. This study aimed to provide a comprehensive understanding on how these conditions change simultaneously and what the final impacts are.

1.3 Research Objectives

The objectives of this project were: (1) understand the extent to which complete streets affect travel behavior of local residents; (2) assess how such effects may differ among different land use context; (3) explore potential barriers preventing people from using complete streets; (4) compare street users' exposure (in particular pedestrians and cyclists) to UFPs and other co-pollutants on complete and incomplete streets, and (5) evaluate the difference in street users' perception of complete and incomplete streets.

2 MATERIALS AND METHODS

2.1 Before-After Study

The before-after comparison method utilized a natural experimental design by conducting exact same measurements on the same section of streets, before and after their retrofit from incomplete streets into complete streets. This method used the same section of streets as their own ‘control’ condition and therefore minimized the interferences from factors such as demographic and socio-economic characteristics. The limitation of this method was that it did not control for factors such as natural fleet turnover and the time needed for people to adapt to the retrofit complete streets.

2.1.1 Before-After sites selection and description

We first evaluated dozens of potential complete streets projects in California, especially in Los Angeles County. After collecting information and comparing more than 10 potential study sites in Southern California, we selected two most promising retrofit projects: Ocean Park Boulevard site as described in section 2.1.1.1 and Michigan Avenue site as described in section 2.1.1.2 for the before-after study, given their contents, their neighborhood location, and most importantly, their estimated timeframe. For air quality measurements, data were collected at both sites. We only conducted neighborhood survey on Michigan Avenue site because Ocean Park Boulevard site had been retrofitted into a complete street before this project was officially awarded. The air quality measurements on Ocean Park Boulevard before retrofit were supported by other funding sources.

2.1.1.1 Ocean Park Boulevard site

We selected the section of Ocean Park Boulevard between Neilson Way and Lincoln Boulevard in Santa Monica, California as the study site. A map of the studied section of Ocean Park Boulevard is shown in Figure 1. The street view changed substantially after the retrofit, as shown in Figure 2.The studied section had a complex terrain with two hills (maximum elevation difference of 20 m) in a length of 1 km. Ocean Park Boulevard is an arterial residential road, with traffic volume ranging from 900 to 1200 vehicles per hour during the study. The roadway included one lane in each direction, a cycle lane, and a sidewalk for the complete length. The surrounding area consisted mainly of residential houses on both the north and south sides of the roadway and remained unchanged after the complete street retrofit; other than emissions from roadways adjacent to Ocean Park Boulevard, there appears to be no substantial direct PM sources.

Figure 1. Map of studied section on Ocean Park Boulevard. The small map shows the location of study area relative to other areas, and the big map shows the details of the study area and the studied section of Ocean Park Boulevard.

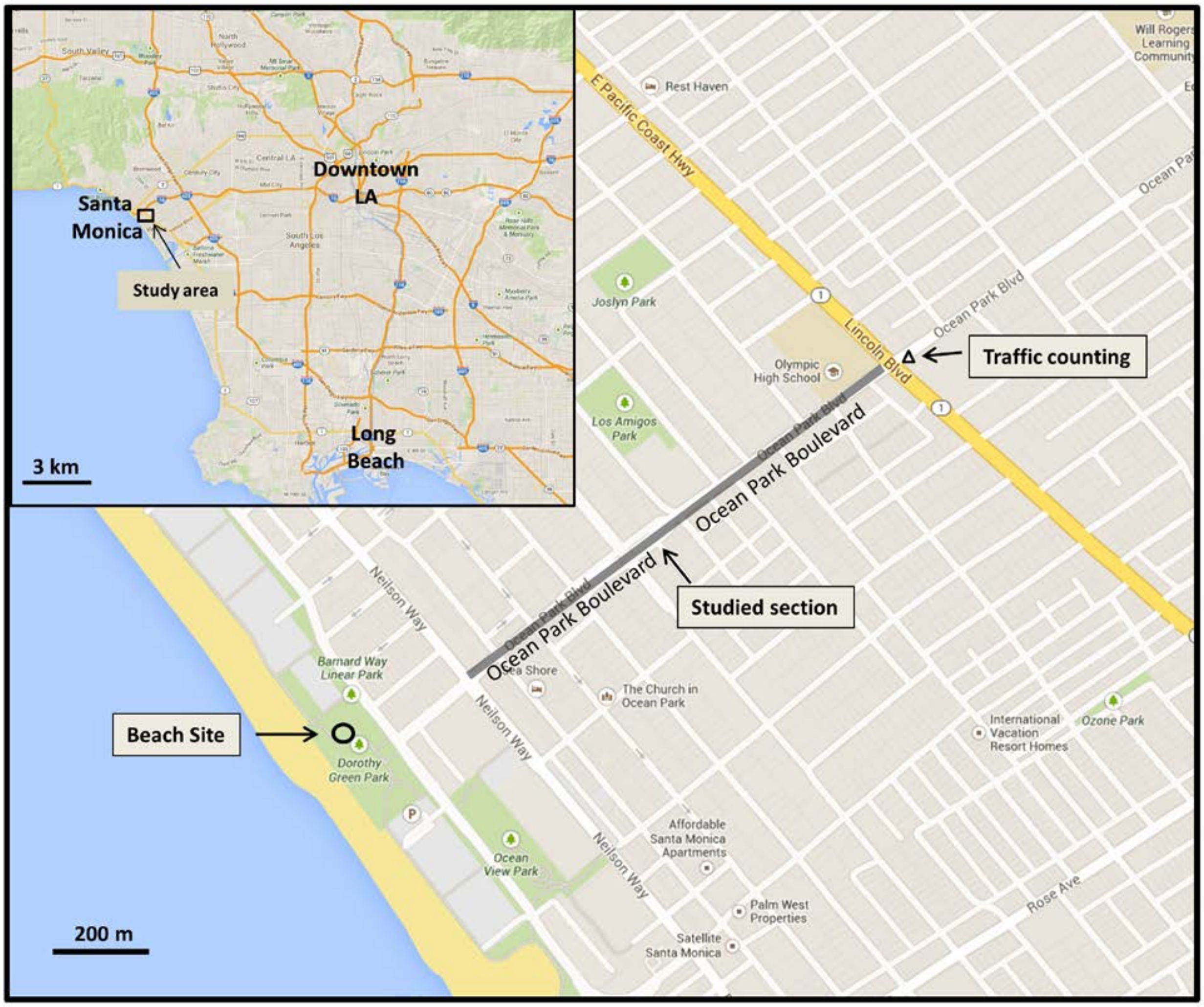


Figure 2. Photos of Ocean Park Boulevard before and after the complete street retrofit. Photo (a) was taken before retrofit in 2011, at approximately the middle point of the studied section and photo (b) was taken in 2013 after retrofit, at the same location. Photo (c) was taken before retrofit in 2011 at the intersection of Ocean Park Boulevard and Lincoln Avenue, and photo (d) was taken at the same location after retrofit in 2013.

2.1.1.2 Michigan Avenue site

This project locates in a residential neighborhood in Santa Monica, CA (see Figure 3 for the location of this project). A priority of the City of Santa Monica to follow the success of the Ocean Park Blvd Green Street Project, the Michigan Avenue Neighborhood Greenway (MANGo) project has been funded partially by a Caltrans Environmental Justice Grant.

The MANGo project (see project map in Figure 4) aimed to create an inviting shared street space along Michigan Avenue and adjoining streets within Santa Monica. The three-mile greenway is expected to reduce cut-through traffic, provide residents and visitors with a safe and comfortable place to walk, interact with neighbors, play, travel, and will connect the community to key destinations and neighborhoods (note that no transit service is available along the Michigan Avenue). Since there is no widely agreed engineering definition of a complete street besides various best practice recommendations, we considered Michigan Avenue a complete street even it does not have transit service. With the arrival of the Expo Line (light rail) in the near future, the greenway would provide a link from the neighborhood to new Expo stations and some of Santa Monica's most significant attractions – the beach, downtown Santa Monica, the Civic Center and Bergamot Station. Additionally, the greenway would offer a key connection to the broader bicycle network both in the City of Santa Monica and to the surrounding Los Angeles region. The conceptual design of the first phase of MANGo (retrofit of the Michigan Ave between Lincoln Blvd and 20th street – the dark green section in Figure 4) was approved by the Santa Monica City Council unanimously on Feb 11, 2014 and the construction was completed within the 2014-15 fiscal year.

Figure 3. Map of studied section on Michigan Avenue. The small map shows the location of study area relevant to other areas, and the big map shows the details of the studied section of Michigan Avenue.

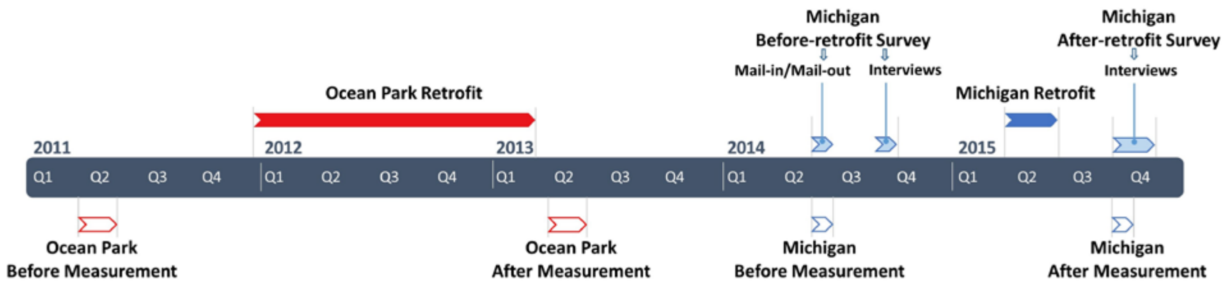
Figure 4. Map of Michigan Avenue Neighborhood Greenway project.

(Source: City of Santa Monica, CA)

2.1.2 Before-After experimental methods

In this section, the methods for measuring on-road air quality, total and heavy-duty vehicle traffic volume, pedestrian and cyclist volume, and neighborhood survey in the before-after study are described in detail. Figure 5 shows the overall timeline of this before-after study. More details on experimental methods are provided in the following subsections.

Figure 5. Timeline of the before-after study at the Ocean Park Boulevard and Michigan Avenue sites.



2.1.2.1 Traffic, pedestrians, and cyclists counting

On Ocean Park Boulevard, the traffic counting location was at the Ocean Park Blvd and Lincoln Blvd intersection (see Figure 1). On Michigan Avenue, the traffic counting location was at the Michigan Avenue and 14th Street intersection (see Figure 3). Each sampling day consisted of three two-hour sampling sessions in the following periods: morning (7:30 to 9:30), afternoon (12:30 to 14:30), and evening (17:00 to 19:00 for Ocean Park Boulevard site and 16:00 – 18:00 for Michigan Avenue site). Researchers manually counted the total traffic volume, pedestrian volume, and cyclist volume for eight five-minute intervals in each two-hour sampling session. For Ocean Park Blvd, we also quantified the emission-weighted traffic volume in both before and after retrofit measurements. An Emission Unit (EU) is defined as an index quantifying PM emissions of a given vehicle when normalized to the fleet average. Based on existing literatures (Small and Kazimi 1995; Quiros, Zhang et al. 2013), one EU was defined as the emissions from one fleet average vehicle. The exact value of this average vehicle emission was less important because the relative ratios between higher-emitting vehicles and fleet-average vehicles were used. Based on a literature review conducted and implemented for the before-retrofit study (Quiros, Lee et al. 2013), motorized vehicles were divided into seven emission categories: light-duty vehicles 1978 and after (1 EU), light-duty vehicles 1977 and before (50 EU), solid waste collection trucks (9 EU), class 5 and 6 diesel light-duty trucks (24 EU), school buses (26 EU), class 7 and 8 heavy-duty diesel trucks (39 EU), and public city buses (6 EU) (Small and Kazimi 1995; California Air Resources Board 2002; California Air Resources Board 2006; California Air Resources Board 2011). We obtained the number of vehicles within each category from video footage recorded at the same time frequency and location as the street-specific traffic volume. We conducted the categorization of vehicle types manually.

Specifically, to limit the potential person-to-person inconsistency, one student researcher examined all the video footages and identified the light-duty vehicles 1977 and before by their shape and general appearance. The classified vehicle volumes were multiplied by the respective EUs to obtain the emissions-weighted traffic volume, in unit of EUs per hour.

2.1.2.2 On-road air quality measurements

On Ocean Park Boulevard, the before-retrofit measurements had nine sampling days (seven weekdays and two weekends) between March 22nd, 2011 and April 21st, 2011, and the after-retrofit measurements had five sampling days (three weekdays and two weekends) in April 2013. On Michigan Avenue, the before-retrofit measurements had two sampling days (one weekday and one weekend) in May 2014 while the after-retrofit measurements had two sampling days (one weekday and one weekend) in October 2015. Figure 5 visualizes the timeline of the construction of both Ocean Park Boulevard retrofit and Michigan Avenue retrofit, as well as the before and after measurements and surveys.

We avoided conducting measurements on holidays and school breaks since on these days the traffic volumes are not representative to the normal conditions. Fewer sampling days were used for the Michigan Avenue site because the data collected on Ocean Park Boulevard had small day-to-day variation. Since both sites are located in the Santa Monica area and share similar meteorological conditions, the day-to-day variation in Michigan Avenue was also expected to be small. At both before-after study sites, a consistent sea breeze (eastward from the ocean) developed each day. It starts in the mid-morning, reaches its maximum early to mid-afternoon, and dies out in the early evening. The meteorological data obtained from the Ocean Park Boulevard site and Michigan Avenue site were similar, as presented in Appendix A.

In each two-hour session, two researchers were sampling in roundtrips along the study section of the street, one for walking and cycling modes and the other for driving mode and background measurements. The retrofit did not change the distances from vehicles to the biking and walking paths in the before and after measurements. For Ocean Park Blvd, the background levels were measured at a beach site, while for Michigan Ave the background site was located at the center of the Woodlawn Cemetery. Each researcher carried one set of instruments to sample UFP and PM2.5 and record data every second.

UFP and PM2.5 sampling instruments were carried by hand for walking modes. For cycling mode, instruments were either carried in a backpack or mounted to a seat post-mounted clamp-on rack to a mountain bicycle. Later for the Michigan Avenue site measurement, we installed a basket in front of the bicycle to hold the sampling instruments. We used passenger vehicles for the driving modes with instruments placed on the passenger seat. For the Ocean Park Boulevard before-retrofit measurements, we used the vehicle for the driving mode under both window-fully-open and window-closed conditions. For the Ocean Park Blvd after-retrofit and Michigan Ave measurements, we only used window-fully-open condition to reflect the on-road concentrations of UFP and PM2.5.

We measured UFP with two portable condensation particle counters (CPC, TSI model 3007, TSI, Inc., Shoreview, MN, USA), one for walking and cycling, and the other for driving and background measurement. To keep the CPC 3007 working appropriately, we either horizontally mounted it on the bike or placed it in the bicycle basket for cycling measurements and carried by hand for walking measurements. The CPC 3007 for driving mode was securely placed on the passenger seat of a regular passenger vehicle and kept horizontal for proper measurements. For the Ocean Park Blvd before-retrofit measurements, we also used a water-based Condensation Particle Counter WCPC (TSI Model 3785, TSI, Inc., Shoreview, MN, USA) for UFP concentrations.

PM2.5 concentrations were measured by two DustTrak units (TSI model 8520, TSI Inc., Shoreview, MN, USA) for all modes. Because the DustTrak instrument utilizes a light-scattering sensor to determine the PM2.5 concentration and different aerosols have different light scattering capabilities, the direct readings from DustTrak need to be corrected. In this study, all DustTrak PM2.5 data were divided by a factor of 2.4 corresponding to U.S. EPA Federal Reference Method gravimetric values determined by Zhang and Zhu (2010). This conversion factor is within 10% of that reported by a previous study (Yanosky, Williams et al. 2002).

Before and after each session, we synchronized all instruments and set them to record data at one-second intervals for subsequent data validation. We regularly performed quality assurance (QA) by collocation tests throughout the study. We placed both sets of instruments downwind of a major street for at least 20 minutes to capture a wide range of UFP and PM2.5 concentrations. Then we used the data collected from collocation tests to correct the instrument readings from one set against the other, to make sure the data were comparable. The two sets of data were well correlated ($R^2 \geq 0.82$).

2.1.2.3 Neighborhood survey method

The neighborhood survey aimed at residents in the most adjacent area of the first phase of the MANGo project (within the black polygon of Figure 6). This study area is part of four census block groups (indicated by the red polygons in Figure 6).

Figure 6. Map of neighborhood survey areas near Michigan Avenue.

Table 1 provides a comparison of key housing, socio-demographic, and travel variables based on recent data (obtained from the American Community Survey 2012: https://www.census.gov/programs-surveys/acs/) among the City of Santa Monica (including five Zip Codes: 90401-90405), the 90404 Zip Code (including six Census Tracts from CT701502-701802), the 701802 Census Tract, which contains the study area and partially covers areas of four block groups.

Table 1. A comparison of the study area to larger geographies

	City	Zip Code	Census Tract	Block Group			
	Santa Monica	90404	701802	7018021	7018022	7018023	7018024
Number of Housing, Units	51633	10530	1940	660	514	490	276
% White Non-Hispanic Population	67.7	51.2	40.4	29.5	45.6	55.0	38.5
% Speaks English	73.4	64.2	61.8	56.0	63.0	75.1	55.0
% Education, < High School	4.2	8.3	14.8	16.5	6.2	14.2	24.3
Household Inc., Median ($)	74746	61429	57404	48438	55819	65064	69758
Household Inc., Average ($)	117798	82163	72228	64095	66210	79149	90905
% Population in Poverty, Total	11.4	15.6	26.5	27.3	25.9	25.3	27.0
% Housing, Occ. Structure w/ 1 Unit Detached	19.5	12.4	16.1	14.1	21.4	8.4	24.6
Household, Median Vehicles	1.8	1.7	1.6	1.6	1.5	1.6	1.6
% Employment, Car, Truck, Van to Work	75.7	72.1	74.6	71.1	86.6	61.6	82.7
% Employment, Public Transportation to Work	3.7	6.2	9.3	12.2	3.3	14.0	4.4
% Employment, Walk to Work	5.7	9.2	5.4	8.4	3.3	4.1	3.2
% Employment, Bicycle to Work	2.0	2.0	5.7	8.2	3.0	6.4	2.8

We designed the household survey (see Appendix B) by adapting well-tested questions from Mineta Transportation Institute's 2010 Pedestrian and Bicycling Survey Users' Manual (Kevin J. Krizek, Ann Forsyth et al. 2010), with added questions regarding public transit usage and the California add-on questions of the 2009 National Household Travel Survey (CA-NHTS) regarding the possible barriers to walking, biking, and taking transit.

Based on feedback from the 2012 and 2013 UCLA Complete Street Conference participants (including more than 100 planners, engineers, and local officials with expertise in transportation, the environment, and public health), we further revised the survey questionnaire to reflect the importance of a buffer between cycle path and motor lanes/parked vehicles as well as features of foot path accommodating all ages and the disabled. Specifically, we revised the choice options in the perceived barriers sections.

The survey allowed up to two persons in each household (two adults or one adult plus a teenager) to participate, with only each household's main adult responder to answer questions about household characteristics and barriers to walk, bike, and taking transit (the long form in Appendix B). The other adult or teenager only needed to answer the short form (see Appendix B). The survey questions on specific travel behavior outcomes and barriers to travel included the following aspects:

- Whether respondents have taken public transportation, walked, or bicycled within the last 7 days, last month, or last 3 months.
- On how many days they used public transportation, walked, or bicycled for different trip purposes in the past 7 days.
- On how many days a week they commute by public transportation, foot, or bicycle, on average.
- Typical socio-demographic information, information on key factors that might limit active travel, such as physical disabilities, and information on whether the respondent has regular access to a bicycle or motor vehicle.
- Perceived barriers to walking, bicycling, and public transit usage that will help the reason of change (or lack thereof) in travel behavior of residents.

In addition, several necessary before-after survey related instruments were drafted, including a pilot survey recruitment letter, a pilot survey consent form, a mail-in survey advance notice, a mail-in survey recruitment letter, a mail-in survey consent form, and a mail-in survey follow-up letter. We prepared the survey instruments in English and Spanish, reached out to the City of Santa Monica, obtained endorsement from the Pico Neighborhood Association, identified addresses via the USPS, and planned the survey process. We tested the draft survey questionnaire with face-to-face surveys of 30 local residents. We also asked open-ended questions about people's experience to refine the survey.

2.2 Difference-in-Difference (DID) Study

The Difference-in-Difference (DID) method compares existing complete streets and incomplete streets in different land-use contexts. The design is quasi-experimental because we tried to mimic natural experiments by comparing pairs of streets that are otherwise similar (e.g., transportation functions of streets and community socio-demographics), except one is complete and the other is incomplete. Differences in transportation mode choice, traffic patterns, and on-road air quality between complete and incomplete streets were measured.

2.2.1 DID sites selection and description

In order to obtain a comprehensive evaluation, six test sites, each comprised of a pair of complete and incomplete streets, were selected from the Greater Los Angeles Area. The location of these six test sites are shown in Figure 7. These six test sites are located in three different urban settings representing downtown, urban, and suburban land-use types. They can also be categorized by their function, including business, mixed (partially business and partially residential), and residential, as shown in Table 2. The variation in land-use contexts provides a wide range of traffic volumes and associated on-road air pollutants levels which is useful in differentiating between traffic-related and regional background air pollutants.

With assistance from local municipal planning departments in the Los Angeles - Long Beach - Orange County areas, we selected one pair of complete and incomplete streets in each of the six sites. First, through consulting with planners from different cities and fieldwork, we selected one complete street in each of the land-use contexts based on the most updated design manuals (Institute of Transportation Engineers 2010; Los Angeles County 2011). Then, for each complete street, we located an incomplete “twin” street in the same neighborhood and local transportation network, with similar traffic generation and attraction characteristics such as resident homes, shops, restaurants etc. The incomplete "twin" street was usually selected from an adjacent and/or parallel street with a similar metropolitan location and similar socio-demographics. Therefore, the observed differences in traffic behavior and on-road air quality between the two streets, if any, would be attributable mostly to the complete streets design. The detailed map of each pair of twin-streets can be found in Appendix C.

We are aware of the fact that, for Downtown LA and Glendale sites, the ‘twin’ streets have a different number of motor vehicle lanes. But it is still reasonable to include these two sites because this study focused on the observed differences in traffic volume, on-road air quality, and street users’ flow, and the relationships among these differences, rather than the absolute values observed on complete or incomplete streets.

Figure 7. Locations of the six difference-in-difference (DID) study sites.

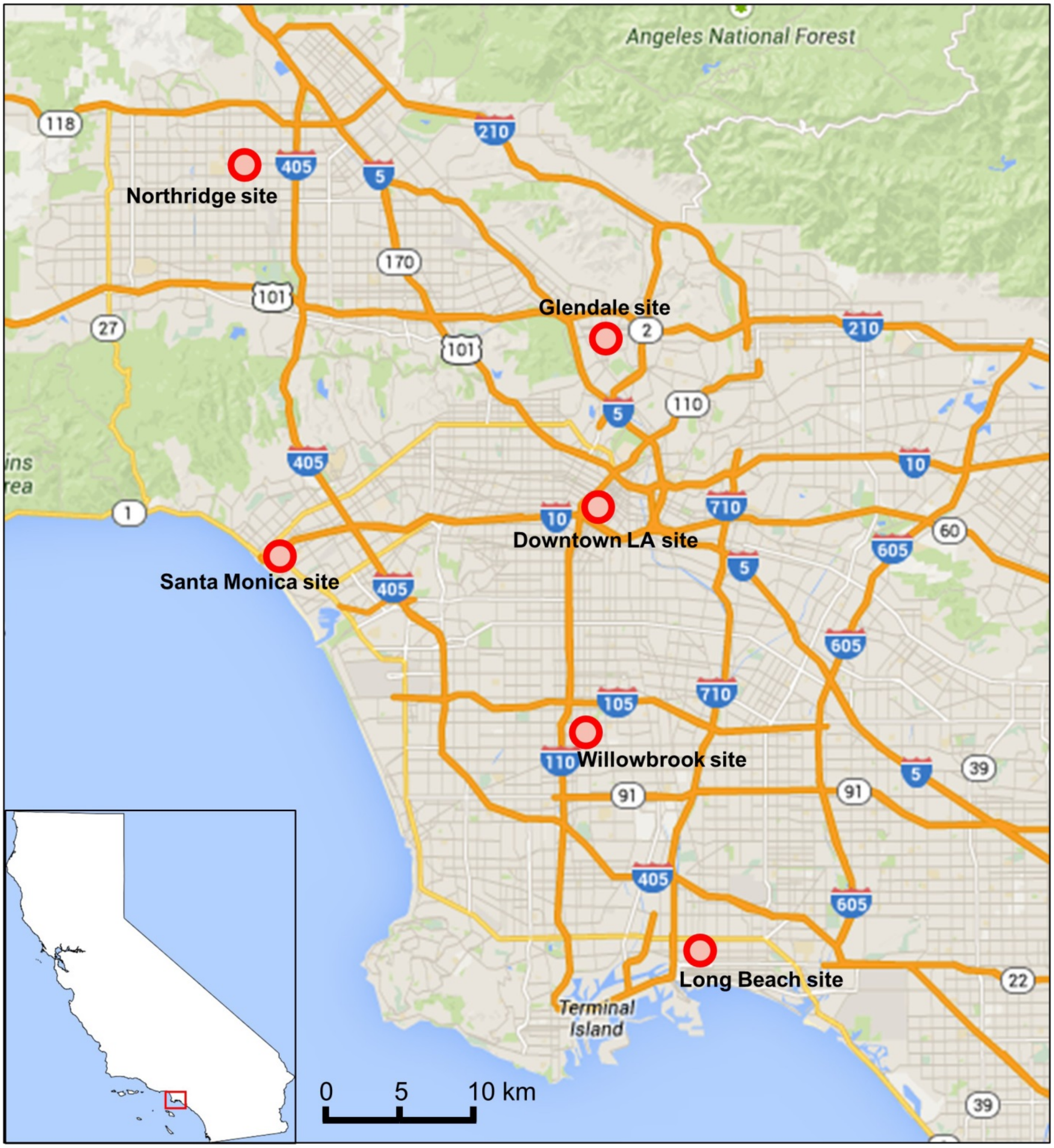


Table 2. Detailed descriptions of the six difference-in-difference (DID) study sites.

Site	Location	Function	Complete Street		Incomplete Street		Boundaries	Distance (m)*	Test season and year**
			St. Name (Num. of lanes)	Length (m)	St. Name (Num. of lanes)	Length (m)			
Downtown LA	Downtown	Business	Spring(2)	800	Main (3)	800	E 3rd St. & E 7th St.	120	Fall 2013 Spring 2014
Santa Monica	Downtown	Business	Sixth(4)	630	Fifth (4)	630	Wilshire Blvd. & Broadway	120	Spring 2014 Fall 2014
Long Beach	Urban	Mixed	Third(2)	800	Fourth (2)	800	Pacific Ave. & Atlantic Ave.	150	Spring 2014 Fall 2014
Willowbrook	Suburban	Mixed	San Pedro(4)	700	Avalon (4)	700	E 115th St. & E 120th St.	400	Fall 2014 Spring 2015
Glendale	Suburban	Residential	Riverdale(2)	900	Vine (1)	1000	S Central Ave. & San Fernando Rd.	240	Spring 2014 Fall 2014
Northridge	Suburban	Residential	Louise(4)	800	Hayvenhurst (4)	800	Lassen St. & Devonshire St.	3200	Fall 2014 Spring 2015

* Distance between the complete street and incomplete street

** Spring season refers to March and April while fall season refers to October and November.

Table 3. Comparison of street design features. The cells with a 'No' are filled with gray color to visualize the contrast.

Site	Street	Foot path	Cycle path	Median	Crossing	Lighting	Intersection	Transit facilities	Traffic calming	Parking	Landscaping	Street furniture	Ecological storm drainage
Downtown LA	Complete	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Incomplete	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Santa Monica	Complete	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No
	Incomplete	Yes	No	Yes	Yes	Yes	Yes	n/a*	No	Yes	Yes	No	No
Long Beach	Complete	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Incomplete	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
Glendale	Complete	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No
	Incomplete	Yes	No	Yes	No	Yes	No	Yes	Yes	No	Yes	No	No
Northridge	Complete	Yes	Yes	Yes	No	Yes	Yes	n/a	Yes	Yes	Yes	No	No
	Incomplete	Yes	No	Yes	No	Yes	Yes	n/a	No	Yes	Yes	No	No
Willowbrook	Complete	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	No
	Incomplete	Yes	No		Yes	Yes	No		No	No	No	No	No

* n/a: not applicable

2.2.2 DID experimental methods

2.2.2.1 DID experiment time frame

We conducted the DID study from October 2013 to March 2015. In order to capture any possible long-term or seasonal variations, we tested each site twice, first in the fall and then in the spring, as shown in Table 2. Spring season tests were conducted in March and April, while fall season tests were conducted in October and November. Within each season and each site, two test days were used, one on a weekday and the other on a weekend, to capture differences due to working schedule traffic patterns (Blanchard and Tanenbaum 2003; Quiros, Lee et al. 2013; Shu, Quiros et al. 2014). Thus this study included a total of 24 test days (6 sites × 4 test days per site), which included 12 weekdays and 12 weekends. None of these 24 test days fell into the duration of school break or holidays, to reflect the most normal and representative traffic conditions. To capture the fluctuation of meteorology and street usage within one day, three measurement sessions- morning (7:00 – 9:00), noon (11:30 – 13:30), and afternoon (16:00 – 18:00) were conducted on each test day. The day-to-day meteorology in the DID study were relatively small because the Greater Los Angeles Area has year-round moderate-to-warm weather. Also the study design, which ensured that the twin-streets were measured concurrently, minimized the impact of the day-to-day meteorology variations.

2.2.2.2 DID traffic volume and speed measurements

Video footages of the complete and incomplete streets were recorded on the first 10 test days in fall 2013 and spring 2014. In each two-hour session, eight five-minute videos were taken with intervals of 10 minutes in between. Two cameras, one on each street, were placed on the sidewalk at the middle point of the studied sections of twin-streets, to capture these video footages. The traffic counts were manually counted later and used to calculate the total traffic volume. The heavy-duty traffic counts were also determined manually, similar to the before-after study. However, since this video footage method is labor intensive and does not provide the traffic speed information, a private company (National Data and Surveying Services, Beverly Hills, CA) was contracted to conduct 24-hour continuous traffic measurements by using pneumatic tube traffic counters. This method was used for the rest 14 test days in fall 2014 and spring 2015. In addition, four days of continuous traffic measurements were conducted on the Downtown LA site in spring 2015, to ensure this continuous traffic measurement cover all the six sites.

For each test day, two pneumatic tube traffic counters were deployed at the approximate center points of the complete street and the incomplete street, respectively. The technicians avoided installing the pneumatic tube counters close to street intersections and traffic lights, since the vehicles tend to slow down or stop when approaching intersections and traffic lights. These counters ran continuously and report the traffic counts, vehicle classification, and fleet speed distribution. The data were then processed with respect to each air quality sampling session to obtain traffic densities.

Traffic densities were calculated from traffic counts and measured traffic speeds. Counted vehicles were categorized into 13 classes according to Federal Highway Administration Standard (Federal Highway Administration 2016). Vehicle speeds were grouped into 13 different levels from less than 15 miles per hour (mph) up to greater than 70 mph, with a 5-mph interval. The time mean speed at each measurement location was calculated by using Equation (1).

$$Time\ mean\ speed = \sum_{1}^{i}(N_i S_i)/\sum_{1}^{i} N_i \qquad (1)$$

where *i* equals to 13 since there are 13 speed categories, N_i is the number of vehicles in speed group *i*, and S_i is the medium value of the range of speed group i, for example, for the speed group 15 -19 mph, S_i equals to 17 mph.

The class 1 to class 3 vehicles were summed and defined as light-duty vehicle flow, while that of class 4 to class 13 were summed and defined as heavy-duty vehicle flow. Another important traffic index, the traffic density was also calculated by dividing flow with the time mean speed, which is the average speed of all fleet on the street, reported by the pneumatic counters. For each two-hour session, the traffic volume difference was calculated by subtracting the average hourly traffic volume measured on the incomplete street from that measured on the complete street. Therefore, a positive value means the complete street has lower traffic volume than the incomplete street.

2.2.2.3 DID on-road UFP and PM2.5 measurements

In each two-hour session, UFP number concentrations and PM2.5 mass concentrations were measured for three transportation modes: walking, cycling, and driving-with-windows-open. Similar methods have been used for other on-road air quality studies (Quiros, Lee et al. 2013; Shu, Quiros et al. 2014) and have been proven to be useful. Compared with stationary air quality measurements on the roadside, this mobile sampling method better captures on-road pollutant levels and represents street users' exposures to traffic emissions.

For each two-hour session, the differences in on-road UFP and PM2.5 concentrations were calculated by subtracting the values measured on the complete street from their counterparts measured on the incomplete street. Therefore, a positive value of this difference suggests that the complete street has better on-road air quality than its incomplete twin.

2.2.2.4 DID pedestrians and cyclists counting

The categories of street users were defined as pedestrians, cyclists, wheel chair users, stroller users, and dog-walkers. For each two-hour session, the numbers of each category of street users on each tested street were manually counted eight times for five-minute intervals. The researchers stayed on the same spots where the pneumatic tube counters were installed and conducted street users counting and classification. In the data processing, these counted numbers were used to calculate the average flow of pedestrians and cyclists of each session, by dividing the counted numbers by the length of counting time. In data analysis, the wheel chair users, stroller users, and dog-walkers were counted into pedestrian category.

For each two-hour session, the difference in street user volume was calculated by subtracting the flow measured on incomplete street from their counterparts measured on complete street. Therefore a positive value indicates that the complete street attracts more pedestrians and cyclists.

2.2.2.5 DID intercept survey

Survey Design and Protocols

We developed the survey in coordination with CARB staff before the pilot study and the full-scale field work. The goal of the surveys was to measure the effect on travel of the multi-modal infrastructure on complete streets compared to the incomplete streets. The basics of the field work included:

- Intercept surveys of pedestrians on each of the paired streets were conducted to assess street users' behavior and attitudes.
- Trained survey teams (two people) were deployed including one counter (using a hand-held tabulator and a count sheet) and one surveyor.
- The counter enumerated all the passers-by (by hour), identified the next eligible respondent for the surveyor to approach, and marked some simple observation data about the non-respondents to help determine potential bias in the respondent population for the intercept survey.
- The surveyor administered the questionnaire to participants, marking the observational data about the participant and reading the questions and marking the participant's answers.

Surveyor Placement

For each site, before sampling started, we conducted a site visit to identify the placement of the surveyors. The field surveyors were generally placed in mirrored locations on each street near bus stops and parking lots to catch people traveling by all means. The surveyor team, comprised of four researchers and placed on the twin-streets in two pairs for each two-hour session, systematically approached each eligible respondent, read the questions to the participant, and recorded his or her answers on the questionnaire. Some street users refused to participate in the survey when being approached, therefore, counts and observations of people refusing the survey were taken during the field study to ensure an overall representative sample of respondents. The surveyors were fielded in pairs for most locations to simultaneously conduct person counts of pedestrians and cyclists - a single surveyor could not do both jobs. In addition, paired surveying has many benefits, including enhanced security for the recorders, someone to cover short breaks, a chance for each to alternate jobs (reducing fatigue), and immediate count of data for estimation of response. The major drawback of this paired survey was that it made the field research team bigger and harder to manage.

Data Collection Instruments

The intercept survey form (Questionnaire) is shown in Appendix D Figure D1. Each form has a unique serial number, starting with the surveyor number plus 001, 002, etc. The number allows the forms to be sorted by location and time of day, in addition to separating the weekday and weekend. In addition, data collection forms include a count form and an assignment sheet. Finally, there are quality control procedures and checklist on each of the location-shift envelopes of completed forms and count sheets, which are shown in Appendix D. This allows us to obtain some observational data about the non-responders.

Training

We conducted the training of surveyors prior to the field surveys, for a 1-2 hour session led by the research team leaders. The documented training procedures are shown in Appendix D.

Pilot Study

We conducted the pilot study on two paired streets in Downtown LA (Historic core) to test the procedures, questionnaire, and survey protocols. We selected two parallel streets (each one-way on opposite directions) for comparison: Spring Street and Main Street from 7^{th} to 3^{rd} Street. Spring Street has 16-25 foot wide sidewalks, multiple transit lines, an in-road striped bicycle lane, and is a highly-used pedestrian throughway. Main Street has 18-22 foot sidewalks, fewer transit lines, no bicycle lanes, and is used less frequently as a pedestrian way. Based on the pilot study experience, we finalized the survey questionnaire questions to better suit the typical response from street users.

Identifying the Respondents and Non-Respondents

To better detect possible non-response bias, the research teams at each location inventoried the total number of pedestrians and their gender.

3 RESULTS AND DISCUSSION

3.1 Before-After Study Results

3.1.1 Ocean Park Boulevard Site Results

This section reports the data collected on the Ocean Park Boulevard before and after the street retrofit. Major findings and their implications are also discussed.

3.1.1.1 Ocean Park site motorized traffic, pedestrian, and cyclist volume results

Figure 8 panel (a) shows that before- and after-retrofit motorized vehicle traffic volumes were approximately equal, ranging from 800 - 1,200 vehicles per hour on weekdays and 400 - 1,200 vehicles per hour on weekends. One-way Analysis of Variation (ANOVA) test showed there was no statistically significant difference in the total traffic volume. This is likely because the complete street retrofit did not significantly change the street's functionality in the street network. However, the emission-weighted traffic volume significantly decreased by 26% on average, as shown in Figure 8 panel (b). The greatest reduction from 2,500 to 1,400 EUs per hour (44%) was observed on weekday evenings, the lowest reduction from 1,600 to 1,400 EU (13%) was observed on weekend evenings.

Figure 8 panel (c) shows that, in general, the traffic volume of pedestrians increased for all measurement sessions except for weekday mornings. The overall pedestrian traffic volume for all periods in the after-retrofit study increased 37% when compared with that of the before-retrofit study. Except for the weekday morning session, all session-average increases were significant ($p<0.05$). This increase in pedestrians is likely due to more desirable aesthetic street qualities after the retrofit. As demonstrated in other studies (Handy, Boarnet et al. 2002; Matsuoka and Kaplan 2008), aesthetic factors such as scenic beauty and the degree of cleanliness play an important role in affecting people's choice of transportation mode (Handy, Boarnet et al. 2002; Matsuoka and Kaplan 2008). Figure 8 panel (d) shows the cyclists volume did not change between the before- and after-retrofit studies. This might be due to several factors: a dedicated bike lane was already present during the before-retrofit study, the slightly hilly topography has not been changed by the retrofit, and the retrofit project did not consider connectivity of bike lanes or paths with adjacent communities or neighborhoods.

Figure 8. Total traffic volume, emission-weighted traffic volume, pedestrian volume and cyclist volume measured on Ocean Park Boulevard Before- and After-retrofit.

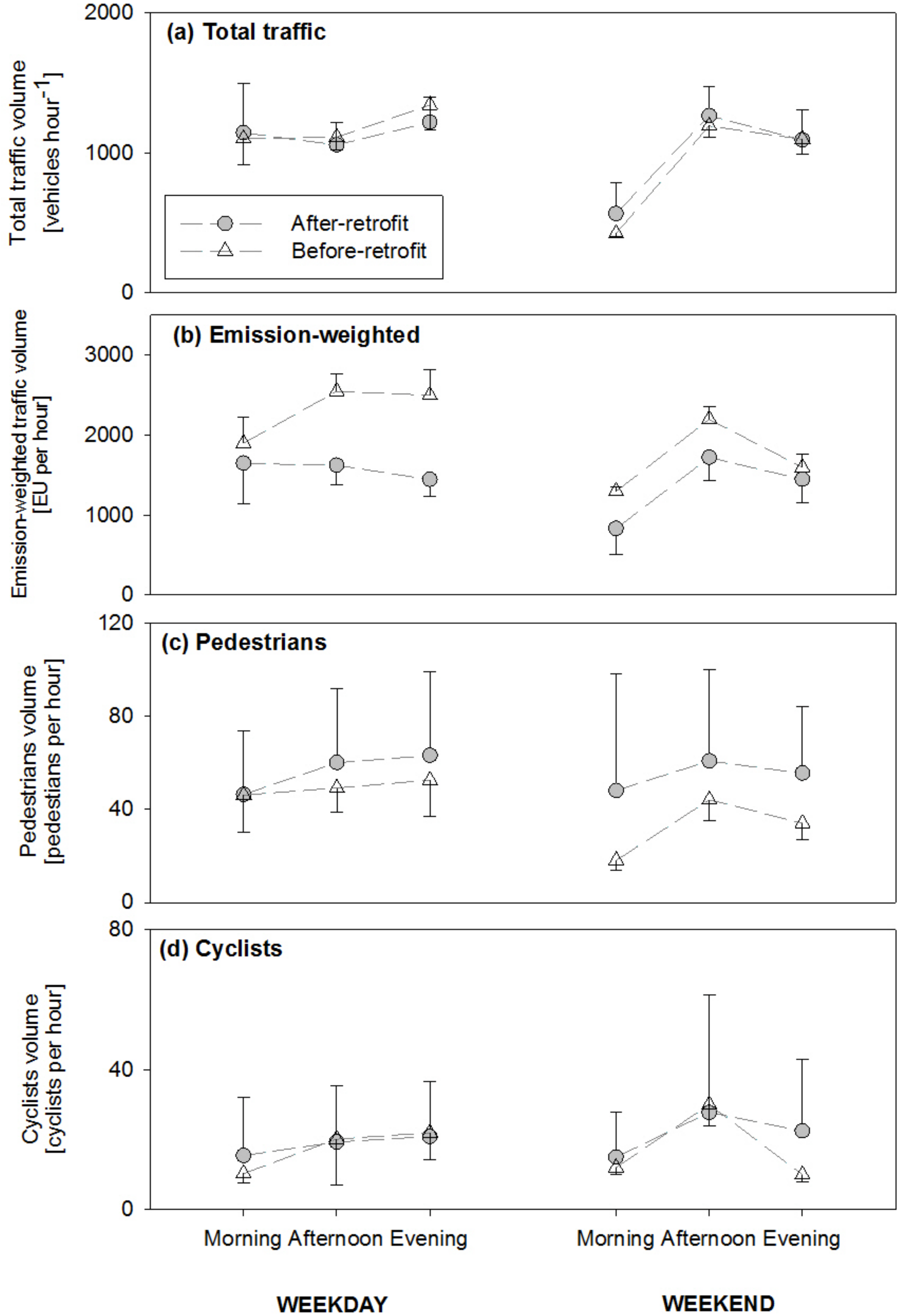
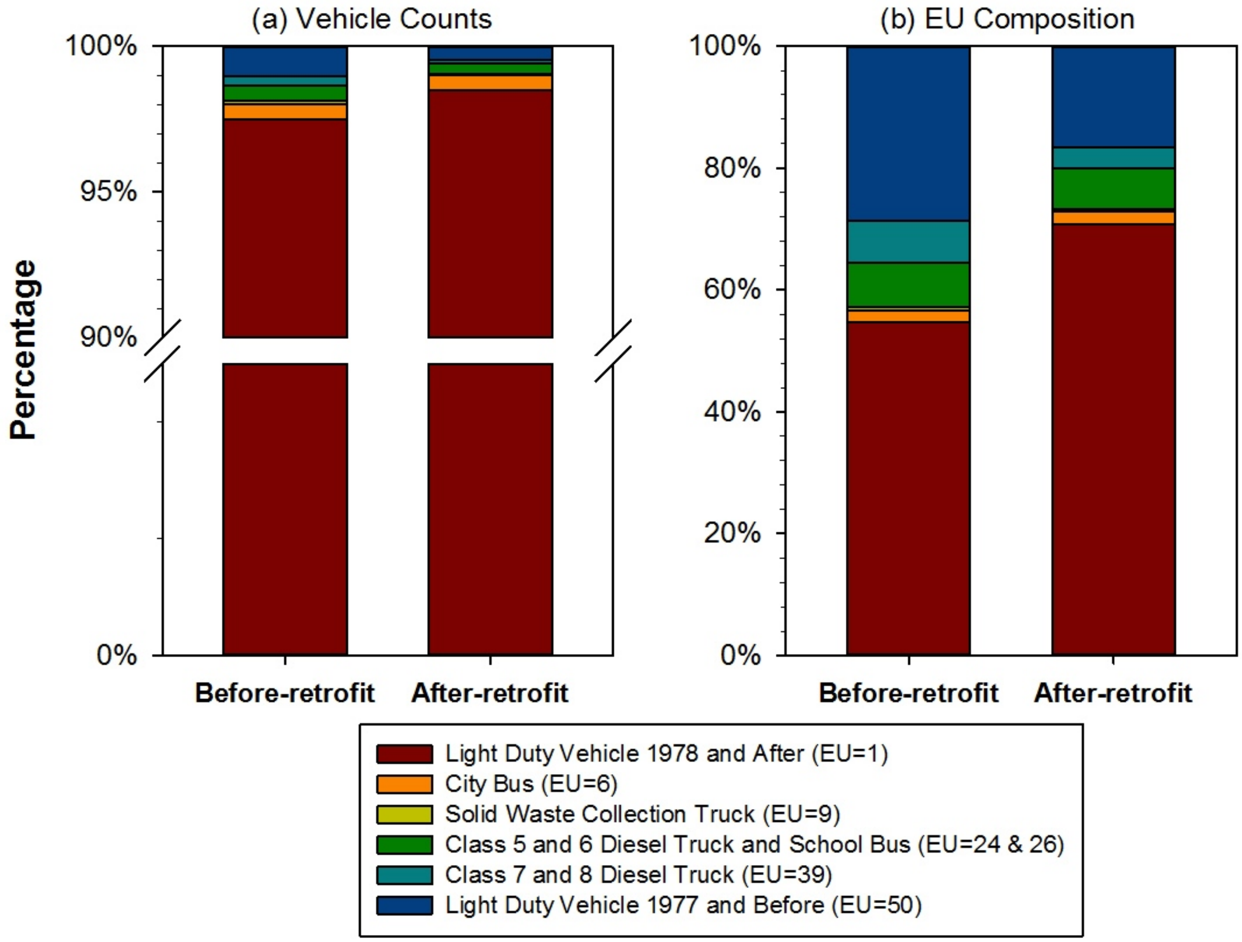


Figure 9 panel (a) shows the change of motorized vehicle counts before and after the retrofit. For both the before- and after-retrofit studies, the majority of motorized vehicles were light-duty vehicles manufactured in 1978 and after, and the percentage of these vehicles increased from 97.5% to 98.5%. The percentages of all other categories of motorized vehicles decreased after the retrofit. The greatest reductions were observed for light duty vehicles manufactured in 1977 and earlier, which was 1.0% before-retrofit and 0.5% after-retrofit. The EU composition of each category showed more obvious change, as seen in panel (b). The light duty vehicles 1977 and before category, which has the highest EU of 50, contributed 28.6% of the total EU before-retrofit and dropped to 16.5% after-retrofit. All other categories with EU>1 decreased more or less after the retrofit, except for the City Bus which increased slightly from 1.9% to 2.2%. Overall, the emission-weighted traffic volume decreased 26% after complete street retrofit. We were not able to identify the real cause of this change in the fleet composition. It might be due to the natural fleet turnover or the complete street retrofit (or both). However, this fleet compositional change may help explain the observed changes of on-road air quality presented in the following section. It is beyond the scope of the current study to determine whether and how the retrofit project led to the observed fleet compositional changes.

Figure 9. Percentage of different categories of motorized vehicles evaluated by traffic counts and emission units, on Ocean Park Boulevard.

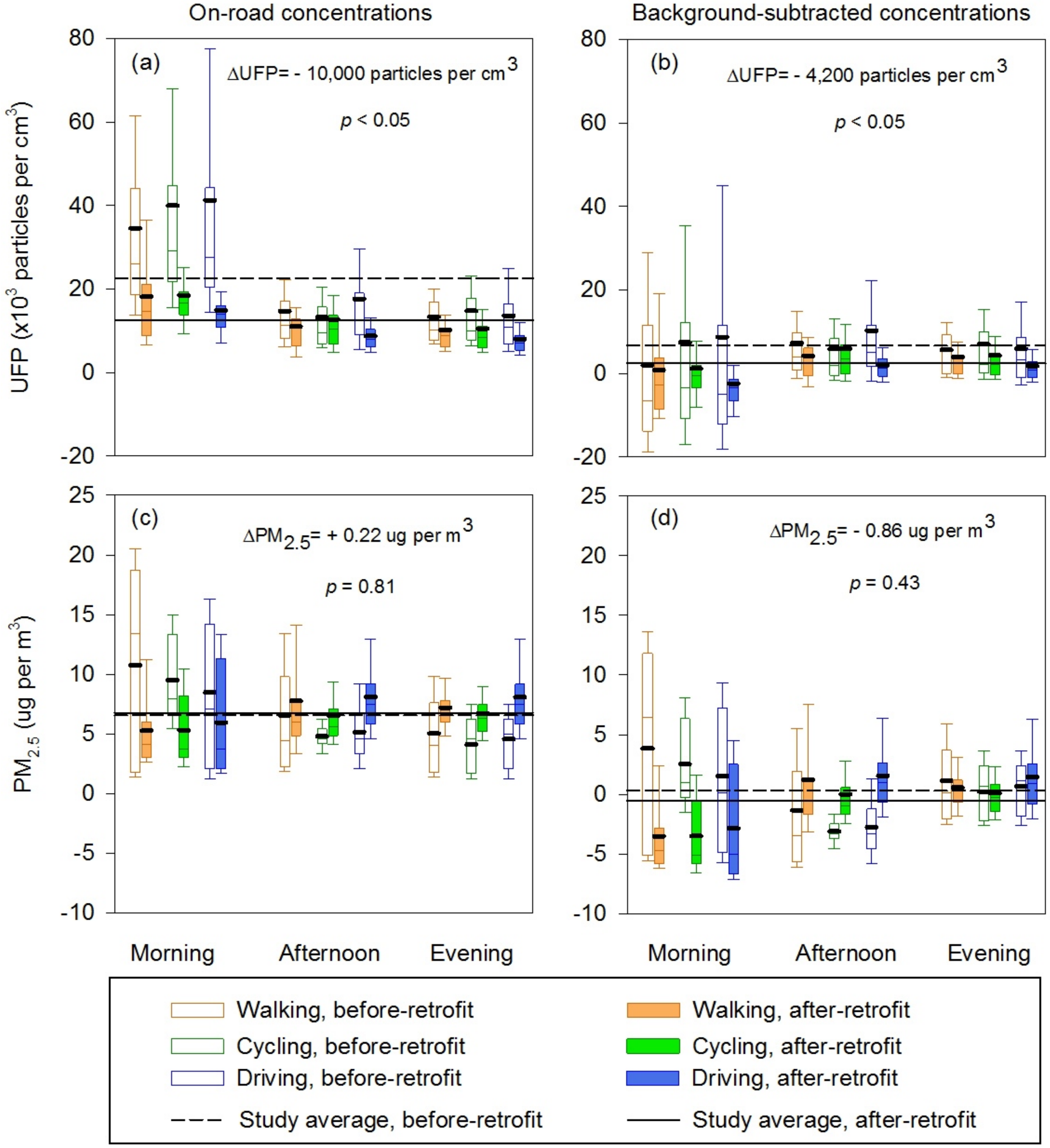


3.1.1.2 Ocean Park site on-road air quality results

Figure 10 compares UFP and PM2.5 concentrations before- and after-retrofit measured by different modes on Ocean Park Boulevard. Study-averaged background UFP decreased 20% while PM2.5 increased 15%. However, these differences were not statistically significant. Study-averaged on-road UFP decreased 43%, from 23,000 particles per cm^3 to 13,000 particles per cm^3 after the retrofit, which was a statistically significant change as shown in Figure 10 panel (a). Study-average on-road PM2.5 concentrations remained the same (3% increase but not statistically significant), as shown in Figure 10 panel (c). For both before- and after-retrofit studies, on-roadway UFP and PM2.5 concentrations were similar between walking, biking, and driving (with windows open) modes. However, it should be noted that the cyclists and pedestrians will receive much larger dose of air pollutants because they have higher ventilation rates compared to drivers. This similarity of results from different transportation modes supports the assertion that, under the meteorological conditions in this study, the position on the roadway (e.g. sidewalk versus bike lane) had no obvious impact on the on-roadway concentration of UFP or PM2.5 experienced by the street user, no matter it is a complete street or incomplete street.

Beach-site-subtracted UFP and PM2.5 concentrations were calculated by subtracting beach-site (i.e., background) concentrations from on-road concentrations. After the retrofit, as shown in Figure 10 panel (b), the overall study average concentration of beach-site-subtracted UFP decreased significantly ($p < 0.05$) by 4,200 particles per cm^3. This reduction can be possibly explained by the decrease in percentage of high-emitting vehicles (i.e., EU >1 shown in Figure 9). For beach-site-subtracted PM2.5, as shown in Figure 10(d), the change was not statistically significant. This indicates PM2.5 is not a good indicator for on-road emissions because the majority of emitted particles are in the ultrafine size range. Overall, it was demonstrated that the air quality on the Ocean Park Blvd was improved in terms of UFP concentrations after street retrofit.

Figure 10. Comparison between before- and after-retrofit UFP and PM2.5 concentrations on Ocean Park Blvd. Panels (a) and (c) present the on-road concentration of UFP and PM2.5 while panels (b) and (d) present the background-subtracted concentrations, to estimate the contribution by traffic emissions.*



* Due to the changes in wind direction, the on-road concentrations were occasionally lower than the beach site concentration, which yielded some negative concentration values in panels (b) and (d).

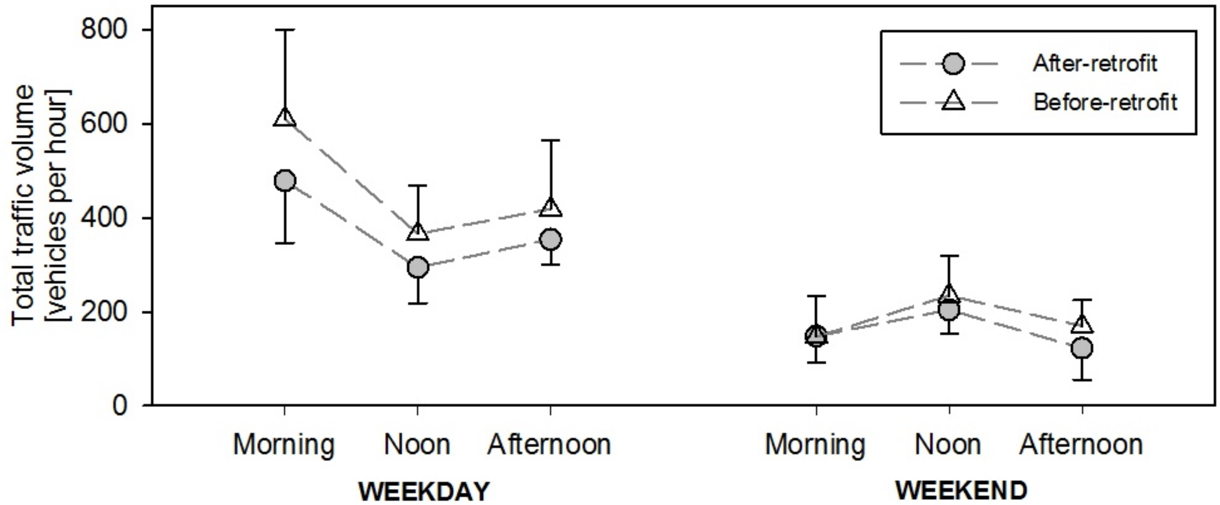
3.1.2 Michigan Avenue site results

This section reports the data collected on the Michigan Avenue before and after the street retrofit. Major findings and their implications are also discussed.

3.1.2.1 Michigan Site traffic volume results

The motorized vehicle flow measured on Michigan Avenue before and after street retrofit is shown in Figure 11.

Figure 11. Total traffic volume comparison before and after complete street retrofit at Michigan Avenue site.



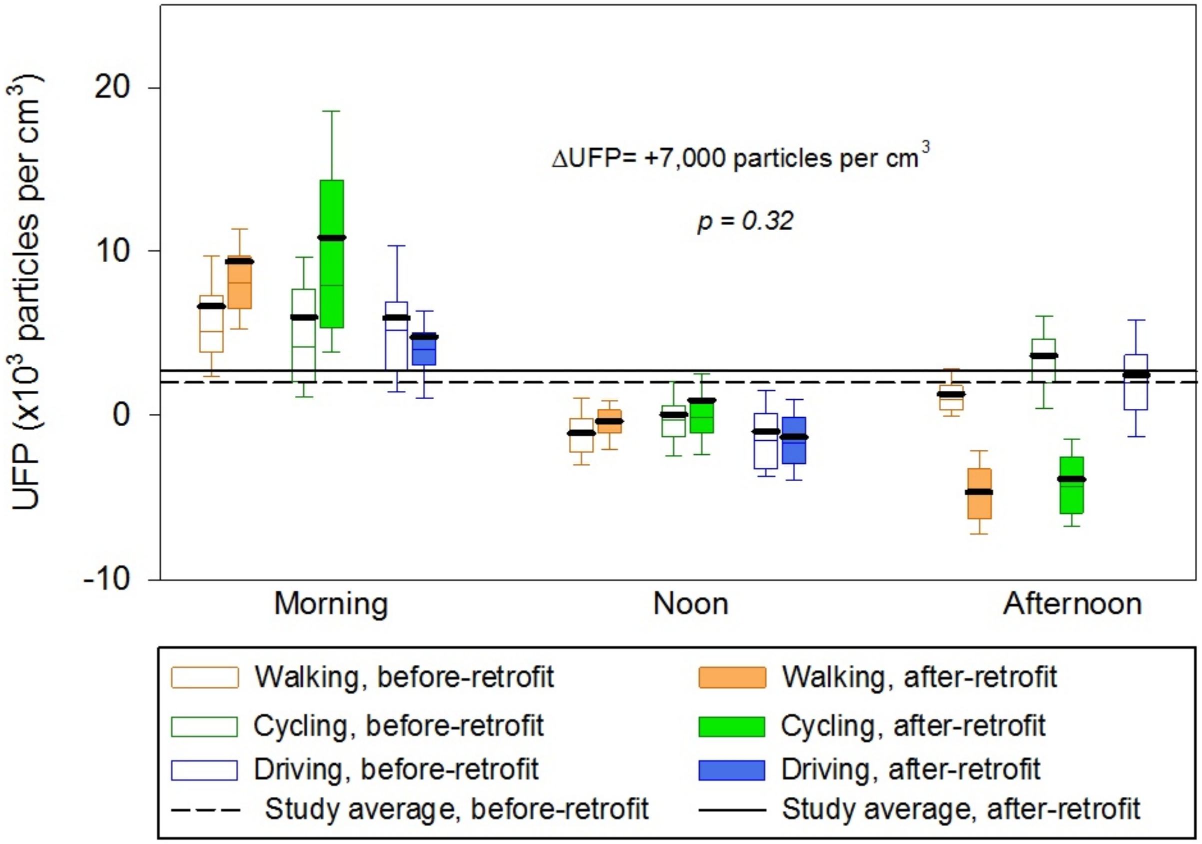
In general, the traffic volume on Michigan Avenue was lower than that measured on Ocean Park Boulevard (see Figure 8 panel (a)), but the weekday-weekend difference in traffic volume was also more obvious on Michigan Avenue. After the retrofit, the traffic volume on weekdays decreased by 22%, 20%, and 15% for the morning, noon, and afternoon sessions, respectively, on Michigan Avenue. On weekends, the traffic volume was similar in morning session before- and after-retrofit, but decreased by 13% and 28% in noon and afternoon sessions, respectively. Overall, the total traffic flow on Michigan Avenue decreased 16% after the retrofit, but this change was not statistically significant.

3.1.2.2 Michigan site on-road UFP and PM2.5 results

For Michigan Avenue site, similar to the method used in Figure 10 panels (b) and (d), the average concentrations of UFP and PM2.5 measured at the background were calculated for each session and then subtracted from the on-road concentrations. The background-subtracted UFP and PM2.5 are shown in Figure 12 and Figure 13, respectively.

As shown in Figure 12, the average of background-subtracted UFP was 2000 particles per cm^3 before the retrofit. It increased to 2700 particles per cm^3 after the retrofit. The background-subtracted UFP concentrations measured before and after the complete street retrofit were not statistically different.

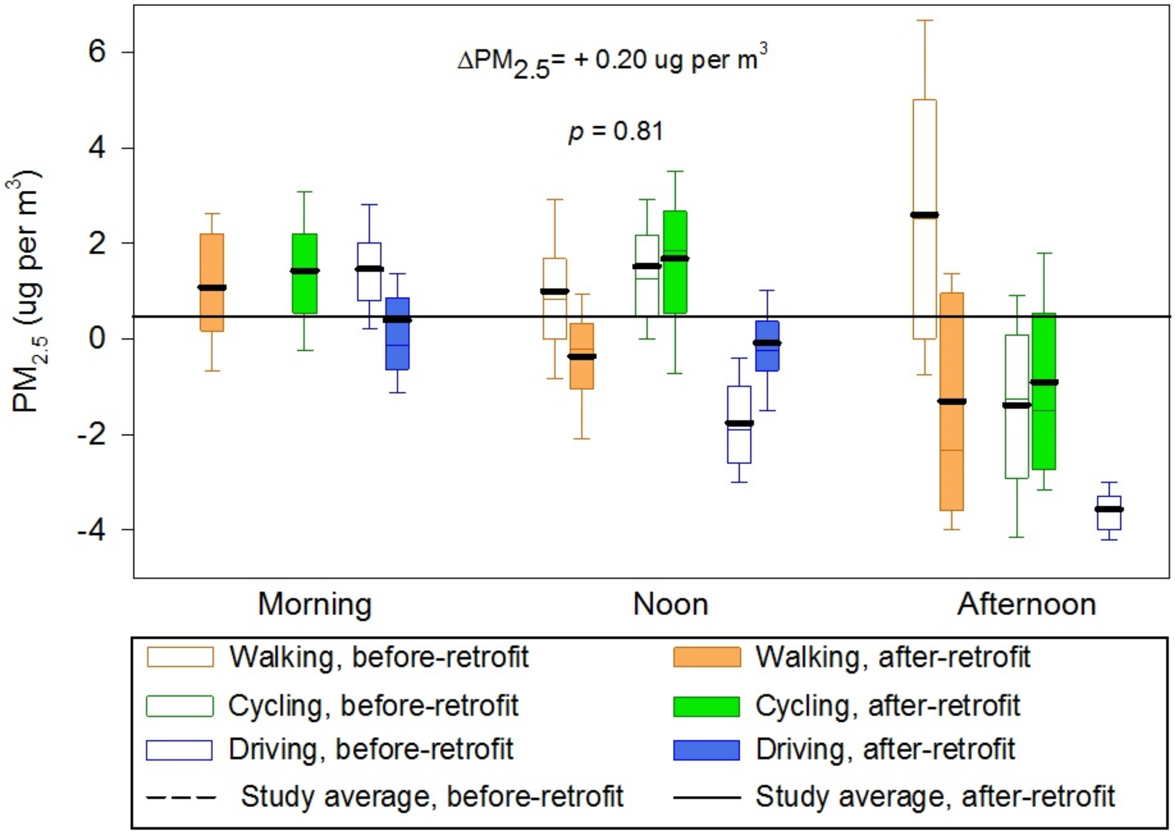
Figure 12. Background-subtracted UFP concentrations measured on Michigan Avenue.*



* The bar of after-retrofit driving mode is missing due to instrument failure.

As shown in Figure 13, the averages of background-subtracted PM2.5 were 0.46 µg per m^3 before the retrofit, and increased to 0.48 µg per m^3 after the retrofit. These background-subtracted PM2.5 concentrations were not statistically different before and after the complete street retrofit.

Figure 13. Background-subtracted on-road PM2.5 concentrations measured on Michigan Avenue.*



* The outliers are shown by dots for each box. There are three bars missing due to instrument failure. The lines of before- and after-retrofit averages are overlapping because the differences between them are small.

3.1.3 Comparison of air quality results from two before-after studies

The two before-after study sites, the Ocean Park Boulevard site and Michigan Avenue site, were located in the Santa Monica area and shared the same meteorology conditions. However, based on field observations, the Ocean Park Boulevard was closer to the Santa Monica beach and therefore tends to have more recreational travel trips, compared with Michigan Avenue site, which was mainly residential and further away from the beach. In terms of total traffic volume, both sites showed no significant changes in the total traffic volume before and after the retrofit projects. For background-subtracted UFP, the Ocean Park Boulevard site showed a decrease of 4,200 particles per cm^3 after retrofit, which is statistically significant, possibly because of the decrease in the emission-weighted traffic volume. On the Michigan Avenue site, we did not find significant changes in background-subtracted UFP, perhaps due to the limited number of sampling sessions. For background-subtracted PM2.5, both sites did not show significant changes before and after the retrofit projects, suggesting that UFP was a better indicator for traffic-induced on-road air quality change.

3.1.4 Before-After neighborhood survey results

We administered the before-retrofit survey by mail-in/mail-out surveys to 600 randomly selected households in the study area in May 2014 with in-home interviews of non-responding households in the sample in September 2014. For the mail-in/mail-out surveys, we provided an upfront financial incentive of $5 to each household in the sample. In the end, we obtained valid responses from 165 households and 207 individuals, a response rate of 27.5%. In light of the relatively low response rate of the mail surveys, we conducted the after-project survey with only in-home interviews of the same 600 addresses in the sample in September to early October of 2015. A total of 188 households and 212 individuals provided valid responses, a response rate of 31.3%. Compared to census tract 101802 (see Figure 6 and Table 1), the sample population is more white (52% in the before MANGo sample and 50% in the after MANGo sample, compared to 40.4% in the census tract in 2012) and more likely to live in a single family house (17.8% in the before MANGo sample and 20.4% in the after MANGo sample, compared to 16.1% in the census tract in 2012).

3.1.4.1 Travel behavior before and after MANGo

The most recent time of each type of travel
We used ordered logit regression analyses to model individual traveler's mode choice measured by the most recent time of choosing a travel mode.

The categories of the most recent time include:
1 – last seven days;
2 – last month;
3 – last three months;
4 – not in last three months.

In the ordered logit analysis, the estimated coefficient of MANGo (dummy variable indicating before – 0 – or after – 1 – the Michigan Avenue Neighborhood Greenway or MANGo project) indicates the ordered log-odds estimate for the MANGo project on the expected mode choice frequency level holding other variables in the model constant. That is, compared to before the MANGo project, a traveler's ordered log-odds of choosing the mode during a category of recent time period (the dependent variable) would move from a lower category (more recently/frequently) to a higher category (less recently/frequently) by the estimated coefficient while the other variables in the model were held constant. Similar interpretations can be made for control variables such as age (and age squared used to capture the potential non-linear effect), gender (male = 1 and female = 0), access to an automobile, and access to a bicycle. Note that the control variable bike_acc (access to a bicycle) is likely endogenous (i.e., correlated with unobserved variables) especially when it is included in the regressions on the frequency of bicycle modes (q3c-q3e) because the decisions of biking and bike ownership are likely jointly made.

The travel modes include:
q3a – by private motor vehicle (Models 1-2);
q3b – by public transit (Models 3-4);

q3c – by bicycle to access public transit (Models 5-7);
q3d – by bicycle as the main mode for utility trips (Models 8-10);
q3e – by bicycle as the main mode for recreational trips (Models 11-13);
q3f – by walking to access public transit (Models 14-16);
q3g – by walking as the main mode for utility trips (Models 17-19);
q3h – by walking as the main mode for recreational trips (Models 20-22).

For clarity, the dependent variables in the results tables (under model specification numbers) are presented in its variable code (e.g. q3a) together with a brief language description.

Table 4 presents the regression results. For each of the travel modes, we present two or three model specifications including one specification with a single regressor of MANGo and one or two specifications with multiple control variables in addition to MANGo. The single-regressor specifications (i.e., columns 1, 3, 5, 8, 11, 14, 17 and 20) provide results of a simple before-after comparison. The other regressions with multiple regressors further control for covariates including age, gender, car ownership and bike ownership. The estimated coefficients (and their standard errors) of MANGo in Table 4 suggest that the MANGo project increases the frequency (represented by a negative coefficient of MANGo) for public transit (q3b), bicycle access to public transit (q3c), walking access to public transit (q3f), walking for utility trips (q3g), and recreational walking (q3h), while decreases the frequency of traveling by private motor vehicle (q3a) and biking for utility trips (q3d). However, none of these estimates are statistically significant across different model specifications. Overall, the results suggest that the MANGo project likely increased the frequency of using cycling and walking to access public transit in the sample population, as suggested by the statistically significant negative coefficients in columns 5 and 14. Note that in columns 8-10, the estimated coefficients of MANGo are positive, suggesting that the MANGo project is associated with less frequent use of biking for utility purposes. However, the only statistically significant estimate is that of column 10, when bike ownership, a likely endogenous variable, is included in regression.

Table 4 Determinants of the most recent time of each type of travel.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	**q3a Auto**	**q3a Auto**	**q3b Transit**	**q3b Transit**	**q3c Bike_transit**	**q3c Bike_transit**	**q3c Bike_transit**
mango	0.32	0.52	-0.10	-0.059	-0.43*	-0.35	-0.33
	(0.34)	(0.39)	(0.20)	(0.20)	(0.24)	(0.25)	(0.26)
age		-0.053		-0.0013		-0.021	0.020
		(0.052)		(0.034)		(0.048)	(0.050)
age2		0.00072		0.00020		0.00066	0.00022
		(0.00054)		(0.00037)		(0.00058)	(0.00059)
male		-0.37		-0.18		-0.52**	-0.38
		(0.39)		(0.20)		(0.25)	(0.26)
auto_acc		-3.05***		1.34***		0.80*	1.32***
		(0.44)		(0.38)		(0.42)	(0.47)
bike_acc							-1.93***
							(0.36)
Observations	418	404	410	397	409	396	395

(to be continued)

Table 4 (continued).

	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
VARIABLES	**q3d Bike_util**	**q3d Bike_util**	**q3d Bike_util**	**q3e Bike_recr**	**q3e Bike_recr**	**q3e Bike_recr**	**q3f Walk_transit**	**q3f Walk_transit**	**q3f Walk_transit**
mango	0.14	0.30	0.42*	-0.077	0.023	0.030	-0.33*	-0.25	-0.26
	(0.20)	(0.21)	(0.23)	(0.20)	(0.20)	(0.22)	(0.20)	(0.20)	(0.21)
age		-0.10**	-0.064		-0.085**	-0.043		0.066**	0.063*
		(0.042)	(0.046)		(0.039)	(0.043)		(0.033)	(0.033)
age2		0.0015***	0.0012**		0.0013***	0.00086*		-0.00045	-0.00041
		(0.00049)	(0.00054)		(0.00045)	(0.00049)		(0.00036)	(0.00036)
male		-0.64***	-0.47**		-0.54***	-0.35		-0.20	-0.23
		(0.21)	(0.23)		(0.20)	(0.23)		(0.20)	(0.21)
auto_acc		-0.21	0.59		-0.46	0.19		1.51***	1.45***
		(0.41)	(0.49)		(0.44)	(0.50)		(0.39)	(0.39)
bike_acc			-2.94***			-2.86***			0.30
			(0.33)			(0.31)			(0.21)
Observations	407	394	393	407	394	393	411	398	397

(to be continued)

Table 4 (continued).

	(17)	(18)	(19)	(20)	(21)	(22)
VARIABLES	**q3g Walk_util**	**q3g Walk_util**	**q3g Walk_util**	**q3h Walk_recr**	**q3h Walk_recr**	**q3h Walk_recr**
mango	-0.21	-0.073	-0.073	-0.17	-0.12	-0.12
	(0.20)	(0.21)	(0.21)	(0.21)	(0.21)	(0.22)
age		-0.023	-0.019		-0.088***	-0.080**
		(0.033)	(0.033)		(0.031)	(0.032)
age2		0.00046	0.00042		0.00099***	0.00089***
		(0.00034)	(0.00035)		(0.00033)	(0.00033)
male		0.083	0.12		0.18	0.27
		(0.21)	(0.21)		(0.21)	(0.22)
auto_acc		0.087	0.14		-0.53	-0.43
		(0.42)	(0.43)		(0.38)	(0.38)
bike_acc			-0.21			-0.42*
			(0.22)			(0.22)
Observations	411	398	397	411	398	397

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted

Frequency of each type of travel in the last seven days

The second measure of individual travelers' mode choice behavior is the frequency of using a mode in the last seven days. We use both nonlinear – the ordered logit regressions and linear – the ordinal least squares (OLS) regressions to estimate the MANGo project's effects on each travel mode including:

q4 – transit for commute (Table 5);
q5 – transit for non-commute trips (Table 6);
q6 – bicycle to access transit (Table 7);
q7 – bicycle for commute (Table 8);
q8 – bicycle for non-commute utility trips (Table 9);
q9 – bicycle for recreational trips (Table 10);
q10 – walk to access transit (Table 11);
q11 – walk for commute (Table 12);
q12 – walk for non-commute utility trips (Table 13);
q13 – walk for recreational trips (Table 14).

Different from the previous section, a positive estimated coefficient of MANGo suggests the increase in frequency of using a mode in the last seven days here. The difference between the ordered logit models (where no R-squares is reported) and the OLS models (where R-squares are reported) is that estimated coefficients represent log-odds in ordered logit regressions while coefficients in the OLS results directly represent the increase in frequency of using the mode of the dependent variable associated with a unit difference in a regressor.

Applying the OLS regressions here is less rigorous than the ordered logit regressions because of the limited range of values of the dependent variables (0 through 7). However, the use of the OLS regressions allows us conveniently implement a local DID strategy to further test for causality. The DID is estimated by an interaction term (mango_dist) between the MANGo dummy and the distance of an individual's residence to the Michigan Avenue. The expectation is that, if the MANGo project affects travel behavior, it should first and foremost affect those residing closest to the project site (Michigan Avenue). The distance variable (dist) takes the value 1 if a residence is within five standard lots (0 – 250 feet), 2 if a residence is between six and 20 lots (250 – 1000 feet), and 3 if a residence is 21 lots or further (beyond 1000 feet) from the Michigan Avenue. A standard lot's width is 50 feet (15.24 meters) in the neighborhood.

The model results in Table 5 and Table 6 suggest that the MANGo project has a statistically insignificant positive effect on travelers' use of transit for commute and for non-commute trips during the last seven days. Interestingly, the local DID models (models 3 and 6 in both tables) point to a somewhat puzzling spatial heterogeneity: residents living closest to the Michigan Avenue take slightly fewer transit trips after MANGo, while residents living further away from the Michigan Avenue take more transit trips after MANGo. This finding seems to point to some unobserved transit improvement along the Pico Blvd, which is roughly parallel to the Michigan Avenue but closer to the residents living further away from the Michigan Avenue.

Table 5. Determinants of the frequency of using transit for commute in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)
mango	0.12	0.021	-0.99**	0.13	0.022	-0.87**
	(0.34)	(0.22)	(0.40)	(0.35)	(0.22)	(0.40)
age				-0.059	-0.040	-0.030
				(0.071)	(0.044)	(0.044)
age2				0.00039	0.00026	0.00017
				(0.00090)	(0.00053)	(0.00053)
male				-0.39	-0.27	-0.20
				(0.35)	(0.22)	(0.22)
auto_acc				-1.80***	-1.68***	-1.69***
				(0.59)	(0.47)	(0.46)
mango_dist			0.64***			0.57***
			(0.21)			(0.22)
Constant		0.69***	0.69***		3.50***	3.23***
		(0.16)	(0.16)		(0.98)	(0.97)
Observations	234	234	234	229	229	229
R-squared		0.000	0.037		0.079	0.11

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1 and 4

Table 6. Determinants of the frequency of using transit for non-commute trips in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)
mango	0.024	0.059	-0.63**	0.019	0.044	-0.59**
	(0.28)	(0.14)	(0.27)	(0.29)	(0.14)	(0.26)
age				-0.068	-0.047**	-0.043**
				(0.042)	(0.022)	(0.022)
age2				0.00064	0.00041*	0.00039*
				(0.00045)	(0.00024)	(0.00023)
male				-0.12	-0.040	-0.012
				(0.30)	(0.14)	(0.14)
auto_acc				-1.51***	-0.99***	-1.03***
				(0.42)	(0.26)	(0.25)
mango_dist			0.45***			0.42***
			(0.15)			(0.15)
Constant		0.46***	0.46***		2.53***	2.43***
		(0.099)	(0.098)		(0.55)	(0.54)
Observations	338	338	338	327	327	327
R-squared		0.001	0.027		0.064	0.087

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1 and 4

Results on bicycle use (Table 7 through Table 10) suggest that, first, the MANGo project has a statistically insignificant positive effect on using a bicycle to access transit in the last seven days, with negligible spatial heterogeneity in the effect (very small coefficients of mango_dist); second, the MANGo project has a statistically insignificant negative effect on using bicycle for commute; third, the MANGo project has a statistically insignificant effect on using bicycle for non-commute utility trips; and finally, the MANGo project has a positive effect on using bicycle for recreational trips in the last seven days, an effect that is statistically significant in some specifications (models 2, 3 and 9 in Table 10). In particular, in the DID models 3, 6, and 9 of each of the tables, the estimated coefficients of the interaction term mango_dist are negative (but not statistically significant enough), suggesting that residents closer to the Michigan Avenue might be more influenced (as expected). The fact that only results for the recreational bicycle trips show some expected significant effects is not surprising because the relatively moderate scale of the MANGo project (a single neighborhood street) may be helpful for some local recreational biking, but not for longer commute or other utility trips.

Table 7. Determinants of the frequency of using bicycle to access transit in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.69	0.18	0.17	0.74	0.17	0.19	0.75	0.16	0.16
	(0.43)	(0.11)	(0.22)	(0.45)	(0.12)	(0.23)	(0.46)	(0.12)	(0.23)
age				0.00030	-0.012	-0.012	-0.043	-0.020	-0.020
				(0.074)	(0.019)	(0.019)	(0.078)	(0.019)	(0.019)
age2				-0.00026	6.3e-05	6.3e-05	0.00023	0.00016	0.00016
				(0.00087)	(0.00020)	(0.00020)	(0.00091)	(0.00020)	(0.00020)
male				0.43	0.032	0.031	0.099	-0.043	-0.043
				(0.43)	(0.12)	(0.12)	(0.45)	(0.12)	(0.12)
auto_acc				-0.66	-0.31	-0.30	-1.10	-0.37*	-0.37*
				(0.67)	(0.22)	(0.22)	(0.71)	(0.22)	(0.22)
mango_dist			0.0071			-0.014			0.0050
			(0.12)			(0.13)			(0.13)
bike_acc							2.32***	0.40***	0.40***
							(0.77)	(0.12)	(0.12)
Constant		0.15*	0.15*		0.80*	0.80*		0.81*	0.80*
		(0.081)	(0.081)		(0.47)	(0.47)		(0.46)	(0.46)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.007	0.007		0.023	0.023		0.054	0.054

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 8. Determinants of the frequency of using bicycle for commute in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)*	(8)	(9)
mango	-0.34	-0.075	-0.37	-0.42	-0.12	-0.35	-0.46	-0.12	-0.46
	(0.34)	(0.19)	(0.35)	(0.36)	(0.19)	(0.36)	(0)	(0.19)	(0.35)
age				0.035	-0.0053	-0.0026	-0.0062	-0.025	-0.022
				(0.083)	(0.039)	(0.039)	(0)	(0.038)	(0.038)
age2				-0.00094	-0.00015	-0.00017	-0.00051	9.4e-05	6.5e-05
				(0.0011)	(0.00047)	(0.00047)	(0)	(0.00046)	(0.00046)
male				0.68*	0.28	0.29	0.49	0.16	0.19
				(0.37)	(0.19)	(0.19)	(0)	(0.19)	(0.19)
auto_acc				0.83	0.13	0.13	0.61	0.042	0.035
				(1.07)	(0.41)	(0.41)	(0)	(0.40)	(0.40)
mango_dist			0.19			0.15			0.22
			(0.19)			(0.19)			(0.19)
bike_acc							21.8	0.85***	0.87***
							(0)	(0.19)	(0.19)
Constant		0.58***	0.58***		0.80	0.73		0.75	0.65
		(0.14)	(0.14)		(0.87)	(0.87)		(0.83)	(0.84)
Observations	234	234	234	229	229	229	229	229	229
R-squared		0.001	0.005		0.041	0.044		0.12	0.124

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7
* Model 7 does not converge

Table 9. Determinants of the frequency of using bicycle for non-commute utility trips in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	-0.17	0.036	0.45	-0.24	-0.025	0.42	-0.27	-0.049	0.31
	(0.25)	(0.18)	(0.35)	(0.26)	(0.18)	(0.35)	(0.29)	(0.18)	(0.34)
age				0.051	0.0050	0.0025	-0.0046	-0.019	-0.020
				(0.049)	(0.029)	(0.029)	(0.056)	(0.028)	(0.028)
age2				-0.00084	-0.00019	-0.00018	-0.00021	9.1e-05	0.00010
				(0.00057)	(0.00031)	(0.00031)	(0.00064)	(0.00030)	(0.00030)
male				0.28	0.22	0.20	-0.014	0.0033	-0.010
				(0.26)	(0.19)	(0.19)	(0.29)	(0.18)	(0.18)
auto_acc				0.21	0.021	0.045	-0.38	-0.18	-0.16
				(0.52)	(0.34)	(0.34)	(0.60)	(0.32)	(0.32)
mango_dist			-0.27			-0.29			-0.24
			(0.20)			(0.20)			(0.19)
bike_acc							3.83***	1.16***	1.15***
							(0.73)	(0.18)	(0.18)
Constant		0.73***	0.73***		0.84	0.90		0.87	0.92
		(0.13)	(0.13)		(0.73)	(0.73)		(0.69)	(0.69)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.000	0.006		0.024	0.031		0.13	0.13

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 10. Determinants of the frequency of using bicycle for recreational trips in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.32	0.28*	0.63**	0.28	0.23	0.57*	0.35	0.21	0.47
	(0.25)	(0.16)	(0.31)	(0.26)	(0.16)	(0.31)	(0.28)	(0.15)	(0.29)
age				0.072	0.0070	0.0051	0.025	-0.014	-0.015
				(0.050)	(0.026)	(0.026)	(0.055)	(0.024)	(0.024)
age2				-0.0012*	-0.00022	-0.00021	-0.00057	3.4e-05	4.10e-05
				(0.00058)	(0.00027)	(0.00027)	(0.00064)	(0.00026)	(0.00026)
male				0.40	0.18	0.16	0.034	-0.019	-0.029
				(0.26)	(0.16)	(0.16)	(0.29)	(0.16)	(0.16)
auto_acc				-0.54	-0.50*	-0.49	-1.34**	-0.68**	-0.66**
				(0.45)	(0.30)	(0.30)	(0.55)	(0.28)	(0.28)
mango_dist			-0.22			-0.22			-0.17
			(0.18)			(0.18)			(0.17)
bike_acc							3.57***	1.03***	1.02***
							(0.62)	(0.16)	(0.16)
Constant		0.53***	0.53***		1.09*	1.14*		1.11*	1.15*
		(0.12)	(0.12)		(0.64)	(0.64)		(0.600)	(0.60)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.009	0.014		0.046	0.051		0.16	0.16

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

The below four tables (Table 11 through Table 14) estimate the frequency of walking trips during the last seven days. Results of Table 10 suggest that the MANGo project seems to have a statistically insignificant effect on walking to access transit (q10) in the sample population, except that the residents living closest to the Michigan Avenue are slightly negatively affected, while residents living further away from the Michigan Avenue are positively affected. Similar to the previous discussion on the transit use behavior in the neighborhood, this finding seems to suggest some unobserved transit improvements along the Pico Blvd.

Table 11. Determinants of the frequency of walking to access transit in the last 7 days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.066	-0.024	-1.11***	-0.051	-0.082	-1.04***	-0.045	-0.074	-1.02***
	(0.26)	(0.18)	(0.35)	(0.27)	(0.18)	(0.35)	(0.27)	(0.18)	(0.35)
age				-0.11***	-0.084***	-0.079***	-0.10***	-0.079***	-0.074**
				(0.040)	(0.029)	(0.028)	(0.040)	(0.029)	(0.029)
age2				0.00094**	0.00070**	0.00067**	0.00085**	0.00064**	0.00062**
				(0.00043)	(0.00030)	(0.00030)	(0.00043)	(0.00031)	(0.00031)
male				-0.21	-0.26	-0.22	-0.16	-0.21	-0.17
				(0.28)	(0.19)	(0.18)	(0.29)	(0.19)	(0.19)
auto_acc				-1.57***	-1.28***	-1.33***	-1.52***	-1.23***	-1.28***
				(0.41)	(0.34)	(0.33)	(0.42)	(0.34)	(0.33)
mango_dist			0.71***			0.63***			0.62***
			(0.20)			(0.19)			(0.20)
bike_acc							-0.33	-0.27	-0.24
							(0.28)	(0.19)	(0.18)
Constant		0.78***	0.78***		4.20***	4.06***		4.20***	4.06***
		(0.13)	(0.13)		(0.72)	(0.71)		(0.72)	(0.71)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.000	0.038		0.089	0.12		0.095	0.12

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Given the results in Table 12, there seems to be some evidence that the MANGo project has positively affected the choice of walking as the main mode for commute (q11). However, the interaction term mango_dist seems to be fairly insignificant, especially when more control variables are included (models 6 and 9 in the below Table 12). Given the general but spatially indifferent increase in walking among commuters after the MANGo project, we cannot be very confident in suggesting the MANGo project's positive effect on walking among local commuters.

Table 12. Determinants of the frequency of walking for commute in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.47	0.47*	-0.085	0.62*	0.51**	0.33	0.62*	0.52**	0.41
	(0.30)	(0.26)	(0.48)	(0.32)	(0.24)	(0.45)	(0.33)	(0.24)	(0.45)
age				-0.30***	-0.25***	-0.25***	-0.28***	-0.24***	-0.23***
				(0.060)	(0.049)	(0.049)	(0.060)	(0.049)	(0.049)
age2				0.0030***	0.0025***	0.0025***	0.0027***	0.0023***	0.0023***
				(0.00072)	(0.00059)	(0.00059)	(0.00072)	(0.00059)	(0.00059)
male				-0.22	0.057	0.070	-0.10	0.14	0.15
				(0.32)	(0.24)	(0.24)	(0.33)	(0.24)	(0.24)
auto_acc				-0.61	-0.63	-0.64	-0.49	-0.57	-0.57
				(0.65)	(0.52)	(0.52)	(0.66)	(0.51)	(0.51)
mango_dist			0.35			0.11			0.061
			(0.26)			(0.24)			(0.24)
bike_acc							-0.75**	-0.62**	-0.61**
							(0.33)	(0.25)	(0.25)
Constant		0.73***	0.73***		6.67***	6.61***		6.70***	6.67***
		(0.19)	(0.19)		(1.08)	(1.09)		(1.07)	(1.08)
Observations	234	234	234	229	229	229	229	229	229
R-squared		0.014	0.022		0.20	0.20		0.22	0.22

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 13 suggests an expected positive but statistically insignificant effect of the MANGo project on non-commute utility walking trips (q12) by local residents. The interaction term mango_dist does have the expected negative sign in the DID models 3, 6 and 9, indicating that the positive effect of the MANGo project declines for residents living further away from the project. But the estimates are statistically insignificant.

Finally, Table 14 also suggests an expected positive but statistically insignificant effect of the MANGo project on recreational walking trips by local residents, with the interaction term mango_dist highly insignificant. Thus no conclusion could be drawn on the MANGo project's recreational walking travel effects.

Table 13. Determinants of the frequency of walking for non-commute utility trips in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.17	0.25	0.48	0.10	0.17	0.65	0.11	0.19	0.70
	(0.19)	(0.25)	(0.47)	(0.20)	(0.25)	(0.48)	(0.20)	(0.25)	(0.48)
age				0.019	0.0016	-0.0012	0.021	0.0074	0.0047
				(0.032)	(0.040)	(0.040)	(0.032)	(0.040)	(0.040)
age2				-0.00035	-0.00018	-0.00017	-0.00038	-0.00025	-0.00024
				(0.00034)	(0.00043)	(0.00043)	(0.00035)	(0.00043)	(0.00043)
male				-0.065	-0.029	-0.050	-0.043	0.025	0.0054
				(0.21)	(0.26)	(0.26)	(0.21)	(0.26)	(0.26)
auto_acc				0.15	0.17	0.20	0.17	0.23	0.26
				(0.38)	(0.46)	(0.46)	(0.38)	(0.46)	(0.47)
mango_dist			-0.15			-0.32			-0.34
			(0.27)			(0.27)			(0.27)
bike_acc							-0.14	-0.31	-0.32
							(0.21)	(0.26)	(0.26)
Constant		1.99***	1.99***		2.18**	2.25**		2.17**	2.25**
		(0.17)	(0.17)		(0.99)	(0.99)		(0.99)	(0.99)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.003	0.004		0.016	0.021		0.020	0.025

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 14. Determinants of the frequency of walking for recreational trips in the last seven days.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.26	0.39	0.093	0.28	0.42	0.18	0.29	0.44	0.25
	(0.19)	(0.28)	(0.54)	(0.20)	(0.29)	(0.55)	(0.20)	(0.29)	(0.55)
age				0.063*	0.073	0.074	0.065**	0.079*	0.080*
				(0.032)	(0.045)	(0.045)	(0.032)	(0.046)	(0.046)
age2				-0.00071**	-0.00082*	-0.00081*	-0.00074**	-0.00088*	- 0.000889*
				(0.00035)	(0.00049)	(0.00049)	(0.00035)	(0.00049)	(0.00049)
male				-0.23	-0.34	-0.33	-0.21	-0.28	-0.27
				(0.20)	(0.29)	(0.30)	(0.21)	(0.30)	(0.30)
auto_acc				0.43	0.62	0.61	0.47	0.70	0.68
				(0.37)	(0.53)	(0.53)	(0.38)	(0.53)	(0.53)
mango_dist			0.19			0.16			0.13
			(0.30)			(0.31)			(0.31)
bike_acc							-0.17	-0.37	-0.37
							(0.21)	(0.30)	(0.30)
Constant		2.44***	2.44***		0.60	0.56		0.59	0.56
		(0.20)	(0.20)		(1.13)	(1.14)		(1.13)	(1.14)
Observations	338	338	338	327	327	327	326	326	326
R-squared		0.006	0.007		0.023	0.024		0.028	0.029

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Overall, the results of the MANGo project on the local sample population's travel mode choice in the last seven days suggest that the MANGo project has insignificantly affected the local residents' use of transit, bicycle or walking for travel except for the increase in recreational biking. The somewhat unexpected findings of transit use and walking to transit probably indicate the hard-to-control covariates on transit level of service further away from the MANGo project site.

Frequency of each type of travel in a typical week by commuters
The third measure of individual commuters' mode choice behavior is the frequency of using a mode in a typical week. Again, we use both nonlinear – the ordered logit regressions and linear – the ordinal least squares (OLS) regressions to estimate the MANGo project's effects on each commute mode including:

q18a – walking (Table 15);
q18b – biking (Table 16);
q18c – transit (Table 17);
q18d – driving (Table 18);
q18e – car passenger (Table 19).

The model specifications and interpretation of estimated coefficients in Tables 14-18 are similar to the previous section. The results in the following five tables suggest that first, the MANGo project has an insignificant (although overall positive) effect on walking among commuters (Table 14); second, the MANGo project has no effect on biking among commuters, indicated by the large standard errors of the estimated coefficients of MANGo and mango_dist (Table 15); third, again, some evidence that the MANGo project is associated with negative effects of commuters' choice of transit due to potential off-site improvement in transit service along the Pico Blvd (Table 16); fourth, the MANGo project has no effect on driving or carpooling among local commuters (Tables 17-18). These findings about commuter mode choice are not surprising given the limited spatial scale of the MANGo project, as discussed earlier.

Table 15. Determinants of the frequency of walking for commute in a typical week.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.26	0.37	-0.72	0.24	0.36	-0.33	0.24	0.36	-0.32
	(0.22)	(0.30)	(0.57)	(0.23)	(0.30)	(0.56)	(0.23)	(0.30)	(0.56)
age				-0.080*	-0.14**	-0.13**	-0.074	-0.13**	-0.12*
				(0.047)	(0.060)	(0.061)	(0.047)	(0.061)	(0.061)
age2				0.00051	0.0011	0.00097	0.00044	0.00096	0.00088
				(0.00057)	(0.00073)	(0.00073)	(0.00058)	(0.00073)	(0.00073)
male				-0.19	-0.12	-0.085	-0.17	-0.075	-0.040
				(0.23)	(0.30)	(0.30)	(0.23)	(0.30)	(0.30)
auto_acc				-0.62	-0.77	-0.76	-0.57	-0.69	-0.69
				(0.44)	(0.65)	(0.65)	(0.45)	(0.65)	(0.65)
mango_dist			0.69**			0.44			0.43
			(0.30)			(0.30)			(0.30)
bike_acc							-0.21	-0.39	-0.37
							(0.24)	(0.31)	(0.31)
Constant		1.70***	1.70***		5.90***	5.68***		5.87***	5.66***
		(0.22)	(0.22)		(1.32)	(1.33)		(1.31)	(1.33)
Observations	297	297	297	291	291	291	291	291	291
R-squared		0.005	0.022		0.085	0.092		0.090	0.096

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 16. Determinants of the frequency of biking for commute in a typical week.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	-0.12	0.023	0.25	-0.11	0.050	0.34	-0.018	0.062	0.29
	(0.26)	(0.21)	(0.40)	(0.26)	(0.21)	(0.40)	(0.28)	(0.20)	(0.37)
age				0.044	0.028	0.024	-0.012	-0.0018	-0.0045
				(0.057)	(0.043)	(0.043)	(0.063)	(0.040)	(0.041)
age2				-0.00072	-0.00049	-0.00046	-0.00013	-0.00016	-0.00014
				(0.00070)	(0.00052)	(0.00052)	(0.00078)	(0.00049)	(0.00049)
male				0.073	0.15	0.13	-0.16	-0.018	-0.029
				(0.26)	(0.21)	(0.21)	(0.28)	(0.20)	(0.20)
auto_acc				-0.44	-0.75	-0.75	-1.69**	-1.01**	-1.01**
				(0.57)	(0.46)	(0.46)	(0.73)	(0.43)	(0.43)
mango_dist			-0.15			-0.18			-0.14
			(0.21)			(0.22)			(0.20)
bike_acc							3.27***	1.32***	1.32***
							(0.57)	(0.21)	(0.21)
Constant		0.88***	0.880***		1.24	1.33		1.34	1.41
		(0.15)	(0.15)		(0.94)	(0.94)		(0.88)	(0.88)
Observations	297	297	297	291	291	291	291	291	291
R-squared		0.000	0.002		0.023	0.025		0.15	0.15

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 17. Determinants of the frequency of taking transit for commute in a typical week.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	-0.29	-0.23	-1.02***	-0.24	-0.23	-0.97***	-0.26	-0.23	-0.96***
	(0.29)	(0.18)	(0.33)	(0.30)	(0.18)	(0.33)	(0.30)	(0.18)	(0.33)
age				-0.029	-0.010	-0.0012	-0.017	-0.0028	0.0059
				(0.061)	(0.036)	(0.036)	(0.062)	(0.036)	(0.036)
age2				1.00e-04	-2.99e-05	-0.00012	-4.78e-05	-0.00011	-0.00019
				(0.00076)	(0.00044)	(0.00043)	(0.00077)	(0.00044)	(0.00043)
male				-0.068	0.028	0.069	0.023	0.069	0.11
				(0.30)	(0.18)	(0.18)	(0.31)	(0.18)	(0.18)
auto_acc				-1.47***	-1.06***	-1.06***	-1.33***	-1.00**	-1.00**
				(0.50)	(0.39)	(0.39)	(0.51)	(0.39)	(0.39)
mango_dist			0.50***			0.47***			0.46**
			(0.18)			(0.18)			(0.18)
bike_acc							-0.59*	-0.33*	-0.32*
							(0.31)	(0.19)	(0.18)
Constant		0.74***	0.74***		2.19***	1.95**		2.16***	1.93**
		(0.13)	(0.13)		(0.79)	(0.79)		(0.79)	(0.79)
Observations	297	297	297	291	291	291	291	291	291
R-squared		0.006	0.032		0.044	0.066		0.054	0.076

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 18. Determinants of the frequency of driving for commute in a typical week.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.0033	-0.082	0.40	-0.012	-0.11	0.12	-0.012	-0.11	0.12
	(0.21)	(0.30)	(0.56)	(0.21)	(0.29)	(0.55)	(0.21)	(0.29)	(0.55)
age				0.20***	0.26***	0.26***	0.20***	0.26***	0.26***
				(0.045)	(0.059)	(0.059)	(0.046)	(0.059)	(0.060)
age2				-0.0021***	-0.0027***	-0.0027***	-0.0021***	-0.0027***	-0.0027***
				(0.00054)	(0.00071)	(0.00071)	(0.00054)	(0.00071)	(0.00072)
male				-0.15	-0.12	-0.13	-0.13	-0.11	-0.12
				(0.21)	(0.29)	(0.29)	(0.21)	(0.29)	(0.29)
auto_acc				1.29**	1.70***	1.70***	1.33**	1.71***	1.71***
				(0.52)	(0.63)	(0.63)	(0.52)	(0.64)	(0.64)
mango_dist			-0.31			-0.15			-0.15
			(0.30)			(0.30)			(0.30)
bike_acc							-0.15	-0.065	-0.069
							(0.23)	(0.30)	(0.30)
Constant		4.05***	4.05***		-2.85**	-2.77**		-2.85**	-2.78**
		(0.22)	(0.22)		(1.29)	(1.30)		(1.29)	(1.30)
Observations	297	297	297	291	291	291	291	291	291
R-squared		0.000	0.004		0.11	0.11		0.11	0.11

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Table 19. Determinants of the frequency of commuting as a car passenger in a typical week.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
mango	0.056	0.041	-0.55	0.30	0.17	-0.042	0.30	0.17	-0.026
	(0.24)	(0.23)	(0.44)	(0.26)	(0.23)	(0.41)	(0.26)	(0.21)	(0.40)
age				-0.33***	-0.32***	-0.32***	-0.32***	-0.31***	-0.31***
				(0.052)	(0.044)	(0.044)	(0.053)	(0.044)	(0.044)
age2				0.0036***	0.0035***	0.0035***	0.0035***	0.0034***	0.0034***
				(0.00062)	(0.00053)	(0.00053)	(0.00063)	(0.00053)	(0.00053)
male				-0.33	-0.19	-0.18	-0.25	-0.14	-0.13
				(0.26)	(0.21)	(0.22)	(0.26)	(0.22)	(0.22)
auto_acc				-1.46***	-1.08**	-1.08**	-1.39***	-1.00**	-1.00**
				(0.47)	(0.47)	(0.47)	(0.47)	(0.47)	(0.47)
mango_dist			0.38			0.14			0.12
			(0.24)			(0.22)			(0.22)
bike_acc							-0.63**	-0.44*	-0.43*
							(0.26)	(0.22)	(0.22)
Constant		1.05***	1.05***		8.56***	8.49***		8.52***	8.46***
		(0.17)	(0.17)		(0.95)	(0.96)		(0.95)	(0.96)
Observations	297	297	297	291	291	291	291	291	291
R-squared		0.000	0.009		0.20	0.20		0.21	0.21

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Estimated constant cuts omitted in the ordered logit models 1, 4 and 7

Conclusion and discussion of before-after travel behavior comparison

The statistical analysis of before-after project travel behavior of neighborhood residents of the MANGo project examined three closely related factors: the most recent time of each type of travel, the frequency of each type of travel in the last seven days, and the frequency of each type of travel in a typical week by commuters. In aggregate, the results suggest that the MANGo project has resulted in an increase in recreational biking and likely also some increase in the use of biking and walking to access public transit in the sample of local residents. However, it does not seem that the MANGo project has meaningfully changed the main mode of commuters. These findings are unsurprising given the limited spatial scale of the MANGo project and possibly also the relatively short time window the after-project survey allowed the residents to adjust their travel behavior (the after-survey was conducted three months after the project was finished).

The above results point to limited travel behavior changes of residents living within a walkable distance to a complete streets retrofit project in an urban residential neighborhood setting. For policy makers and regulatory agencies, this suggests that one may need to pay more attention to the estimated mode-shift related benefits (e.g., congestion relief, public health, and greenhouse gas emissions reduction) of such projects relative to their costs. Of course, more studies are needed to provide a set of comprehensive evidence for decision making.

It is hard to compare this study's results to the existing literature because of the scarcity of similar studies at this moment – our study is likely one of the very first natural-experimental analyses of complete street projects. In addition, because each complete street project has its distinct characteristics in terms of its location, scale, detailed changes to street landscape, etc., the external validity of any single-project study is limited. It would be extremely helpful to at least focus on two extensions of such a study in the future. First, a follow up survey of local residents after a longer time period would be helpful because residents' travel behavior may need more time to adjust to the changes in local travel environment. Second, different study settings should be tested because complete streets likely have economies of spatial scale. That is, a network of complete streets may be much more effective in changing travel behavior than the aggregate of independent individual complete streets.

3.1.4.2 Stated travel barriers

One adult in each sampled households answers the barrier question to (doing more of) biking, walking, and taking transit, respectively. It is hard to identify any statistically significant difference in the stated travel barriers before and after the MANGo project (note that the standard deviations in the below tables are quite large, indicating the fairly diverse opinions among local adult residents). So the analyses below mainly focus on the top barriers chosen by the local residents.

Stated barriers for biking
Table 20 below summarizes the proportion (and standard deviation) of respondents who select each of the barrier choices for (doing more) biking. The most selected barriers are almost identical before and after the MANGo project. They include “too busy”, “too many things to carry”, “too many cars in traffic”, “fast traffic”, “not enough bike lanes or wide curb lanes”, and “unsafe street crossings”, all of which were chosen by 20% or more respondents. The MANGo project, even having some traffic calming and biking/walking-enabling effects, has not changed the stated opinion of local residents about the barriers to biking (based on two-sample t-tests), perhaps due to its limited spatial scope. It is also possible that we may observe more changes of residents' perceived barriers to biking after a longer time period after the project (i.e., changes in lifestyle happen slowly).

Table 20. Stated barriers for biking.

Barrier	Before MANGo		After MANGo	
	Mean	Std. Dev.	Mean	Std. Dev.
Too busy	0.280	0.45	0.294	0.45
No interesting places to go to	0.054	0.23	0.011	0.23
Can't afford it (bike, bike maintenance, parts, clothing, etc.)	0.071	0.26	0.080	0.26
Too many things to carry	0.321	0.47	0.310	0.47
Small children along	0.089	0.29	0.107	0.29
Don't know how to bike	0.042	0.20	0.037	0.20
Health restrictions	0.107	0.31	0.096	0.31
I don't like to sweat	0.054	0.23	0.096	0.23
Biking messes up my clothes and/or hair	0.083	0.28	0.043	0.28
No one to bike with	0.089	0.29	0.070	0.29
My neighbors/friends don't bike	0.054	0.23	0.027	0.23
Fear of street crime	0.083	0.28	0.091	0.28
Not enough light at night	0.143	0.35	0.182	0.35
Too many cars in traffic	0.399	0.49	0.476	0.49
Fast traffic	0.339	0.47	0.358	0.47
Air pollution	0.119	0.32	0.070	0.32
No nearby paths or trails	0.161	0.37	0.155	0.37
Not enough tree shade	0.077	0.27	0.059	0.27
Not enough bike lanes or wide curb lanes	0.262	0.44	0.230	0.44
Unsafe street crossings	0.196	0.40	0.203	0.40
Unsafe streets due to pot holes, bumpy road	0.185	0.39	0.123	0.39
I simply do not like biking	0.071	0.26	0.102	0.26
I don't have any barriers to biking	0.137	0.34	0.134	0.34
Other	0.185	0.39	0.123	0.39

Number of observations: 168 before MANGo and 187 after MANGo. Mean and Std. Dev. are the proportion and standard deviation of respondents who select each of the barrier choices. For example: 0.280 means 28% of respondents selected this barrier.

Stated barriers for walking

Table 21 below summarizes the proportion (and standard deviation) of respondents who select each of the barrier choices for (doing more) walking. The two most selected barriers are also the same before and after the MANGo project: "too busy" and "I simply do not like walking". It seems that people do not walk not due to very specific reasons in local built environment, but as a habitual choice given their lifestyle. The MANGo project has yet to or may not be able to generate a short-term change in residents' lifestyle. One possible reason is again the limited spatial scale of the project. It is also possible that we may observe more changes of residents' perceptions after a longer time period after the project (as previously stated, changes in lifestyle happen slowly).

Table 21. Stated barriers for walking.

Barriers	Before MANGo		After MANGo	
	Mean	Std. Dev.	Mean	Std. Dev.
Too busy	0.270	0.45	0.288	0.45
No interesting places to go to	0.101	0.30	0.045	0.21
Too many things to carry	0.226	0.42	0.181	0.39
Small children along	0.044	0.21	0.062	0.24
Health restrictions	0.101	0.30	0.085	0.28
I don't like to sweat	0.038	0.19	0.051	0.22
No one to walk with	0.063	0.24	0.051	0.22
Fear of street crime	0.170	0.38	0.130	0.34
Fear of neighborhood dogs	0.057	0.23	0.034	0.18
Not enough light at night	0.138	0.35	0.136	0.34
My neighbors don't walk	0.031	0.18	0.028	0.17
Too many cars in traffic	0.113	0.32	0.062	0.24
Fast traffic	0.113	0.32	0.124	0.33
Air pollution	0.094	0.29	0.085	0.28
No nearby paths or trails	0.082	0.27	0.090	0.29
No nearby parks	0.101	0.30	0.062	0.24
No (good) sidewalks	0.069	0.25	0.028	0.17
Not enough tree shade	0.063	0.24	0.085	0.28
Unsafe street crossings	0.107	0.31	0.113	0.32
Unsafe streets due to pot holes, bumpy road	0.057	0.23	0.034	0.18
I simply do not like walking	0.038	0.19	0.045	0.21
I don't have any barrier to walking	0.296	0.46	0.347	0.48
Other	0.075	0.26	0.034	0.18

Number of observations: 159 before MANGo and 177 after MANGo. Mean and Std. Dev. are the proportion and standard deviation of respondents who select each of the barrier choices. For example: 0.270 means 27% of respondents selected this barrier.

Stated barriers for taking transit

Table 22 below summarizes the proportion (and standard deviation) of respondents who select each of the barrier choices for taking (more) transit. While the MANGo project itself does not have a transit component, it is still useful to see residents' opinions about barriers for using transit and whether those barriers have much to do with the design of local roads (e.g., the Michigan Avenue). Both before and after the MANGo project, residents were more concerned with barriers such as "(transit) does not accommodate my schedule", "(transit) does not get me to where I want to go", and "transit vehicles are too slow". While the differences are statistically insignificant (according to two-sample t-tests), it seems that before the MANGo project, residents commented more often on the "unreliable schedule" of transit, while after the MANGo project, residents were more likely to indicate that "I don't have any barrier to taking transit". These seem to support the earlier regression results regarding transit. There might have been some concurrent improvements in transit service offsite from the MANGo project. We have not been able to obtain detailed evaluations of transit level of service on the bordering streets of our study area (i.e., Pico Boulevard and Lincoln Boulevard), but we do know that the City of

Santa Monica did have multiple transit improvement project going on during our study period, such as bus stop retrofit and improved service near Santa Monica College on Pico Boulevard (according to bigbluebus.com). These changes could have led to the somewhat unexpected findings regarding the association between the MANGo project and local residents' travel behavior related to transit.

Table 22. Stated barriers for taking transit.

Barriers	Before MANGo		After MANGo	
	Mean	Std. Dev.	Mean	Std. Dev.
Does not accommodate my schedule	0.388	0.49	0.389	0.49
Does not get me to where I want to go	0.350	0.48	0.328	0.47
Transit vehicles are too slow	0.313	0.46	0.250	0.43
Infrequent service	0.188	0.39	0.140	0.35
Unreliable schedule	0.263	0.44	0.183	0.39
I don't like transfers	0.150	0.36	0.111	0.32
Transit costs too much	0.069	0.25	0.061	0.24
Transit may be associated with low social status	0.038	0.19	0.039	0.19
My neighbors or friends don't take transit	0.063	0.24	0.028	0.16
Buses are uncomfortable and/or unsanitary	0.163	0.37	0.150	0.36
Transit vehicles are not safe	0.056	0.23	0.061	0.24
Unsafe to walk or bicycle to and/or from stops	0.088	0.28	0.033	0.18
Unsafe around transit stops	0.113	0.32	0.061	0.24
Not enough shade to or from transit stops	0.050	0.22	0.056	0.23
Not enough shade at transit stops	0.119	0.32	0.106	0.31
I simply do not like taking transit	0.150	0.36	0.194	0.40
I don't have any barrier to taking transit	0.169	0.38	0.211	0.41
Other	0.125	0.33	0.128	0.33

Number of observations: 160 before MANGo and 180 after MANGo. Mean and Std. Dev. are the proportion and standard deviation of respondents who select each of the barrier choices. For example: 0.388 means 38.8% of respondents selected this barrier.

3.2 Difference-in-Difference (DID) Study

In this section, the results of traffic volume, pedestrian and cyclist volume, and their ratios are first presented separately (section 3.2.1 through section 3.2.3). Then the on-road air quality results are presented in Section 3.2.4. Then all the information is integrated and the relationships among these measurement results are explored (section 3.2.6). The intercept survey results are presented in section 3.2.6. Finally, the key findings in the DID study are summarized (section 3.2.7).

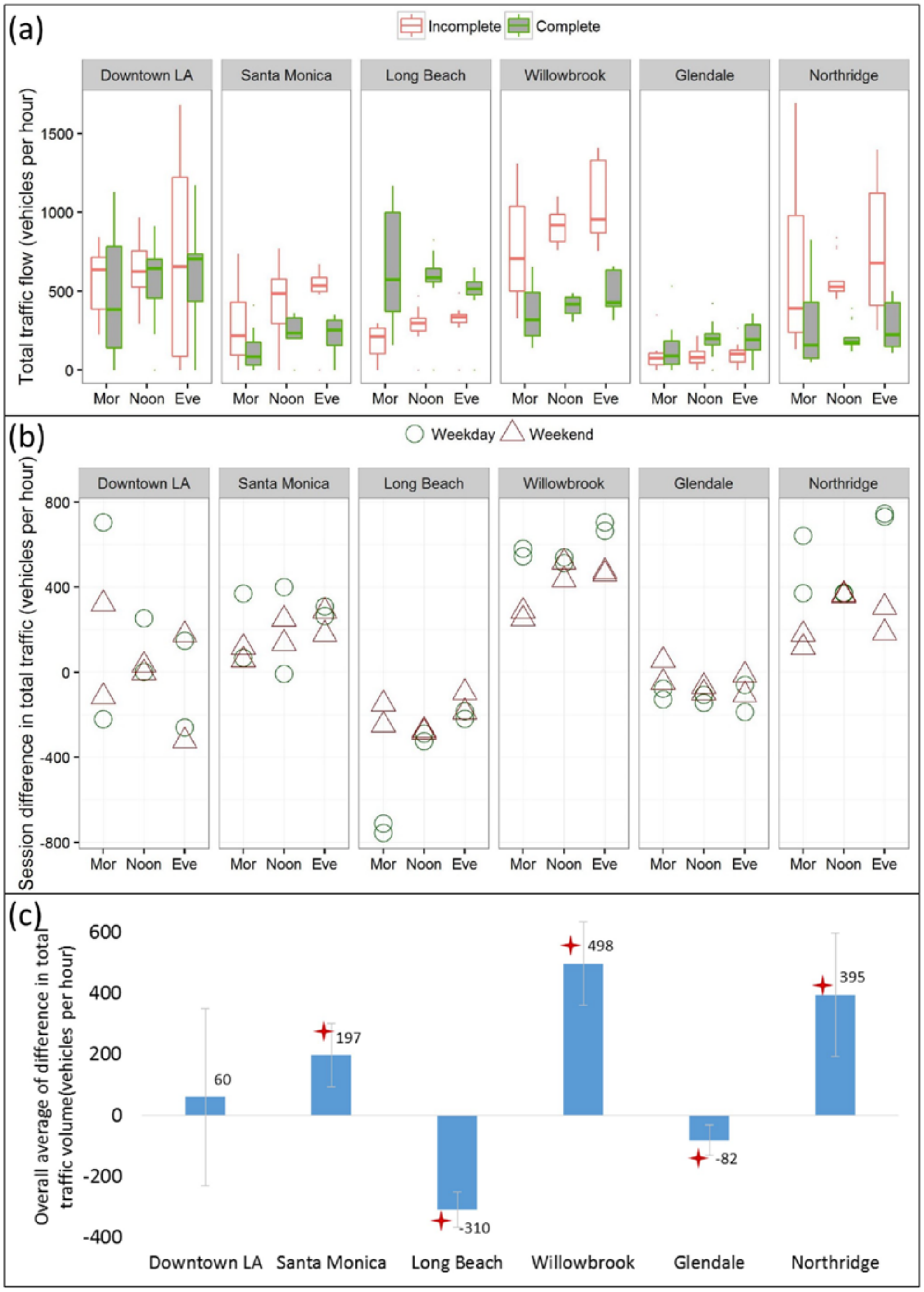
In sections 3.2.1, 3.2.2, and 3.2.4, the data are presented in the following fashion: for each type of measurement data, one figure with three panels is used. First, the averages of each two-hour session are presented as box-and-whisker plots in panel (a). Second, the differences between these paired sessions are shown in panel (b). These differences are defined as "session-wise differences" to represent the difference between complete and incomplete streets. Third, in panel (c), the bars show the averages of the data points in panel (b), for each site. Shapiro test was first used to check if the data points in panel (b) were normally distributed or not. Based on the Shapiro test result, either t-test or Wilcoxon test was followed to determine if the differences were statistically different with zero, for each site. Small red stars are used in panel (c) to indicate the sites with overall averages that were statistically significant different with zero. Finally, to further summarize the findings of each measurement, the averages of all the site-wise differences were presented in a table at the end of each section.

3.2.1 DID traffic volume and traffic speed results

3.2.1.1 Total traffic volume results

Figure 14 panel (a) shows that the total traffic volume of each session can have large variation on the same street, and the total traffic volume at different sites are on the same order of magnitude. Figure 14 panel (b) shows the session-wise differences of total traffic volume and the color of points differentiate the weekday and weekend results. A positive value means that the total traffic volume is higher on the incomplete street than on the complete street. Figure 14 panel (c) shows the average of data points in panel (b) across the sessions for each site. For the Santa Monica, Willowbrook, and Northridge sites, the incomplete streets had statistically significant higher total traffic volume than the complete streets. At the Long Beach and Glendale sites, the complete streets had significantly higher total traffic volume than the incomplete streets. The Downtown LA site showed no significant difference. This finding demonstrated that complete streets' impacts on the total traffic volume are site-specific. We were not able to identify the real causes of this total traffic difference between complete and incomplete streets. It was possible that the complete streets indeed changed the people's choice of transportation modes and led to less usage of motorized vehicles. It was also possible that the complete streets simply displaced the traffic volume onto other neighboring streets. In addition, the total traffic volume could potentially be largely determined by factors other than the complete street features, such as street connectivity, traffic light settings, or the origins and destinations of the trips on these streets. A more detailed analysis between the traffic volume and time mean speed and related discussions can be found in Appendix E.

Figure 14. Total traffic volume results from the DID study. Panel (a) shows the total traffic volumes measured on each street. Points in panel (b) represent the differences in total traffic volume, for each two-hour session. The positive value in panel (b) means the incomplete street has higher total traffic volume. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages are statistically different with zero.

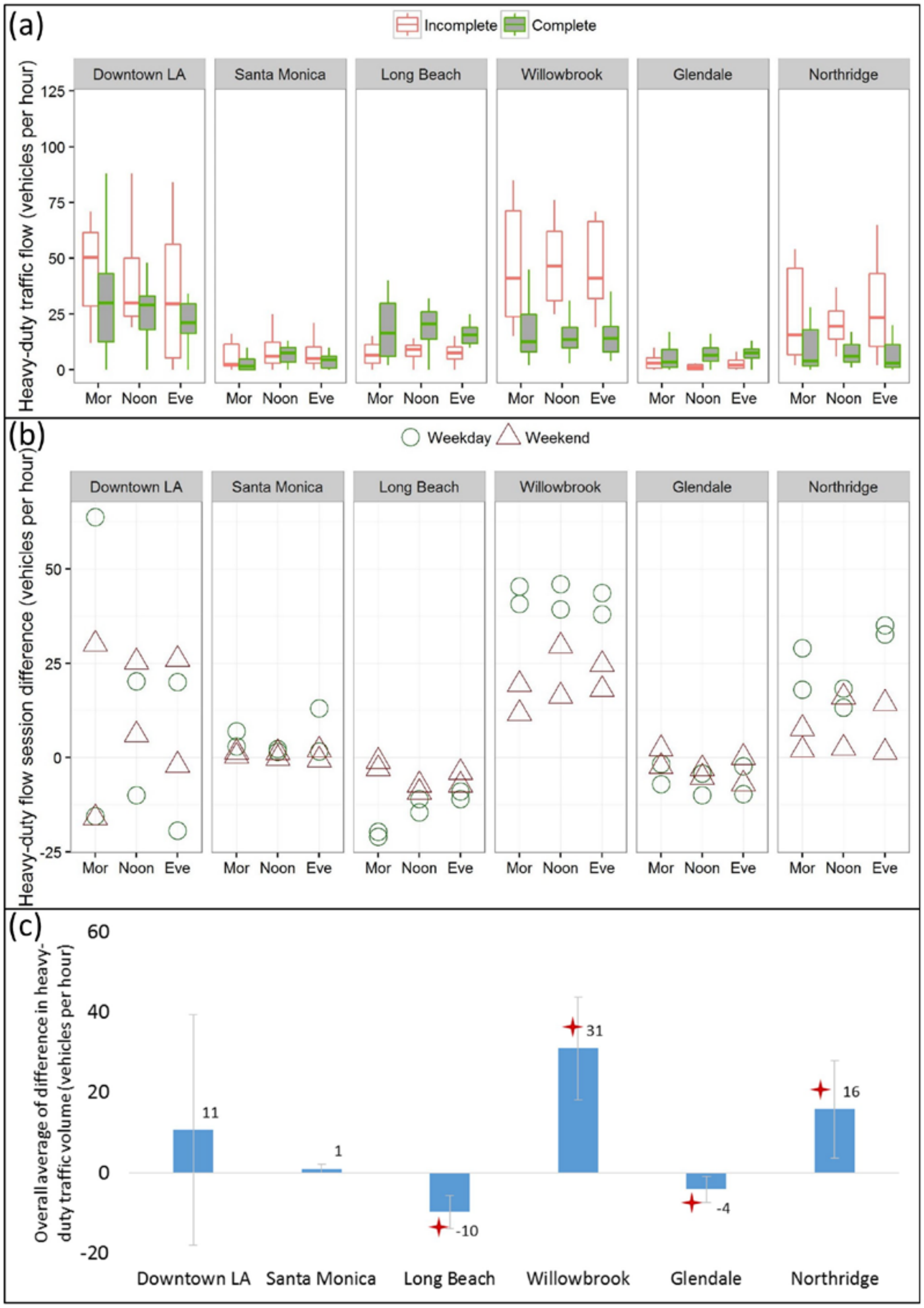


3.2.1.2 Heavy-duty vehicle traffic volume results

Heavy-duty vehicle traffic volume, as found in the Ocean Park Boulevard before-after study, has larger impacts on the on-road air quality compared to the regular motorized vehicles. Therefore, the heavy-duty vehicle traffic volume data were also analyzed and presented in the same fashion as the total traffic volume. Figure 15 shows the heavy-duty vehicle traffic volume results. Figure 15 panel (a) shows the heavy-duty vehicle traffic volume measured on each site. The Santa Monica site and Glendale sites had lower heavy-duty vehicle traffic volume and also smaller variations compared with other sites. Figure 15 panel (b) shows the session-wise difference in heavy-duty vehicle traffic volume and the color differentiates the weekdays and weekends. A positive value means that the incomplete streets have higher heavy-duty vehicle traffic volume than the complete streets. Figure 15 panel (c) shows the average of session-wise differences data across sessions for each site. At the Willowbrook site and Northridge sites, the heavy-duty vehicle traffic volume on the incomplete streets was significantly higher than that on the respective complete streets. The Long Beach and Glendale sites had just the opposite, similar to the finding for total traffic volume. The Downtown LA site showed no significant difference in heavy-duty vehicle traffic volume. The Santa Monica site, which had a statistically significant difference in total traffic volume, did not show a statistically significant difference in heavy-duty vehicle traffic volume, possibly because the heavy-duty vehicle traffic volume was low at this site.

Some factors that were not measured in this study could potentially affect the observed heavy-duty vehicle traffic volume. For example, the streets in the downtown and business areas were more likely to have stores and restaurants, which potentially attract more heavy-duty vehicles for delivery and pickup merchandise. The street cleaning schedule could also be different at different sites, so the chances for street cleaning trucks and garbage trucks to show up on each street may be different. For future studies, a larger number of test days are recommended in order to minimize the impacts of these unmeasured factors.

Figure 15. Heavy-duty vehicle traffic volume results from the DID study. Panel (a) shows the heavy-duty vehicle traffic volumes measured on each street. Points in panel (b) represent the differences in heavy-duty vehicle traffic volume between the twin-streets, for each two-hour session. The positive value in panel (b) means the incomplete street has higher heavy-duty vehicle volume. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages are statistically different with zero.



3.2.1.3 DID traffic volume results summary

The session differences in total traffic and heavy-duty traffic over all six sites were lumped together and underwent statistical tests to check the overall differences between complete and incomplete streets. The results are summarized in Table 23. It was found that the incomplete streets had 127 vehicles per hour more total traffic volume and 7 vehicles per hour more heavy-duty vehicle traffic volume, when compared with the complete streets, and both differences were statistically significant. While statistical significance was not observed for each individual site, the result from all observations over the six sites support the argument that complete streets have lower total traffic volume and heavy-duty vehicle traffic volume than the paired incomplete streets. On the aspects of exposure and public health, this finding suggests that on average, complete streets may potentially reduce street users' exposure to traffic-related air pollutants. This study, however, was not designed to determine why the complete streets had lower traffic volume. It is possible that the complete streets have made more people chose walking or cycling over driving and led to a reduction in total traffic volume. It is also possible that the complete streets simply displaced the traffic volume onto other neighboring streets.

Table 23. Summary statistics of total and heavy-duty vehicles session differences. A positive value indicates that the incomplete streets have higher flow

	Sample size	**mean** [vehicles per hour]	**Standard deviation** [vehicles per hour]	**Normally distributed?**	**Statistically significant? (*p*<0.05)**
Total traffic	72	127	312	Yes	Yes
Heavy-duty	72	7	17.0	No	Yes

3.2.2 DID pedestrians and cyclists results

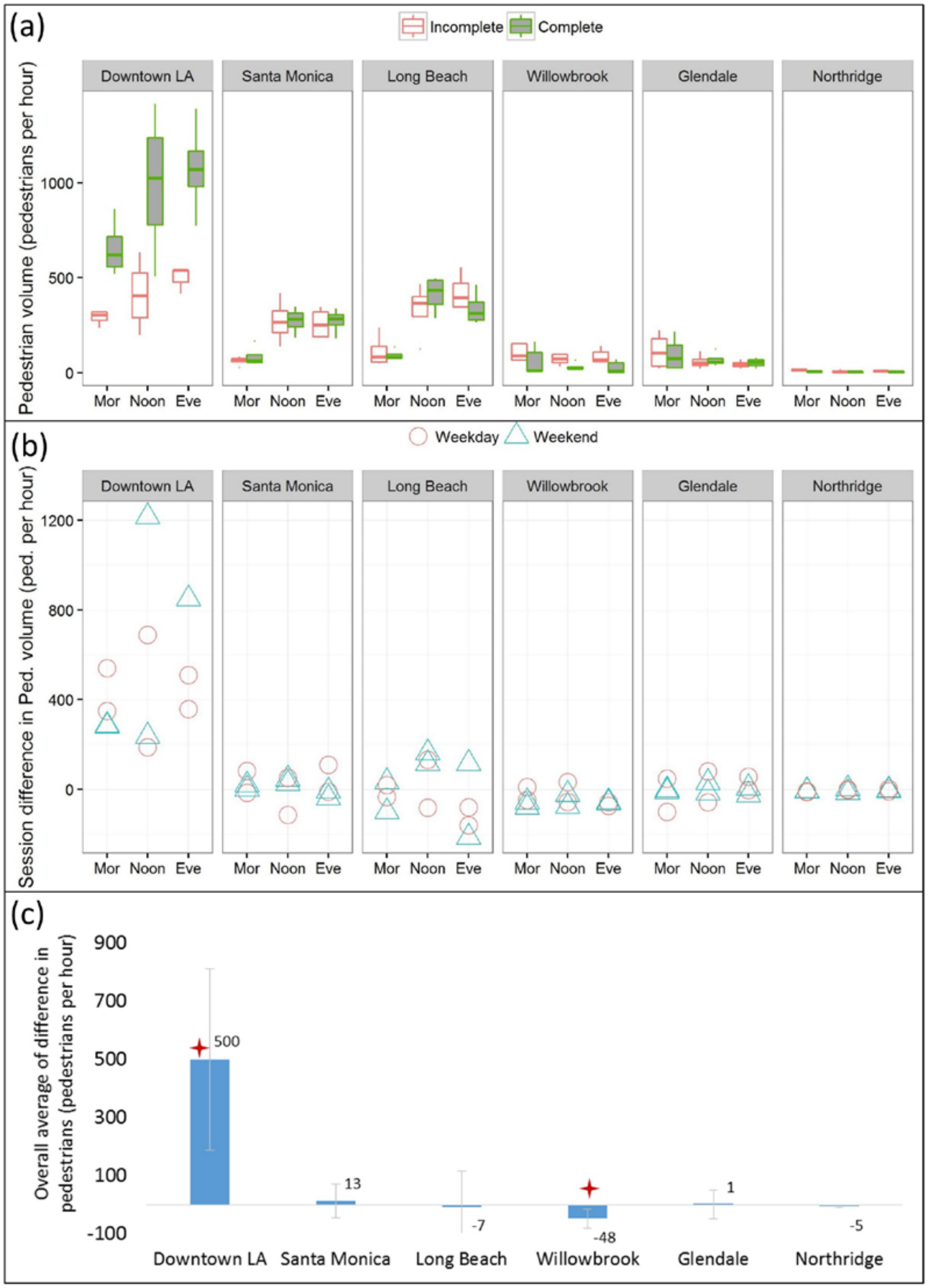
3.2.2.1 DID pedestrians flow results

Pedestrians flow data were analyzed similar to traffic data, and as such, are presented in a similar fashion below. Figure 16 panel (a) shows the absolute values of pedestrian volume measured at each site on both complete and incomplete streets. The pedestrians flow at different sites covers three orders of magnitude. At the Downtown LA site, the pedestrian volume was as high as ≥ 1,000 pedestrians per hour while at the Northridge site, it was as low as ≤ 10 pedestrians per hour. This suggests that pedestrian volume is highly affected by the location and function of the streets (see Table 2). The Downtown LA, Santa Monica, and Long Beach sites, which are located in the urban environment, had higher pedestrian volume on both complete and incomplete streets when compared with the rest of the sites, which are located in suburban or residential areas. Figure 16 panel (b) shows the session-wise differences in pedestrian volume between complete and incomplete streets. In Figure 16 panel (b), positive values indicate that the complete streets had higher pedestrian volume than the incomplete streets. Figure 16 panel (b) shows that, at the Downtown LA site, the pedestrian volume on the complete street was usually a few hundred pedestrians per hour higher than on the incomplete street. For one session, the difference reached more than 1,000 pedestrians per hour on one weekend. Some features, such as restaurants, coffee shops, and parklets (i.e., a sidewalk extension that provides more space and amenities for people using the street) on the complete street, might have contributed to the higher street user volume.

Figure 16 panel (c) shows that, when averaged across all sessions for each site, the Downtown LA site had 500 per hour more pedestrian volume on the complete street, than on the incomplete street. While at the Willowbrook site, the complete street had 48 per hour lower pedestrians flow when compared with its twin incomplete street. These differences were statistically different from zero. The rest of the four sites did not show any statistically significant difference in pedestrian volume between the complete and incomplete streets.

This finding indicates that the Downtown LA site has unique characteristics in terms of pedestrian volume. Based on field observation, one possible reason is that the complete street at the Downtown LA site (Spring Street) has many more restaurants and cafes compared with its twin incomplete street (Main Street). It should be noted that restaurants and cafes (or more shops in general) were not technically a ‘street design feature’, thus not considered a criteria in selecting complete streets. However, because the three measurement sessions approximately overlap with the time periods when people usually go out and take meals, we observed large amount of pedestrians on the Spring Street. While for the Willowbrook site, there are transit facilities (bus stops) on the incomplete street and this might help explain why the incomplete street had slightly higher pedestrian volume than the complete street at Willowbrook. Nevertheless, a further examination of the street feature of transit facilities as shown in Table 3 and the overall pedestrian volume differences as shown in Figure 16 panel (c) indicates the pedestrian volume on a street was not determined by whether or not transit facilities exist on the street. Taking the Downtown LA site for example, the pedestrian volume on the complete street was significantly higher, even though both the complete and incomplete streets at this site had transit facilities. Thus, a simple ‘yes or no’ categorization was probably not good enough to fully characterize street features such as reported in Table 3.

Figure 16. Pedestrians volume results from the DID study. Panel (a) shows the pedestrians volumes on each street. Points in panel (b) represent the differences in pedestrian volume between the twin-streets, for each two-hour session. The positive value in panel (b) means the complete street had higher pedestrian volume. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages were statistically different with zero.

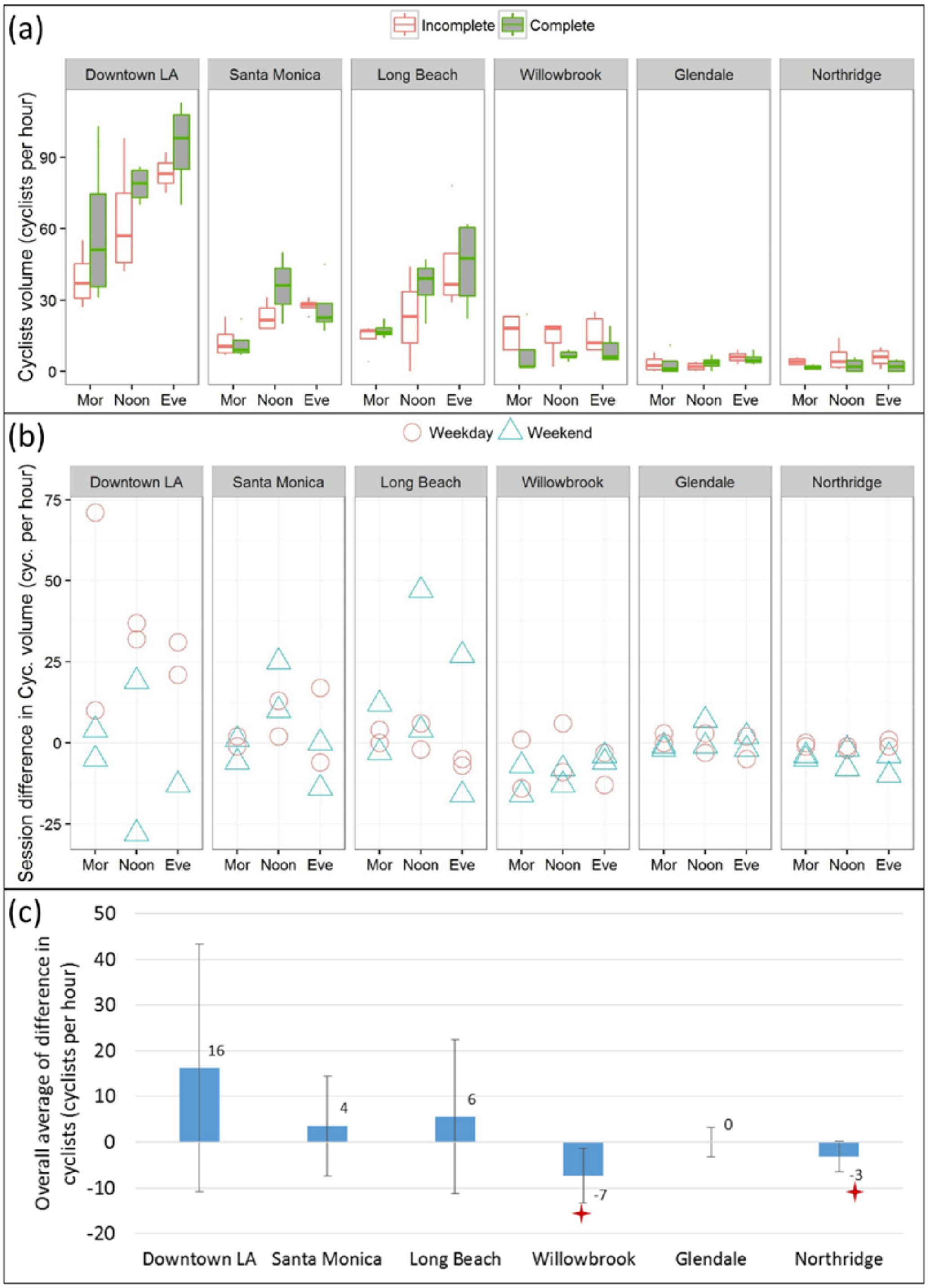


3.2.2.2 DID cyclist volume results

Similarly, cyclist volume data were analyzed and presented in Figure 17. Figure 17 panel (a) shows the cyclist volume measured from each session, on complete and incomplete streets, respectively. The ratios of cyclist volume to pedestrian volume were similar at each site, ranging from 5% to 25%. Cyclist volume, similar to pedestrian volume, was largely affected by the location and function of the streets. Figure 17 panel (b) shows the session-wise difference in cyclist volume between complete streets and incomplete streets. Positive values indicate that the complete street had higher cyclist volume than the twin incomplete street. Figure 17 panel (c) shows that, only at the Willowbrook and Northridge sites, the incomplete street had higher cyclist volume than the complete street, and the differences are statistically significant. The averages of the differences were only 7 cyclists per hour and 3 cyclists per hour for the Willowbrook and Northridge sites, respectively. The other four sites had no statistically different cyclist volume on the complete and incomplete streets. Overall, complete streets do not seem to have a great impact on the number of cyclists.

Besides the number of cyclists on the streets, the complete streets can possibly impact the cyclists' health by changing the concentrations of air pollutants the cyclists exposed to as well as changing the safety of cycling on the streets. The cyclists usually have 2 – 5 times higher respiration rates when compared with car drivers, because cyclists have elevated activity levels (Zuurbier, Hoek et al. 2009; Bigazzi and Figliozzi 2014). Many studies have investigated the cyclists' exposure to air pollutants compared to that of vehicle drivers and found that cyclists have similar or higher exposure to traffic-related air pollutants, including Volatile Organic Compounds (VOCs), NO_2, CO, UFP, and PM2.5, when compared with vehicle drivers and passengers (van Wijnen, Verhoeff et al. 1995; Rank, Folke et al. 2001; Briggs, de Hoogh et al. 2008; de Nazelle, Fruin et al. 2012; Panis, Willems et al. 2012; Quiros, Lee et al. 2013). On the other hand, studies also have shown that the health benefits of cycling still overweight its risks, because of the elevated physical activity levels (De Hartog, Boogaard et al. 2010; Rojas-Rueda, de Nazelle et al. 2011). In this study, the impacts of complete streets on the on-road pollutant levels and on the street safety were evaluated and presented in later sections.

Figure 17. Cyclist volume results from the DID study. Panel (a) shows the cyclist volume measured on each street. Points in panel (b) represent the differences in cyclist volume between the twin-streets, for each two-hour session. The positive value in panel (b) means the complete street has higher cyclist volume. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages are statistically different with zero.



3.2.2.3 DID pedestrians and cyclist volume results summary

The results of statistical tests on the session-wise differences in pedestrian volume and cyclist volume for all six sites are summarized in Table 24. The statistical test results showed that, for all the six sites, the session-wise differences in pedestrian volume and cyclist volume were not significantly different from zero, suggesting that complete streets had similar pedestrian and cyclist volumes when compared with incomplete streets. However, it should be noted that, at the Downtown site, the complete street had 500 per hour more pedestrian volume than the incomplete street, which is also statistically significant.

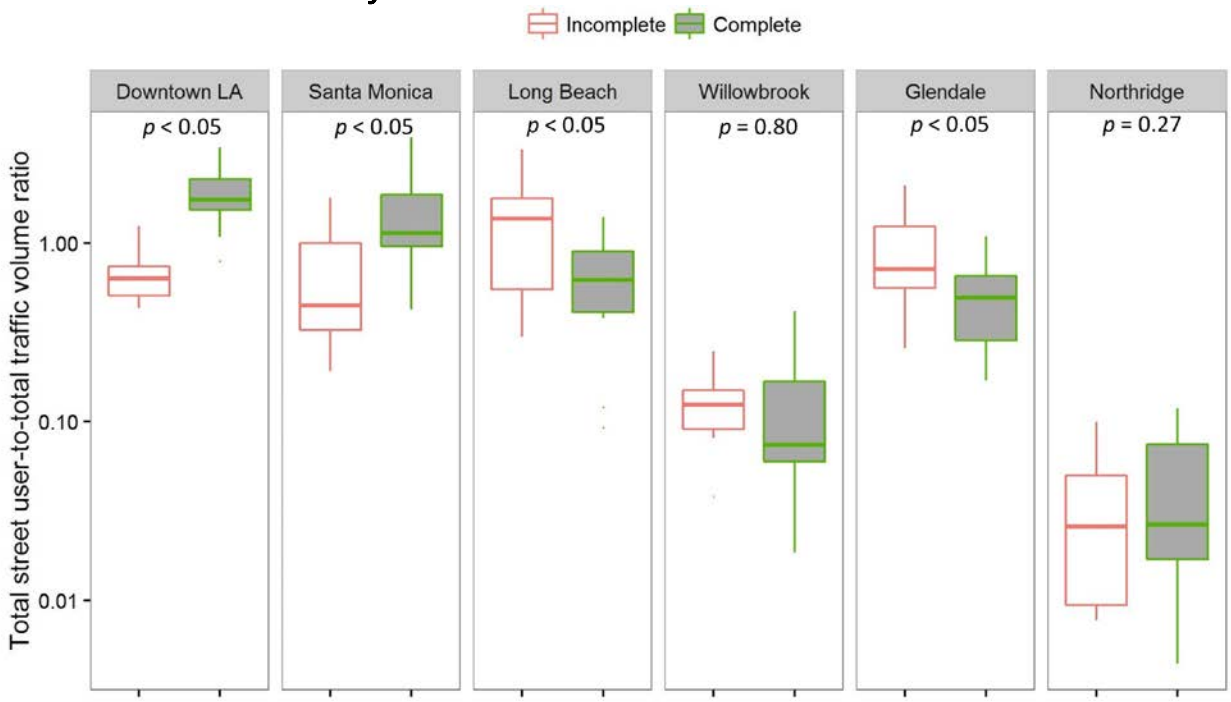
Table 24. Summary statistics of total street users, pedestrians, and cyclists session differences. A positive mean value indicates that the complete street has higher flow.

	Sample size	**mean** [pedestrians per hour]	**Standard deviation** [pedestrians per hour]	**Normally distributed?**	**Statistically Significant? (*p<0.05*)**
Pedestrians	72	65	225	No	No
Cyclists	72	2	15	No	No

3.2.3 Ratios among traffic, pedestrian, and cyclist volumes

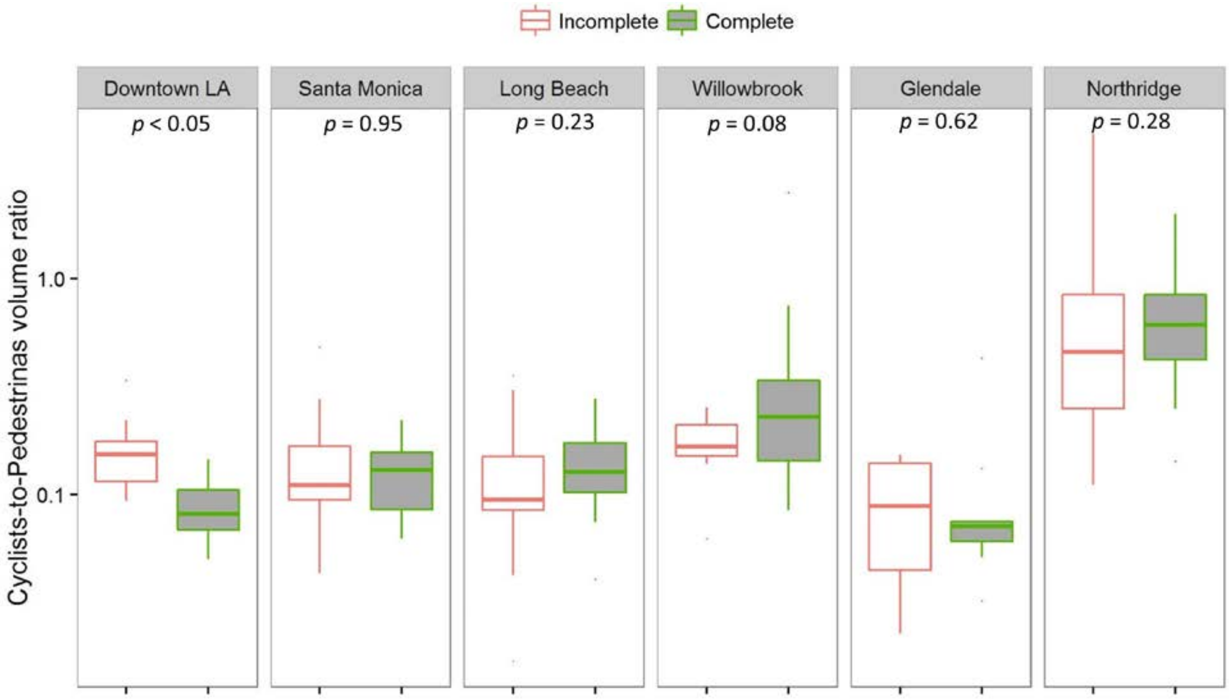
The intermodal ratios (e.g., cyclist volume vs. pedestrian volume) were another set of indexes to reflect the traffic conditions and street usages. The ratio between total street user volume (which equals to the sum of cyclists volume and pedestrians volume) and the total traffic volume are shown in Figure 18. Overall, the suburban and residential sites (i.e., the Northridge site) had lowest ratio between total street users volume to total traffic volume. For Downtown LA site and Santa Monica site, this ratio was statistically higher on the complete streets than on the incomplete streets. This finding suggests that if a complete street project is constructed in the downtown and business area, it is more likely to bring positive impacts to the pedestrians and cyclists.

Figure 18. Ratios between total street users volume to total traffic volumes measured on different streets. The total street user volume was the sum of pedestrian volume and cyclist volume.



Similarly, the ratio between cyclists volume to pedestrians volume are shown in Figure 19. This ratio can be used to assess the street users' choice between walking and cycling at each site. Interestingly, although the Northridge site, which is in the suburban and residential area, had much less absolute value of cyclists and pedestrians, the ratio between cyclists volume to pedestrians volume was higher, compared with those at the rest five test sites. In the suburban area, people may choose to use bicycles more often when they need some short-trip transportation, since the public transition is less available in these areas. This observation suggests that a dedicated bicycle lane may be an important street feature to add when a complete street project is constructed in suburban and residential areas.

Figure 19. Ratio between cyclist volume and pedestrian volume measured on different streets.



3.2.4 DID on-road air quality results

3.2.4.1 DID on-road UFP results

Similar to the analysis described above for traffic, the UFP and PM2.5 data were analyzed and presented in the same fashion below. For each two-hour session, the geometric means of UFP measured on the complete and incomplete streets were calculated and presented in Figure 20 panel (a). The boxes present the distribution of these session-wise geometric mean values for each site, with different colors for complete and incomplete street, respectively. Figure 20 panel (a) shows that, for each site, morning sessions usually have higher UFP concentrations than the noon and afternoon sessions. This is consistent with the findings in the before-after study, as shown in Figure 10 panel (a).

Figure 20 panel (b) presents the session differences in UFP concentrations between complete and incomplete streets. Each point represents the difference between the geometric mean of UFP concentrations measured for each of the two-hour session on the twin incomplete and complete streets. The color differentiates measurement modes (i.e., walking, cycling, and driving). A positive value means that, in that specific session, the geometric mean of UFP concentrations on the incomplete street was higher than that on the complete street. The large variations in the data points demonstrate that it is necessary to use a large number of sampling sessions, as have been done in this study, to capture the overall difference of on-road UFP concentrations between incomplete and complete streets.

Figure 20.UFP concentration results from the DID experiments. Panel (a) shows the on-road UFP concentrations. Points in panel (b) represent the differences in UFP between twin-streets, for each two-hour session. The positive value in panel (b) means the incomplete street has higher UFP concentration. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages are statistically different with zero.

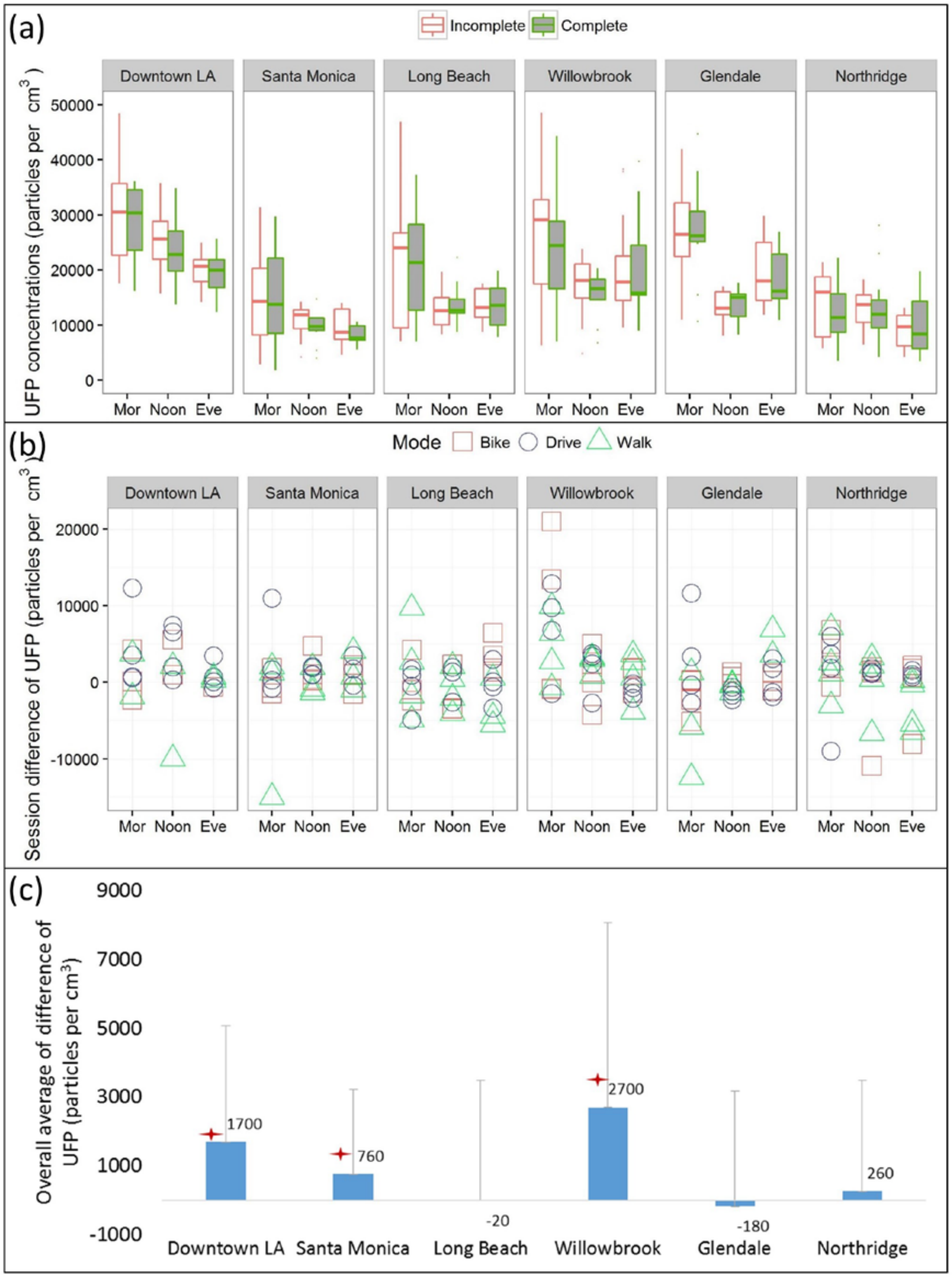
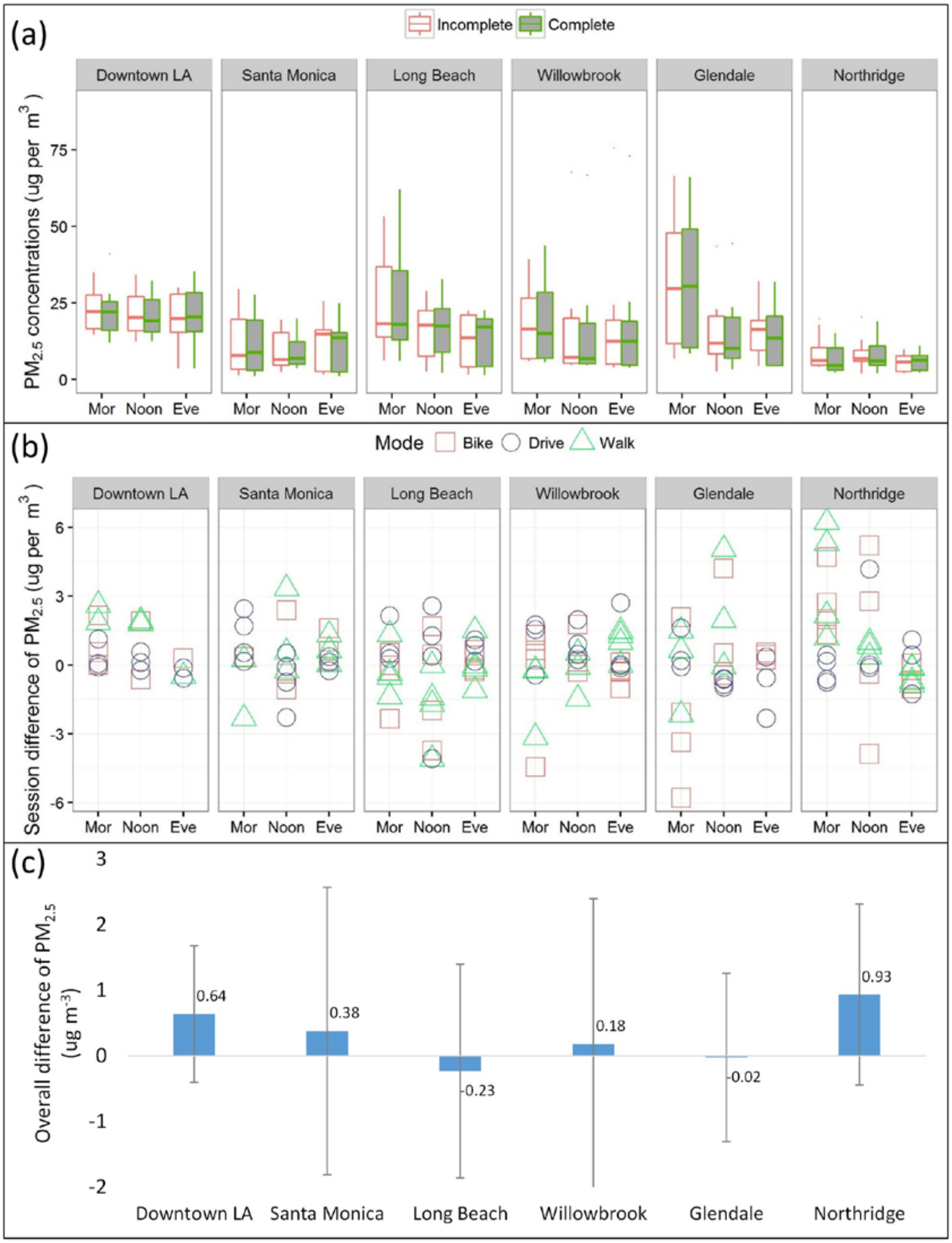


Figure 20 panel (c) presents the site-wise average values of the session differences in UFP concentrations as shown in Figure 20 panel (b). A small red star was used to indicate those sites with an overall average statistically different than zero. Downtown LA, Santa Monica, and Willowbrook sites showed overall averages greater than zero, suggesting at these three sites, the UFP concentrations on the incomplete streets were statistically higher than those on the complete streets. This finding suggests that complete streets may, but not always, have lower UFP concentrations than incomplete streets. This is not surprising since traffic volumes on complete streets were not always lower than that on the incomplete streets (see section 3.2.1).

3.2.4.2 DID on-road PM2.5 results

Similar to the UFP data, the PM2.5 results are presented in the three panels in Figure 21. Compared with UFP concentrations, PM2.5 concentrations were more consistent across different sites as shown in Figure 21 panel (a). This is reasonable because it is well known that PM2.5 concentrations are more homogeneously distributed at a regional scale while UFP concentrations drop rapidly with increasing distance from the direct sources(Zhu, Hinds et al. 2002a; Zhu, Hinds et al. 2002b). Figure 21 panel (b) shows the differences of session-wise PM2.5 between incomplete streets and complete streets. A positive value means that the incomplete street has higher PM2.5 concentration than the complete street. The color differentiates the modes (i.e., walking, cycling, and driving) of PM2.5 measurements. Data points in Figure 21 panel (b) were further averaged across each site and all measurement modes and presented in panel (c). Statistical test results showed that, for all six sites, the PM2.5 concentrations on the complete and incomplete streets were not significantly different. This finding is also consistent with the findings of the before-after study, as shown in Figure 10 panel (c) and Figure 13.

Figure 21. PM2.5 concentration results from the DID study. Panel (a) shows the on-road PM2.5 concentrations. Points in panel (b) represent the differences in PM2.5 between the twin-streets, for each two-hour session. The positive value in panel (b) means the incomplete street has higher PM2.5 concentration. Panel (c) shows the average value of all points in panel (b), and the red plus signs indicate the sites where the overall averages are statistically different with zero.



3.2.4.3 DID on-road UFP and PM2.5 results over all sites

To obtain an overview of UFP and PM2.5 for all six sites, the data points in Figure 20 panel (b) and Figure 21 panel (b), were lumped together, respectively, to assess if the session-wise differences for UFP and PM2.5 levels were significantly different from zero. The results of statistical tests are summarized in Table 25. Across all six sites, the complete streets had 1300 particles per cm^3 lower on-road UFP and 0.30 µg per m^3 lower PM2.5 concentrations than the incomplete streets. It should be noted that, for PM2.5 data, even though statistical significance was not found at any one particular site, the overall six sites data were statistically significant (different from zero) due to the increased sample size. These findings were consistent with the traffic volume and heavy-duty vehicle traffic volume results: compared with incomplete streets, the complete streets had significantly lower total traffic volume and heavy-duty vehicle volume. It should be noted, the means of UFP and PM2.5 difference, 1,300 particles per cm^3 and 0.3 µg per m^3, were only approximately 7% and 2% of their respective average concentrations measured in this study. This finding indicates that complete streets may bring some positive environmental benefits by reducing street users' exposure to air pollutants, but the impacts are relatively small and site-specific.

Table 25. Statistics of UFP and PM2.5 for all session-wise differences over all six sites

	Sample size	**mean**	**Standard deviation**	**Normally distributed?**	**Statistically significant? ($p<0.05$)**
UFP	185	1300 [particles per cm^3]	3800 [particles per cm^3]	No	Yes
PM2.5	172	0.30 [µg per m^3]	1.74 [µg per m^3]	No	Yes

3.2.5 Exploring relationships among DID measurements

In this section, the relationships among the session-wise differences in total and heavy-duty vehicle traffic volume, pedestrian and cyclist volume, and on-road UFP and PM2.5 are explored. Table 26 summarizes the location and function of each site and whether or not significant differences between on-road UFP and PM2.5 were found at these sites. The Downtown LA, Santa Monica, and Willowbrook sites, which showed significant difference in UFP, did not show significant difference in PM2.5. For the Long Beach, Glendale, and Northridge sites, neither UFP nor PM2.5 show statistical significant difference. The data suggest that UFP concentration was more likely to be affected by the street type (complete street or incomplete street), compared to PM2.5. Table 26 also shows that the location and function of the test sites are not necessarily related to any of the significant differences in UFP, PM2.5, pedestrian volume, and cyclist volume. This suggests that there are probably other factors, for example, population density in the study area, that have more direct impacts on these indexes.

Table 26. Summary of on-road air quality, traffic volume, and street users differences on each site

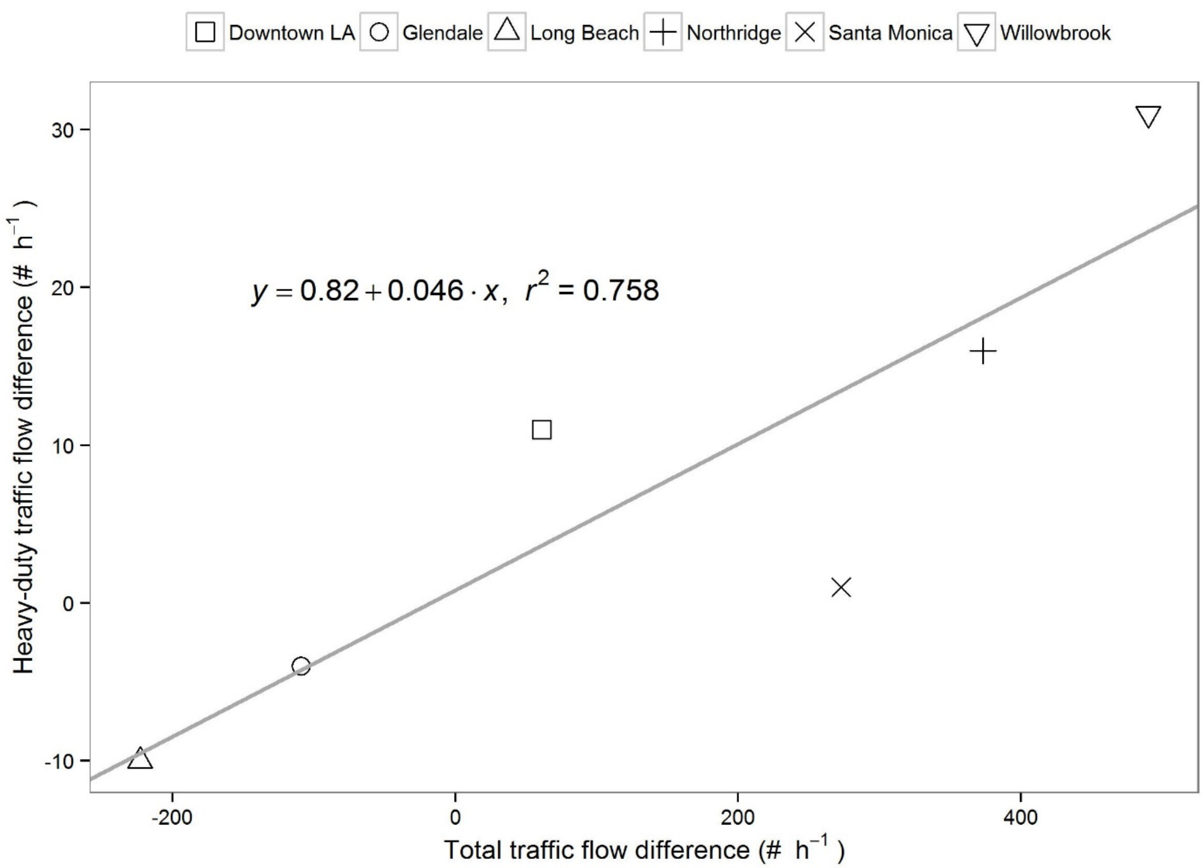
Site	Location	Function	Difference between complete and incomplete street					
			UFP	PM2.5	Total Traffic	Heavy-duty	Pedestrians	Cyclists
Downtown LA	Downtown	Business	-				+	
Santa Monica	Downtown	Business	-		-			
Long Beach	Urban	Mixed			+	+		
Willowbrook	Suburban	Mixed	-		-	-	-	-
Glendale	Suburban	Residential			+	+		
Northridge	Suburban	Residential			-	-		-

‘ + ‘ means significant higher values on complete street, and ‘ – ‘ means significant lower values on complete street. A blank cell means that there is no statistical difference. The cells with ‘ + ‘ or ‘ – “ signs are also color-coded to show better contrast.

It is expected that certain measures for on-road air pollutants (e.g., UFPs) and traffic index (total traffic volume, heavy-duty vehicle traffic volume, pedestrian volume, or cyclist volume) may be correlated. For example, if there are more vehicles on complete streets, it is expected that the on-road UFP concentrations will be higher too. To further explore such correlations, the site-wise average of differences in total traffic volume, heavy-duty vehicle traffic volume, pedestrian volume, cyclist volume, UFP and PM2.5 (values in the panel (c) of Figure 14 to Figure 17) were plotted in pairs and linear regression was used to describe their relationship.

Figure 22 shows the relationship between total traffic volume differences and heavy-duty flow differences. These two traffic indexes were highly correlated with each other, meaning if higher total traffic volume is observed on the complete street than the incomplete street, the heavy-duty vehicle traffic volume can also be expected to be higher on the complete street.

Figure 22. Relationship between total traffic volume differences and heavy-duty vehicle traffic volume differences.



In the following data analysis, both total traffic volume differences and heavy-duty vehicle flow differences are used as x-axis and other indexes are shown as y-axis.

Figure 23 shows the relationships between UFP and PM2.5 differences versus total and heavy-duty vehicle flow differences. Panels (a) and (b) show that both total traffic volume and heavy-duty vehicle traffic volume were positively correlated with the UFP differences. The heavy-duty vehicle traffic volume had even higher r-squared value, meaning it is more closely correlated with UFP differences. This is consistent with the findings in the Ocean Park Boulevard before-after study; namely that heavy-duty vehicles with greater emission factors are important sources of on-road UFP. Panels (c) and (d) show that the PM2.5 concentration differences were less correlated with either total traffic volume or heavy-duty vehicle traffic volume, compared with UFP.

Figure 23. Relationships between UFP and PM2.5 differences and traffic volume differences.

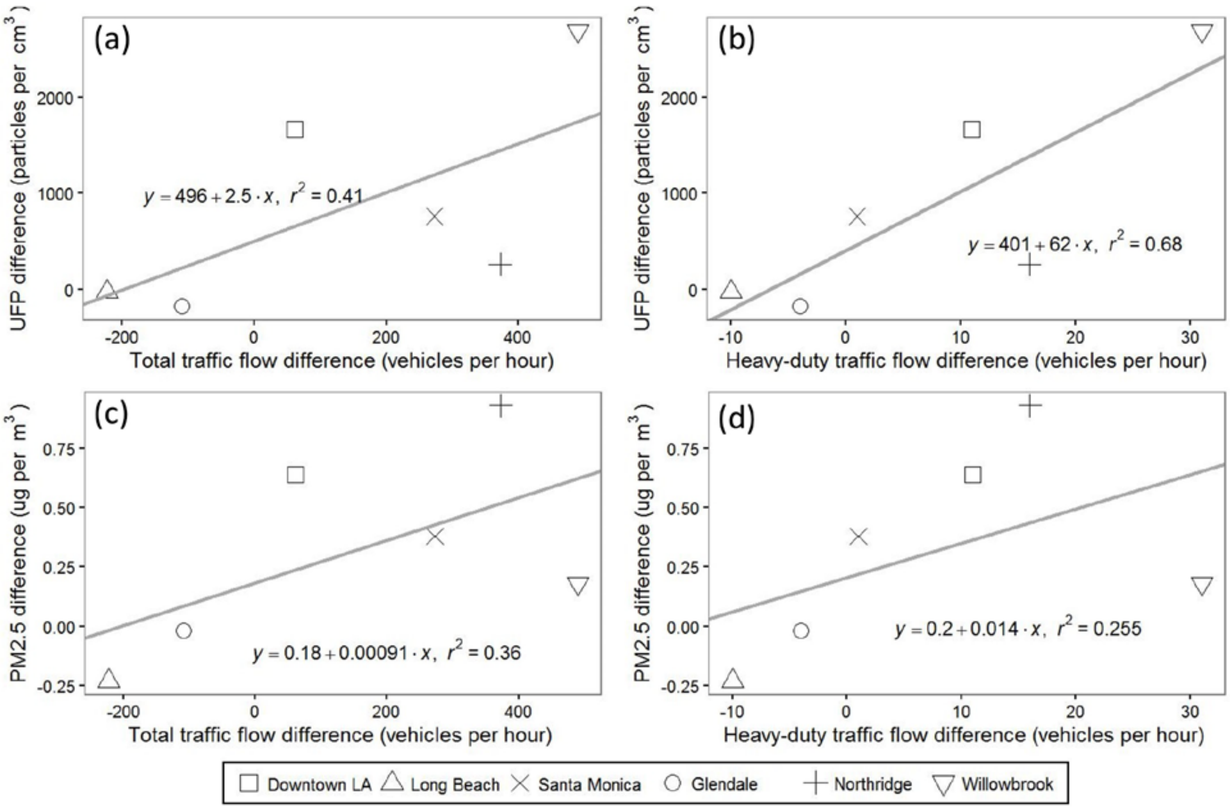
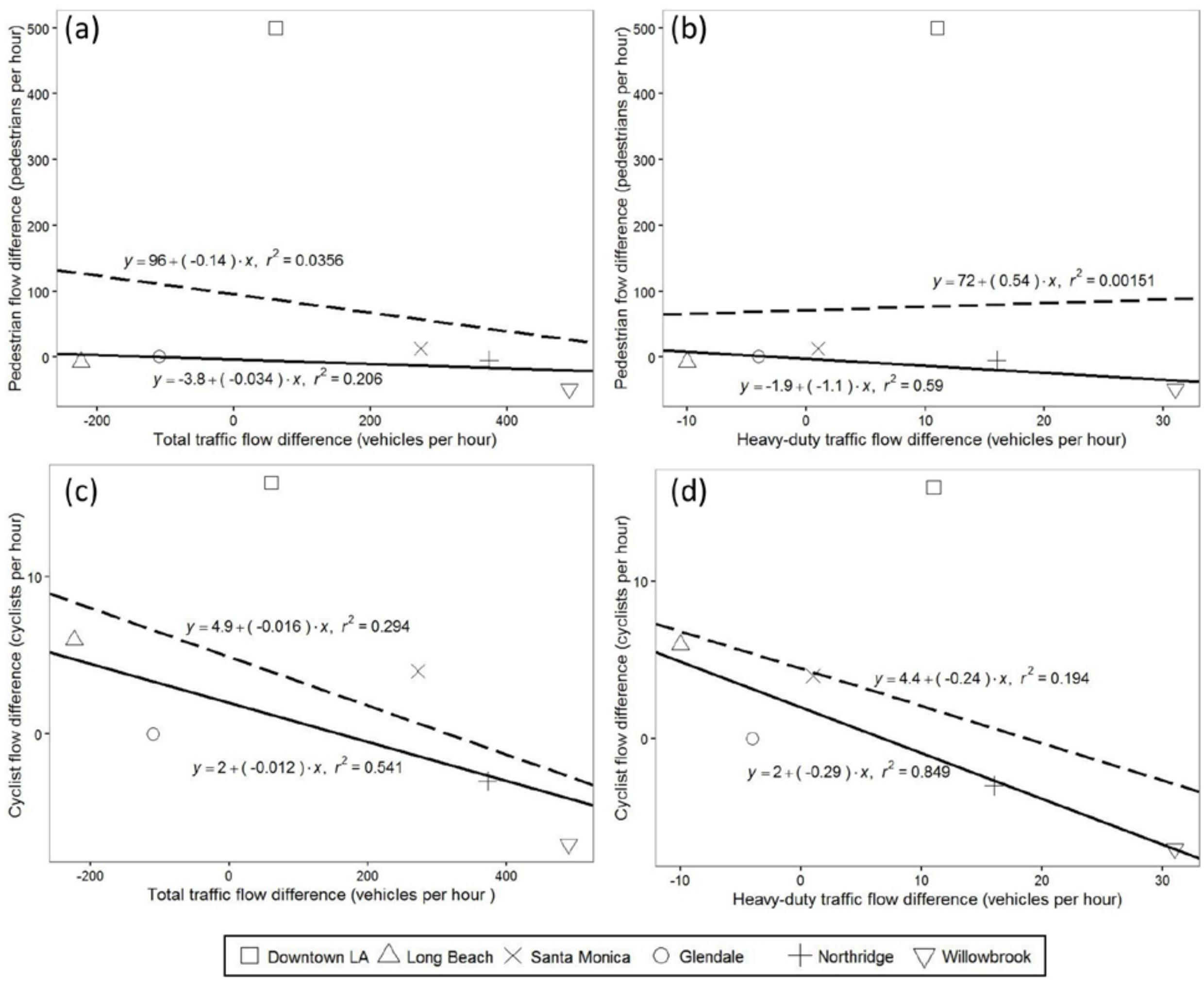


Figure 24 shows the relationship between pedestrian volume and cyclist volume differences versus total and heavy-duty vehicle flow differences. Panels (a) and (b) show that Downtown LA site had much higher pedestrian volume differences between its complete and incomplete street. For the remaining five sites, when the total traffic volume or the heavy-duty vehicle traffic volume differences increase, the pedestrian volume difference decrease slightly. This suggests that the total traffic volume had a negative impact on the pedestrian volume, meaning if a street, whether complete or incomplete, has high traffic volume, it tends to have lower pedestrian volume. Similarly, panels (c) and (d) show that both the total traffic volume and heavy-duty vehicle traffic volume had the same impact on cyclist volume. When a street, whether complete or incomplete, has high traffic volume or high heavy-duty vehicle traffic volume, it tends to have lower cyclist volume. It should be noted that, the Downtown LA site may be considered as an outlier for the regression analysis in these panels, because this site had pedestrian and cyclist volume that were several times higher than those measured at the rest five sites. Once removed, the negative correlations became clearer and stronger as shown by the solid regression lines in the four panels. Without the Downtown LA site, the greatest and strongest negative correlation was observed between cyclist and heavy-duty vehicle traffic volume.

Figure 24. Relationships between pedestrians and cyclist volume differences and traffic volume differences. The dashed lines show the regression of all six sites, while the solid lines show the regression with Downtown LA site data excluded.



3.2.6 DID intercept survey results

3.2.6.1 Survey summary statistics

A total of 774 completed intercept surveys were used in the analysis. There were 714 people we approached on the streets refused to participate in the survey due to many different reasons. The summary of the refusal log is shown in Table 27. Table 28 shows the distribution of sites and the number of completed intercept surveys for each pair of streets at each location.

Table 27. Number of survey refusals by gender and reasons.

	Men	Women	Total
Busy/ no time	246	152	398
No English	48	27	75
No reason/Brush Off	94	82	176
Working	7	13	20
Responded Another time	10	5	15
Younger than 18 years old	6	2	8
Other	13	9	22
Total	424	290	714

Table 28. Number of completed intercept surveys by location and street type.

Site	Counts			Percentage		
	Complete	Incomplete	Total	Complete	Incomplete	Total
Downtown LA	149	113	262	35%	32%	34%
Glendale	40	31	71	10%	9%	9%
Long Beach	102	84	186	24%	24%	24%
Northridge	17	18	35	4%	5%	5%
Santa Monica	98	85	183	23%	24%	24%
Willowbrook	14	23	37	3%	6%	5%
Total	420	354	774	100%	100%	100%

The demographic data collected include gender, race/ethnicity, age, education, household size, and employment status. Overall, there is no statistical difference in these attributes between the surveyed people on complete streets and on incomplete streets (non-parametric tests of the distributions showed no significant differences at the 0.05 level), except for the percent of respondents by employment status. People on complete streets were more likely to be employed overall than people surveyed on the incomplete streets.

Table 29 shows the distribution of respondents by gender. In the overall sample of respondents, men comprise 60 percent, slightly lower on the incomplete streets and consistent with the percent of refusers by gender. Women comprise 40 percent of the overall respondents, slightly higher on the incomplete streets.

Table 29. Gender/Sex of respondents by street type.

	Street Type				Total	
	Complete		Incomplete			
	n	%	n	%	n	%
Men	255	61%	206	58%	461	60%
Women	165	39%	148	42%	313	40%
Total	420	100%	354	100%	774	100%

Table 30 shows the mix of respondents by race/ethnicity. Overall, the plurality of respondents identified as white (36%), followed by Latino/Hispanic (26%), and African-American (15%). People identified as Asian, mixed and 'other' are also represented. Without a complete count of street users by racial identification, we cannot know if some groups responded at a lower rate than their proportion on the street.

Table 30. Race/Ethnicity of respondents by street type.

	Street Type					
	Complete		**Incomplete**		**Total**	
	n	**%**	**n**	**%**	**n**	**%**
White	150	36%	131	37%	281	36%
Latino/Hispanic	119	28%	82	23%	201	26%
African American	69	16%	47	13%	116	15%
Asian	41	10%	34	10%	75	10%
Mixed	20	5%	31	9%	51	7%
Native American	4	1%	8	2%	12	2%
Other	16	4%	20	6%	36	5%
Total	419	100%	353	100%	772	100%

It should be noted that the general population in these tested areas may have different race/ethnicity distributions than that of the sampled street users in this study. More detailed descriptive of the survey data can be found in Appendix D.

3.2.6.2 Examining the subjective questions

A total of 774 intercept surveys were completed; 420 on complete streets and 354 on incomplete streets. This sample size allows us to detect a significant difference in the attitudinal data at 90 percent confidence interval (± 10 percent). The qualitative factors were ranked by respondents on a 5-point Likert scale (strongly agree to strongly disagree). Positive and negative directions were inter-mixed to increase cognitive engagement. The ranked factors were analyzed using a non-parametric test of independent samples to identify whether the factors which respondents found important were the same for people on complete streets compared with people on the incomplete streets. The test used a ± 10 percent confidence limit in keeping with the sample design—although a ± 5% test was also run and the results were the same.

In general, as shown in Table 31 and Table 32, the respondents on complete streets agreed with the positive statements about their experience on the street. People on the complete streets were more likely than their counterparts (on incomplete streets) to agree that the street had shade and interesting things to do, and that they felt secure walking on the street. People on complete streets were also more likely to disagree that the intersections were hard to across. On the other hand, people surveyed on the incomplete streets were more likely than their counterparts to agree that the street had wide sidewalks.

Table 31. Summary of ranked factors (% strongly agree or somewhat agree) by street type.

	Complete	Incomplete
Wide Sidewalks	78%	82%
Clean and Maintained	68%	67%
Shade and Trees	77%	64%
Interesting Things	79%	65%
Feel Secure	80%	72%
Intersections Hard to Cross	22%	29%
Too Much Traffic	42%	37%

Table 32. Likert scale means for factors between complete streets and incomplete streets (Lower score=Tend to Agree).

	"Agree" Mean	
	Complete	Incomplete
Street has Wide Sidewalks	1.91	1.83
Clean and Maintained	2.35	2.25
Street has Shade**	1.99	2.39
Interesting Things**	1.96	2.33
Feel Secure**	1.85	2.10
Walk More	2.02	2.12
Intersections Hard to Cross**	3.88	3.63
Too Much Traffic	3.06	3.11

** indicate significant differences between the samples on complete and incomplete streets at the 95% confidence interval based on Mann-Whitney test.

The statistical test results on the DID survey data by each site are summarized in Table 33. The results show that not all pairs of streets are equal in terms of street users' perceptions. For the Northridge and Willowbrook sites, there were no significant differences between the complete and incomplete streets, due to the small number of survey forms collected at these two sites.

Table 33. Significant findings for each DID Pair.

Site	Street	Score of each question: Wide side walk	Intersection hard to cross	Too much traffic	Clean	Shade	Interesting things to do	Secure	Walk more
Downtown LA	Complete	2.54	3.70	2.58	3.414	1.95	1.67	2.16	2.28
	Incomplete	1.75	3.67	2.79	3.135	2.28	2.17	2.28	2.20
Santa Monica	Complete	1.73	4.03	3.20	1.520	1.43	2.02	1.52	2.02
	Incomplete	1.63	3.88	3.17	1.518	1.65	1.94	1.64	1.96
Long Beach	Complete	1.37	4.22	3.37	1.882	2.74	1.79	1.84	1.59
	Incomplete	1.75	3.78	3.52	1.607	2.79	1.99	2.20	2.01
Northridge	Complete	2.33	3.33	3.83	1.611	2.39	3.67	1.94	1.95
	Incomplete	1.47	3.35	3.47	1.647	1.47	3.29	1.12	2.61
Glendale	Complete	1.50	3.65	3.40	1.675	1.48	2.08	1.50	3.07
	Incomplete	1.90	3.19	2.71	2.097	2.71	3.32	1.81	2.22
Willowbrook	Complete	2.29	3.57	3.21	3.357	3.14	3.86	2.79	1.94
	Incomplete	2.70	2.78	2.96	3.739	3.74	3.43	3.00	1.71

* The shaded cells indicate the pairs that are statistically differences ($p<0.05$).

Overall, there were four questions which showed statistically significant results for all six sites: the complete streets (1) had more shade, (2) had more interesting things to do, (3) were more secure to walk on, and (4) had intersections that were easier to cross. It should be noted, only the last factor – intersection treatments – was part of the set of characteristics that defines a complete street (see Table 3).

3.2.6.3 DID intercept survey findings

The survey results show that people favor walking in one type of environment over another—the analysis of activity type shows a difference between complete streets and incomplete streets in different areas. Based on the information in Table 32, people are more likely to use incomplete streets for utilitarian trips to work and school and to access transit, and more likely to use complete streets for an activity like exercise. This finding is also consistent with the MANGo before-and-after results of an increase of recreational biking.

Underscoring the activity-type analysis, the stated preference data suggest that people want to walk on streets where they feel safe and secure, where there is shade and interesting things to see and do, and where the intersection is easy to cross. When asked why they chose this street, people on complete streets were twice as likely to say that it "was a nice place to walk". Importantly, people who were intercepted on both complete streets and incomplete streets did not agree with the statement "I would walk more if all streets were like this one" indicating that street design is just one factor in people's decision to walk. This result again supports the MANGo before-and-after household survey results on barriers to walk more. In earlier research (McGuckin 2012), some of the barriers to walking 'more' were collected via a large travel survey (the CA add-on to the National Household Travel Survey). In the California National Household Travel Survey (CA-NHTS), the most common reason people gave for not walking more was that they were "too busy", just as we found in the before-and-after study. This reason was selected by twice as many respondents as selected the "difficulty crossing the street" reason. Some of the relevant factors selected by respondents in the CA-NHTS are echoed in the current study, specifically 'streets too wide' and 'unsafe intersections', indicating that intersection treatment is important to creating walkable communities.

3.2.7 Discussion on DID results

The DID study results showed that the complete streets and incomplete streets can have quite different traffic volumes, pedestrian and cyclist volumes, and on-road UFP and PM2.5 concentrations. The complete streets did not always have favorable conditions (i.e., lower pollutant concentrations, lower traffic volume, higher pedestrian and cyclist volume etc.) when compared with incomplete streets. This finding is consistent with those in other related research on complete streets. For example, a recent study (Smart Growth America and National Complete Streets Coalition 2015) found that the change in motorized vehicle trips were mostly ranging from -50% to +50% after complete street retrofit projects at 37 sites across the U.S.

Overall, the DID study findings demonstrated that the pairs of streets at different sites have different results, which means that there is not a general conclusion that applies to all complete streets. Based on the measured data and the field observations, there are many possible reasons for the observed inconsistency across the six study sites. First of all, different sites have very different characteristics such as population density and function. For example, the Downtown LA site has a large number of street users because it is located in an area with large population density. Second, the function of the test site, or the destination of transportation can make huge differences in the street usage. For example, the Northridge and Willowbrook sites had very few street users because in these suburban areas, people have to drive to destinations. Thus, it is expected that the impacts of complete streets at these different sites are different. Finally, the selection of the incomplete street could potentially make a difference in the findings. For example, at Glendale site, the incomplete street is much narrower than the complete street, and has speed bumps to reduce the driving speed. It is thus not surprising that results at this site are different from the other sites.

4 SUMMARY AND CONCLUSIONS

In summary, the findings of this study suggest that complete streets may have positive impacts on some, but not all, tested parameters. The before-after study on Ocean Park Boulevard found that the background-subtracted UFP concentrations were significantly decreased after the complete street retrofit, but the background-subtracted PM2.5 concentrations did not. For the before-after study on Michigan Avenue, both background-subtracted UFP and PM2.5 did not change significantly after complete street retrofit. In terms of traffic volume, both Ocean Park Boulevard and Michigan Avenue had similar total traffic volume before and after their respective complete street retrofit. Further data analysis showed that the Ocean Park Boulevard had significantly lower emission-weighted traffic volume, which might explain why the background-subtracted UFP concentrations decreased significantly. However, the Before-After study was not able to determine whether the decrease in emission-weighted traffic volume on Ocean Park Boulevard was due to the complete street retrofit or the natural fleet turnover (or both). Similarly, the DID study was not able to identify the real causes for the traffic volume difference between complete and incomplete streets. There were several possible reasons. The complete streets might have changed the people's choice of transportation modes and led to less motorized vehicle usage. Or, the complete streets might have simply displaced the traffic volume onto other neighboring streets.

Both the Before-After study and the DID study found that the complete streets are likely to have higher pedestrian and cyclist volume, especially in downtown and business areas. The possible reasons for this difference were that people usually found the complete streets (1) had more shade, (2) had more interesting things to do, (3) were more secure to walk on, and (4) had intersections that were easier to cross, according to the intercept survey. In addition, the function of streets also played an important role. For example, the complete street at the Downtown LA site (Spring Street) attracted much more pedestrians compared to its twin incomplete street, most likely because it has many more restaurants and cafes.

One important finding from this study is that not all complete streets are created equal. The differences in traffic volume, street usage, and on-road air quality between complete and incomplete streets had large variations among the six tested sites. The location and function of complete street also affect the traffic volume, street usage, and on-road air quality. In general, the complete streets in residential areas seem to have limited impacts on street users, because the pedestrian and cyclist volumes are usually low in these areas, compared with those in the downtown and business areas. For example, at the Downtown LA site in our DID study, complete street was found to have 500 per hour higher pedestrian volume than the incomplete street, while on other suburban or residential sites, this difference was much less and not statistically significant. These results highlight the importance on deciding where to retrofit an incomplete street into a complete street.

The DID study also showed that, on average for all six sites, the UFP and PM2.5 concentrations on the complete streets were 1300 particles per cm^3 and 0.3 µg per m^3 lower than those on the incomplete streets, respectively. These differences in UFP and PM2.5 concentrations were correlated with the observed differences in total traffic volume and heavy-duty vehicle traffic volume between complete and incomplete streets. Results suggested that, on average, the complete street had likely brought environmental benefits because of the decreased UFP and PM2.5 concentrations. However, it should also be noted that, such reductions were only 7% and 2% of their respective on-road average concentrations, suggesting the benefits of complete streets were limited.

The two survey studies also revealed some interesting facts about peoples' perception and behavioral response to the complete streets. Intercept survey results revealed that the street users believed that the complete streets had more shades, had more interesting things to do, easier to cross, and were more secure to walk on. The results of the before-after neighborhood surveys suggest that the MANGo project has resulted in an increase of recreational biking, and probably also some increase in using biking and walking to access public transit in the sample of local residents. But it does not seem that the MANGo project has meaningfully changed the main mode of commuters. These findings are not surprising given the limited spatial scale of the MANGo project and possibly also the relatively short time window the after-project survey allowed the residents to adjust their travel behavior (the after-survey was conducted three months after the project was finished). In addition, the before-after survey results revealed that important barriers keeping people from biking more include "too busy", "too many things to carry", "too many cars in traffic", "fast traffic", "not enough bike lanes or wide curb lanes", and "unsafe street crossings". Major barriers keeping people from walking more include "too busy" and "I simply do not like walking". Major barriers to taking transit include "(transit) does not accommodate my schedule", "(transit) does not get me to where I want to go", and "transit vehicles are too slow".

Overall, we consider the findings in this report preliminary, mainly because they are difficult to generalize to other geographic areas. The scope of current study was limited to the Greater Los Angeles Area in a time frame of a few years. As has been shown in this study, the differences between complete and incomplete streets are site-specific and may have large variations, depending on the street location and function. Therefore, cautions should be taken when extrapolating the findings from this study to other areas.

5 RECOMMENDATIONS

Based on results in this study, we recommend prioritize constructing complete streets projects in the downtown and business areas over those in the suburban and residential areas. By doing so, the potential environmental benefits brought by the complete streets may be shared by many more people and could potentially achieve more significant public health improvement.

We also recommend CARB to fund long-term studies to further investigate the environmental and health impacts of complete streets. Although this study covered a timeframe from 2011 to 2015, the test days were relatively sparse and the repeated measurements at the same site were limited, due to the limited funding and resources. Considering the daily and seasonal variations in traffic and weather conditions, continuous measurement in several consecutive days or weeks is preferred. In addition, since it is still not clear how long it would take for the pedestrians, cyclists, and drivers to adapt to the newly constructed complete streets environment, longitudinal survey study on the pedestrians, cyclist, drivers as well as residents live nearby the complete streets is recommended to fulfill this knowledge gap. Long-term studies can help us better understand this adaptation process.

On the aspect of measurement, we recommend that more quantitative and objective measurements can be carried out in future studies. For example, other traffic-related air pollutants such as NO_2 and CO could be measured to reflect the environmental impacts of complete streets. The measurement of street user volume and classification of motorized vehicles could potentially be automated by adapting computer vision technologies to make results more accurate, more objective, and less labor-intensive. It may also be possible to utilize smart phone technologies to better track the movement and activities of pedestrians, cyclists, and drivers on the streets in the future, better measure the street usage with higher time resolution. It is also important to better quantify street design features so more rigorous data analysis can be performed in the future.

We also recommend future complete street studies to include drivers' perception on the complete and incomplete streets, potentially by conducting focus group discussion. The drivers' perception on the streets could be an important factor on their choices of streets and therefore needs to be better understood.

In addition, we recommend that future complete streets retrofits be implemented in contiguous road networks and encompass the entire distance of trips that local residents usually undertake. By doing so, a more robust study could be conducted to investigate the potential of complete streets to change residents' travel behavior.

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IX. LIST OF INVENTIONS REPORTED AND COPYRIGHTED MATERIALS PRODUCED

1. Quiros, D., Lee, E., Wang, R. and Zhu, Y. (2013) “Ultrafine particle exposures while walking, cycling, and driving along an urban residential roadway.” Atmospheric Environment 73: 185 - 194

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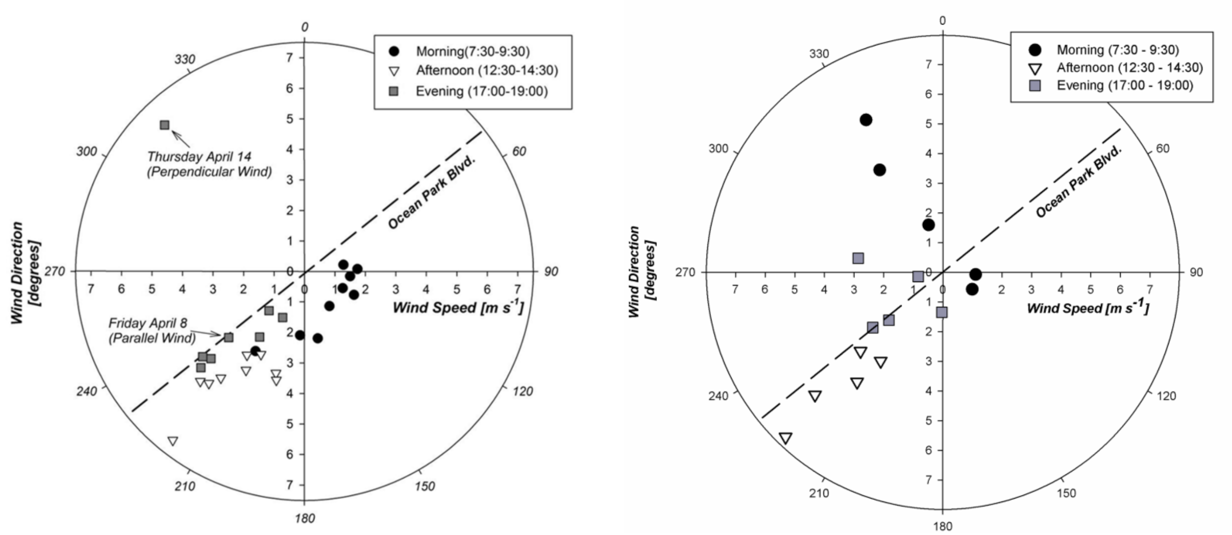
Appendix A. Meteorological conditions comparison of the before-after study

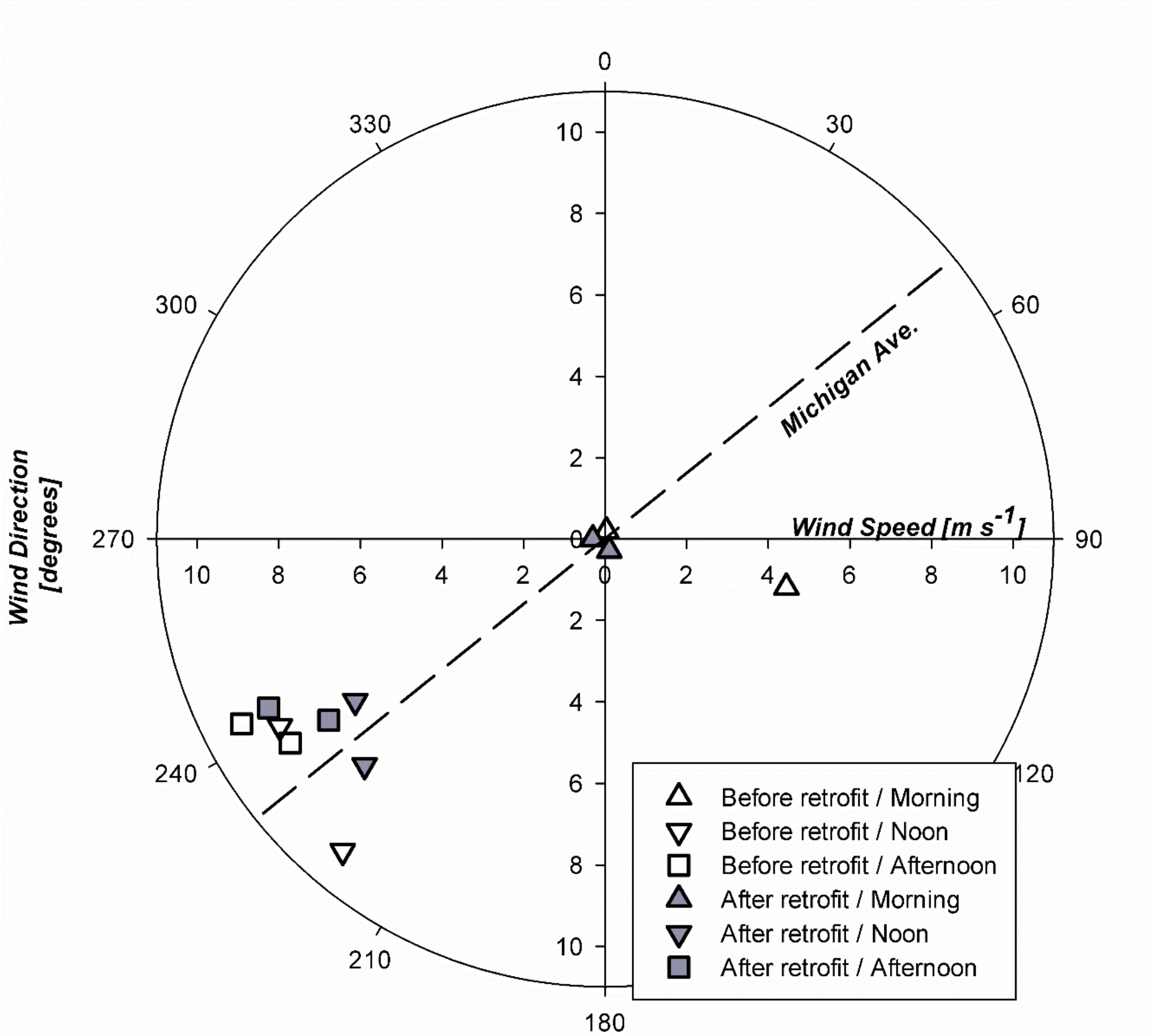
Figure A1. Ocean Park Boulevard site wind speed and direction



(a) Before-retrofit study (b) After-retrofit study

As shown in Figure A1, panel (a) shows the Before-retrofit conditions and panel (b) shows the After-retrofit conditions. The air quality data obtained in the two outlier sessions in the After-retrofit study, as indicated in panel (b), has been excluded in the data analysis.

Figure A2. Michigan Avenue site wind speed and direction



As shown in Figure A2, the wind pattern in the Before-retrofit test days and the After-retrofit test days were very similar. The metrological conditions obtained from Michigan Avenue site were also similar to those on the Ocean Park Boulevard site, since both sites are located in the Santa Monica, CA area.

Appendix B. Before-and-After Survey Forms.

Figure B1. Page 1 of long survey form

SHEET ONE: To be answered by an adult (YOU)

QUESTIONS ABOUT YOUR RECENT TRAVEL

1. What is today's date? Month: __ Day: ____

2. Were you out of town during the last 7 days? ☐ Yes ☐ No

If yes, how many days?________

3. Check one box for each line below to tell us THE MOST RECENT TIME you used each type of travel.

Type of Travel	Last 7 Days	Last Month	Last 3 Months	Not Used in the Last 3 Months
a) Passenger/driver of an automobile (car, SUV, truck, or van) or motorcycle	☐	☐	☐	☐
b) Public transit (bus or rail)	☐	☐	☐	☐
c) Bicycle to or from public transit	☐	☐	☐	☐
d) Bicycle to a destination OTHER THAN public transit (e.g., to a job, store, park, or friend's house)	☐	☐	☐	☐
e) Bicycle for recreation or exercise w/o a destination	☐	☐	☐	☐
f) Walk to or from public transit	☐	☐	☐	☐
g) Walk to a destination OTHER THAN public transit (e.g., to a job, store, park, or friend's house)	☐	☐	☐	☐
h) Walk for recreation, exercise, or to walk the dog, w/o a destination	☐	☐	☐	☐

In the last 7 days, how many days did you: ***(Write 0 if none apply)***

4. Take public transit to OR from work or school (SKIP if work/school do not apply)	# of days: ________
5. Take public transit to get somewhere OTHER than work/school (e.g., shopping)	# of days: ________
6. Bicycle to OR from public transit (e.g., to a bus stop)	# of days: ________
7. Bicycle to OR from work or school (SKIP if work/school do not apply)	# of days: ________
8. Bicycle to get somewhere OTHER than work, school, or public transit (e.g., to go shopping or dining. Do NOT include biking for exercise)	# of days: ________
9. Ride a bicycle for exercise or recreation, without a destination for the trip	# of days: ________
10. Walk to OR from public transit (e.g., to a bus stop)	# of days: ________
11. Walk to OR from work or school (SKIP if work/school do not apply)	# of days: ________
12. Walk to get somewhere OTHER than work, school, or public transit. (e.g., to go shopping or dining. Do NOT include walking for exercise)	# of days: ________
13. Walk for exercise or recreation, without a destination for the trip	# of days: ________

QUESTIONS ABOUT YOUR GENERAL TRAVEL

	Yes	No
14. Do you currently have a health condition that impairs your ability to walk?	☐	☐
15. Do you currently have a health condition that impairs your ability to bike?	☐	☐
16. In the last 7 days, did you have access to a working BICYCLE?	☐	☐
17. In the last 7 days, did you have access to an automobile (driver or passenger)	☐	☐

18. DURING A TYPICAL WEEK, how many days does your daily commute include any of the forms of transportation to the right?		**# of days:**
	Walking	________
	Biking	________
	Transit	________
	Driving	________
	Car Passenger	________

Check any box below if the item keeps YOU from biking or doing more biking.

☐ Too busy	☐ Too many cars in traffic
☐ No interesting places to go to	☐ Fast traffic
☐ Can't afford it (bike & bike mainatence, etc...)	☐ Air pollution
☐ Too many things to carry	☐ No nearby paths or trails
☐ Small children along	☐ Not enough tree shade
☐ Don't know how to bike	☐ Not enough bike lanes or wide curb lanes
☐ Health restrictions	☐ Unsafe street crossings
☐ I don't like to sweat	☐ Unsafe streets due to pot holes, bumpy road
☐ Biking messes up my clothes and/or hair	☐ I simply do not like biking
☐ No one to bike with	☐ I don't have any barriers to biking
☐ Neighbors/friends don't bike	**OTHER, PLEASE SPECIFY:**
☐ Fear of street crime	
☐ Not enough light at night	

Page 1 of 2

Figure B2. Page 2 of long survey form

Check any box below if the item keeps YOU from walking or doing more walking.	
☐ Too busy	☐ Fast traffic
☐ No interesting places to go to	☐ Air pollution
☐ Too many things to carry	☐ No nearby paths or trails
☐ Small children along	☐ No nearby parks
☐ Health restrictions	☐ No (good) sidewalks
☐ I do not like to sweat	☐ Not enough tree shade
☐ No one to walk with	☐ Unsafe street crossings
☐ Fear of street crime	☐ Unsafe streets due to pot holes, bumpy road
☐ Fear of neighborhood dogs	☐ I simply don't like walking
☐ Not enough light at night	☐ I don't have any barriers to walking
☐ My neighbors don't walk	**OTHER, PLEASE SPECIFY:**
☐ Too many cars in traffic	

Check any box below if the item keeps YOU from taking transit or doing more of it.	
☐ Does not accommodate my schedule	☐ Transit vehicles are not safe
☐ Does not get me to where I want to go	☐ Unsafe to walk or bicycle to and/or from stops
☐ Transit vehicles are too slow	☐ Unsafe around transit stops
☐ Infrequent service	☐ Not enough shades to or from transit stops
☐ Unreliable schedule	☐ Not enough shade at transit stops
☐ I don't like transfers	☐ I simply don't like taking transit
☐ Transit costs too much	☐ I don't have any barriers to transit
☐ Transit may be associated with low social	**OTHER, PLEASE SPECIFY:**
☐ My neighbors or friends don't take transit	
☐ Buses are uncomfortable and/or unsanitary	

QUESTIONS ABOUT YOU

19. What year were you born? Year: ________

20. What is your gender? ☐ Male ☐ Female

21.What is your race or ethnicity? (Check all that apply)

☐ African American or Black Islander	☐ Caucasian
☐ American Indian or Alaskan Native	☐ Native Hawaiian or other Pacific Islander
☐ Asian	☐ Don't know
☐ Hispanic or Latino	Other, please explain:

22. Which working status categories best describe you? (Check all that apply)

☐ Working for pay OUTSIDE the home	☐ Going to school
☐ Working for pay INSIDE the home	☐ Retired
☐ Looking for work	Other, please explain:
☐ A homemaker	

23.Your height: ______ feet ______ inches

23.Your weight: ______ lbs

QUESTIONS ABOUT YOUR HOUSEHOLD

a. You live in a	☐ house ☐ townhouse ☐ condo/apartment ☐ other
b. Are you a renter of your residence?	☐ Yes ☐ No
c. How long have you lived in this neighborhood?	_________ Years AND _________Months
d. How many people live in your household, including you?	Number of people 12 years and YOUNGER:_________ Number of people 13 years and OLDER:_________
e. How many working motor vehicles are there in your household? (e.g., cars, trucks, or motorcycles.)	Number of working motor vehicles:_________

f. Please mark an "X" below to indicate the TOTAL ANNUAL COMBINED household income.

|__________|__________|__________|__________|__________|__________|__________|

0 $20,000 $40,000 $60,000 $80,000 $100,000 $120,000 more

Thank you!

Page 2 of 2

Figure B3. Page 1 of short survey form

SHEET TWO: To be Answered by an Second Household Member (teenager or older)

QUESTIONS ABOUT YOUR RECENT TRAVEL

1. What is today's date? Month: __ Day: ____

2. Were you out of town during the last 7 days? ☐ Yes ☐ No
If yes, how many days?________

3. Check one box for each line below to tell us THE MOST RECENT TIME you used each type of travel.

Type of Travel	Last 7 Days	Last Month	Last 3 Months	Not Used in the Last 3 Months
a) Passenger/driver of an automobile (car, SUV, truck, or van) or motorcycle	☐	☐	☐	☐
b) Public transit (bus or rail)	☐	☐	☐	☐
c) Bicycle to or from public transit	☐	☐	☐	☐
d) Bicycle to a destination OTHER THAN public transit (e.g., to a job, store, park, or friend's house)	☐	☐	☐	☐
e) Bicycle for recreation or exercise w/o a destination	☐	☐	☐	☐
f) Walk to or from public transit	☐	☐	☐	☐
g) Walk to a destination OTHER THAN public transit (e.g., to a job, store, park, or friend's house)	☐	☐	☐	☐
h) Walk for recreation, exercise, or to walk the dog, w/o a destination	☐	☐	☐	☐

In the last 7 days, how many days did you:	***(Write 0 if none apply)***
4. Take public transit to OR from work or school (SKIP if work/school do not apply)	# of days: ________
5. Take public transit to get somewhere OTHER than work/school (e.g., shopping)	# of days: ________
6. Bicycle to OR from public transit (e.g., to a bus stop)	# of days: ________
7. Bicycle to OR from work or school (SKIP if work/school do not apply)	# of days: ________
8. Bicycle to get somewhere OTHER than work, school, or public transit (e.g., to go shopping or dining. Do NOT include biking for exercise)	# of days: ________
9. Ride a bicycle for exercise or recreation, without a destination for the trip	# of days: ________
10. Walk to OR from public transit (e.g., to a bus stop)	# of days: ________
11. Walk to OR from work or school (SKIP if work/school do not apply)	# of days: ________
12. Walk to get somewhere OTHER than work, school, or public transit. (e.g., to go shopping or dining. Do NOT include walking for exercise)	# of days: ________
13. Walk for exercise or recreation, without a destination for the trip	# of days: ________

QUESTIONS ABOUT YOUR GENERAL TRAVEL

	Yes	No
14. Do you currently have a health condition that impairs your ability to walk?	☐	☐
15. Do you currently have a health condition that impairs your ability to bike?	☐	☐
16. In the last 7 days, did you have access to a working BICYCLE?	☐	☐
17. In the last 7 days, did you have access to an automobile (driver or passenger)	☐	☐

18. DURING A TYPICAL WEEK, how many days does your daily commute include any of the forms of transportation to the right?	**# of days:**
Walking	________
Biking	________
Transit	________
Driving	________
Car Passenger	________

Page 1 of 2

Figure B4. Page 2 of short survey form

QUESTIONS ABOUT YOU

19. What year were you born? Year: _________

20. What is your gender? ☐ Male ☐ Female

21.What is your race or ethnicity? (Check all that apply)

☐ African American or Black Islander	☐ Caucasian
☐ American Indian or Alaskan Native	☐ Native Hawaiian or other Pacific Islander
☐ Asian	☐ Don't know
☐ Hispanic or Latino	Other, please explain:

22. Which working status categories best describe you? (Check all that apply)

☐ Working for pay OUTSIDE the home	☐ Going to school
☐ Working for pay INSIDE the home	☐ Retired
☐ Looking for work	Other, please explain:
☐ A homemaker	

23.Your height: ______ feet ______ inches

23.Your weight: ______ lbs

Thank you!

Page 2 of 2

For the before-after survey, the long form was answered by the main adult of the household. The shorter form was answered by another adult or a teenager (if any) in the same household.

Appendix C. Detailed maps of each pair of DID study twin-streets

Figure C1. Map of Downtown LA twin-streets

Figure C2. Map of Santa Monica twin-streets

Figure C3. Map of Long Beach twin-streets

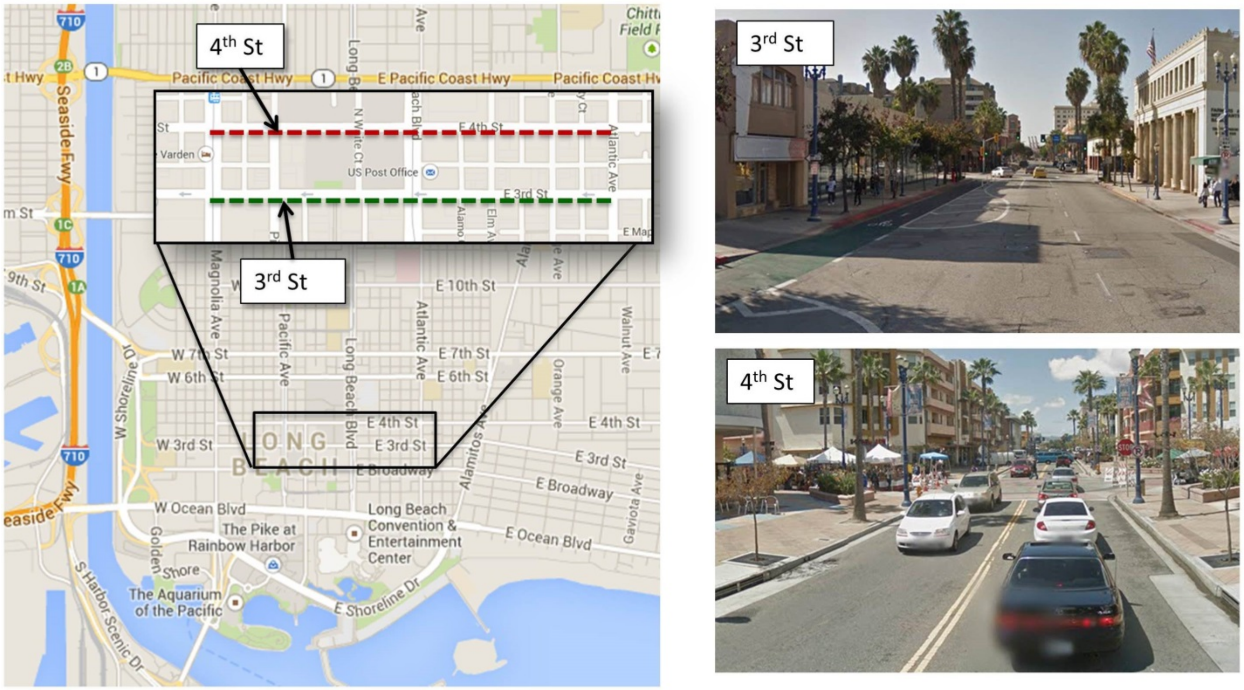
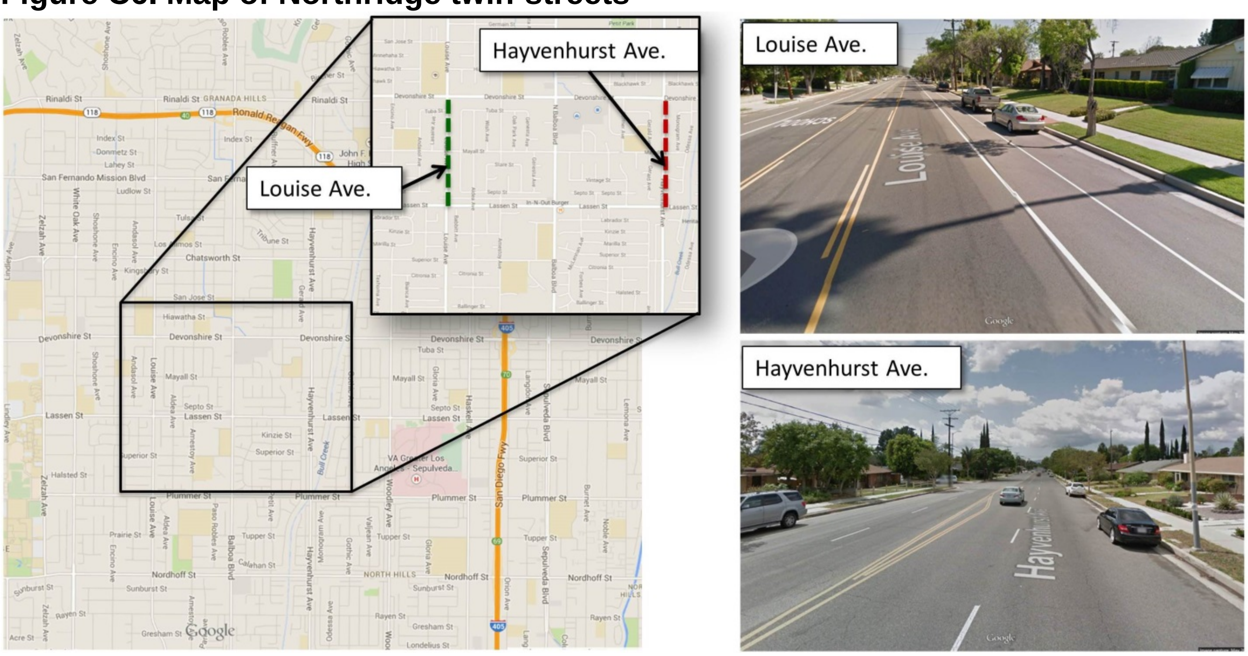


Figure C4. Map of Glendale twin-streets

Figure C5. Map of Willowbrook twin-streets

Figure C6. Map of Northridge twin-streets



Appendix D. Survey questionnaire and detailed survey data and analysis

Figure D1. Survey questionnaire used in DID study

Complete Streets Research Project	Interviewer Number:____________ Form No:________________	Street:____________________________ Today's Date ____/ ____/ 2015

Introduction: "The California Air Resources Board and UCLA are working to figure out how to make the streets more walkable. I only have a few short questions about your travel here today. Your answers will be kept confidential and used to improve the city."

Make sure this respondent is eligible:

Has this person been interviewed before (today)? *[] Yes [] No (if 'No'): Is he/she 18 or older? [] Yes [] No*

Please mark, do not ask:

Q1. Time of interview (*circle hour*): 6am—7am—8am— 9am—10am—11am—12pm—1pm—2pm—3pm—4pm—5pm—6pm

Q2. Sex/Gender: 1[] Male 2[] Female

Q3. At intercept the respondent was: 1[] Walking 2[] Biking 3[] Waiting for a bus 4[] Parking 5[] Other:_______

Q4. What **Activity** brings you here today? 1[] Work/school 2[] Shopping/coffee/meal 3[] Exercise 4[] Social activity/Meeting friends 5[] Bus Stop 6[]Other_____________________

Q5. **How did you arrive** here today? (choose all that apply):
1[] Auto driver 2[] Auto passenger 3[] Transit (Metro rail or bus) 4[] Motorcycle
5[] Bicycle 6[] Walk 7[] Other______________________

Q6. **How long** will it take you to get from where you started to where you are going? (the time for your total trip)
1[] less than 5 minutes 2[] 5-15 minutes 3[] 15-30 minutes 4[] 30 –60 minutes 5[] More than an hour

Q7. About **how often** do you come here (including today)?
1[] Today is the first time 2[] a few times a year 3[] Once a month or more 4[] Once a week or more 5[] Everyday

Q8. On a scale of 1-5, how much do you **AGREE** with the following statements? Please circle one.

	1 Strongly Agree	2 Somewhat Agree	3 Not Sure	4 Somewhat Disagree	5 Strongly Disagree
a) This street has **WIDE SIDEWALKS** to walk /bike on:	1	2	3	4	5
b) The **INTERSECTIONS** on this street are hard to cross:	1	2	3	4	5
c) There is **TOO MUCH TRAFFIC** on this street:	1	2	3	4	5
d) This street is **CLEAN AND WELL-MAINTAINED:**	1	2	3	4	5
e) There is **SHADE OR TREES** on this street:	1	2	3	4	5
f) There are **INTERESTING** things to do and see:	1	2	3	4	5
g) I feel **SECURE** (from crime) walking/biking here:	1	2	3	4	5
h) I would **WALK/BIKE MORE** if all streets were like this one:	1	2	3	4	5

Q9. Why did you choose **this street** over others for this trip (check all that apply and add Other):
1[] Convenient for this trip 2[] A nicer place to walk/bike 3[] A safer place to walk/bike 4[] Other ___________________

For statistical purposes, please answer the following questions. ALL INFORMATION WILL BE KEPT CONFIDENTIAL:

Q10. What is your zipcode at home?___________ Q11. What city/town is that?_________________

Q12. How many people live in your home (including yourself):_________ Q13. Are you employed? 1[] Yes 2[] No

Q14. What level of education have you completed? 1[] HS Grad or less 2[] Some college 3[] College grad or more

Q15. What year were you born? _________ Q16. How would you describe yourself ethnically? _________

Thank you for your time today! Please let us know if there is anything more you would like to tell us:

Training Memorandum

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Training Agenda:

1. Introductions and purpose of the study
2. Go through the questionnaire item by item
3. Go through count procedures--conduct test and training
4. Role play Respondent--Interviewee roles, discuss refusal avoidance
5. Questions, round-table discussion
6. Administrative matters (time sheets, emergency contact)

Introduction
This memorandum provides instructions on how you are to participate as a field surveyor for the research project assessing the impact of complete streets. To help you do your job effectively, and overcome people's possible reluctance to participate, this memorandum offers background information, the purpose of the survey, how to contact the survey administrators, and what you have to do during the survey. Your specific daily assignment will be given to you, along with a unique field surveyor number, separately.

Purpose of the Study
Traditional streets in many cities in the US have historically used measures of auto through-put to determine the most effective design. The design elements of complete streets try to provide safe, pleasant, and accessible ways to walk and bike, and to ensure that transit is efficient and convenient.

This study is part of a larger research program to gather evidence as to how complete streets change the way people think about getting around. These data will be used by policy makers and planners to help improve urban design, and also used to estimate the potential to reduce air pollution through behavior change.

What You Need to Do

Over the course of the survey you will be part of a small group of people selected to conduct the field survey. The field surveyors will be deployed at selected spots for the assigned hours in pairs: one surveyor and one tabulator. Surveyors will intercept and survey people in the study area, completing one questionnaire for each participant. Tabulators will be counting the number of people passing by, identifying the selected person for the surveyor to approach, and keeping track of refusals. These jobs are the most important part of the project, and possibly the hardest. The research results are only as good as the data collected. Please keep that in mind as you conduct the surveys and tabulate/track refusals.

As a field surveyor your job is to complete the tasks listed. Each of these tasks will be reviewed in detail during training—if you have any questions at any time do not hesitate to ask.

Administrative Matters

It is important that you keep a few things in mind that are crucial to your success in this study.

Punctuality and Appearance

It is essential that you report to your assignment on time. People who fail to report on time will be dismissed without pay.

You will be facing the public daily during field work. The willingness of people to respond to the survey depends a lot on how you look. Therefore, please present a neat appearance and wear your UCLA hat and ID tag when on your survey assignment. Be sure and wear your Name Tag/ID Badge where it can be seen.

Demeanor

Be courteous and friendly! Getting people to participate in the survey is paramount to the success of the survey—and your behavior makes all the difference. For instance, some people will not like the survey and will tell you so. Reply politely that UCLA and California Air Resources Board are trying to help create a more livable community and improve air quality. These improvements will benefit everybody.

If the person becomes abusive, or indicates that they do not want anything to do with the survey, say something like “I am sorry, thank you anyway”. In any event, do not get involved in an argument.

But quite frankly, most people are really interested in having a more walkable street and a more sustainable and healthy community. Sometimes they may confuse you with someone trying to sell something, or rush by because they are in a hurry. But many people will take a few minutes of their time to answer this short survey.

If someone is willing but truly too busy to respond at the moment, give them an survey form (with your survey ID number, the serial number, and street and data already marked) and a return envelope. They can mail in their responses and be included in the survey.

Supervisors

A supervisor will be in the study area during your shift. You will meet them before your assignment to pick up your materials and you will meet them after your shift to return your materials. Your supervisor may observe you from time to time to review your work and make sure you are following the required survey protocols. If you have problems, your supervisor is the person to talk to. Please report any problems to your supervisor as soon as possible.

Detailed Data Analysis

Table D1 shows the reasons of refusal during the DID study survey by gender. More than half of both men and women who had refused to participate the survey used the reason of "Busy/No time".

Table D1. Distribution of reasons for refusals by gender

	Men	Women	Total
Busy/ no time	58%	52%	56%
No English	11%	9%	11%
No reason/Brush Off	22%	28%	25%
Work	2%	4%	3%
Responded Another time	2%	2%	2%
Younger than 18 years old	1%	1%	1%
Other	3%	3%	3%
Total	100%	100%	100%

Table D2 shows that the people surveyed on the complete and incomplete streets had similar distribution of employment status. On both complete and incomplete streets, approximately 70% of the survey participants were employed. This similarity ensured that the survey results obtained on complete and incomplete streets were not interfered by the factor of employment status.

Table D2. Employment status of respondents by street type

	Complete		Incomplete		Total	
	n	%	n	%	n	%
Employed	297	74%	238	69%	535	72%
Not Employed	106	26%*	107	31%*	213	28%
Total	403	100%	345	100%	748	100%

* Difference is significant

Table D3 shows that the education levels of people who participated in the survey on complete streets and incomplete streets were similar. This ensured that the survey results were not interfered by the education level of respondents. Table D4 shows that the survey respondents also had similar activities, no matter whether they are surveyed on the complete or incomplete street.

Figure D2 shows that the survey respondents had similar mode of arrival to the study area, no matter whether they are surveyed on the complete or incomplete street. This ensured that their responses were not interfered by the factor of how they have arrived at the street.

Figure D3 shows that the survey respondents had similar frequency of visit to the complete and the incomplete street. Approximately 50% of the respondents visit the study area every day and approximately 30% of them visit the study area once a week. It suggests that most of the respondents were familiar with the streets when they were surveyed. This similarity ensured that the survey results were not interfered by the factor of frequency of visit.

Table D5 summarizes the distribution of activity by location type and function. The two Downtown sites, Downtown LA site and Santa Monica site, had dominant number of response when compared with other sites in the urban and suburban area.

Table D3. Education level of respondents by street type

	Complete		Incomplete		Total	
	n	%	n	%	n	%
HS Grad or less	70	17%	71	21%	141	18%
Some College	114	28%	73	21%	187	24%
College Grad or more	223	55%	200	58%	423	55%
Total	407	100%	344	100%	751	100%

Table D4. Activity at destination by street type

	Complete		Incomplete	
	Frequency	Percent	Frequency	Percent
Work/School	95	23%	67	19%
Shopping/Meal	103	25%	65	19%
Exercise	61	15%	55	16%
Social Activity	40	10%	36	10%
Bus stop	11	3%	15	4%
Other	108	26%	113	32%
Total	418	100%	351	100%

Figure D2. Mode of arrival to study area by street type

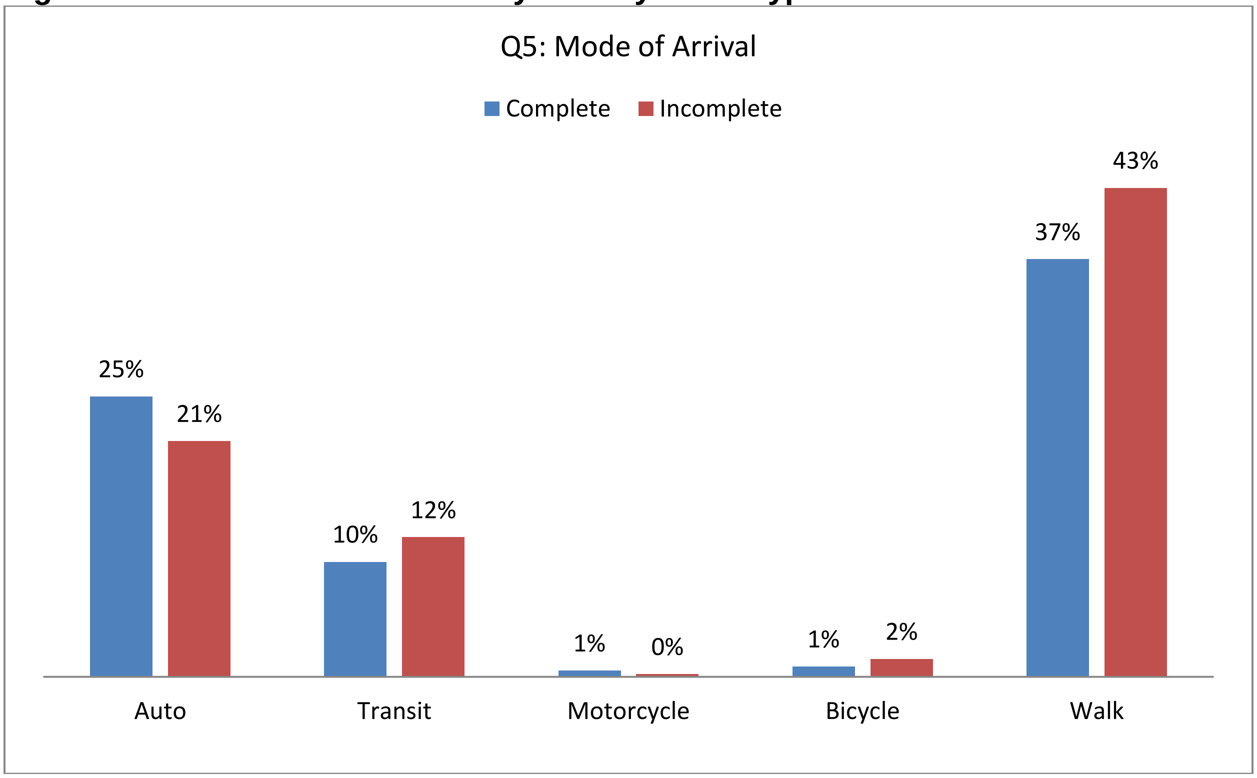


Figure D3. Frequency of visit by street type

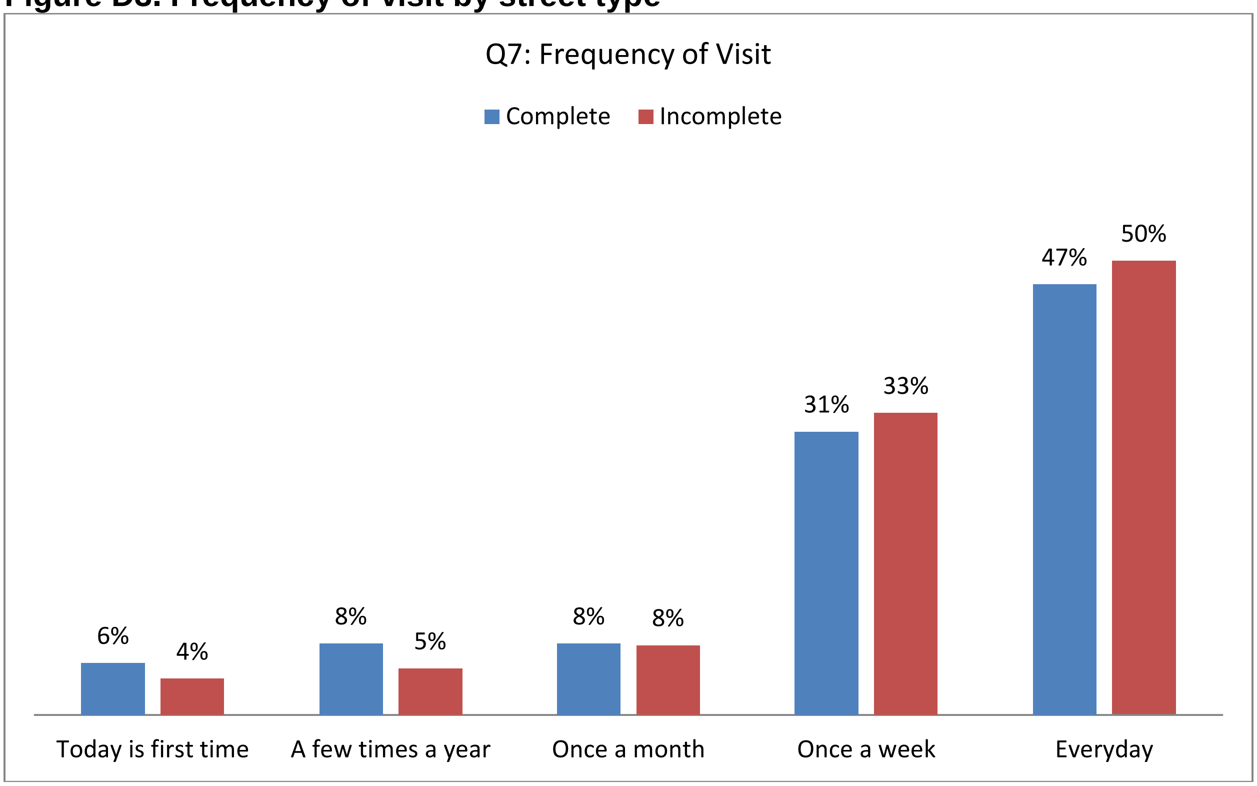
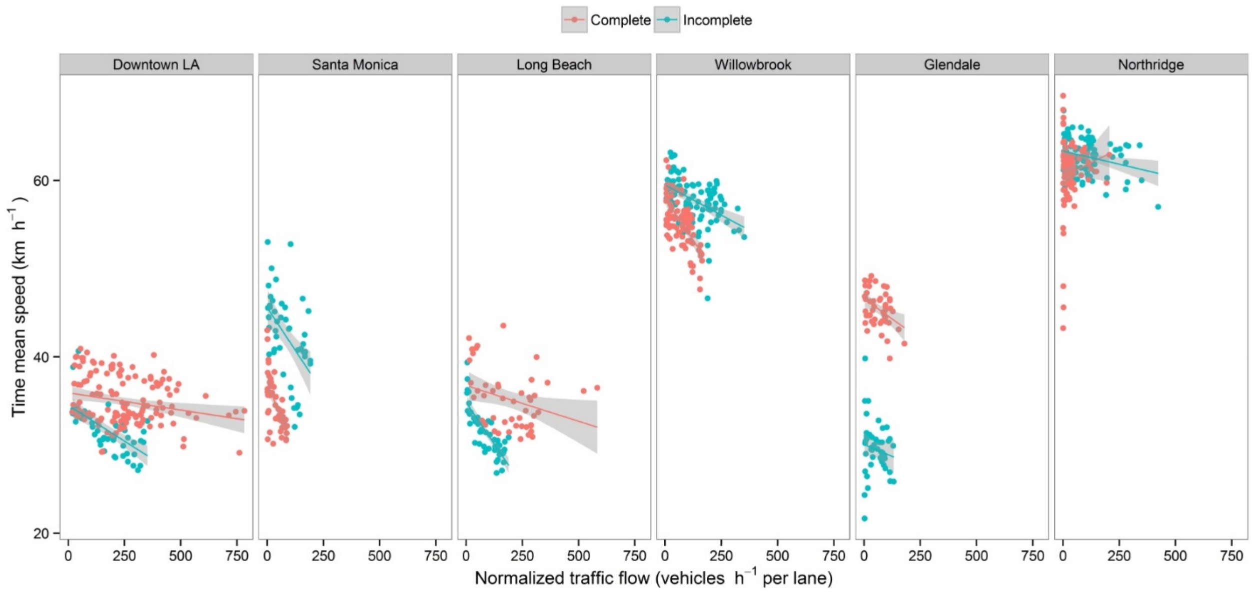


Table D5. Distribution of location type and function by activity

	Location	Downtown	Suburban	Urban	Total
Work/school	Complete	79%	5%	16%	100%
	Incomplete	54%	33%	13%	100%
Shop/Coffee/Meal	Complete	61%	3%	36%	100%
	Incomplete	51%	0%	49%	100%
Exercise	Complete	46%	36%	18%	100%
	Incomplete	51%	22%	27%	100%
Social/Meet Friends	Complete	53%	20%	28%	100%
	Incomplete	61%	19%	19%	100%
Bus Stop	Complete	82%	9%	9%	100%
	Incomplete	60%	27%	13%	100%
Other	Complete	45%	30%	25%	100%
	Incomplete	60%	24%	16%	100%
Total	Complete	59%	17%	24%	100%
	Incomplete	56%	21%	24%	100%

Appendix E. Detailed traffic data

Figure E1. Relationship between traffic volume and time mean speed on complete and incomplete streets. Each point shows a one-hour average of normalized traffic volume and its corresponding hone-hour average of time mean speed.



All the data in Figure E1 are 24-hour continuous data measured by pneumatic tube. For Downtown LA, these traffic data were not obtained on the on-road air quality test days.

As shown in Figure E1, for the sites except Willowbrook and Northridge, the complete and incomplete streets showed distinct clusters, meaning the complete and incomplete streets had different characters of traffic. For example, at the Downtown LA site, when the lane-normalized traffic volumes are the same, the complete street has higher time mean speed. However, at the Santa Monica site, the trend is the opposite. This makes it difficult to draw a solid conclusion on whether the differences come from the differences in the street design. We also noted the differences of traffic volume on the studied streets could also change from day to day. Thus, to reach a solid conclusion on the impact of complete street on traffic volume, long-term measurements are needed.