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Developing Public Health Performance Measures to Capture the Effects of Transportation Facilities on Multiple Public Health Outcomes

FINAL REPORT

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16. Abstract

Increasingly, federal transportation and public health agencies are working together to identify transportation investments that improve public health. Investments in transportation infrastructure represent one method to utilize transportation to improve public health outcomes. The ideal transportation investment is one that not only provides safe access for pedestrians, bicyclists, motorists and transit riders, but it also promotes more utilitarian or recreational trips for walking and biking in an environment of safe air quality. However, public health objectives can be at conflict when designing transportation infrastructure to support active commuting. For example, infrastructure investments may be made that promote physical activity through utilitarian commuting, yet at the same time, the investment may be made in an area that is characterized by poor air quality or creates an unsafe condition. The purpose of the research is to identify potential performance measures that can foster improved decision making around these investments. The key research contribution is the development of performance measures that can be used in the field to evaluate multiple public health concerns and improve decision making. Secondly, it advances strategies to effectively capture the dimension of safety and physical activity in a manner that considers the conditions under which pedestrian and bicycling activity is likely to increase. The objectives of the project are accomplished through the use and integration of multiple methods, including student-based project learning, expert surveys, content analysis and quantitative statistical techniques.

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Executive Summary

Creating safe, livable, pedestrian and cyclist friendly communities can have a number of positive impacts on public health. Transportation infrastructure plays a key role in as it can influence active commuting, defined as utilitarian trips made via foot or bicycle. Increasing active commuting has been identified as one way that transportation and public health agencies can collaborate to address multiple public health outcomes. Although a number of studies evaluate the effects of transportation facilities on individual public health outcomes such as safety, physical activity and air quality, there is a lack of evidence of the joint effect of different types of transportation infrastructure on all three objectives. The purpose of the proposed project is to develop project level performance measures to evaluate the effects of transportation facilities on the multiple public health objectives of safety, air quality and physical activity. The research addresses the problem of a lack of decision making tools that allow for the evaluation of competing public health objectives. The goal of the research is to improve the information available to decision-makers on the relationship between different types of transportation facilities and multiple public health outcomes.

Primary Objective: To develop public health performance measures for transportation infrastructure, at the level of road segments and intersections, with a focus on safety, physical activity and air quality.

Secondary Objectives: Pilot the measures and develop easy-to-comprehend educational materials that can be used in the field to evaluate the different features of transportation infrastructure and their impact on public health.

Many local governments and regions have engaged in efforts to increase opportunities for active commuting. For example, locally-based programs, such as Safe Routes to School (SRTS) that focus on the development of active transportation infrastructure, have received federal support to improve safety on walking and bicycling routes to school and encourage more children and families to travel using these modes. The program is designed to work at the community level in five areas (evaluation, education, encouragement, engineering and enforcement) to address health, safety and traffic concerns that include: increasing safe, convenient physical activity for children; decreasing traffic congestion; and improving air quality for communities. To these ends, the program provides funding to build transportation facilities to facilitate walking and biking safely to school. In addition to SRTS, a number of local governments and Metropolitan Planning Organizations (MPOs) have placed an increased emphasis on investing in active transportation infrastructure and have started to incorporate public health measures into their regional transportation plans.

However, in order to achieve public health objectives, decisions made at the project level, defined as the specific transportation infrastructure along a road segment or intersection, are critical. Decisions made at the project level are critical because they are the closest to users of the roadway or intersection and public health objectives can be potentially conflicting at times. While evidence suggests a relationship between the built environment, locally-based interventions, and public health outcomes, there is less evidence of the holistic effects of particular types of transportation infrastructure on public health objectives. For example, evaluations of engineering and infrastructure improvements associated with SRTS programs have focused on the potential for infrastructure improvements to increase walking and cycling by addressing safety concerns (2). However, at the same time, while active modes of transportation may improve physical activity, increasing physical activity might also expose students to higher levels of air pollutants. For example, reduced exposure to air pollutants while using active transportation modes to school might depend upon the volume of the roadway that they travel along (4). Thus, more remains to be known as to the relationship between the transportation infrastructure at the project level and public health objectives, and those responsible for project level decisions need decision making tools.

The development of performance measures that consider multiple public health goals at the project level of transportation infrastructure can enhance knowledge in this area. The current state-of-the-practice is to focus on mobility and safety performance measures when assessing transportation alternatives. While the safety performance measures are important to decision-makers, they may only capture part of the public health objectives in programs such as SRTS or in regional transportation plans. Difficulties arise because the safety impacts of different transportation facility alternatives are challenging to predict and the objectives can be conflicting.

The objectives of the research were accomplished through the integration of several different methods, all of which are detailed in the subsequent chapters. Primary tasks included an extensive literature review related to the use of public health and transportation performance measures and the features of transportation infrastructure associated with more favorable public health outcomes. The research team examined studies and reports dealing with the effects of transportation infrastructure design features on actual and perceived safety; walkability, bikeability, and physical activity; and air quality and pollutants. The research team also inventoried different types of transportation facilities to identify and select project-level performance measures that relate to the public health dimensions of interest. The performance measures were benchmarked and calibrated using expert feedback obtained from surveys of professionals with transportation engineering, safety and public health expertise. The completion of these tasks resulted in the following deliverables:

- Transportation Infrastructure Safety Performance Measures for Pedestrians and Cyclists: The Pedestrian Safety Assessment Index (PSAI) and the Bicyclist Safety Assessment Index (BSAI)
- A Methodology for Analyzing Pedestrian, Cyclist and Vehicle Conflicts
- Transportation Infrastructure Physical Activity Performance Measures for Pedestrians and Cyclists: The Walkability Assessment Index (WAI) and Bikeability Assessment Index (BAI)
- Performance Measures for Air Quality Assessment of Pedestrian and Bicycling Routes
- The Development of Field-Based Data Collection Tools to Improve Decision Making

The report is organized in the following manner. The first chapter summarizes the relationship between transportation infrastructure and public health objectives, provides an overview of the research methodology and discusses the research limitations. Subsequent chapters present the methodological details of the development of each performance measure and the supplemental materials that can be used in the field for evaluation.

Chapter 1. Research Overview

1.1 Research Objectives

The research objectives are as follows:

1. To identify potential performance measures that can improve transportation infrastructure decision making
2. To develop tools that empower policy makers to evaluate multiple public health concerns in transportation infrastructure investments
3. To advance thinking on how to more effectively capture the dimension of safety and physical activity
4. To help promote transportation investments that facilitate multiple public health objectives

1.2 Key Terms and Definitions

Active Transportation – Also referred to as active commuting, defined as any form of human-powered transportation. In this research the definition is limited to those forms such as walking or bicycling.

Transportation Facility – The transportation infrastructure and its associated elements and elemental options.

Transportation Infrastructure-Defined generally as the framework that supports the transport system. In this research the infrastructure of focus is road segments and intersections.

Transportation Infrastructure Elements—The features associated with a particular road segment or intersection. For example, if a bike lane is present or not.

Transportation Infrastructure Elemental Options – The characteristics of the transportation infrastructure element. For example, the width of the bike lane or whether it is protected or not.

Transportation Infrastructure Investments – Targeted improvements focused on a particular road segment or intersection that attempt to improve the transportation infrastructure.

1.3 Background and Significance

Increasingly public health outcomes have been prioritized by regional transportation planning entities, local governments, and federal level agencies. For example, Safe Routes to School (SRTS) is an example of one program aimed at improving public health outcomes through interventions in the transportation system that promote active commuting to school. The goal of the program is threefold, to reduce reliance on motor vehicles and improve air quality, increase safety, and also to increase physical activity among students and community residents. To these ends, the program provides funding to build transportation facilities to facilitate active commuting, such as walking and biking, safely to school. In addition to SRTS, a number of local governments and metropolitan planning organizations (MPOs) have an increased interest in using transportation infrastructure investments to improve public health outcomes. However, despite some key studies and evaluations (1,2,3), there remains a lack of quantitative evidence of the comprehensive effects of different types of transportation facilities on multiple public health outcomes. Likewise, the tools available to inform decision-making often focus on one objective over another, lacking a synthesis of the relationship between different transportation infrastructure elements and multiple public health objectives. Of particular importance is the need to determine if, certain transportation infrastructure investments prioritize some public health objectives over others and the potential implications for public health. Decision makers need tools that help them to determine if investment in one area, say implementing an intervention to promote physical activity conflicts with safety objectives.

The focus of this project is to generate performance measures that can be applied to different types of transportation infrastructure to determine its potential for improving public health outcomes. However, the research does not aim to generate performance measures that measure outcomes in terms of the population, but rather target performance measures that measure different elements of transportation infrastructure that can be modified or enhanced to improve the likelihood that public health objectives can be realized. The research team starts from the perspective that active transportation is one way that public health objectives can be addressed through the transportation system, and focuses on the relationship between three public health objectives, safety, physical activity and air quality and active transportation. The research team considers two modes of active transportation, walking and bicycling. In this chapter, the relationship between transportation infrastructure and public health objectives is summarized, an overview of the research methodology is provided as well as discussion of the limitations of the performance measures and tools developed. In subsequent chapters, the research team's methodological approach to developing each performance measure is detailed, along with supplemental materials that can be used in the field for evaluation and decision making.

Active Transportation and Public Health Outcomes. Active transportation has been identified as one way to link public health goals to the transportation system, specifically goals related to safety, air quality and physical activity. For example, the Healthy People 2020 report identifies performance measures established around safety, many of which are related to reducing vehicle crashes and reducing pedestrian and cyclist fatalities and injuries (see Chapter 2 for a detailed review). Likewise, the Healthy People 2020 reports identifies a number of performance measures related to active commuting and physical activity, as a way to reduce obesity and other related cardiac diseases (see Chapter 3 for a detailed review). These performance measures target individual behavior, for example, increasing the number of people riding their bike or walking to school, as well as the features of the transportation system in which active commuting may occur.

Despite this connection, the evidence is mixed as to the overall effect of active transportation on improved public health outcomes (4). For example, epidemiological evidence suggests that sedentary middle class US adults demonstrate a favorable association between increased energy expenditure and improved health outcomes (5). However, the results of active commuting interventions may be mixed because it depends on multiple factors, including the type of active commuting one engages in, individual and behavioral characteristics, and the type of transportation infrastructure that supports active commuting. The type of transportation infrastructure, or the transportation facility, can lead to mixed effects because it could create conflict among multiple public health objectives. For example, in unsafe environments, increased active commuting may increase the likelihood of pedestrian or cyclist injuries. Measures that help evaluate the performance of different types of transportation facilities as they relate to walking and biking can provide better information. In the next section, the transportation facility factors that influence different public health objectives are reviewed.

Transportation Elements Linked to Physical Activity, Safety and Air Quality. There are several investments that can be made to alter the transportation infrastructure to increase the likelihood that individuals engage in active transportation. The research considers the different types of transportation infrastructure elements and elemental options and their performance on the public health objectives of safety, physical activity and air quality. Performance measures are created using indices that measure how the different elemental options that a transportation facility contains interact to influence public health objectives. The research team adopts that assumption that the more 'positive' elements that a road segment or intersection includes, physical activity might increase, or at the very least, the potential might be greater, barring any other external forces that may be at work. Or, conversely, the absence of one or more of the positive elements may lead to a reduction in the likelihood of walking or biking. However, for some of the factors mentioned above, there can be mixed results so multiple measures or indicators are considered and tested for reliability and validity.

The elements and options used to construct the indices are detailed in the subsequent chapters; however a brief summary is provided here. Measures for physical activity focus on elements of the physical characteristics of the infrastructure correlated with an increased likelihood that individuals engage in walking or biking. Overall, transportation facilities that have *good lighting*, '*adequate' sidewalks*, *street connectivity*; *flat, straight terrain;* are *clean*, *tidy and provide a sense of place*, with *low traffic* have been found to increase physical activity among those living within proximity to their destination when the weather is fair.

Measures for safety include measuring conflicts on a qualitative ordinal scale, which advances current measures that typically rely upon crash data only. This includes vehicle-pedestrian, pedestrian-bike, and vehicle-bike conflict analysis. The research team considers both intersecting movements (moving in opposite directions) and overtaking movements (moving parallel to each other) for bike-pedestrian and vehicle-bike conflict analysis and the factors that influence severity of conflicts. Many of the features of the transportation infrastructure that encourage walking and biking are also related to safety concerns. For example, *sidewalks*, *street connectivity*, *traffic*, *presence of crossing guards* and *crosswalk improvements*, *street lighting*, and *community trust* are all factors that are associated with safety, and, in turn, can enhance walking and biking.

Measures for air quality primarily focus on pollutant levels at intersections or other critical locations such as hospitals and schools as well as along corridors and active transportation infrastructure. The factors selected for each public health objective, safety, physical activity and air quality, are detailed in each of the respective sections.

1.4 Methodology

The unit of analysis for performance measure development is the project level -- the transportation facility, which includes the type of infrastructure, elements and elemental options. The infrastructure is defined as a corridor or intersection or other similar attractor with one or more road segments. The specific focus is on the elements of infrastructure investments that are related to active modes of transportation, primarily walking and bicycling. The public health objectives under consideration include safety, air quality and physical activity. The research objectives were accomplished through the integration of several different methods, all of which are detailed in the subsequent chapters. Primary tasks included an extensive literature review related to the use of public health and transportation performance measures and the features of transportation infrastructure associated with more favorable public health outcomes. The research team examined studies dealing with the effects of transportation infrastructure design features on actual and perceived safety; walkability, bikeability, and physical activity; and air quality and pollutants regulated by the National Ambient Air Quality Standards (NAAQS). Numerous studies and reports were reviewed, including articles published in leading public health and transportation industry journals; studies conducted by various university research centers; published safety, physical activity and air quality guidelines and checklists; and research undertaken by government agencies at all levels. The research team also inventoried different types of transportation facilities to identify and select project-level performance measures that relate to the public health dimensions of interest-- air quality, physical activity and safety.

The performance measures were benchmarked and calibrated using expert feedback obtained from surveys of professionals with transportation engineering, safety and public health expertise. A fuzzy scaling approach was used to analyze the expert feedback and create the safety and physical activity performance measures—the specifics of which are described in the respective chapters. Experts were identified through outreach to nonprofit organizations, Metropolitan Regional Planning (MPOs) organizations, and review of state and public health websites. This resulted in a sample of 132 experts from national transportation, planning, and public health agencies and advocacy organizations. However, the greatest percentage of responses were provided by experts working in the Dallas-Fort Worth Metropolitan Area, likely due to the strong ties between the researchers and the regional MPO. The survey response rate was 36% (n=47). About 38% of the respondents were experts with 10+ years of experience, 22% were experts with 5-10 years of experience, and the rest (40%) were experts with less than 5 years of experience. The educational attainment of respondents varies based on doctorate degree (13%), master degrees (46%), bachelor degrees (32%), and associate degrees (9%).

An electronic survey was sent to the sample. The survey used a scenario approach to gather expert feedback. The scenarios were designed to collect expert feedback on the relationship between different transportation elements, elemental options and their relationship to safety and physical activity. A copy of the survey is provided in Appendix 1.X, at the end of the report. Each section of the survey is described below:

Safety Survey: The safety questions gather expert feedback on the severity and risk for conflict in certain contexts, the importance of specific road elements to increase safety (number of traffic lanes to cross, sidewalks condition and connectivity, existence of buffer zones, lighting, surface condition, driveways, and parking restrictions), and how the presence or absence of those elements can impact safety. Separate questions are asked for road segments and intersections. The data from this survey was used to create the Pedestrian Safety Assessment Index (PSAI) and the Bicycle Safety Assessment Index (BSAI) (detailed in Chapters 2 and 3).

Physical Activity: The physical activity section asks experts to rate the importance of specific elements (e.g. presence of crosswalks, bike infrastructures, pavement treatments, compliance to ADA standards, sidewalks conditions, lighting conditions, traffic signals, and connectivity between activities) in influencing walkability/bikeability. Experts are also asked how adjusting an element or different elemental options alter the walkability and/or bikeability along a road segment or intersections. Separate questions are asked for road segments and intersections. The data from this survey was used to create the Walkability Assessment Index (WAI) and the Bikeability Assessment Index (BAI) (detailed in Chapter 4).

The survey used skip-logic, allowing respondents to self-identify their areas of expertise and directing them to the appropriate survey. Professionals who identified as having an expertise in pedestrian and bicycle safety, as well as walkability and/or bikeability (38.3%) received both the Safety and Physical Activity Survey. Professionals who identified as having an expertise in only pedestrian and bicycle safety (6.4%) received the Safety Survey. Professionals who identified as having an expertise in only physical activity and walkability and/or bikeability (55.3%) received the Physical Activity Survey.

The methodology used to create the air quality performance measures is presented in Chapter 5.

1.5 Limitations

The researchers expect that decision makers can use the safety and physical activity indices to carefully plan policy or programs to achieve safety, health and environmental objectives in local communities. However, a few limitations are of note.

The indices developed here are focused on road segments and intersections. However, the indices can be easily expanded to corridors and transportation networks. Vehicle Miles Travelled (VMT) or length-based weighted indices are a way to obtain the network or corridor level indices. Adjusting the indices in this manner would allow transportation agencies to evaluate two or more corridors, regions and networks that help them in investment decision making process, strategic planning, policy or programming analysis and resource planning. This becomes particularly important for thinking about safety and physical activity as it relates to overall network connectivity.

Secondly, the indices account for a variety of factors at road segments and intersections when analyzing a given facility environment; however, not all possible factors were used in developing the weights. In most cases, in the field, a combination of factors might influence safety, physical activity or environmental outcomes as opposed to a single factor. However, the index methodology employed here does not consider all possible factors related to either pedestrians or bicyclists on a given roadway segment and intersection. Rather, the research team prioritized the factors that were found to be most prevalent in the literature as well as those that can be easily observed in the field by trained observers. The research team made this decision in order to balance the need for a concise and time-considerate survey. Shorter and more concise surveys often yield higher response rates, and initial piloting of the survey indicated that time was a concern. Future research should also consider the level of traffic volume, percent of turning movement at the intersection, street connectivity, and attractors (for pedestrians and bicyclists), and decision makers may want to account for these differences. Also, any changes to the assumptions of base conditions may impact designation of green zones. However, despite the limitations, the index methodology helps to distinguish the weighted impacts of major transportation elements and adjustments to those elements—i.e., which investments may have the greatest impact.

Third, while the indices were created using expert feedback, expanding the pool of experts and relevant backgrounds can enhance and stabilize the decision boundaries. The study lacks sensitivity analysis of index boundaries for different safety levels. Transportation experts represent the greatest proportion of experts in the sample and expanding to include more experts from public health or healthcare organizations may be beneficial. One way of performing sensitivity analysis is to separate the survey responses by profession (like, engineers, planners, safety analysts, and healthcare experts) and develop index boundaries separately for each group to assess the movement of index boundaries.

Fourth, the conflict analysis methodology would benefit from further research and validation. The approach can be compared and tested against existing methods to assess its relative strengths. While the approach is validated using expert data, it is not validated with actual data from field to evaluate the conflicts. The conflict categories and safety impact levels are obtained from the expert survey. As survey population (currently a mix of planners, engineers, safety analysts, healthcare professionals etc.) changes or survey is repeated over a time, the study may show fluctuations in the proposed categories.

The indices developed are for an urban environment and the general population of pedestrians and bicyclists. While the physical activity indices do account for elements related to American Disability Association (ADA) compliance, the safety indices do not address the standards explicitly. The factors that influence the severity and risk of conflict may need to be reviewed to determine if those apply consistently across ADA populations. Future research should consider elements and elemental options to address these needs.

Despite these limitations and areas for future research, the developed indices provide an analytical framework to assess the safety and physical activity environment of transportation infrastructure. The tools can help decision makers evaluate any potentially competing public health objectives. The research team recommends that transportation agencies use the developed safety and physical activity indices as an evaluation tool to assess impacts of policy decision making.

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Chapter 2. Safety Performance Measures

2.1 Research Objectives

The research team presents a sketch planning metric, called a safety index, as a qualitative surrogate safety measure to assess pedestrian and bicyclist safety at both segments and intersections. The metric meets the need for a practical approach to evaluating existing transportation infrastructure conditions that can be applied across different contexts. The index-based analytical tool can help transportation agencies in the decision making process related to active transportation investments.

2.2 Safety Assessment Index

The research team developed a qualitative measure for assessing the safety of intersection and segments in line with conflict analysis. The conflict methodology is presented in detail in Chapter 3. Two indices, the Pedestrian Safety Assessment Index (PSAI) and Bicyclist Safety Assessment Index (BSAI) are developed as safety performance measures related to transportation infrastructure. Based on a literature review, the research team identified typical infrastructure elements that may influence the safety of pedestrians and bicyclist. The following section briefly presents the influence of some factors on the safety of pedestrians or cyclists.

2.3 Literature Review

As mentioned previously, Healthy People 2020 permeates livable community initiatives undertaken by other federal agencies (1). However, increasing physical activity is not the sole goal of Healthy People 2020, but it also permeates livable community initiatives undertaken by other federal agencies. Increasing physical activity and active commuting are viewed as a way to enhance livability. Fabish and Hass (2) identify livability objectives as encompassing environmental goals (air quality, open space, and greenhouse gas emissions), economic goals, land use goals (compact, mixed used development), transportation goals (such as walkability, accessibility, and transportation choices), equity goals, and community development (sense of place, safety and public health). In this section of the report, public health goals related to safety are discussed and the intersection between safety and transportation infrastructure.

Table 2.1 illustrates the Healthy People 2020 performance measures established around safety. Concerns of safety are also prioritized by transportation agencies, particularly as it relates to pedestrians and bicyclists. According to the National Highway Traffic Safety Administration (NHTSA) in the United States, 4,743 pedestrians were killed and 76,000 were injured in traffic crashes during 2012 (*3*). Pedestrian fatalities account for 14 percent of total fatalities. Over 70 percent of pedestrian fatalities occurred at non-intersections and almost 73 percent of fatalities were in an urban setting. Child pedestrians between ages 5 and 15 accounted for about 22 percent fatalities (*3*). In the U.S, there were 1.51 pedestrian fatalities per 100,000 residents in the population. The states of Texas and Michigan had 1.83 and 1.31 pedestrian fatalities per 100,000 residents in the population (*3*).

In 2012, 726 pedal cyclist fatalities (2.2 percent of total fatalities) and 49,000 injuries occurred (*3*). Sixty-nine percent of fatalities occurred in an urban area and 31 percent at intersection locations. Average pedal cyclist fatality rate for U.S was 2.31 per 100,000 population, with Texas and Michigan having 2.15 and 1.92 fatality rate per 100,000 resident population (*3*). Though ages 45 to 54 had the highest fatality rate, the highest injury rate occurred for the age group between 10 and 15 (*3*). From 2003 to 2012, 174 school-age children died in school-transportation-related crashes, 55 were occupants of school transportation vehicles and 119 were pedestrians (*3*).

The above trends and public health objectives are significant enough that researchers continue to conduct multiple studies to understand the governing factors for crashes, establish the relationship between crashes and influencing factors, and develop tools to assess impacts. Factors affecting the crash occurrence of pedestrians and cyclists and the frequency of different types of crashes were widely reported in the literature. In general, literature reviews reflect the main determinants of non-motorized traffic crashes are vehicle speed, transportation facility characteristics, land use, and environmental factors. Factors include: the characteristics of the built environment, which can influence the *severity* of pedestrian injuries (*4*,*5*), risk exposure and proximity to public schools (6); intersections (*7*); the types of participants involved in an accident (i.e., vehicle and a cyclist) (*8*); land use activity, roadside design, use of traffic control devices, and traffic exposure (*9)*; the age of the individual, speed limit on the roadway, location of the crash, and time of day (*10*). The Transit Cooperative Research Program (TCRP) Report 95 (chapter 16) describes the spatial factors that influences bicycling and walking (*11*).

Table 2.1 Healthy People 2020 Safety Objectives and Measures

National Objective	**Baseline**	**Desired Goal**	**Data Sources**
Reduce fatal injuries	Injury deaths (age adjusted, per 100,000 population); 59.7 (2007)	53.7	National Vital Statistics System-Mortality (NVSS-M), CDC/NCHS; Population Estimates, Census
Reduce unintentional injury deaths	Unintentional injury deaths (age adjusted, per 100,000 population) 40.4 (2007)	36.4	National Vital Statistics System-Mortality (NVSS-M), CDC/NCHS; Population Estimates, Census
Reduce unintentional nonfatal injuries	Emergency department visits for nonfatal unintentional injuries (age adjusted, per 100,000 population; 9.233.5 (2008)	8,310.10	National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP), CDC/NCIPC and CPSC; Population Estimates, Census
Reduce motor vehicle crash-related deaths per 100,000 population	Motor vehicle crash deaths (age adjusted, per 100,000 population), 13.8 (2007)	12.4	National Vital Statistics System-Mortality (NVSS-M), CDC/NCHS; Population Estimates, Census
Reduce motor vehicle crash-related deaths per 100 million vehicle miles traveled	Motor vehicle crash deaths on public roads (per 100 million vehicle miles); 1.3 (2008)	1.2	Fatality Analysis Reporting System (FARS), DOT/NHTSA
Reduce nonfatal motor vehicle crash-related injuries	Nonfatal motor vehicle crash injuries on public roads (per 100,000 population); 771.4 (2008)	694.3	General Estimates System (GES), DOT/NHTSA; Population Estimates, Census
Reduce pedestrian deaths on roads	Pedestrian deaths on public roads (per 100,000 population); 1.5 (2008)	1.4	Fatality Analysis Reporting System (FARS), DOT/NHTSA; Population Estimates, Census
Reduce nonfatal pedestrian injuries on public roads	Nonfatal pedestrian injuries on public roads (per 100,000 population); 22.6 (2008)	20.3	General Estimates System (GES), DOT/NHTSA; Population Estimates, Census
Reduce pedal cyclist deaths on public roads	Pedal cyclist deaths on public roads (per 100,000 population); .24 (2008)	.22	Fatality Analysis Reporting System (FARS), DOT/NHTSA; Population Estimates, Census

Transportation Infrastructure Elements and Safety. In this section a review of the transportation infrastructure elements that influence safety is provided.

Crosswalks. Crosswalks are an important element of safety—absence of them can have a negative impact on safety whereas the presence of them can have a positive impact. Likewise, the characteristics and features of the crosswalk can matter. First, the absence of *crosswalks* creates potential conflicts between vehicles and pedestrians who want to cross the streets. The presence of marked crosswalks informs pedestrians of preferred crossing locations and vehicles of the potential of pedestrians crossing. Second, the type of crosswalks matter as they vary in visibility, and those that are more visible, like the ladder, continental or staggered continental types, enhance safety. Third, the type of signal used at the crosswalk matters. When pedestrian activity is high, it is essential to provide a *pedestrian signal* phase. Improvements, like *pedestrian signal counters*, and lead pedestrian phases can enhance the safety of pedestrians and may also eliminate high-risk situations when pedestrians are crossing the street. Pedestrian signals can also be accompanied by 'No *Right Turn on Red (RTOR)'* restrictions to increase the percentage of right-turning vehicles that yield to pedestrians. Pedestrian crossings at locations of sharp curves or fixed objects obstructing pedestrian line of sight become a potential safety concern.

Traffic Calming Features. Vehicle speed is also an important factor in safety for which infrastructure improvements can address. *Traffic calming features* are physical features that reduce the negative impact of motor vehicles use by slowing their speed (*12*). By slowing traffic speed, these features improve walking and bicycling conditions, increase the visibility of pedestrians and even alert the drivers to potential hazards. The street traffic calming features along the midblock street section (defined as a part of the street that does not have intersection operational influence) create a safer and slower traffic movement. Some examples of street traffic calming features include speed humps, speed enforcement, road diet, and rumble strips.

Signage. Pedestrian and bicycle traffic signs are an important measure of safety. Signs inform way finding and changes in traffic control. Signs can increase driver awareness and bring attention to the presence of pedestrians and bicycles. Pedestrian injuries increase as the *number of lanes* increases. A reduction in the number of lanes can reduce crossing distances, thus reducing exposure of a pedestrian to vehicle interaction (*13*). Injury rates are higher on one-way than on two-way streets (*14*). Higher vehicle speeds and vehicle passing opportunity on one-way streets create potential conflicts that are hazardous. *Vehicle speed* is a strongly predictive of pedestrian injury severity. Safer environments are associated with the places having lower speed limits (*15*).

Sidewalks and Bike Lanes. Sidewalks and *bike lanes* can provide a separate pathway for pedestrians and cyclists. The width and surface of the sidewalk or bike lane are important features that can enhance safety. The width of a sidewalk is a primary factor in determining the level of safety and comfort for pedestrians walking down the street (*16*). The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Official (AASHTO) use 5 foot as a minimum criterion for the width of a sidewalk (*17*). A well-maintained and *continuous* sidewalk with few or no impediments or obstructions is crucial to providing a safe walking environment for pedestrians.

The surface of the sidewalk or bike lane can also influence safety, and a fairly level surface offers smooth, safer movement of pedestrians or cyclists. The surface quality of a sidewalk or bike lane may be good, fair, and bad. A good quality sidewalk has very small surface impediments. A fair quality has some cracking, and erosions, but does not pose hazard conditions for walking. The bad quality surface has significant cracking, patching, buckling, weathering, holes, tree root intrusion, vegetative encroachment, standing water or cracks raised a few inches above the surface level that can be detrimental to pedestrian safety (*18*). Similarly, poor surface conditions of bike lanes create hazardous conditions for bicyclists. Generally, fairly leveled bike lanes offer safe and comfortable ride during all weather conditions.

Arterial facilities, where traffic, pedestrian and bicyclist activity is high, create more exposure and conflicts. Potential injury risk increases while using arterial facilities compared to local or collector type facilities. Bad *roadway surface condition* creates a dangerous condition when bicyclists are sharing a lane with vehicular traffic. According to Minnesota DOT Bikeway Facility Design Manual (*19*): "*A typical bicycle lane is a portion of a roadway designated by striping, signing, and pavement markings for the preferential or exclusive use of bicycles*". Sometimes, bike lanes may be present on a roadway with a curb that may or may not have a gutter. Paved shoulders of appropriate width can also accommodate bicycles, but unpaved shoulders do not accommodate bicycles. Traffic barrier protected bike lanes separate the travel lanes from bike lanes. Shared bike lanes on wide outside lanes means that bicycles share the right-of-way with vehicular traffic. At least 5 foot of bike lane width is recommended by Minnesota Department of Transportation (*19*).

Curbs, Medians and Buffer Zones. Curbs, medians and buffer zones provide a physical separation between motor vehicles and pedestrians and bicyclists. Curbs discourage vehicles mounting the curb and prevent parking on the sidewalk that would pose a significant threat to pedestrians. *Driveway* cuts in a street segment, which break up the curb, have the potential for vehicles to cause an obstruction to pedestrians and create a potential conflict point with pedestrians. The *medians* provide refugee for pedestrian crossings and can assist staged crossing if the number of lanes to cross is high. The presence of *buffer zone*, a separate bicycle lane, or parallel on-street parking creates a buffer for pedestrians, supports pedestrian safety.

Characteristics of Land Use. Mixed *land use* with good connectivity (proximity between residences, employment, and goods and services) can increase active commuting, and have an impact on safety. Pedestrian or bicycle injury risk increases with increased proportion of land used for commercial or office purposes.

Lighting. Street and intersection *lighting* enhance the visibility for pedestrian and bicyclists' while using the facility. Sight distance plays a key role in active commuting safety.

Street Width. Finally, the width of the street can influence safety. Wider streets can increase the likelihood of crashes.

Safety Performance Measure Approaches. Two broad types of approaches to study pedestrian, bicycle and vehicle crashes are identified in the literature—quantitative and qualitative. The quantitative methods establish a relationship between number of crashes, the rate of crashes (usually crashes per 100,000 population or crashes per vehicle miles travelled), the occurrence of a crash (binary response variable), occurrence of injury type crash (ordered response variable), and crash affecting factors. Qualitative methods develop a score or index based measure to study the influence of different factors.

Most quantitative studies use ordered probability and multinomial logit models to quantify the relationship between explanatory variables and pedestrian injury severity (*20*). For instance ordered models that consider the effect of various factors (*21, 22*), crossing locations and light conditions (*23*), and rural roadway and area features (*24*) on type of crash are a few examples of such models. AASHTO's Highway Safety Manual (HSM) provides a safety prediction methodology based on regression models to obtain a number of pedestrian or bicycle crashes as a function of transportation related characteristics (*25*). Further details on model form and inference of crash severity from models can be found in selected references (*25, 26*).

Hotspot identification on a given corridor or network and ranking the sites is a very important in resource planning of a non-motorized transportation safety programs. Bayesian Hierarchical approach is used to identify hazardous locations *(27,28).* Although quantitative models are good analytical tools for safety analysis, they are based on a data intensive approach that can be limited in generalizability. These models are developed for a particular location, and transferability to other regions needs calibration of model coefficients. As new crash data is made available, the models need re-calibration. Often, quantitative models consider only a portion of influencing factors. Moreover, model design, development, calibration, and inference could also benefit from the inclusion of expert feedback.

Qualitative methods develop non-crash measures of pedestrian or bicyclist safety measures using a score or index. Generally, index- or score-based methods use ratings by professionals to assess the impact of transportation and roadway environmental factors. In the literature, mostly, crashed based safety performance measures are proposed. These include number of crashes, number of crashes per vehicle-miles travelled, or crashes per 100,000 population. Risk based measures, for instance, the probability of crashes, the probability of injury severity (minor injury, major injury, fatal or no injury), are also considered. Ratings based index measure and scores are developed to assess the quality or condition of the transportation environment for pedestrian and bicycle activities. Conflict analysis, another surrogate safety measure, analyzes safety from observable traffic events other than crashes.

For example, the Walking Security Index (WSI) model considers a wide range of variables that affect pedestrian safety, comfort, and convenience at roadway intersections (*29*). Variables are given ratings based on their levels and the WSI value is the result of the aggregated ratings of all variables. Infrastructure related variables: number of lanes, grade, presence of turning lanes and curb cuts at intersections, and sight distance are considered in the rating systems. The WSI is a composite index score (number) that ranks signalized intersections according to the likelihood that pedestrians' security expectations are matched by experiences (*29*). The index yields a number that is representative of a synthesis of values from more than one variable. WSI is a relative measure and cannot be used for intersections in isolation. The index does not have a typical range of values to report and the index can be hard to interpret for intersections in isolation.

The Pedestrian Intersection Safety Index (PISI) model is a regression based approach that considers PISI ratings (scaling from 1 to 6) as a function of signal controlled and stop controlled crossings, number of through lanes, speed, main traffic Average Daily Traffic (ADT), and land use (*30*). The ratings are obtained from an on-line survey, where evaluators rate the crossing of intersection on a scale of 1 to 6. Later, regression analysis establishes the relation between the survey ratings and features of that intersection. Though ratings are qualitative in nature, the relationship enhances the analytical power. However, the limited number of intersection only features makes it difficult to apply this rating to other areas and segment locations, thus raising questions of transferability.

The Bike Intersection Safety Index (BISI) consists of three separate models representing three possible bicycle movements at intersections—through, right-turn, and left-turns. The model considers a number of variables describing the roadway geometry, traffic control, motor vehicle traffic, and bicycle facilities associated with each intersection. Like PISI, bike models develop a linear relationship with safety ratings (scaled between 1 and 6) and the influencing factors (*31*).

The San Francisco Department of Public Health (SFDPH) developed the Pedestrian Environmental Quality Index (PEQI) to assess the quality of the physical pedestrian environment in San Francisco. The PEQI is a spatial index that primarily quantifies street and intersection environmental factors (*18*). The PEQI data is collected with an observational survey based on visual assessment of street segments and intersections. Indicators are rated on a scale from 1 to 5 (not important, somewhat important, important, very important, and essential) and re-scaled to 1 to 3 for the final indicator scoring. Indicator response categories are assessed on a scale of -5 to +5 (extremely detrimental to ideal) and re-scaled the responses to 0 to 10 for the final indicator response category scores. Aggregated weighted indicator scores are used to calculate an overall score on a maximum scale of 100. The following are the categories of scores that the SFDPH uses for assessment (*18*).

- 100-81 = highest quality, many important pedestrian conditions present
- 80- 61 = high quality, some important pedestrian conditions present
- 60- 41 = average quality, pedestrian conditions present but room for improvement
- 40- 21 = low quality, minimal pedestrian conditions
- 20 and below = poor quality, pedestrian conditions absent

Conflicts (expressed in conflicts per 1000 vehicles entering intersection) have also been proposed as a surrogate safety measure. The advantage of measuring conflicts is that it provides more information about crashes and fatalities as it aims to capture sites of high potential for risk. However, proposed methods vary greatly in details, documentation and application. Pedestrians' exposure to the risk of conflicts with vehicles, bicycles, or other pedestrians is a good surrogate safety measure. Safety analysis using non-collision data mostly rely on traffic conflict analysis (*32,33*). The U.S Department of Transportation Conflict Technique (USDTCT) from FHWA suggests the following steps: first, categorize various elements that induce conflicts, create the level of severity by each element, and finally sum the severity levels of each element and find the overall grade of the severity of the conflict (*32, 33*).

2.4 Methodology

A qualitative, index approach was determined as the best method given the research objectives. Data on the relationship between selected infrastructure elements and safety were obtained by surveying experts. The survey sampled 132 safety engineers, planners, city traffic engineers, and public health professionals, and the research team received 47 complete responses (36% response rate). Of the 47, 21 were from respondents with professional expertise as it relates to safety for pedestrians and cyclists. The survey requested expert feedback on two sets of information on safety: first, the importance of transportation infrastructure elements in providing safe active transportation for pedestrians and bicyclists and then the level of the safety impact of various options under each infrastructure element. For example, experts were given a set of scenarios and asked to indicate if the scenario is safe. They were also asked to rate how changing the different elements in the scenario influenced safety. Experts were asked to rate scenarios at both the segment and intersection. Transportation infrastructure elements, for instance at the segment, refer to number of traffic lanes to cross, driveways, buffer zone, etc. Each element has two or more options. For example, number of traffic lanes has options of 2 lanes, 4 lanes or 4+ lanes. The research team prioritized elements that have been found to impact safety, in an effort to ease the design of the survey. A copy of the survey is included in the Appendix 1.X.

In the survey, each element is evaluated against four levels of importance (least important, moderately important, important, and most important) and every elemental option is evaluated based on three levels of safety impact (negative impact on safety, minimal impact on safety and positive impact on safety). Respondents select a negative impact when infrastructure conditions demand immediate action to improve the condition. Respondents select a minimal impact on safety when a situation needs actions necessary to improve the condition. Respondents select a positive impact on safety when the situation depicts no immediate action is necessary to improve the condition of the infrastructure.

The safety evaluation is completed for both segment and intersection infrastructure elements. The study adopted the HSM definition of a road segment and intersection. According to AASHTO Highway Safety Manual: A roadway segment is "*a section of the continuously travelled way that provides two-way operation of traffic that is not interrupted by an intersection, and consists of homogeneous geometric and traffic control features*" (*34*). Intersections are defined as "*the junction of two or more roadway segments. Intersection related crash is defined as a crash that occurs at the intersection itself or a crash that occurs on an intersection approach within 250 foot of the intersection… " (35*).

Using the survey results, four safety indices to assess pedestrian and bicyclist safety at segments and intersections were constructed. The following section presents the detailed methodology on the development of the Pedestrian Safety Assessment Index (PSAI) at the segment. A summary of the other three indices, Pedestrian Safety Assessment Index (PSAI) at the intersection and the Bicyclist Safety Assessment Index (BSAI) at both intersection and segments, is presented emphasizing how the indices were adjusted for the intersection and/or bicycle specifications.

Pedestrian Safety Assessment Index (PSAI) at Segment. The study assumed that a segment has the following base conditions at mid-block locations.

- Adequate sight distance
- Presence of pavement markings and signage
- No marked crosswalks at mid-block location
- Segment does not have raised median island or median
- No traffic calming features on street segment
- Presence of curb on street segments
- Two-way traffic movement
- Non-commercial land-use at the mid-block location
- Flat (or less than 2 percent grade) sidewalk

The study considered different segment elements as shown in Table 2.2. The survey respondents were asked to rank each element by its level of importance (from least important to most important). Table 1 shows the results of the survey respondents as well as the total responses received for that particular feature. The greatest number of responses in a category represents the importance of that element to safety. For example, Table 2.2 indicates that 13 experts rated speed limit as a most important element, whereas driveways were considered an important element. Experts indicated that the condition of sidewalk was moderately important to important.

Table 2.2 Level of Importance of Road Segment Elements from Survey

Element	Least Important	Moderately Important	Important	Most Important	Total Responses
Number of Traffic Lanes to Cross	0	4	9	8	21
Speed Limit	0	3	5	13	21
Driveways	1	7	10	2	20
Sidewalk Width	2	6	11	2	21
Continuous Sidewalk	0	3	10	8	21
Buffer Zone	1	3	12	5	21
Parking Restrictions near Crosswalk Area	0	6	12	3	21
Sidewalk Street Lighting	1	4	12	4	21
Condition of Sidewalk	2	8	9	2	21

Element Weights. A fuzzy scaling approach was used to calculate the weight of each element, using the expert feedback. The present study derives fuzzy numbers using survey responses. After fuzzy numbers are established for linguistic variables (i.e. for four levels of importance), the geometric mean method (36) evaluates elemental weights. As such, the levels of importance (least important, moderately important, important, and most important) are not given Likert scale weights. The advantage of using fuzzy set theory is that it can address the vagueness and uncertainty in decision making (37). In this case, it can help distinguish between different expert rankings of the infrastructure elements that influence safety. A fuzzy set is defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually [0, 1] (37). A value of zero indicates that the element does not belong to the set, and a completely belonging element is assigned the value of one. However, the element has a certain degree of membership, if the value belongs to the interval. Zadeh (38, 39) indicates that a linguistic variable, which may be more effective in hard to define or complex decisions, may be represented by fuzzy numbers. Commonly, a triangular fuzzy number (TFN) is used because of simple computation (40).

The study uses proportion (defined as the ratio between responses given to a particular level of importance to a total number of responders for any given element) of responses to develop fuzzy weights (also called fuzzy numbers). For instance, any element that is considered least important can have weights of 0.00, 0.04 and 0.10 corresponding to low, median, and high range definition of fuzzy numbers. Once the fuzzy ranges are established for each level of importance (see Table 2.3), elemental weights are calculated using the geometric mean method. A character tilde "~" above a symbol represents a fuzzy set.

Table 2.3 Fuzzy Numbers by Level of Importance

Fuzzy Range	$\widetilde{LI}$	$\widetilde{MI}$	$\tilde{I}$	$\widetilde{SI}$
Low	0.00	0.14	0.24	0.10
Middle	0.04	0.23	0.48	0.25
Upper	0.10	0.38	0.57	0.62

Note: LI – Least Important; MI – Moderately Important; I – Important; SI – Most Important

For any given element, survey respondents select different levels of importance. The geometric mean method calculates the geometric mean of response fuzzy weights. The research team uses the geometric mean technique to define the fuzzy geometric mean ($\widetilde{r_p}$) and fuzzy weights of each element ($\widetilde{w_p}$) (*39*) :

$$\widetilde{r_p} = \left(\widetilde{a_{p1}} \otimes \cdots \otimes \widetilde{a_{pq}} \otimes \cdots \otimes \widetilde{a_{pn}}\right)^{1/n} \quad (1)$$

$$\widetilde{w_p} = \widetilde{r_p} \otimes \left(\widetilde{r_1} \oplus \cdots \oplus \widetilde{r_p} \oplus \cdots \oplus \widetilde{r_n}\right)^{-1} \quad (2)$$

Where $\widetilde{a_{pn}}$ is the fuzzy value of element *p* rated by respondent *n*, and $\widetilde{r_p}$is a geometric mean of for element *p*. $\widetilde{W_p}$ is the fuzzy weight of the p^th element that is indicated by $\widetilde{w_p} = \left(lw_p, mw_p, uw_p\right)$. The lw_p, mw_p and uw_p stand for the lower, middle, and upper values of the fuzzy weight of the pth element. The fuzzy weights $\widetilde{w_p}$ are normalized and then defuzzified using one of the defuzzification methods. Methods of defuzzification include Mean of Maximal (MOM), Centre of Area (CoA), and α-cut. The CoA method is a simple and practical method. Unlike other methods, the CoA does not need the preferences of any evaluators (*41*). Hence, the study uses the CoA method of defuzzification. In the CoA method, non-fuzzy values of the fuzzy weights is calculated using (*41, 42*):

$$D(\widetilde{w_p}) = \left[\left(U(\widetilde{w_p}) - L(\widetilde{w_p})\right) + \left(M(\widetilde{w_p}) - L(\widetilde{w_p})\right)\right]/3 + L(\widetilde{w_p}) \quad (3)$$

Where *D(·)* is the defuzzified value of element weight, *L(·)*, *M(·)*, and *U(·)* represents their lower, median and upper values respectively. The final elemental weights (normalized weights) are shown in the last column of Table 2.4. This indicates that the survey respondents put more weight on parking restrictions near crosswalk areas, number of lanes to cross and continuity of sidewalk facility. Speed limit, driveways, lighting on sidewalk and presence of buffer regions are also given preference. Sidewalk width and condition were given less weight.

Table 2.3 Elemental Fuzzy and Crisp Weights

Element	$\tilde{r}$			$\tilde{w}$			**Element Weight**	**Normalized Element Weight (W)**
	r (L)	**r (M)**	**r (U)**	**w (L)**	**w (M)**	**w (U)**		
Number of Traffic Lanes to Cross	0.1524	0.3259	0.5453	0.0340	0.1153	0.5014	0.2169	0.126
Speed Limit	0.1255	0.2886	0.5667	0.0280	0.1021	0.5210	0.2170	0.115
Driveways	0.1098	0.3076	0.4570	0.0245	0.1088	0.4201	0.1845	0.104
Sidewalk Width	0.0722	0.2878	0.4324	0.0161	0.1018	0.3975	0.1718	0.088
Continuous Sidewalk	0.1561	0.3372	0.5560	0.0348	0.1193	0.5111	0.2217	0.129
Buffer Zone	0.1101	0.3278	0.5047	0.0245	0.1160	0.4640	0.2015	0.110
Parking Restrictions near Crosswalk Area	0.1805	0.3558	0.5148	0.0402	0.1259	0.4733	0.2131	0.136
Sidewalk Street Lighting	0.1123	0.3269	0.4932	0.0250	0.1156	0.4534	0.1980	0.110
Condition of Sidewalk	0.0688	0.2689	0.4160	0.0153	0.0951	0.3824	0.1643	0.084

Note: L – Low, M – Middle, and U – Upper range

Concordance Analysis. Once elemental weights are calculated, the research team evaluates the safety impact of each elemental option using concordance analysis. This is important because whereas the first stage of the analysis provides information on which elements matter, this stage provides information on how adjustments to these different elements influence safety. So, for example, in the previous section, it is apparent that experts give preference to speed limit, this information is limited in providing advice as to how adjusting the speed limit influences the overall safety. The data for the concordance analysis is obtained from the survey responses of the safety impact of each elemental option (see Table 2.5). For instance, the research team analyzes whether speed limit responses (<=20 mph, 21-30 mph, 31-40 mph, and >40 mph) either positively, minimally or negatively impact safety. The research team uses the survey responses and concordance technique to establish the elemental option scores.

Concordance analysis indicates the degree of dominance of one option over others under consideration. However, the method does not require all options under consideration to be directly linked to each other (43). For each element, the comparison of elemental options takes place on a pairwise basis. First, the survey responses are converted to proportion of responses. Then, the degree of dominance (concordance score) of option i over option j is calculated using*:*

$$cs_{i,j}^{k} = p_{i,NS}^{k} \times p_{j,NS}^{k} + p_{i,MS}^{k} \times \left(p_{j,NS}^{k} + p_{j,MS}^{k}\right) + p_{i,MS}^{k} \times \left(p_{j,NS}^{k} + p_{j,MS}^{k} + p_{j,PS}^{k}\right) \quad (4)$$

Where $cs_{i,j}^{k}$ is the concordance score of option *i* over option *j* for element *k*. $P_{i,NS}{}^{k}$, $P_{i,MS}{}^{k}$, $P_{i,PS}{}^{k}$ is the proportion of survey responders that choose option *i* (of element *k*) is negatively impacting, minimally impacting, and positively impacting pedestrian safety respectively. The pairwise comparison establishes concordance scores and the concordance matrix ([CS^k]) of each element. For an element *k* having *m* options the concordance matrix can be shown as:

$$[CS^k] = \begin{bmatrix} - & cs_{12}^k & \cdots & cs_{1m}^k \\ cs_{21}^k & - & \cdots & cs_{2m}^k \\ \cdots & \cdots & - & cs_{pm}^k \\ cs_{m1}^k & cs_{m2}^k & \cdots & - \end{bmatrix} \tag{5}$$

Options Score. The concordance scores in the matrix are row summed (RS) and then normalized to get each elemental option scores (OS). Row sum of an option l for an element k, rs_l^k, is expressed as

$$rs_l^k = \sum_{i=1, i\neq l}^{m} cs_{l,i}^k$$
(6)

Similarly, score for an option *l* for an element *k* defined as:

$$os_l^k = rs_l^k \times (rs_1^k + rs_2^k + \cdots + rs_m^k)^{-1}$$
(7)

Example calculations of proportions (*p*), concordance scores matrix (*CS*), row sums (RS) and elemental option scores (OS) for an segment element, number of traffic lanes, are shown in Table 2.5 and 2.6.

Table 2.4 Proportion of Survey Respondents Indicating Traffic Lanes Options by Safety Impact

Element	Options	Responses			Total Responses	Proportion		
		Negative Impact Safety	Minimal Impact Safety	Positive Impact Safety		Negative Impact Safety	Minimal Impact Safety	Positive Impact Safety
Number of Traffic Lanes to Cross	2 lanes	1	11	9	21	0.0476	0.5238	0.4286
	4 lanes	16	4	1	21	0.7619	0.1905	0.0476
	4 + lanes	20	1	0	21	0.9524	0.0476	0.0000

Table 2.5 Concordance Scores Matrix and Traffic Lanes Elemental Option Scores

Options	**[CS]^k**			**[RS]^k**	**[OS]^k**
	2 lanes	**4 lanes**	**4 + lanes**	**Row Sum**	**Scores**
2 lanes	-	0.9637	0.9977	1.9615	0.495
4 lanes	0.1927	-	0.9637	1.1565	0.292
4 + lanes	0.0726	0.7710	-	0.8435	0.213

Note: - represents not application case in concordance score computation

Once the score for each option is established, final optional scores are expressed as a column matrix. Assuming k total number of elements and each element has m_k options, then the optional score matrix $[OS]$ is expressed as:

$$[OS] = \left[os_1^1 \; os_2^1 \; \cdots \; os_{m_1}^1 \; \cdots os_{m_l}^l \; \cdots os_{m_k}^k \right]^T \tag{8}$$

The options score ranges between 0 and 1. From the survey data, the research team calculated fuzzy weights for each element to indicate the importance of each element in providing a safe pedestrian environment. The product of fuzzy element weights $[\widetilde{\mathrm{W}}]$ and elemental options score $[OS]$ give final fuzzy weighted scores. Using the CoA method of defuzzification, final weighted scores are calculated. Final weighted scores lie between 0 and 1. Table 2.7 shows weighted scores for pedestrian safety elements at any given highway segment. Appendix A, Tables 2A.1-2A.3 list the options score for the other three indices.

Index Calculation. The weighted scores above are then used to calculate an overall index of safety. For a given road segment, summing the weighted scores of the applicable elemental options yields the Pedestrian Safety Assessment Index (PSAI). The value of PSAI, theoretically, lies between 0 and 1. Higher index values represent infrastructure conditions that provide an overall safer pedestrian environment. So, for example, buffer zones (.1061) and continuous sidewalks (.1281) are viewed as being important features that can provide a safer pedestrian environment. Table 2.7 presents the pedestrian segment element weighted scores.

Identification of Safety Zones. The research objective is to obtain PSAI index ranges that will identify safety zones (negatively, minimally, or positively impacting safety) for different infrastructure features. The researchers, initially, designated the infrastructure conditions that negatively, minimally, or positively impacting safety with three color-coded zones: Red, Orange and Green. Red zone conditions will negatively impact safety and a green zone indicates conditions that positively impact safety. The survey data indicate that a given elemental option (for instance, a four-lane road segment) receives responses for all three levels of safety. For example, as illustrated in Table 2.2, 16 experts indicate a four-lane road segment negatively impacts safety, four indicate that it minimally impacts safety, and 1 indicates that it positively impacts safety. Thus, at any given PSAI value, there exist three levels of pedestrian safety with different proportions of safety impact. If PSAI values for all possible infrastructure conditions are developed, then the relationship between proportions of negatively, minimally, and positively impacting safety at each PSAI value can be developed. The relationships are key to identify PSAI index ranges to designate safety zones.

Table 2.6 Pedestrian Segment Elements Weighted Scores

Element	Options	[OS]	$D([\widetilde{W}] \times [OS]^{T})$
		Scores	**Weighted Scores**
Number of Traffic Lanes to Cross	2 lanes	0.4951	0.0622
Number of Traffic Lanes to Cross	4 lanes	0.2919	0.0367
Number of Traffic Lanes to Cross	4 + lanes	0.2129	0.0268
Speed Limit	<= 20 mph	0.3741	0.0429
Speed Limit	21 - 30 mph	0.3076	0.0353
Speed Limit	31 - 40 mph	0.2057	0.0236
Speed Limit	> 40 mph	0.1127	0.0129
Driveways	None	0.3991	0.0415
Driveways	Less than 5 driveways	0.3085	0.0320
Driveways	5 - 10 driveways	0.1752	0.0182
Driveways	More than 10 driveways	0.1172	0.0122
Sidewalk Width	> = 5 ft	0.8600	0.0758
Sidewalk Width	< 5 ft	0.1400	0.0124
Sidewalk Continuous along Segment?	Yes	0.9932	0.1281
Sidewalk Continuous along Segment?	No	0.0068	0.0009
Buffer Zone	Presence of 4 to 6 foot buffer zone	0.9650	0.1061
Buffer Zone	No buffer zone	0.0350	0.0038
Parking Restrictions near Crosswalk Area	Parking restricted within 30 foot distance in advance of crosswalk marking	0.9437	0.1279
Parking Restrictions near Crosswalk Area	No parking restrictions near crosswalk	0.0563	0.0076
Sidewalk Street Lighting	Excellent Visibility	0.6105	0.0669
Sidewalk Street Lighting	Moderate Visibility	0.3313	0.0363
Sidewalk Street Lighting	Poor Visibility	0.0582	0.0064
Condition of Sidewalk	>75 % in Good Condition	0.3406	0.0285
Condition of Sidewalk	50 % - 75 % in Good Condition	0.2940	0.0246
Condition of Sidewalk	25 % - 50 % in Good Condition	0.2154	0.0180
Condition of Sidewalk	< 25 % in Good Condition	0.1500	0.0126

First, the study developed all possible infrastructure condition scenarios. A scenario is defined as the combination of elemental options that could exist at a roadway segment. For instance, the present study considers *nine* segment elements related to pedestrian safety with varying options under each element. In total, the study developed 9,216 scenarios $(3 \text{ options for element } 1 \times 4 \times 4 \times 2 \times 2 \times 2 \times 2 \times 3 \times 4 \text{ options for last element})$ to establish the safety zones. For a given scenario, weighted proportions of survey responders give the proportion of either negative, minimal, or positive levels as shown in equations (9) to (11):

$$P_{NS}^{S_j} = \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j} \cdot p_{i,NS}\right) / \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j}\right) \quad (9)$$

$$P_{MS}^{S_j} = \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j} \cdot p_{i,MS}\right) / \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j}\right) \quad (10)$$

$$P_{PS}^{S_j} = \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j} \cdot p_{i,PS}\right) / \left(\sum_{i=1}^{m} ws_i \cdot \delta_i^{S_j}\right) \quad (11)$$

Where $P_{NS}^{S_j}, P_{MS}^{S_j}, and\ P_{PS}^{S_j}$ are the proportion of negatively impacting, minimally impacting and positively impacting safety due to scenario S_j. $p_{i,NS}, p_{i,MS}, and\ p_{i,PS}$ are the proportion of survey responders that evaluates option *i* as negatively impacting, minimally impacting and positively impacting safety. ws_i is the weighted scores of elemental option *i* (*m* is the total number of elemental options). $\delta_i^{S_j}$ is a dummy variable that takes a value of 1 if elemental option *i* belongs to scenario S_j.

A scattered plot is developed between safety index values of all scenarios on the x-axis and proportion of negatively impacting, minimally impacting and positively impacting safety due to respective scenarios on y-axis. The scattered plot, in Figure 2.1, shows that increasing values of the safety index reflect positively impacting safety conditions of the infrastructure. The lower value of safety index dominates the negatively impacting conditions. There exists an overlapping region of safety levels for safety indices between 0.15 and 0.25.

The safety index, in the scatter plot, shows a non-linear relationship with each safety level. Next, a best possible relationship (or model) between safety index and each level of safety impact is developed (see Table 2.7). Then, the centroid[1] of each curve (or model) is calculated. The model between safety index and minimally impact safety level is non-linear with R^2 value of 0.18. The lower R^2 value is due to the fact that the survey responses are a bit polarized for the elemental options. Survey responders, in most cases, either choose negatively or positively impacting safety for a given infrastructure element. The lower number of responses (or response rate) for minimally impacting safety reflects a polarized relationship. However, the rest of the relationships show good R^2 values. The centroid and corresponding safety index values act as safety zone boundaries.

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[1] Centroid returns the center of area under the curve. The centroid is the point along the x axis (safety index value) about which a given curve (or a relationship model for a given level of safety impact) would balance.

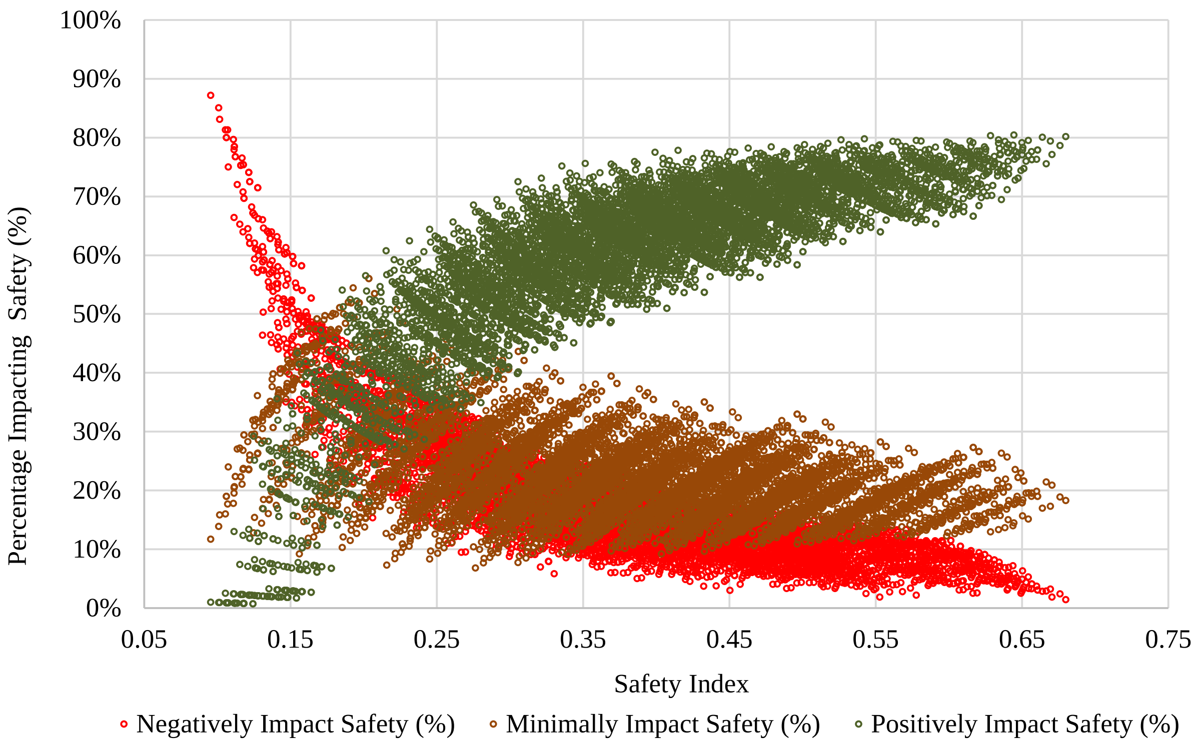

Figure 2.1 Scattered Plot between Safety Index and Percentage Impacting Safety

Table 2.7 Safety Index models by Safety Level

Safety Level	Model	Model R^2	Centroid
Negative Impact Safety (%)	$y = -8.771x^3 + 12.4x^2 - 6.0901x + 1.1544$	0.83	0.1577
Minimal Impact Safety (%)	$y = 0.5994x^2 - 0.7051x + 0.3979$	0.18	0.3311
Positive Impact Safety (%)	$y = 8.9294x^3 - 13.181x^2 + 6.8598x - 0.5593$	0.81	0.5257

Note: y = safety level impact (%); x = index value

The pedestrian safety analysis methodology at a segment is adopted to account for intersections and bicyclist safety at both segment and intersections in order to develop the safety zone boundaries for all four safety indices. Table 2.8 lists the safety index boundaries and the corresponding safety levels. In the field, an observer inventories relevant infrastructure elements and calculates index value and assesses qualitatively the safety level of the existing conditions using Table 8. For instance, if pedestrian safety index value at any segment is less than 0.16, then the corresponding segment conditions would negatively impact safety or need immediate action to improve conditions. Similarly, index values greater than 0.53 will positively impact safety or no immediate action is necessary to improve the condition of the infrastructure. An index value between 0.16 and 0.53 indicates the need for action to improve the overall safety condition.

Table 2.8 Safety Levels by Index Value at both Segments and Intersections

Safety Level (%)	**Pedestrian Index**		**Bicyclist Index**	
	Segment	**Intersection**	**Segment**	**Intersection**
Neg Impact	< 0.16	< 0.14	< 0.25	< 0.14
Neg - Min Impact	>= 0.16 - < 0.33	>= 0.14 - < 0.32	>= 0.25 - < 0.37	>= 0.14 - < 0.30
Min- Pos Impact	>= 0.33 - <= 0.53	>= 0.32 - <= 0.57	>= 0.37 - <= 0.49	>= 0.30 - <= 0.43
Pos Impact	> 0.53	> 0.57	> 0.49	> 0.43

2.5 Implementation of the Field Survey Instrument and Data Collection

The Pedestrian Safety Assessment Index (PSAI) and Bicyclist Safety Assessment Index (BSAI) data are collected through visual assessment of street segments and intersections with an observational survey (Appendix B, Tables 2B.1-2B.4) by a trained observer. The field observation materials were piloted as detailed in Chapter 6. Furthermore, Chapter 6 offers suggestions as to how university students can be engaged in data collection efforts. The research team has created some examples and guidebooks to aid training (see Chapter 7).

The survey is a checklist of questions with close-ended options that is relatively simple to complete. The survey captures broad criteria that potentially affect the safety risk to either pedestrians or bicyclists and the overall walkability and bikeability. Each survey element collects information on one or more responses (elemental options). Each observer completes a separate survey form for each individual intersection and street segment. The data entry in the form is saved in Microsoft Excel database for further analysis. After the data is entered into a database, responses are converted into binary responses and then index values are calculated. For a given road segment, summing the weighted scores of the applicable elemental options (known from the collected survey) yields an index value. A separate index is calculated for roadway segments (each direction) and intersections. Corridor level indexes are simply a length based weighted index of all segments and intersections. For intersections, consider a length of 250 feet in each direction while calculating the weighted index. Similarly, network based index measures are developed for the study area. Once index values are known, the safety level of the facility can be determined. An example of how to implement this is presented in Chapter 7.

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Appendix 2A: Survey Responses and Elemental Options Score

Table 2A.1 Pedestrian – Intersection Elements: Survey Responses, Element Weights and Options Score

Element	Options	Survey Responses				Element Weights	Option Scores
		Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety	Total Responses		
Presence of Crosswalks	Continental/Ladder/Staggered Continental Type on All Directions	0	6	15	21	0.3496	0.1851
	Standard/Parallel Type on All Directions	4	13	4	21		0.1258
	None	16	5	0	21		0.0386
Pedestrian Time Counters	All Directions with Counters	0	3	18	21	0.3482	0.1368
	Two Directions (on Major/Minor Road) with Counters	1	10	10	21		0.1167
	No Counters	12	9	0	21		0.0577
	No Pedestrian Phase	18	1	1	20		0.0370
No Right-Turn-On-Red (RTOR)	No Right-Turn-On-Red on All Directions	1	6	14	21	0.3023	0.1384
	No Right-Turn-On-Red on Two Directions (on Major/Minor Road)	1	13	7	21		0.1144
	Not Present	8	13	0	21		0.0496

Table 2A.2 Bicyclist – Segment Elements: Survey Responses, Element Weights and Options Score

Element	Options	Survey Responses: Negatively Impact Safety	Survey Responses: Minimally Impact Safety	Survey Responses: Positively Impact Safety	Survey Responses: Total Responses	Element Weights	Option Scores
Number of Driveways per Block	None	0	0	21	21	0.2005	0.1177
	Fewer than 5 on Each Direction of Segment per Block	1	13	6	20		0.0762
	5 or More on Each Direction of Segment per Block	19	2	0	21		0.0066
Speed Limit	<= 20 mph	1	2	18	21	0.2131	0.0840
	21 - 30 mph	2	13	6	21		0.0673
	31 - 40 mph	10	11	0	21		0.0439
	> 40 mph	21	0	0	21		0.0179
Type of Bike Lane in the Street Segment Right-of-Way	Bike Lane Adjacent to Vehicular Travel Lane	0	5	16	21	0.1463	0.1100
	Shared Bike Lane with Vehicular Travel Lane	6	11	4	21		0.0363
Bike Lane Continuous along the Street Segment	Yes	1	5	15	21	0.1619	0.1465
	No	16	5	0	21		0.0155
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	0	1	20	21	0.1605	0.0959
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	1	17	3	21		0.0565
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	18	3	0	21		0.0082
Presence of Commercial Land Use/Places	Yes	6	11	3	20	0.1177	0.0445
	No	1	13	7	21		0.0732

Table 2A.3 Bicyclist – Intersection Elements: Survey Responses, Element Weights and Options Score

Element	Options	Survey Responses: Negatively Impact Safety	Survey Responses: Minimally Impact Safety	Survey Responses: Positively Impact Safety	Survey Responses: Total Responses	Element Weights	Option Scores
Presence of Bicycle Lane or Bicycle Boxes at Left Turn Lanes (For Turning Bicyclist Movements)	Present on All Directions	2	6	13	21	0.1451	0.0603
	Present on Two Directions (On Major/Minor Road)	2	10	9	21		0.0531
	Shared Lanes on All Directions	6	12	3	21		0.0317
Presence of Bicycle Lanes or Bicycle Boxes (For Non-Turning Bicyclist Movements)	Present on All Directions	1	3	17	21	0.1433	0.0531
	Present on Two Directions (On Major/Minor Road)	1	9	11	21		0.0472
	Shared Lanes on All Directions	4	15	2	21		0.0303
	None	15	4	1	20		0.0128
No Right-Turn-On-Red (RTOR)	No RTOR on All Directions	2	5	14	21	0.1550	0.0728
	No RTOR on All Directions on Two Directions (On Major/Minor Road)	3	12	6	21		0.0567
	RTOR Allowed on All Directions	12	8	1	21		0.0255
Street Lighting at the Intersection	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	0	2	19	21	0.3197	0.1853
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	1	14	6	21		0.1265
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	20	1	0	21		0.0079
Pavement Markings for Bicyclists	Adequate	0	7	14	21	0.2369	0.2163
	None	15	6	0	21		0.0206

Appendix 2B: Field Data Collection Forms

Table 2B.1 Pedestrian Safety Assessment Index at Segment Data Collection Form (Form Ped Safety Segment)

<table>
<tr><th colspan="4">Pedestrian Safety - Segment - Data Collection Form</th></tr>
<tr><td>Location ID:</td><td colspan="3">Segment ID:</td></tr>
<tr><td>Element</td><td>Options</td><td>EB / NB</td><td>WB / SB</td></tr>
<tr><td rowspan="3">Number of Traffic Lanes to Cross</td><td>2 lanes</td><td></td><td></td></tr>
<tr><td>4 lanes</td><td></td><td></td></tr>
<tr><td>4 + lanes</td><td></td><td></td></tr>
<tr><td rowspan="4">Speed Limit</td><td><= 20 mph</td><td></td><td></td></tr>
<tr><td>21 - 30 mph</td><td></td><td></td></tr>
<tr><td>31 - 40 mph</td><td></td><td></td></tr>
<tr><td>> 40 mph</td><td></td><td></td></tr>
<tr><td rowspan="4">Driveways</td><td>None</td><td></td><td></td></tr>
<tr><td>Less than 5 driveways</td><td></td><td></td></tr>
<tr><td>5 - 10 driveways</td><td></td><td></td></tr>
<tr><td>More than 10 driveways</td><td></td><td></td></tr>
<tr><td rowspan="2">Sidewalk Width</td><td>> = 5 ft</td><td></td><td></td></tr>
<tr><td>< 5 ft</td><td></td><td></td></tr>
<tr><td rowspan="2">Sidewalk Continuous along Segment?</td><td>Yes</td><td></td><td></td></tr>
<tr><td>No</td><td></td><td></td></tr>
<tr><td rowspan="2">Buffer Zone</td><td>Presence of 4 to 6 foot buffer from curb line to sidewalk's near edge / presence of either on-street parking / presence of bike lanes</td><td></td><td></td></tr>
<tr><td>No buffer zone</td><td></td><td></td></tr>
<tr><td rowspan="2">Parking Restrictions near Crosswalk Area</td><td>Parking restricted within 30 foot distance in advance of crosswalk marking</td><td></td><td></td></tr>
<tr><td>No parking restrictions near crosswalk</td><td></td><td></td></tr>
<tr><td rowspan="3">Sidewalk Street Lighting</td><td>Excellent Visibility</td><td></td><td></td></tr>
<tr><td>Moderate Visibility</td><td></td><td></td></tr>
<tr><td>Poor Visibility</td><td></td><td></td></tr>
<tr><td rowspan="4">Condition of Sidewalk</td><td>>75 % in Good Condition</td><td></td><td></td></tr>
<tr><td>50 % - 75 % in Good Condition</td><td></td><td></td></tr>
<tr><td>25 % - 50 % in Good Condition</td><td></td><td></td></tr>
<tr><td>< 25 % in Good Condition</td><td></td><td></td></tr>
</table>

Table 2B.2 Byclist Safety Assessment Index at Segment Data Collection Form (Form Bike Safety Segment)

Bicyclist Safety - Segment - Data Collection Form			
Location ID:	**Segment ID:**		
Element	*Options*	*EB / NB*	*WB / SB*
Number of Driveways per Block	None		
	Fewer than 5 on Each Direction of Segment per Block		
	5 or More on Each Direction of Segment per Block		
Speed Limit	<= 20 mph		
	21 - 30 mph		
	31 - 40 mph		
	> 40 mph		
Type of Bike Lane in the Street Segment Right-of-Way	Bike Lane Adjacent to Vehicular Travel Lane		
	Shared Bike Lane with Vehicular Travel Lane		
Bike Lane Continuous along the Street Segment	Yes		
	No		
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment		
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road		
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment		
Presence of Commercial Land Use/Places	Yes		
	No		

Table 2B.3 Pedestrian Safety Assessment Index at Intersection Data Collection Form (Form Ped Safety Intersection)

Pedestrian Safety – Intersection		
Location ID:	**Intersection ID:**	
Element	*Options*	*Response*
Presence of Crosswalks	Continental/Ladder/Staggered Continental Type on All Directions	
	Standard/Parallel Type on All Directions	
	None	
Pedestrian Time Counters	All Directions with Counters	
	Two Directions (on Major/Minor Road) with Counters	
	No Counters	
	No Pedestrian Phase	
No Right-Turn-On-Red (RTOR)	No RTOR on All Directions	
	No RTOR on Two Directions (on Major/Minor Road)	
	Not Present	

Table 2B.4 Bicyclist Safety Assessment Index at Intersection Data Collection Form (Form Bike Safety Intersection)

Bicyclist Safety - Intersection		
Location ID:	**Intersection ID:**	
Element	*Options*	*Response*
Presence of Bicycle Lane or Bicycle Boxes at Left Turn Lanes (For Turning Bicyclist Movements)	Present on All Directions	
	Present on Two Directions (On Major/Minor Road)	
	Shared Lanes on All Directions	
Presence of Bicycle Lanes or Bicycle Boxes (For Non-Turning Bicyclist Movements)	Present on All Directions	
	Present on Two Directions (On Major/Minor Road)	
	Shared Lanes on All Directions	
	None	
No Right-Turn-On-Red (RTOR)	No Right-Turn-On-Red on All Directions	
	No Right-Turn-On-Red on All Directions on Two Directions (On Major/Minor Road)	
	Right-Turn-On-Red Allowed on All Directions	
Street Lighting at the Intersection	Excellent Visibility of Approaching Figures without Dark Spaces along the Road	
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road	
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road	
Pavement Markings for Bicyclists	Adequate	
	None	

Chapter 3. Conflict Analysis Methodology

3.1 Research Objectives

The objective is to develop a surrogate safety measure using conflict analysis. The research team develops conflict categories (severity of conflicts) and assesses safety impact using factors modified from vehicle-vehicle conflict analysis.

3.2 Conflict Types

A conflict is defined as "an observational situation in which a vehicle (can also be a pedestrian or a bicyclist) and pedestrian (can also be a bicyclist or a vehicle) approach or encroach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged" (*1*). The conflicts between vehicles, pedestrians and bicyclists occur at both intersections and street segments. Vehicular turning movements (either left turns or right turns) form potential conflicts with the pedestrians or bicyclists crossing an intersection. Mid-block or driveway crossings cause conflicts on street segments between pedestrians and vehicles or bicyclists. However, vehicular overtaking of bicyclists occurs mostly on shared bike lanes. In order to perform conflict analysis, the above mentioned conflicting behaviors should be considered. The research team considers two broad types of conflicts for either pedestrian or bicyclist interaction with the transportation infrastructure. Non-overtaking (or angled) conflict type occurs when parties (pedestrians, bicyclists, or vehicles) are not travelling in the same direction. Overtaking conflicts occur between parties that are travelling in the same direction. In total, the study considers following five types of conflicts:

1. Pedestrian – Vehicle
2. Bicyclist – Vehicle
3. Pedestrian – Bicyclist
4. Vehicle – Bicyclist (Overtaking)
5. Bicyclist – Pedestrian (Overtaking)

3.3 Literature Review

A conflict analysis approach is adopted by the research team to study pedestrian and bicyclist safety because it is viewed as a more valuable approach for decision making than traditional measures, such as collision or crash data. Collision or crash data may be biased in that it is dependent upon a party reporting it, and thus, may underrepresent actual issues of safety that exist. Understanding and identifying the rate of conflicts on a segment of intersection may provide a better source of data for local municipalities and decision-makers. Conflicts (or near miss situations) often pose potential safety concerns for pedestrians and bicyclists. Road segments or intersections characterized as high conflict can also serve as a detriment to physical activity. Coupled with crash data, understanding the conflict patterns and their possible causes can help transportation agencies make strategic decisions about active transportation investments. Moreover, conflict measures can act as a sketch planning level performance measure to understand potential safety issues related to transportation facilities.

Pedestrians' exposure to the risk of conflicts with vehicles, bicycles, or other pedestrians is very difficult to assess since it requires tracking the movement of all involved parties in real-time. However, measurement is possible by modifying the techniques used to study vehicle-vehicle conflicts and vehicle-pedestrian conflicts. Pedestrian safety analyses that use non-collision data often rely on traffic conflict analysis (*2-10*). Motorist yielding rate (with respect to pedestrians) has been used to evaluate engineering treatments that aim to improve the safety of pedestrians crossing in marked crosswalks on busy arterial streets (*11*). Vision-based studies related to pedestrians and bicycles have shown increasing potential to better understand conflicts (*12-19*). The trajectories of vehicles, pedestrians, and bicyclists from vision based techniques can, not only help to track movements in space and time, but also evaluate the potential conflicts and severity between them.

Both qualitative methods (based on road user response to conflicts) and quantitative approaches are proposed in the literature (*20-28*). The U.S Department of Transportation Conflict Technique (USDTCT) from Federal Highway Admiration (FHWA) categorizes various elements that induce conflicts, create the level of severity by each element, sum the severity levels of each element and then finds the overall grade of the severity of the conflict (*23*). Like USDTCT, the Swedish Traffic Conflicts Technique (STCT) (*21*), and the Institute of Highways and Transportation Conflicts Technique (IHTCT) (*22*) were developed for vehicle-to-vehicle conflict analysis. For instance, the modeling interaction between left-turning vehicles and pedestrians at signalized intersections (*29*), assessing the efficiency of safety regulations for vulnerable road users at intersections (*30*), and qualitative categorization of conflict types and severity (*31*) are some cross applications of vehicle-vehicle conflict based methods. These techniques were also adopted for vehicle-pedestrian conflict analysis. A modified version of the IHTCT method is used to develop vehicle-pedestrian conflict analysis method (*1*).

3.4 Methodology

The research team first identified characteristics of a conflict, classifying the type, factors that influence the potential seriousness of the conflict, and a conflict category. Conflict type is defined as the parties that are involved in the conflict and the nature of their relationship. Five different conflict types are considered, three non-overtaking and two over-taking, as listed in Tables 3.1 and 3.2. Conflict factors are those factors that have been identified in the literature as influencing the seriousness of the conflict (*1*). The factors that influence the seriousness of the conflict differ when considering a non-overtaking or over-taking type of conflict. Two factors: *separation distance* and *severity of evasive action* are considered important in analyzing non-overtaking conflicts. Separation distance indicates how much space is between the two parties involved in the conflict. Evasive action indicates the type of action that a pedestrian or bicyclist could take in a conflict. For overtaking conflicts, two factors: *lateral separation distance* and *speed* are considered important. Participants in a conflict may take evasive actions. Only evasive actions and distances definitions related to pedestrian or bicyclists are considered given the scope of the research. Tables 3.1 and 3.2 list the definitions of the two factors for all five conflict types considered in the research.

Table 3.1 Conflict Analysis Factors Definition for Non-overtaking Conflicts

<table>
<tr><th rowspan="2">Non-overtaking Conflict Type</th><th colspan="2">Factors</th></tr>
<tr><th>Severity of Evasive Action</th><th>Separation Distance</th></tr>
<tr><td>Pedestrian – Vehicle</td><td>Pedestrian Actions (Four Rating Levels) (1):
1. Light: A change from a walk to stop
2. Medium: A change from a walk to jog
3. Heavy: A change into a sprint. This is likely combined with a change of course after the deceleration or acceleration
4. Emergency: Take emergency action such as jumping out of the street and may be coupled with a fast, sporadic change of course</td><td>Three Rating Levels (1):
1. Far: Greater than one car length (> 20 ft) is available
2. Medium: Between half and one car length (10 ft to 20 ft)
3. Short: Less than half car length (< 10 ft)</td></tr>
<tr><td>Bicyclist – Vehicle</td><td>Bicyclist Actions (Four Rating Levels):
1. Light: A slight change in speed and no change in direction
2. Medium: A normal stop or moderate change in speed and no change in direction
3. Heavy: A hard stop or controlled change in direction
4. Emergency: An abrupt, uncontrolled change in direction</td><td>Three Rating Levels:
1. Far: Greater than one car length (> 20 ft) is available
2. Medium: Between half and one car length (10 ft to 20 ft)
3. Short: Less than half car length (< 10 ft)</td></tr>
<tr><td>Pedestrian – Bicyclist</td><td>Bicyclist Actions (Four Rating Levels):
1. Light: Cruising away from pedestrian with a change of direction
2. Medium: A moderate but controlled deceleration and likely combined with a change of direction
3. Heavy: A sharp, less controlled deceleration and no change of direction
4. Emergency: A sudden, uncontrolled deceleration or no change of direction

Pedestrian Actions (Four Rating Levels):
1. Light: A change from a walk to stop
2. Medium: A change from a walk to jog
3. Heavy: A change into a sprint. This is likely combined with a change of course after the deceleration or acceleration
4. Emergency: Take emergency action such as jumping out of the street and may be coupled with a fast, sporadic change of course</td><td>Three Rating Levels:
1. Far: Greater than one bicycle length (> 10 ft) is available
2. Medium: Between half and one bicycle length (5 ft to 10 ft)
3. Short: Less than half bicycle length (< 5 ft)</td></tr>
</table>

Table 3.2 Conflict Analysis Factors Definition for Overtaking Conflicts

Overtaking Conflict Type	Factors	
	Lateral Distance	Speed
Vehicle – Bicyclist (Overtaking)	Two Rating Levels: **1.** Close: Lateral distance between vehicle and bicyclist is <= 3 ft **2.** Far: Lateral distance between vehicle and bicyclist is > 3 ft	Vehicle Speed (Four Rating Levels): **1.** Slow: <= 10 mph **2.** Average: 11 - 20 mph **3.** Moderate: 21 - 40 mph **4.** Fast: > 40 mph
Bicyclist – Pedestrian (Overtaking)	Two Rating Levels: **1.** Close: Lateral distance between pedestrian and bicyclist is <= 3 ft **2.** Far: Lateral distance between pedestrian and bicyclist is > 3 ft	Bicyclist Speed (Three Rating Levels): **1.** Slow: <= 10 mph **2.** Average: 11 - 20 mph **3.** Fast: > 20 mph

Finally, the conflict category is defined as a grade that indicates the seriousness of the conflict situation, as a function of conflict type and factors. The rating levels for each factor are added to determine an overall grade category for a conflict. Summing all of the factors' grades will create an overall grade for the conflict category (A to D). Conflict categories range from A to D, with category "*A"* conflicts being characterized "serious" and category B, C, and D conflicts corresponding to conflicts with decreasing severity. Each category is defined below. There are four categories of conflicts (*32*):

- Category A is a serious incident in which a collision is narrowly avoided.
- Category B is an incident with significant potential for a collision where separation decreases and incident may result in a time critical response to avoid a collision.
- Category C is an incident characterized by moderate time and/or distance to avoid a collision.
- Category D is an incident with no immediate safety consequences but met the definition of a conflict such as encroachment of the space/area of a roadway surface designated for a single vehicle/person

Expert Ratings. A survey of experts was used to develop conflict categories for each combination of factors. The survey asked experts to use the different factors to grade the conflict, hence placing it into one of the four categories, A to D. The survey sample included 132 safety engineers, planners, city traffic engineers, and public health professionals, and the research team received 47 complete responses (36% response rate). Of the 47, 21 were from respondents with professional expertise as it relates to safety for pedestrians and cyclists. Grading conflicts has the potential to produce two categories of conflict for same situation (one for vehicle and other for a pedestrian). However, the present method asks respondents to focus only on grading severity for the pedestrian or bicyclist.

The survey asked respondents to rate the risk of collision based on the factors listed in Tables 3.1 and 3.2. For example, if survey respondents think that when the separation distance between a vehicle and pedestrian is *far* and the severity of evasive action taken by the pedestrian is *light*, a situation of "no immediate safety concern" results, then they select conflict category "D". For a given combination of factors, the conflict category is determined based on the majority of the survey responses. Using the same factors, survey respondents are asked to categorize the type of safety situation a combination of factors creates. Types of the safety situation include: *safe* (no likelihood of collision), *moderately safe* (low likelihood of collision) or *not safe* (high likelihood of collision). This yields an overall safety level. This approach yields two data points for the conflict and helps the research team determine under which conditions a safety concern is present. For example, a conflict can be rated B or C, yet still present a not safe condition. In another situation, a conflict can be rated B or C and present a moderately safe condition. The survey questions are adjusted and repeated to gather similar data from respondents on the other conflict types (See Tables 3.3-3.7).

Table 3.3 Pedestrian – Vehicle Conflict Categories and Safety Level

Pedestrian – Vehicle Conflict Analysis Factors	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Pedestrian, Far (> 20 ft)	D	C	B/C*	A/B*
	Safe	Moderately Safe	Moderately Safe	Not Safe
Separation Distance Vehicle-Pedestrian, Medium (10 - 20 ft)	C	C	B	A
	Moderately Safe	Not Safe	Not Safe	Not Safe
Separation Distance Vehicle-Pedestrian, Short (< 10 ft)	A	A	A	A
	Not Safe	Not Safe	Not Safe	Not Safe

* shows two possible conflict categories for that factor level combination

For pedestrian-vehicle conflicts, the survey respondents rated conflicts as category D for light evasive action and when separation distance is far. Two findings stand out from the data—the importance of emergency evasive action and the closeness of the separation distance between the pedestrian and vehicle. The data suggest that for a given distance between vehicles and pedestrians, the severity of conflict increases when evasive actions change from light to emergency. The severity level of conflict increases even as the distance between pedestrian and vehicles decreases when emergency evasive actions must be taken. Likewise, for short distances irrespective of evasive action type, the survey respondents rated the conflict type as category A and labeled the situation *not safe* (or more likelihood of crashes). Table 3.3 shows that the survey respondents gave more weight to separation distance when rating a conflict situation for a safety level. For most of the medium and short separation distances, respondents chose the conflict situation as *not safe* irrespective of evasive action type. This could be explained due to the fact that distance measure is easier to rate compare to evasive action in the absence of actual visual observation of conflict in the field. Similar observations are made from other non-overtaking conflict types (see Tables 3.4 and 3.5).

Table 3.4 Bicyclist – Vehicle Conflict Categories and Safety Level

Bicyclist – Vehicle Conflict Analysis Factors	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Bicyclist, Far (> 20ft)	Safe	Safe	Not Safe	Not Safe
	D	C	B	A
Separation Distance Vehicle-Bicyclist, Medium (10 - 20 ft)	Moderately Safe	Not Safe	Not Safe	Not Safe
	C/D*	C	A	A
Separation Distance Vehicle-Bicyclist, Short (< 10 ft)	Not Safe	Not Safe	Not Safe	Not Safe
	A	A	A	A

* shows two possible conflict categories for that factor level combination (equal number of responses)

Table 3.5 Bicyclist - Pedestrian Conflict Categories and Safety Level

Bicyclist - Pedestrian Conflict Analysis Factors	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Bicycle-Pedestrian, Far (> 10 ft)	D	D	B/C*	A
	Safe	Moderately Safe/Safe*	Moderately Safe	Not Safe
Separation Distance Bicycle-Pedestrian, Medium (5 - 10 ft)	C	B	B	A
	Moderately Safe	Not Safe	Not Safe	Not Safe
Separation Distance Bicycle-Pedestrian, Short (< 5 ft)	B	A	A	A
	Not Safe	Not Safe	Not Safe	Not Safe

* shows two possible conflict categories for that factor level combination (equal number of responses)

Survey respondents were asked to rate the conflict situation using both lateral distance and speed factors for overtaking conflict types (see Table 3.6 and 3.7). At slow speeds, the lateral distance does not change the severity (or safety level) of the conflict and the situation is rated as a category D or safe. However, the survey data indicate there are two levels of change in severity of conflicts for lateral distance change under increasing speed range. Far lateral distance during overtaking creates a safe conflict situation. At higher speeds, short lateral distances create unsafe conflict situations, as evidenced by survey respondents rating these as conflict category A.

Table 3.6 Vehicle – Bicyclist Overtaking Conflict Categories and Safety Level

Vehicle – Bicyclist Overtaking Conflict Analysis Factors	Vehicle Speed, Slow (<= 10 mph)	Vehicle Speed, Average (11-20 mph)	Vehicle Speed, Moderate (21-40 mph)	Vehicle Speed, Fast (40+ mph)
Lateral Distance Vehicle - Bicyclist, Close (<= 3 ft)	C/D*	B	A	A
	Safe	Moderately Safe	Not Safe	Not Safe
Lateral Distance Vehicle - Bicyclist, Far (> 3 ft)	D	D	C	B
	Safe	Safe	Moderately Safe	Moderately Safe

* shows two possible conflict categories for that factor level combination (equal number of responses)

Table 3.7 Bicyclist – Pedestrian Overtaking Conflict Categories and Safety Level

Bicyclist – Pedestrian Overtaking Conflict Analysis Factors	Bicycle Speed, Slow (<= 10 mph)	Bicycle Speed, Average (11-20 mph)	Bicycle Speed, Fast (20+ mph)
Lateral Distance Bicycle - Pedestrian, Close (<= 3 ft)	D	A	A
	Moderately Safe	Not Safe	Not Safe
Lateral Distance Bicycle - Pedestrian, Far (> 3 ft)	D	C	C
	Safe	Moderately Safe/Safe*	Not Safe

Trained observers in the field can use the grade categories produced by this analysis to rate conflicts in a given context. A trained observer can rate the conflicts using the factors listed in Table 3.1. Tables 3.3 to 3.7 provide the information on the conflict type, the conflict rating, and its safety level. The following section describes how to obtain conflict information from field observations.

3.5 Field Data Collection

The research team has developed a survey form that can be used to collect conflict data in the field (see Appendix 3B, Table 3B.1). The field observation materials were piloted as detailed in Chapter 6.

The data collection covers both intersection and street segments. Vehicular turning movements (either left turns or right turns) form potential conflicts with the pedestrians crossing an intersection. Mid-block or driveway crossings cause conflicts on street segments. Vehicular overtaking occurs mostly on shared bike lanes. Though the surveys were only piloted at school locations, other potential locations where significant conflicts occur may also be considered. Situations, where either vehicle or pedestrian are hypersensitive in avoiding collisions, or yield to each other courteously, may not constitute a conflict. Thus, field observation team may avoid classifying those as conflict situations. Survey data should be collected when either pedestrian or bicyclist activities are predominant (for instance, evening school closing times are better for data collection at school locations). Also, adverse weather conditions can affect pedestrian or bicyclist activities, avoid surveying on those days.

Calculation of a Conflict Category. Once an observer identifies a conflict situation, the appropriate response from factors distance and evasive action are marked ("×") on the form. Using Tables 3.3 to 3.7, the observer identifies conflict category corresponding to the marked responses. If multiple parties (pedestrians or bicyclists) are involved in a given conflict situation, treat the parties as one group where the worst conflict grade among all involved will prevail.

3.6 Summary

The research team developed surrogate safety performance measures that are simple to collect from the field. Based on existing literature, the research team uses distance, speed or evasive action factors to assess the severity of conflict category. Conflict categories range from A to D, with category "*A*" conflicts being characterized "serious" and category B, C, and D conflicts corresponding to conflicts with decreasing severity. The research team also developed the relationship between conflict category and three safety levels: *safe* (no likelihood of collision), *moderately safe* (low likelihood of collision) or *not safe* (high likelihood of collision).

On a given street segment, information on number of conflicts, percent of conflicts by each conflict category, or percent of safety impact by three safety levels can be useful in corridor planning or enhancement programs, safety analysis, safety related investment decision making, strategic planning to encourage active transportation, area-level planning or engineering analysis. In lieu of crash data or crash models, conflict analysis acts as a surrogate safety measure. Conflict analysis at an intersection and segment can be scaled up to the corridor or network-wide analysis using weighted measures of conflict data (for instance, vehicle miles travelled based measures). In addition to angled, or non-overtaking, conflicts, the study also developed overtaking conflicts. The overtaking conflicts information is useful to evaluate shared versus dedicated facilities for bicyclist or pedestrians. The agencies can perform proactive monitoring using conflict data and its associated safety impact information.

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Appendix 3A: Conflict Analysis Data Collection Forms

Table 3A.1 Vehicle – Pedestrian Conflict Data Collection Form

Vehicle - Pedestrian Conflict Data Collection Form

Highway Name / Location Name :

Intersection Major Street : Intersection Minor Street :

Survey by : Date : Weather Condition :

Time (from - to) : Comments :

Veh / Ped	Separation Distance between Vehicle and Pedestrian						Severity of Evasive Action								Conflict Category
Ped.	Short		Medium	X	Long		Emergency		Heavy	X	Medium		Light		B
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		
Ped.	Short		Medium		Long		Emergency		Heavy		Medium		Light		

Chapter 4. Physical Activity Performance Measures

4.1 Research Objectives

The research objective is to develop performance measures to evaluate the effect of transportation infrastructure on physical activity. To accomplish the objective the research team developed the Walkability Assessment Index (WAI) and Bikeability Assessment Index (BAI), which can be used to evaluate walkability and bikeability at road segments and intersections.

4.2 Physical Activity Indices

The research team developed a qualitative measure for assessing the walkability and bikeability at intersection and segments. Two indices, Walkability Assessment Index (WAI) and Bikeability Assessment Index (BAI) are developed as physical activity performance measures related to the transportation infrastructure. The research team conducted a literature review to identify the infrastructure elements that have been found to be associated with increases or decreases in the likelihood that individuals engage in walking or biking in a given context. Transportation infrastructure that promotes walking and biking can also influence public health by encouraging individuals to engage in more physical activity.

4.3 Literature Review

The purpose of the literature review is to summarize the intersection between public health and transportation goals in the built environment and to provide the background as to the rationale that informs the development of the physical activity indices. While there are uniform measures identified for physical activity in Healthy 2020, the measures and data sources for evaluating the performance of different transportation infrastructure elements are not specified. To fill this gap, a review of transportation infrastructure elements that impact physical activity is included. The review concludes with the identification of potential areas of overlap between physical activity and transportation infrastructure, with a particular focus on summarizing the transportation infrastructure elements that can promote walking and biking. The literature review consists of a review of recent existing transportation plans, documents and guidebooks, or secondary analyses of the aforementioned, published in the TRID between 2011-2014. In addition, relevant scholarly articles were identified in key public health journals if they were published since 2000, and by using the search terms “built environment”, “physical activity” and “active commuting”. Finally, web sites, reports and recommendations of key nonprofit and advocacy groups focused on physical activity, nonmotorized modes of travel, and public health were consulted.

Physical Activity and Public Health. Healthy People 2020 is the federal government’s initiative to establish science-based, 10-year national objectives for improving the health of all Americans (1). Physical activity has been identified as an integral part of Healthy People 2020 for both adults and children. Public health authorities recommend that children and adults get 60 minutes of moderate- to vigorous-intensity physical activity per day and limit the time spent engaging in sedentary activity (2). In doing so, it establishes benchmarks, performance measures and performance standards for addressing general health status, health-related quality of life and well-being, disparities and determinants of health.

Increasing physical activity is not only on the agenda of public health community, but it is also a concern of the transportation community, under the Congressional Non-Motorized Pilot Program and as a participating agency in the Partnership for Sustainable Communities. As Robert Johns the Associate Administrator and Director of the Volpe National Transportation Systems Center emphasized, there is a need to move away from existing concerns of air quality and safety towards goals related to increased physical activity. Related to this are challenges in "developing standardized measures of walking and biking, developing tools to estimate health and economic benefits and identifying best practices to incorporated within transportation planning and decisions" (3, p. 4).

In regards to physical activity, Healthy People 2020 establishes several objectives and measures, some of which can be influenced or addressed through increased active and recreational commuting and interventions in the built environment. These and relevant data sources are presented in Table 4.1, but in short, there is a lack of clear measures for objectives related to the built environment and transportation.

Table 4.1 Physical Activity Objectives and Measures

National Objective	**Baseline**	**Desired Goal**	**Data Sources**
Reduce the proportion of adults who engage in no leisure-time physical activity.	36.2 (2008)	32.6	National Health Interview Survey (NHIS), CDC/NCHS
Increase the proportion of adults who engage in aerobic physical activity of at least moderate intensity for at least 150 minutes/week or 75 minutes/week of vigorous intensity or an equivalent	43.5 (2008)	47.9	National Health Interview Survey (NHIS), CDC/NCHS
Increase the proportion of adults who engage in aerobic physical activity of at least moderate intensity for more than 300 minutes/week, or more than 150 minutes/week of vigorous intensity, or an equivalent combination	28.4	31.3	National Health Interview Survey (NHIS), CDC/NCHS
Increase the proportion of adolescents who meet current Federal physical activity guidelines for aerobic physical activity	28.7 (2011)	31.6	Youth Risk Behavior Surveillance System (YRBSS), CDC/NCHHSTP
Increase the proportion of the Nation's public and private schools that provide access to their physical activity spaces and facilities for all persons outside of normal school hours (that is, before and after the school day, on weekends, and during summer and other vacations)	28.8 (2006)	31.7	School Health Policies and Practices Study (SHPPS), CDC/NCHHSTP
Increase the proportion of trips of 1 mile or less made by walking by adults aged 18 years and older	No Baseline	Increase desired	To be determined

Table 4.1 Continued

National Objective	Baseline	Desired Goal	Data Sources
Increase the proportion of trips of 1 mile or less made to school by walking by children and adolescents aged 5 to 15 years	No Baseline	Increase desired	To be determined
Increase the proportion of trips of 5 miles or less made by bicycling by adults aged 18 years and older	No Baseline	Increase desired	To be determined
Increase the proportion of trips of 2 miles or less made to school by bicycling by children and adolescents aged 5 to 15 years	No Baseline	Increase desired	To be determined
Increase community-scale policies for the built environment that enhance access to and availability of physical activity opportunities	No baseline	Increase desired	To be determined
Increase street-scale policies for the built environment that enhance access to and availability of physical activity opportunities	No baseline	Increase desired	To be determined
Increase transportation and travel policies for the built environment that enhance access to and availability of physical activity opportunities	No baseline	Increase desired	To be determined

Transportation Performance Measures in Use. The Oregon Least Cost Planning (OLCP) Working Group, a taskforce focused on livable and sustainability community initiatives within the Oregon State DOT, conducted an extensive analysis to identify performance measures currently in use in transportation plans or projects (4). Documents reviewed included the Puget Sound Regional Council (PSRC) Transportation 2040, Central Indiana Transit Task Force: Central Indiana Transportation Plan (CITP), Portland Metro 2035 Regional Transportation Plan (Metro RTP), United Kingdom Department of Transport NATA Refresh –Project Evaluation Framework, Lake Oswego to Portland Transit Project Health Impact Assessment (LOPT HIA) and the Health Impact Assessment on Policies Reducing Vehicle Miles Traveled in Metropolitan Areas (VMT HIA). An abbreviated list of indicators that are also related to Healthy 2020 goals of physical activity, safety and air quality are presented in Table 4.2.

Table 4.2 Related Transportation Performance Indicators

General Indicator	Specific Indicator	Source & Type (Quant or Qual)
Air Quality	Tons of transportation-related air pollution	NATA (Quant & Qual) CITP (Quant) LOPT HIA (Quant & Qual) ECEAP HIA (Qual) Metro RTP (Quant) VMT HIA (Qual)
Physical Activity	-Percent mode share of active modes (transit, biking, walking) -Vehicle Miles Traveled (total and per capita)	NATA (Quant & Qual) PSRC (Qual) LOPT HIA (Quant & Qual) ECEAP HIA (Qual) Metro RTP (Quant) VMT HIA (Qual)
Safety	-Accident Cost Savings	PSRC (quant)
Safety	-Crash rates, injuries and fatalities (disaggregated by mode)	NATA (Quant & Qual) LOPT HIA (Qual) ECEAP HIA (Qual) VMT HIA (Qual)
Transportation Choice	-Percent of households within ¼ mile of transit, in walkable neighborhoods, or within ¼ mile of a bicycle route -Number of transportation options available vs auto accessibility	NATA (Qual) CITP (Quant) Metro RTP (Quant)
Accessibility	-Access to healthy food retail, healthcare, recreation facilities, open space, public spaces and social services -Number and percent of homes within a ½ mile of the regional trail system	LOPT HIA (Qual) Metro RTP (Quant)
Travel Time	Motor vehicle and transit travel time between key origins and destinations	Metro RTP (Quant)
Streetscape/Journey Ambiance	Travel corridor aesthetics and anticipated user stress levels	NATA (Qual)

Other indicators have been reviewed in the NCHRP 08-74 Interim Report on Sustainabiilty Performance Measures for State DOTs and Other Transportation Agencies, TRB Sustainable Transportation Indicators Subcommittee Report; Greater Portland-Vancouver Indicators GPVI Project, and Smart Mobility: A Caltrans Handbook. In addition, the Smart Growth America Network has an extensive resource list to consult regarding performance measurement (5). However, while these performance measures are useful for Metropolitan Planning Organizations

(MPOs) or other local governments evaluating overall outcomes from transportation investments, they are not as effective at evaluating a particular type of infrastructure at the project level. Therefore, based on this review of literature, the research team has identified a methodology to develop performance measures to evaluate the potential effect of different types of transportation infrastructure that can influence physical activity. This is in contrast to evaluating how it performs on human behavior, and is valuable because it helps decision makers select the appropriate types of investments that may yield the desired human performance outcomes.

Transportation Infrastructure Elements and Elemental Options Associated with Physical Activity. In the field of transportation, performance measures can be focused on broad outcomes, identification of indicators (outputs) related to those outcomes and strategies for implementation. They can also occur at different levels. For example, the City of Portland collects data on bicycle use and crashes involving bicycles. The data are then used in performance measures related to bicycle use-- the number of cyclists per day is compared to reported bicycle crashes on an annual basis. Performance measures are also established for corridor level or project level evaluations, This is the preferred approach given the research objectives of this project, for example enabling decision makers to evaluate overall sidewalk availability or bicycle facility availability (6). For example, the Lancaster Avenue Project included a performance measure called a "great pedestrian street". Indicators that lead to a "great pedestrian street" include total sidewalk area, curb extensions, crosswalk lengths, median widths, pedestrian refuges, walkability, perceived safety, aesthetic components, streetscape features and lighting. A "great pedestrian street" can be realized by the addition of wider sidewalks, an enhanced streetscape environment, sidewalk extensions, pedestrian countdown signals, midblock crosswalks, and on-street parking at key locations. Finally, performance measures can be designed to convey overall progress to the public. For example, the Delaware Valley Regional Planning Commission (DVRPC) uses a dashboard to track progress on performance measures, using a colored dial to indicate if progress is positive (green), negative (red) or neutral or baseline (yellow).

There is a robust literature that identifies elements of the built environment associated with physical activity and active commuting. These relationships have been identified using both objective and subjective measures. Good lighting, access to 'adequate' sidewalks, street connectivity; distance or proximity to a destination, 'fair' weather , flat, straight terrain, urbanized areas (has a relationship to density as does retail and 'purposeful' clusters), tidinesss, imageability and traffic have been identified as factors that promote physical activity and active commuting (7, 8, 9, 10, 11, 12, 13, 14). Each of these factors and the association with physical activity is elaborated upon below.

'Adequate' Sidewalks: Sidewalks have been found to have a positive effect on physical activity, assuming they are adequate. Adequate sidewalks have been characterized as those that are wide, are on the same side of the street as the destinations to which people travel, and that promote overall street connectivity. Sidewalks have been measured based on whether or not they are present (7, 14), if they aid same side of street connectivity, and the width (9). Data collection efforts have been both through observation, street inventories and surveys.

Street Connectivity: Street connectivity has a positive effect on physical activity. Boone-Heinonen et al (13) measured street connectivity as the number of links (street segments), nodes (intersections), and intersection density, and found that greater connectivity increased physical activity within a 1 km buffer. The data in that study were obtained from ESRI Street Map 2000 and matched with national longitudinal survey data on adolescents and physical activity.

Distance and Proximity: Shorter distance and closer proximity to a destination has a positive association with physical activity (7, 8, 9, 10, 11). Specifically, trips of less than ½ mile (or 10 min walk) increase the likelihood that one walks to a destination. For example, Babey et al, when considering distances of ½ mile, 1/2 mile to 1 mile, 1-2 miles, and greater than 2 miles, found that shorter trips increased active commuting (10). Berke et al found that distances less than 440 m were associated with more active commuting (11), and Addy et al found that trips within a .5 mile radius or 10 minute walk were more likely to be active commutes (7). Agrawal and Schimek found that the average walk trips are .5 miles based on the US DOT National Household Travel Survey (8).

'Fair' Weather: Fair weather, defined as no extreme temperatures or no precipitation, has been found to increase physical activity. Specifically, Ahlport et al found that bad weather reduces physical activity, including precipitation and temperature extremes, either cold or hot (9). This finding was based on focus group data gathered from a group of parents with elementary-age children.

Tidiness : Routes that are tidier are also associated with active commuting and physical activity. Tidiness of a route has been captured based on the amount of disorder and trash found along a particular route. Boehmer found that people are more likely to walk along routes that are perceived and inventoried as more tidy (12). In Boehmer's study, tidiness was measured as the weighted sum of beer/liquor cans, cigarette/cigar butts, condoms, drug-related paraphernalia, garbage/litter, and abandoned cars found along particular routes.

Imageability and Scenicness: Imageability is defined as a place that is made distinct. Boehmer found that routes in places that are more distinct are associated with increased physical activity (12). Brownson et al found that individuals are more likely to walk along routes that are perceived as more scenic (14). Scenic-ness has been measured using survey data capturing if respondents are more likely to walk when they perceive a route as scenic, including attributes such as rolling hills, greenery, and other natural features.

Street Safety: Boehmer found that street safety has an association with physical activity and active commutes, and when street safety increases, so does physical activity (12). In Boehmer's study, street safety is a variable that captures and collapses some of the factors above into an overall indicator, and is measured as the unweighted sum of the number of traffic lanes, connectivity, street design characteristics to reduce speed, traffic calming devices, aggressive drivers, crossing aids and street lighting.

However, several of the characteristics above have mixed effects on physical activity such as walking or biking. These include the street lighting, density, urbanization, traffic, and terrain. Part of these differences may be attributed to the purpose of the trip, utility or recreation, other mediating factors in the built environment, the measurement and operationalization of the variables, and data collection methods. Furthermore, there could be other social and policy variables that mediate the relationships and effects.

Street Lighting: Street lighting is typically measured through survey data collected from a sample population, in which respondents are asked to rate the street lighting as good, fair or poor, or simply respond yes or no if the street lighting is good. Although Addy et al found that good street lighting increased physical activity (7), Brownson et al found that it did not have an association when considering other factors such as sidewalks, enjoyable scenery, heavy traffic, and hilly routes (14). It is important to note that the sample population and questionnaires used to capture this data was different, and thus could explain some of the differences. Furthermore, Brownson et al captured more variables than did Addy et al, which could contribute to the findings. A physical inventory of the lighting in a particular location may aid in resolving some of these discrepancies.

Density: Density has been captured in several different ways. The density findings are mixed, and vary based on the purpose of the trip, recreation versus utility (8), the mixture and types of establishments that compose the density (11), as well as the measures used to capture density (11). Agrawal and Schimek found that for utility trips, density has a positive association with increased walking, but the same was not found for recreational trips (8). Agrawal and Schimek measured density as the number of households per square mile in a block group. In some cases, urbanization or urbanicity is used as a density proxy. For example, Boone-Heinonen et al found inconsistent results of the effect of 'urbanicity' when categorizing urbanicity as high or low based on the area of developed land as a proportion of a total area with an 8k radius (13). Berke et al captured different types of land uses (retail and purpose clusters, grocery stores and markets, and office complexes) and density (11). Berke et al found that greater density where a residence is located increases physical activity, measuring density as more dwelling units per acre of the parcel where a residence is located. However, they also found differences based on the type of land uses. When considering the effects of different types of land use and clustering, they found that proximity to key destinations, such as clusters of destination points (retail, grocery stores and restaurants) increases walking, and higher residential density at the level of the respondent's parcel was associated with more walking within the neighborhood. However, they also found that too large of a number of destination points, and high concentration of office buildings may have a negative effect. For example, in dense urban environments, one might expect that walking increases as it is easier and more efficient to cover a short distance on foot rather than by car, particularly if there are adequate sidewalks. When considering density and land use mixtures as an indicator or variable, it appears it is important to consider the purpose of including these factors in the analysis. For example, density may be an important factor particularly in studies that aim to capture or distinguish between utility and recreational trips, or how facility location in a particular type of location may influence the willingness of one to walk or not.

Traffic: Data on traffic has been measured using both survey and focus group data, and are thus largely perceptual. Ahlport et al found that 'heavy traffic', defined as a continual stream of cars passing by, reduces the likelihood of walking (9). Conversely, Brownson et al, using data from the US Physical Activity Survey, found that traffic was associated with increased physical activity (14). The mixture of findings suggest that in certain contexts traffic has a differential effect, and could be perhaps mitigated by other features of the environment and utility of the trip.

For example, along rural roads or in suburban areas, heavy traffic may be a deterrent, particularly if there is not assistance in crossing the road or if the volume is not bumper to bumper, but rather it is a high speed road with a constant moving flow. However, in other areas, heavier traffic may make pedestrians feel safe in that they are not in isolation.

Terrain: Terrain also has mixed effects on physical activity. Ahlport et al found that extremely hilly or routes with sharp curved reduced the likelihood that one engaged in walking or biking (9). Ahlport et al explained this as possibly due to the fact that these routes may be viewed as less safe. However, Brownson et al found that hilly routes had a positive association with increased physical activity (14). Brownson et al attributed this finding to the fact that hillier routes may be more scenic, and thus, people are more likely to enjoy walking or biking along more scenic routes. Thus, taken together it suggests a need to determine an optimal variation in terrain that promotes interest in walking or biking, without being perceived as too dangerous. It also illustrates the need to capture and control for other variables along a route that could mitigate or influence the effects of terrain.

Social and Context Specific Factors that Influence Physical Activity: In addition to infrastructure characteristics, there are social and context-specific factors that an influence physical activity. The SRTS program is one effort at encouraging physical activity that has been studied. In these studies, factors have been identified specific to schools and policies that have a positive effect on active commuting to school include living within a "no bus zone", presence of crossing guards, and Safe Route to School Interventions that were made along a typical route to school (9, 15).

The literature also suggests that demographic, socioeconomic and social supports can influence physical activity and active commuting. While in many cases these effects fall outside the realm of the built environment and what investments in a transportation facility may do, they are of concerns as to the decisions made surrounding where and when to invest, and limitations of the built environments' influence on physical activity. Specific factors that have been associated with patterns of physical activity and active commuting, include education level, race and ethnicity, income, housing type, age, parental characteristics, community trust, and perceptions of the activity in community (7, 8, 10). However, for several of the demographic and socioeconomic variables, mixed effects have been reported.

Education: Higher levels of education have a positive effect on active commuting or greater physical activity.

Income: Inconsistent effects have been found for income and physical activity and active commuting. Based on the US DOT National Household Survey, Agrawal and Schimek found a negative association between income and active commuting (8). Babey et al in a literature review reported that to date there are no consistent effects of income on active commuting or physical activity (10). The inconsistency of the findings suggests that differences such as purpose of physical activity and other characteristics of the built environment may mediate these effects, as may other individual, perceptual factors not captured through income or education.

Race and Ethnicity: Race and ethnicity have also been found to have inconsistent effects on physical activity and active commuting. Agrawal and Schimek, using the US DOT National Household Travel Survey Data found that Asians, Latinos and Blacks were less likely that nonhispanic whites to actively commute for utility trips (9). However, Babey et al found that African Americans are less likely to actively commute, but Latino and mixed races are more likely to engage in active commuting, which contradicts some of the previous state and national level research (10). Babey et al utilized data from the California Health Interview Survey, and they caution that there could be variation by state, as the major studies in this area have focused on North Carolina and California This suggests additional contextual factors outside the built environment that may influence the relationship between race and ethnicity, physical activity and active commuting.

Housing type: Agrawal and Schimek found that living in an apartment, duplex, row house has a positive effect on active community for utility trips (8).

Community Trust: Addy et al, relying upon only survey data, found that individuals that trust the community in which they live are more likely to engage in physical activity and active commuting (7).

While these sets of factors are outside the scope of this study, they are important considerations above and beyond the transportation infrastructure that can influence whether or not a particular investment yields the intended public health outcomes.

Indicators of Physical Activity and the Built Environment. As illustrated in Table 4.1, there are a number of objectives related to elements of the transportation infrastructure or how people commute from place to place that lack baselines, specific goals, or established performance measures. The goal is to merely increase or decrease these factors and it is less clear as to what data sources can or should be obtained for evaluation and measurement as well as baseline estimates. This gap is also recognized in the US National Physical Activity Plan. For example, Strategy 1 in the plan calls for, "Increased accountability of project planning and selection to ensure infrastructure supporting active transportation and other forms of physical activity", and calls for the establishment of performance measures for transportation planning that are specific to physical activity and health (16). Specific measures called for in the plan include systematic measurement of all trips, commutes, school and other trips, and standardized reporting and recording of crash and injury data for all travel modes including pedestrians, bicyclists and transit riders. Yet, the plan lacks a specific set of metrics and indicators. Thus, there is a need to identify indicators that are valid and reliable estimates of the factors that have been found to influence physical activity in the built environment to identify potential indicators.

In general, measures used to monitor physical activity utilize both subjective and objective sources of data, in qualitative and quantitative forms. Each type is subject to different threats that must be addressed to enhance its reliability and validity. Objective measures of physical activity include direct observation or the use of technology or other types of devices that track the activity of participants (17). For objective measures that aim to measure overall physical activity and whether or not it is increasing or decreasing among a target population, reliability studies are used to evaluate the minimum number of days required to produce reliable estimates of usual physical activity and to account for potentially important differences in weekend versus weekday activity behavior or differences in activity patterns in a given day. Objective measures identified and used in the literature to measure overall physical activity include the StepWatch, the Uptimer, pedometers, heart rate flex method, and accelerometers (18).

Subjective measures of physical activity include self- or proxy- report measures including questionnaires, activity logs and diaries (18). These are the common sources of data for the national surveys listed in Table 4.1 including the National Health Interview Survey, the Youth Risk Behavior Surveillance System, and the School Health Policies and Practices Study. Other paper-based measures identified in the literature include the Children's Activity Participation and Enjoyment Scale (CAPE) and the Physical Activity Questionnaire for Adolescents (18). Subjective measures require evidence of content or construct validity to ensure sensitivity to differences in activity levels and patterns, can vary considerably in terms of the specificity of type, duration, frequency and intensity of physical activity measured. Subjective measures are more time and resource intensive in terms of data collection efforts.

Summary. In summary, at the level of the transportation infrastructure, there are several features and investments that can be altered to increase physical activity. One might suspect that the more 'positive' features that a particular route or facility includes, physical activity might increase through active commuting, or at the very least, people may be more likely to engage in active commuting. Taken together, transportation facilities that have *good lighting*, '*adequate' sidewalks, street connectivity*; *flat, straight terrain;* are *clean, tidy and provide a sense of place*, with *low traffic* might increase physical activity among those living within a proximity to their destination when the weather is fair. However, for some of the factors mentioned above, there can be mixed results so multiple measures or indicators may need to be considered and tested for reliability and validity. These elements include street lighting, density, urbanization, traffic, and terrain.

4.4 Methodology

The research team creates physical activity indices to indicate the degree to which different transportation infrastructure elements promote walking or biking. Physical activity indices using expert-based feedback are determined to be the most viable approach to creating performance measures at the level of the transportation infrastructure. The elements that have been found to be associated with physical activity are used to create the index.

In order to gain insight on the impact of selected infrastructure elements and their options, the research team conducted a survey of experts. The survey sampled 132 safety engineers, planners, city traffic engineers, and public health professionals, and the research team received 47 complete responses (36% response rate). Of the 47, 44 were from respondents with professional expertise as it relates to the factors that influence pedestrian and bicyclist activity. Survey respondents were asked to rate the importance of transportation infrastructure elements in providing a walkable or bikeable transportation environment. Survey respondents were also asked to rate the level of walkability/bikeability of different options under each infrastructure element. Level of walkability (bikeability) has options of either *definitely improves walkability (or bikeability), neutral effect on walkability (or bikeability), discourages walkability (or bikeability)*. For example, a transportation infrastructure element could be a buffer zone, and an elemental option is the type of buffer zone. A copy of the survey is included in Appendix 1.X.

Survey respondents evaluate each element against four levels of importance (least important, moderately important, important, and most important) to walkability or bikeability, and every elemental option is evaluated based on three levels of walkability/bikeability (definitely improves, neutral effect and discourages walkability). This allows the research team to identify which elements are most important, as well as which types of options under each element are important. For example, the survey is designed to discover how buffer zones might compare to sidewalk condition, as well preferred options within each element (type of buffer zone, specific sidewalk condition, etc.) Respondents are instructed to select "discourages walkability" when the infrastructure element option is strong likely to reduce walkability. Survey respondents are asked questions about both segment and intersection infrastructure elements and options.

In total, the research team developed three safety indices that cover walkability and bikeability at segments and intersections, following the same methodology as the safety index development. Details can be found in the methodological section of safety performance measures. The following section presents analysis output on the Walkability Assessment Index (WAI) at the segment. A summary of the other two indices: Bikeability Assessment Index (BAI) at the segment and Walkability/Bikeability Assessment Index at intersection is presented, emphasizing how the indices were adjusted for the intersection and/or bicycle specifications.

Walkability Assessment Index (WAI) at Segment. The survey began by providing baseline conditions for the road segment. Table 4.3 lists the infrastructure elements and base conditions survey respondents were asked to consider.

Table 4.3 Base Conditions of the Infrastructure Elements-Road Segment

Road Segment Elements	Base Conditions
Speed	30 mph
Buffer Zone	Parallel Parking
Street Lighting (Visibility from a distance of 13 feet)	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment
Driveways	None
Obstructions on Sidewalk	None
Tidiness	Clean and Uncluttered
Traffic Calming Devices	Present
Traffic Signals	HAWK
Sidewalk Width	5 feet
Surface Condition	Paved and Level
ADA Compliant	Yes
Median Type	Yes, Greater than 6 feet Raised
Connectivity	All Major and Minor Arterials from Local/Collector Streets Connect to Most Activity Centers

Table 4.4 illustrates the respondent rankings in regards to the importance of each element (from least important to most important).

Table 4.4 Level of Importance of Road Segment Elements from Survey

Element	Least Important	Moderately Important	Important	Most Important	Total Responses
Speed (mph)	1	3	28	10	42
Buffer Zone	1	6	19	18	44
Street Lighting Conditions	1	7	26	10	44
Number of Driveways along Road Segment per Block	2	18	21	3	44
Sidewalks Free of Obstructions	0	6	22	16	44
Tidiness of Surrounding Environment	4	17	22	1	44
Traffic Calming Features	2	15	18	9	44
Traffic Signals	2	11	23	6	42
Sidewalk Width	3	3	30	7	43
Surface Condition	0	12	23	8	43
ADA Compliant	4	12	19	9	44
Median Type	7	18	18	1	44
Connectivity to Activities Center	1	7	18	18	44

Element Weights. In order to calculate the weight of each element, the study follows a fuzzy scaling approach. The study uses the proportion (for any given element, it is defined as the ratio between responses given to a particular level of importance to a total number of responders) of responses to develop fuzzy weights (also called as fuzzy numbers). Once the fuzzy ranges are established for each level of importance, elemental weights are calculated using the geometric mean method. The elemental weights indicate the importance of that particular element to encouraging walking and biking.

Concordance Analysis. Once elemental weights are calculated, the study evaluates walkability/bikeability of each elemental options. For instance, the study analyzes whether speed limit responses, <=20 mph, 21-30 mph, 31-40 mph, and >40 mph, either definitely improves walkability (or bikeability), neutral effect on walkability (or bikeability), discourages walkability (or bikeability). The researchers use survey responses and concordance technique to establish the elemental option scores (see Table 4.4). The product of fuzzy element weights and elemental options score will give final fuzzy weighted scores. Using Center of Area (CoA) method of defuzzification, final weighted scores are calculated. Final weighted scores lie between 0 and 1. Table 4.5 shows weighted scores for pedestrian walkability elements at any given highway segment. Appendix 4A, Tables 4A.1 and 4A.2 list the options score for other two indices. The weighted score is the product of the option score and the element weight.

Index Calculation. For a given road segment, summing the weighted scores of the applicable elemental options yields the Walkability Assessment Index (WAI). The value of WAI, theoretically, lies between 0 and 1. Higher index values represent infrastructure conditions that encourage walkability and bikability, hence providing a more favorable environment for physical activity. Weighted scores are presented in Table 4.5.

Table 4.5 Pedestrian – Walkability at Segment: Elements, Survey Responses, Element Weights, and Options Score

Element	Element Options	Definitely improves walkability	Neutral effect on walkability	Discourages walkability	Total Responses	Element Weight	Option Scores	Weighted Scores
Speed (mph)	20 miles per hour	33	10	1	44	0.0966	0.3902	0.0377
	30 miles per hour	3	38	2	43		0.2968	0.0287
	35 miles per hour	1	27	15	43		0.2361	0.0228
	Greater than 40 miles per hour	0	4	39	43		0.0769	0.0074
Buffer Zone	Landscaping and parallel parking	33	8	3	44	0.0706	0.2833	0.0200
	Parallel parking and bike lane	31	11	2	44		0.2767	0.0195
	Parallel parking	14	27	2	43		0.1761	0.0124
	Dedicated bike lane	28	15	1	44		0.2639	0.0186
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment	39	5	0	44	0.0899	0.5754	0.0517
	Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road Segment	5	27	12	44		0.3409	0.0306
	Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment	0	1	43	44		0.0838	0.0075
Number of Driveways along Road Segment per Block	None	31	11	0	42	0.0782	0.3867	0.0302
	Less than 5 driveways	13	28	3	44		0.3193	0.0250
	5-10 driveways	0	25	18	43		0.2029	0.0159
	More than 10 driveways	0	6	38	44		0.0911	0.0071
Sidewalks Free of Obstructions	None	37	7	0	44	0.0840	0.3842	0.0323
	More than 75%	2	12	30	44		0.1629	0.0137

Element	Element Options	Definitely improves walkability	Neutral effect on walkability	Discourages walkability	Total Responses	Element Weight	Option Scores	Weighted Scores
	25% - 50%	0	17	26	43		0.1689	0.0142
	Less than 25%	15	16	13	44		0.2839	0.0239
Tidiness of Surrounding Environment	Clean	36	8	0	44	0.0689	0.3854	0.0266
	Illegal graffiti	1	20	23	44		0.2372	0.0163
	Littering and trash overflow	0	2	42	44		0.1568	0.0108
	Vacant building	0	15	28	43		0.2206	0.0152
Traffic Calming Features	Raised median and crosswalk	38	6	0	44	0.0690	0.3352	0.0231
	Speed bump	17	26	0	43		0.2372	0.0164
	Roundabout	9	25	10	44		0.1516	0.0105
	Speed enforcement	25	18	1	44		0.2759	0.0190
Traffic Signals	Hawk	31	12	1	44	0.0807	0.3022	0.0244
	In pavement flashing light and/or walk sign with flashing beacon	33	9	2	44		0.3065	0.0247
	On pavement warning sign	19	23	2	44		0.2385	0.0192
	Crosswalk markings (without any pedestrian walk sign)	7	32	5	44		0.1528	0.0123
Sidewalk Width	3 feet	0	11	33	44	0.0858	0.0392	0.0034
	5 feet	11	30	3	44		0.2096	0.0180
	8 feet	40	4	0	44		0.3771	0.0323
	12 feet	40	3	1	44		0.3741	0.0321
Surface Condition	More than 75% in good condition	31	10	3	44	0.0951	0.3660	0.0348
	75-50% in good condition	7	21	16	44		0.2772	0.0264
	50-25% in good condition	1	12	31	44		0.2075	0.0197
	Less than 25% in good condition	1	0	43	44		0.1494	0.0142
ADA Compliant	ADA Complaint	37	7	0	44	0.0606	0.3575	0.0217
	Unpaved sidewalk	0	2	42	44		0.2000	0.0121

Element	Element Options	Definitely improves walkability	Neutral effect on walkability	Discourages walkability	Total Responses	Element Weight	Option Scores	Weighted Scores
	Accessible ramp partially blocked	1	6	37	44		0.2207	0.0134
	Uneven ramp slope	0	8	35	43		0.2218	0.0134
Median Type	Type 1	35	9	0	44	0.0517	0.3907	0.0202
	Type 2	6	28	10	44		0.2780	0.0144
	Type 3	1	18	25	44		0.2011	0.0104
	Type 4	1	5	38	44		0.1302	0.0067
Connectivity to Activities Center	All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities	37	7	0	44	0.0690	0.5294	0.0365
	Minor Arterials from Locals and Collectors Street Connect to Some Activities	18	21	5	44		0.3991	0.0275
	Individual Links with No System Level Connection with Activities	0	10	33	43		0.0716	0.0049

Identification of Walkability Zones. The research objective is to obtain WAI index ranges that will identify different ranges of walkability impact for a given infrastructure element option (definitely improves, neutral effect or discourages walkability). The research team, initially, designated the infrastructure conditions that definitely improves, neutral effect or discourages walkability with three color-coded zones: Red, Orange, and Green respectively. The survey shows, a given elemental option (for instance, traffic calming features) received responses for all three levels of walkability impact. According to survey respondents, each option contributes to a certain degree for three levels of pedestrian walkability. Thus, at any given WAI value, there can exist three levels of pedestrian walkability with different proportions of impact. By developing WAI values for all possible infrastructure conditions, then the relationship between the proportions of definitely improve, neutral effect, and discourages walkability at each WAI value can be developed. The relationships are key to identify the WAI index ranges to designate walkability zones.

First, the research team developed all possible infrastructure condition scenarios. A scenario is defined as the combination of elemental options that could exist at a roadway segment. Next, the research team developes a best possible relationship between walkability index and each level of walkability impact (see Table 4.6). Next, the centroid of each model is calculated. The model between walkability index and neutral effect on walkability is non-linear with R^2 value of 0.27. The lower R^2 value is due to the fact that the survey responses are at the extremes, i.e., respondents either select discourages or improves walkability for a given infrastructure condition. However, the rest of relationships show good R^2 values. The centroid and corresponding index values act as walkability zone boundaries.

Table 4.6 Walkability Index Models by Physical Activity Level

Physical Activity Level	Equation	Model R^2	Curve Centroid
Discourages walkability (%)	$y = 11.9057x^3 - 6.8788x^2 - 1.1240x + 0.7768$	0.91	0.10
Neutral effect on walkability (%)	$y = 19.7215x^3 - 21.9331x^2 + 6.63480x - 0.2438$	0.27	0.24
Definitely improves walkability (%)	$y = -31.6272x^3 + 28.8118x^2 - 5.5108x + 0.4671$	0.74	0.32

Note: y = walkability impact (%); x = index value

The research team developed the physical activity level boundaries for all three indices. Table 4.7 lists the index boundaries and corresponding physical activity levels. In the field, an observer can inventory relevant infrastructure elements, calculate the index value and assess qualitatively the activity level of the existing infrastructure conditions using Table 4.7. For instance, if walkability index value at any segment is less than 0.10, then the corresponding segment conditions would discourage walkability or need immediate action to improve conditions. Similarly, index value greater than 0.32 will definitely improve walkability. An index value between 0.10 and 0.32 suggests that some actions are necessary to improve the condition.

Table 4.7 Physical Activity Levels by Index Value at both Segments and Intersections

Walkability and/or bikeability and/or accessibility	Segment		Intersection
	Walkability Index	Bikeability Index	Walkability / Bikeability Index
Discourages	< 0.10	< 0.08	< 0.12
Discourages - Neutral Effect	>= 0.10 - 0.24	>= 0.08 - 0.23	>= 0.12 - 0.26
Neutral Effect - Definitely Improves	>= 0.24 - 0.32	>= 0.23 - 0.37	>= 0.26 - 0.41
Definitely Improves	>= 0.32	>= 0.37	>= 0.41

4.5 Field Survey Data Collection

The index data is collected through visual assessment of street segments and intersections with an observational survey (Appendix 4B, Tables 4B.1- 4B.3) by a trained observer. The field observation materials were piloted as detailed in Chapter 6. An example implementation case is provided in Chapter 7.

Each observer completes a separate survey form for each individual intersection and street segment. The survey is a checklist of questions with close-ended options that is relatively simple to fill in the field. The research team has developed training manual to aid training. The data entry in the form is saved in Microsoft Excel database for the necessary analysis. After the data is entered into a database, responses are converted into binary responses and then index values are calculated. For a given road segment, summing the weighted scores of the applicable elemental options (known from field survey) yields index value. Once index values are known, using Table 4.7, physical activity level of the facility is designated.

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Appendix 4A: Survey Responses and Elemental Options Score

Table 4A.1 Bikeability at Segment: Elements, Survey Responses, Element Weights and Options Score

Element	Elemental options	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability	Total Responses	Element Weight	Scores	Weighted Scores
Number of Vehicle Lanes	One Lane	21	19	4	44	0.1236	0.3474	0.0429
	Two Lanes	10	27	5	42		0.3114	0.0385
	Three Lanes	4	11	29	44		0.1953	0.0241
	More than Four Lanes	3	4	37	44		0.1459	0.0180
Speed Limit (mph)	Less than or equal 20 mph	33	11	0	44	0.1271	0.3911	0.0497
	30 mph	13	28	3	44		0.3188	0.0405
	35 mph	2	28	14	44		0.2289	0.0291
	More than 40 mph	0	2	42	44		0.0611	0.0078
Bicycle Lane Types	Curbside with colored parked car buffer	32	11	0	43	0.1301	0.2574	0.0335
	Curbside with protection by flex posts	33	11	0	44		0.2589	0.0337
	Raised curb barrier	36	8	0	44		0.2754	0.0358
	Curbside with colored buffer	25	18	1	44		0.2083	0.0271
Bicycle Lane Width (Without a Buffer Zone)	12 feet	33	11	0	44	0.1413	0.3417	0.0483
	8 feet	28	14	2	44		0.3148	0.0445
	6 feet	17	20	7	44		0.2451	0.0346
	Equal or less than 4 feet	4	14	26	44		0.0984	0.0139
Tidiness of Surrounding Environment	Clean	35	9	0	44	0.0953	0.3908	0.0372
	Illegal graffiti	0	36	8	44		0.2577	0.0245
	Littering and trash overflow	1	8	35	44		0.1060	0.0101
	Vacant building	0	33	11	44		0.2454	0.0234

Element	Elemental options	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability	Total Responses	Element Weight	Scores	Weighted Scores
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment	37	7	0	44	0.1384	0.5550	0.0768
	Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road Segment	14	26	4	44		0.3997	0.0553
	Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment	0	4	40	44		0.0453	0.0063
Number of Driveways along Road Segment per Block	None	34	8	0	42	0.1321	0.3905	0.0516
	Less than 5 driveways	17	24	3	44		0.3267	0.0432
	5 - 10 driveways	0	20	24	44		0.1756	0.0232
	More than 10 driveways	0	7	37	44		0.1072	0.0142
Connectivity to Activities Center	All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities	36	8	0	44	0.1122	0.5057	0.0567
	Minor Arterials from Locals and Collectors Street Connect to Some Activities	20	20	4	44		0.3938	0.0442
	Individual Links with No System Level Connection with Activities	1	17	26	44		0.1005	0.0113

Table 4A.2 Walkability and Bikeability at Intersections: Element Weights and Options Score

Element	Elemental options	Definitely improves walkability and/or bikeability and/or accessibility	Neutral effect on walkability and/or bikeability and/or accessibility	Discourages walkability and/or bikeability and/or accessibility	Total Responses	Element Weight	Scores	Weight ed Scores
Presence of Crosswalk	All Four Legs	35	9	0	44	0.1222	0.5411	0.0661
	Only at Two Legs	7	22	15	44		0.3299	0.0403
	None	0	8	36	44		0.1290	0.0158
Crosswalk Length (Number of Traffic Lanes to Cross)	1 Lane/Direction	36	8	0	44	0.1424	0.3897	0.0555
	2 Lanes/Direction	15	24	5	44		0.3144	0.0448
	3 Lanes/Direction	1	14	29	44		0.1737	0.0247
	4 Lanes/Direction	1	4	39	44		0.1222	0.0174
Intersection Pavement Treatments	Raised intersection with crosswalk	31	12	1	44	0.0804	0.3478	0.0280
	Intersection treatment not raised	21	23	0	44		0.3071	0.0247
	Only crosswalk raised	22	21	1	44		0.3092	0.0249
	No treatment	0	8	36	44		0.0359	0.0029
Compliance to ADA Standards	All direction slope <1:12	34	10	0	44	0.1283	0.5289	0.0679
	Presence of grates	2	15	27	44		0.2874	0.0369
	No curb ramps	0	3	41	44		0.1837	0.0236
Presence of a Left Turn Bike Lane	Bike box	28	13	3	44	0.0908	0.4460	0.0405
	Left turn lane	22	19	3	44		0.4058	0.0368
	Only through	8	26	10	44		0.1482	0.0135

Element	Elemental options	Definitely improves walkability and/or bikeability and/or accessibility	Neutral effect on walkability and/or bikeability and/or accessibility	Discourages walkability and/or bikeability and/or accessibility	Total Responses	Element Weight	Scores	Weighted Scores
Presence of a Bike Box	Bike box	26	14	4	44	0.0994	0.4683	0.0465
	Two stage turn queue	15	22	7	44		0.3870	0.0385
	None	4	16	24	44		0.1447	0.0144
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	36	8	0	44	0.1605	0.5559	0.0892
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	8	30	6	44		0.3647	0.0585
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	0	5	39	44		0.0794	0.0127
Advanced STOP/YIELD Sign	In All Directions	30	14	0	44	0.0972	0.5052	0.0491
	In Two Directions	17	23	3	43		0.4133	0.0402
	None	1	15	27	43		0.0815	0.0079
No Right Turn on Red (RTOR) Sign	No Right-Turn-On-Red in All Directions	25	18	1	44	0.0788	0.4790	0.0378
	No Right-Turn-On-Red in Two Directions	16	24	4	44		0.4081	0.0322
	Right-Turn-On-Red Allowed in All Directions	2	18	24	44		0.1129	0.0089

Appendix 4B: Field Data Collection Forms

Table 4B.1 Walkability Assessment Index at Segment Data Collection Form (Form PA Walk Segment)

Physical Activity - Segment - Walkability - Data Collection Form			
Location ID:	**Segment ID:**		
Element	*Options*	*EB / NB*	*WB / SB*
Speed (mph)	20 miles per hour		
	30 miles per hour		
	35 miles per hour		
	Greater than 40 miles per hour		
Buffer Zone	Landscaping and parallel parking		
	Parallel parking and bike lane		
	Parallel parking		
	Dedicated bike lane		
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment		
	Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road		
	Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment		
Number of Driveways along Road Segment per Block	None		
	Less than 5 driveways		
	5-10 driveways		
	More than 10 driveways		
Sidewalks Free of Obstructions	None		
	More than 75%		
	25% - 50%		
	Less than 25%		
Tidiness of Surrounding Environment	Clean		
	Illegal graffiti		
	Littering and trash overflow		
	Vacant building		
Traffic Calming Features	Raised median and crosswalk		
	Speed bump		
	Roundabout		
	Speed enforcement		
Traffic Signals	Hawk		
	In pavement flashing light and/or walk sign with flashing beacon		
	On pavement warning sign		
	Crosswalk markings (without any pedestrian walk sign)		
Sidewalk Width	3 feet		

Physical Activity - Segment - Walkability - Data Collection Form			
Location ID:	**Segment ID:**		
Element	*Options*	*EB / NB*	*WB / SB*
	5 feet		
	8 feet		
	12 feet		
Surface Condition	More than 75% in good condition		
	75-50% in good condition		
	50-25% in good condition		
	Less than 25% in good condition		
ADA Compliant	ADA Complaint		
	Unpaved sidewalk		
	Accessible ramp partially blocked		
	Uneven ramp slope		
Median Type	Type 1 (See below)		
	Type 2 (See below)		
	Type 3 (See below)		
	Type 4 (See below)		
Connectivity to Activities Center	All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities		
	Minor Arterials from Locals and Collectors Street Connect to Some Activities		
	Individual Links with No System Level Connection with Activities		

Median Type

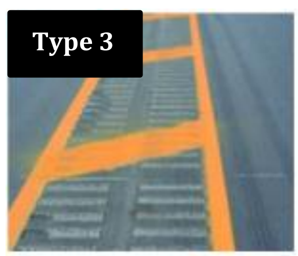

Table 4B.2 Bikeability Assessment Index at Segment Data Collection Form (Form PA Bike Segment)

Physical Activity - Segment - Bikeability - Data Collection Form			
Location ID:	**Segment ID:**		
Element	*Options*	*EB / NB*	*WB / SB*
Number of Vehicle Lanes	One Lane		
	Two Lanes		
	Three Lanes		
	More than Four Lanes		
Speed Limit (mph)	Less than or equal 20 mph		
	30 mph		
	35 mph		
	More than 40 mph		
Bicycle Lane Types	Curbside with colored parked car buffer		
	Curbside with protection by flex posts		
	Raised curb barrier		
	Curbside with colored buffer		
Bicycle Lane Width (Without a Buffer Zone)	12 feet		
	8 feet		
	6 feet		
	Equal or less than 4 feet		
Tidiness of Surrounding Environment	Clean		
	Illegal graffiti		
	Littering and trash overflow		
	Vacant building		
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment		
	Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road		
	Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment		
Number of Driveways along Road Segment per Block	None		
	Less than 5 driveways		
	5 - 10 driveways		
	More than 10 driveways		
Connectivity to Activities Center	All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities		
	Minor Arterials from Locals and Collectors Street Connect to Some Activities		
	Individual Links with No System Level Connection with Activities		

Table 4B.3 Walkability/Bikeability Assessment Index at Intersection Data Collection Form (Form PA Intersection)

Physical Activity - Intersection - Walkability/Bikeability		
Location ID:	**Intersection ID:**	
Element	*Options*	*Response*
Presence of Crosswalk	All Four Legs	
	Only at Two Legs	
	None	
Crosswalk Length (Number of Traffic Lanes to Cross)	1 Lane/Direction	
	2 Lanes/Direction	
	3 Lanes/Direction	
	4 Lanes/Direction	
Intersection Pavement Treatments	Raised intersection with crosswalk	
	Intersection treatment not raised	
	Only crosswalk raised	
	No treatment	
Compliance to ADA Standards	All direction slope <1:12	
	Presence of grates	
	No curb ramps	
Presence of a Left Turn Bike Lane	Bike box	
	Lett turn lane	
	Only through	
Presence of a Bike Box	Bike box	
	Two stage turn queue	
	None	
Street Lighting Conditions	Excellent Visibility of Approaching Figures without Dark Spaces along the Road	
	Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road	
	Poor Visibility of Approaching Figures with Dark Spaces Present along the Road	
Advanced STOP/YIELD Sign	In All Directions	
	In Two Directions	
	None	
No Right Turn on Red (RTOR) Sign	No Right-Turn-On-Red in All Directions	
	No Right-Turn-On-Red in Two Directions	
	Right-Turn-On-Red Allowed in All Directions	

Chapter 5. Air Quality Assessment for Performance Measurement of Physical Activity

5.1 Research Objectives

The research objective is to create performance measures to evaluate the relationship between air quality and characteristics of different walking and cycling routes. The tools developed will allow users to identify pollutant concentration levels (CO, NO_2 and PM_{10}/$PM_{2.5}$) along the activity path of major urban arterials. A better understanding of the different levels of pollutant concentration at the project-level will help identify locations with high pollution and help decision makers select more desirable walking and bicycling routes in order to optimize public health.

5.2 Air Quality: Pollutant Concentration Prediction

The research team developed a quantitative measure for assessing the air quality along a road segment. Four major pollutants (CO, NO_2, $PM_{2.5}$ and PM_{10}) are deemed important for the assessment. The research team accomplished the objective by performing a comprehensive literature review to identify different inputs for conservative situations, worst-case scenarios. The team develops project-level emission rate estimation models for base conditions using the EPA's Motor Vehicle Emission Simulator (MOVES) and then uses the output (emission rate) as an input in CL4 (a graphical interface for CALINE4) to assess the dispersion along an urban arterial. The study identifies critical and conservative exposure values (that can create minor irritation to mortality) and uses them as the exposure levels to categorize different potential health impacts.

5.3 Literature Review

In addition to several objectives related to physical activity, Healthy People 2020 states a number of objectives of concern related to air quality (1). Objectives are established that both aim to increase walking and bicycling to reduce dependency on vehicles, reducing the amount of airborne toxic emissions, and reducing the location of schools near highways. These are presented in Table 5.1.

However, these objectives can be competing, and compromise public health objectives. For example, idling cars at stoplights or in school zones can release toxins into the air and compromise the pedestrian and bicyclist routes. Likewise, the speed limit and traffic volume along a given pedestrian or bicyclist route can also have an impact. Thus, a comprehensive assessment of the air quality is important for identifying pedestrian and bicyclist exposure level at the project-level. This assessment is important in order to invest in transportation infrastructure that fosters physical activity in a healthy way.

Table 5.1 Air Quality Objectives and Measures

National Objective	Baseline	Desired Goal	Data Sources
Increase trips made to work by bicycling	Trips to work by bicycling (%) .5 (2008)	.6	American Community Survey, Census
Increase trips made to work by walking	2.8 (2008), Trips to work by walking (%)	3.1	American Community Survey, Census
Reduce the risk of adverse health effects caused by area sources of airborne toxics	Airborne toxic emissions from area sources (#, millions of tons), 1,300,000 (2005)	Decrease desired	National Emissions Inventory (NEI), EPA
Reduce the risk of adverse health effects caused by major sources of airborne toxics	Airborne toxic emissions from major sources (number, millions of tons) 800,000 (2005)	Decrease desired, 700,000	National Emissions Inventory (NEI), EPA
Reduce the amount of toxic pollutants related into the environment	Toxic pollutants released into the environment (tons) 1,940, 973 (2008)	Decrease, 1,750,000	Toxic Release Inventory (TRI), EPA
Reduce the number of public schools located within 150 meters of major highways	3.3 (2010-2011)	3	Common Core of Data (CCD), ED/NCES

5.3.1. Health Risks Associated with Air Pollution

Any arterial air quality standards need to be based on the potential health impacts associated with exposure to the pollutant. The adverse health impact associated with air pollution varies depending on the type of pollutant, the magnitude, the exposure duration and frequency, and the associated toxicity. Oxidative stress, inflammation, and genetic defects represent some of the basic mechanisms where the vapor and particulate phases of pollutants induce negative health effects (2,3). Cardiovascular and respiratory diseases, chronic obstructive pulmonary diseases (COPD), cancer, and birth defects denote some of the major diseases that may be caused by air pollution (4,5). A recent study also found that inflammation and oxidative stress induces cognitive decline and neuropathology in the brain (6). Gasoline and diesel powered motor-vehicles provide a major source of air pollution in urban areas and emit pollutants into the air due to improper and incomplete burning of fossil fuels (7,8). Out of this heterogeneous mixture of pollutants, the following paragraphs discuss carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter ($PM_{2.5}$ and PM_{10}) for their negative impact on human health.

Carbon monoxide (CO) is an odorless, colorless and tasteless toxic gas formed in the motor vehicle combustion chamber due to an inefficient supply of oxygen (9). CO has more affinition (300 times) towards hemoglobin than oxygen and produces carboxyhemoglobin as soon as it comes in contact with it and thus impedes the blood’s ability to carry oxygen to body tissues and vital organs (9). In fact, a small amount of CO can dramatically reduce the oxygen level in the human body and can create headache, nausea, rapid breathing, weakness, exhaustion, dizziness and confusion (10). On the other hand, a huge amount of CO exposure can create irreversible brain damage that can lead to death. NAAQS provides both long-term (8-hour average) and short-term (1-hour average) standards for CO; these are 9 parts per million (ppm) and 35 parts per million (ppm), respectively.

Another carcinogen pollutant emitted from motor vehicles is reddish-brown nitrogen dioxide (NO_2), which is formed when fuel is burned at high temperatures. The EPA has mandated NO_2 concentration standards by taking the 98^{th} percentile of the 1-hour daily mean averaged over three years and the annual daily mean; these are 100 parts per billion (ppb) and 53 ppb, respectively. When a human inhales a high concentration of NO_2, it can irritate lungs and lower resistance to respiratory infection. Acute respiratory illness in children may be caused by frequent exposure to concentrations that are typically much higher than the NAAQs (11).

Particulate matter, one of the major hazardous components of air pollution, is a complex mixture of solid and liquid particles that vary in origin, chemical composition and physical properties (12-16). Aerodynamic diameters are usually used for characterizing coarse particles (diameter $\leq 10\mu m$), fine particles (diameter $\leq 2.5\mu m$) and ultra-fine particles (diameter ≤ 0.1 μm) (13). $PM_{2.5}$ particles largely originate from fossil fuel burning, and they contribute to roughly 800,000 premature deaths per year globally (17). Particulate matter can penetrate deep into the small airways, alveoli, and blood stream and can create inflammation and vasoconstriction (6).

5.3.2. Physical Activity and Health Response to Air Pollution

Outdoor physical activity requires an increased oxygen level with an increase in exercise intensity. With an increased respiratory uptake, people start breathing through the mouth, which bypasses the nasal filtration mechanism and increases the amount of pollution inhaled that travels into the respiratory system. This increases the amount of air pollution inhalation, which may amplify the adverse effects on health (14,18). Research has shown that both the ventilation and deposition fractions (the fraction of inhaled particles retained in the lungs) increase significantly during outdoor activities (18-21), which may lead to temporary decreases in lung function (22,23), increased levels of inflammatory markers in the pulmonary system (22,24), reduced vasodilation (25) and impairments in exercise performance (26). Although these health issues intensify with the level of activity for recreational users, some utilitarian users may face similar exertion levels. While many researchers (27-31) have found that the benefits of physical activity outweigh the risks due to air pollution exposure, others have shown that the reverse seems true (32). Exposure to air pollution during physical activity appears greater than static exposure rates; therefore, the air quality standards along urban arterials need to consider the potential for a more significant health impact.

5.3.3. Acute vs Chronic Exposure

Motor vehicle exhaust emission represents the single largest source of regional air pollution in urban areas. The public's concern regarding human exposure to road traffic air pollution has increased tremendously with the increasing number of pedestrian and bicyclist activities near roadways (33,34). Research has shown that a walking or bicycling route closer to heavy-traffic roadway is associated with symptoms of respiratory dysfunction, cardiopulmonary disease and even mortality from stroke (35,36), thus, a comprehensive assessment of the air quality appears important for identifying pedestrian and bicyclist exposure levels, which will in turn help in transportation infrastructure investment that fosters physical activity in a healthy way.

The built and natural environment and other temporal and spatial conditions have a direct or indirect influence on exposure level. According to Zhu et al. (37), pollutant concentrations adjacent to and downwind of major traffic routes remain higher than the regional background level. The monitoring stations capture pollution concentrations from both mobile and stationary sources, but they do not capture the large temporal and spatial span of human activities and peak hour concentrations (38,39). Hence, a finer spatial and temporal resolution for air quality monitoring and forecasting seems necessary to capture short-term and localized exposures that pose acute threats to human health (40,41). The evidence indicates that arterial air quality standards should focus on acute exposure during physical activity; however, chronic exposure may be considered as a secondary standard for all nearby facilities and residents.

5.4 Methodology

A proper assessment of the detrimental effect of motor vehicle pollution exposure on people engaged in physical activity continues to draw more attention from communities. The study develops project-level air quality performance measures and a sketch planning tool to assess and compare air quality conditions along alternative activity paths and infrastructure links. The authors adopt a simple generalized approach for estimating the exposure level to determine the potential health risks. Traffic volume and speed limit represent two major parameters that directly impact air pollution emissions (42). A sketch planning tool that connects these aforementioned parameters together generates potential air quality performance measures at the project-level (along a segment). Keeping this objective in mind, the research team considers a one-mile long hypothetical urban arterial with a sidewalk and bike lane where both utilitarian and recreational activities take place. At this initial stage, the research team develops a project-level MOVES model for Tarrant County in Texas and Kalamazoo County in Michigan to estimate the emission rate along the arterial by assuming free flow conditions. The temporal and spatial variables along with traffic characteristics, facility characteristics, topography and meteorology must be input into MOVES. Detailed travel activity data can be a good source of traffic related variables, but to generalize the tool for numerous traffic conditions, the research team calculates the Vehicle Specific Power (VSP) for different vehicle types. Based on the VSP and the vehicle fleet proportions for each vehicle class, the study determines the emission rates for different combinations of traffic volume and speed. Figure 5.1 shows the steps associated with finding the emission rate. AERMOD is the state-of-the practice dispersion modeling system, which is based on a planetary boundary layer turbulence structure and scaling concept. CAL3QHC is another dispersion model that is based on CALINE3 and considers delays and queues at signalized intersections. The generalized approach taken in this study does not require a complex scenario analysis; hence, CALINE4 can estimate the air pollution concentration at different receptor locations. Link geometry, traffic, and meteorological conditions represent some other input variables required for modeling in CALINE4.

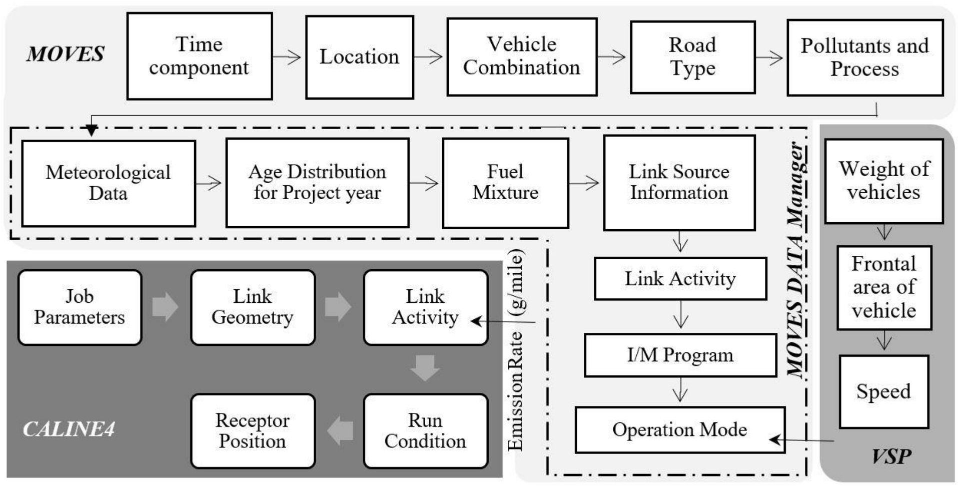

Figure 5.1 Steps in development of project level performance measure for air quality.

5.4.1. Project-Level Emission Rate Estimation by MOVES

This study uses the EPA's latest version (MOVES2014a) of motor vehicle emission measurement simulator to estimate the emission rates of CO, NO_2 and $PM_{10}/PM_{2.5}$. The authors select a mixed fleet with diesel and gasoline to represent the likely vehicle combination in both Tarrant and Kalamazoo County and passenger car, passenger truck, light commercial truck, school bus and single unit short-haul truck to represent the likely source type in both counties. The experimental design considers a total of four traffic volumes (50, 250, 500 and 750 vph) and four speed limits (30, 35, 40 and 45 mph) for the emission rate calculation. MOVES's default age distribution tool provides the fleet distribution for 2020. Cold temperature and low humidity increases the emission rate (43); therefore, to create the worst case scenario, this study uses an analysis period for weekdays of January 2020 from 8:00 AM-9:00 AM. Using Tarrant County in Texas and Kalamazoo County in Michigan reflects the variation between temperature and humidity related emission rates for southern and northern climates. The MOVES database already has default average hourly humidity and temperature data, which is based on thirty years of average data from the National Climatic Data Center. In this study, thirty years of historical temperature and humidity data of Tarrant and Kalamazoo County are collected from the National Oceanic and Atmospheric Administration (NOAA) and Weather Underground website. While the January average low temperature of Tarrant County (35.5 ℉) is higher than that of (19.9 ℉) Kalamazoo County, the average humidity (60%) is lower than the average humidity (65.4%). The different vehicle fractions present on the hypothetical urban segment use the vehicle class percentages found in the research of Hallenbeck, et.al.'s study, which is represented in the following Table 5.2.

The operating modes segment the drive cycle into different activities to characterize different emission rates. In this study, the research team only considers vehicles in a 'running' mode as the major drive cycle because when people are walking or doing physical activity along a road segment, the pollutants only result from cruising or accelerating conditions. The 'running' mode needs average speed or Vehicle Specific Power (VSP) to be input as the operating mode parameter.

TABLE 5.2 Fractions of Hourly Vehicles Present at a One-mile Section

VEHICLE TYPE ID	VEHICLE NAME	HOUR FRACTION
21	Passenger Car	0.4245
31	Passenger Truck	0.5085
32	Light Commercial Truck	0.03
43	School Bus	0.007
52	Single Unit Short-haul Truck	0.03

A study by Song, et al. (44), finds that the mean of the VSP distribution strongly correlates with the VSP value when cruising at the average travel speed. The emissions associated with any given driving pattern are modeled based on the distribution of time spent in different operation modes, which are defined based on VSP and speed values. The drive cycles that represent typical operations at different average speeds for each vehicle type are used to translate the average speed (V) information into VSP distributions. The vehicle frontal area (A) and the aerodynamic drag coefficient (Cd) are calculated for different vehicle types and used in a generalized form of the VSP equation (45). Table 5.3 presents different vehicles and their associated drag friction values and VSP calculation for 30 mph. A total of 128 (4-pollutants*4-traffic volume*4-speed limit*2-locations) emission rates are estimated in MOVES for this study. Table 5.4 shows vsp calculations for different speed range.

TABLE 5.3 Calculation of Vehicle Specific Power (VSP) for Different Vehicle Types

	Weight of vehicles (m)		**Front Area[2] (A)**	**Drag Coefficient (Cd)**	**Speed (V)**	**Grade (g)**	**VSP**	**VSP Bin**
Unit	**lb**	**Kg**	**m^2**		**(m/s)**		**W/Kg**	
Passenger Car	3690[3]	1673.7	2	0.28	13.41	0	23.507	28
Passenger Truck	10000[4]	4535.9	3.3	0.36[5]	13.41	0	23.546	28
School Bus	26000[2]	11793.4	5	0.7	13.41	0	23.597	28
Light Commercial Truck	14000[2]	6350.2	3.3	0.5	13.41	0	23.543	28
Sing Unit Short-haul Truck	64000[6]	29029.9	5.2	0.9	13.41	0	23.4	28

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[2] *vehicle frontal area, calculated from http://hpwizard.com/aerodynamics.html*
[3] *average weight of five recent passenger car models from car and driver. retrieved from* http://www.caranddriver.com/features/drag-queens-aerodynamics-compared-comparison-test-drag-queens-performance-data-and-complete-specs-page-7
[4]*vehicle weight class and categories. retrieved from* http://www.afdc.energy.gov/data/
[5] *vehicle coefficient of drag list. retrieved from* http://ecomodder.com/wiki/index.php/vehicle_coefficient_of_drag_list
[6] *truck size and weight. retrieved from* https://www.fhwa.dot.gov/reports/tswstudy/proceed.pdf

Table 5.4 Calculation of Vehicle Specific Power (VSP) for different speed range

SourceType	30mph	Cd*A	v	V^3	.5*ρ*B1*D1	E1/m	g*Cr	g*Grade	1.1*a	VSP	VSP Bin
21	Passenger Car	0.56	13.4	2411.49	814.99	0.487	0.1324	0	1.595	23.652	28
31	Passenger Truck	1.19	13.4	2411.49	1728.94	0.381	0.1324	0	1.595	23.546	
32	School Bus	3.50	13.4	2411.49	5093.68	0.432	0.1324	0	1.595	23.597	
43	Light Commercial Truck	1.65	13.4	2411.49	2401.31	0.378	0.1324	0	1.595	23.543	
52	Sing Unit Short	4.68	13.4	2411.49	6810.98	0.235	0.1324	0	1.595	23.400	

SourceType	35mph	Cd*A	v	V^3	.5*ρ*B1*D1	E1/m	g*Cr	g*Grade	1.1*a	VSP	VSP Bin
21	Passenger Car	0.56	15.7	3833.04	1295.41	0.774	0.1324	0	1.595	27.808	29
31	Passenger Truck	1.19	15.7	3833.04	2748.13	0.606	0.1324	0	1.595	27.640	
32	School Bus	3.50	15.7	3833.04	8096.33	0.687	0.1324	0	1.595	27.721	
43	Light Commercial Truck	1.65	15.7	3833.04	3816.84	0.601	0.1324	0	1.595	27.635	
52	Sing Unit Short	4.68	15.7	3833.04	10825.95	0.373	0.1324	0	1.595	27.407	

SourceType	40mph	Cd*A	v	V^3	.5*ρ*B1*D1	E1/m	g*Cr	g*Grade	1.1*a	VSP	VSP Bin
21	Passenger Car	0.56	17.9	5716.14	1931.83	1.154	0.1324	0	1.595	32.041	30
31	Passenger Truck	1.19	17.9	5716.14	4098.23	0.904	0.1324	0	1.595	31.790	
32	School Bus	3.50	17.9	5716.14	12073.91	1.024	0.1324	0	1.595	31.910	
43	Light Commercial Truck	1.65	17.9	5716.14	5691.99	0.896	0.1324	0	1.595	31.783	
52	Sing Unit Short	4.68	17.9	5716.14	16144.54	0.556	0.1324	0	1.595	31.443	

SourceType	45mph	Cd*A	v	V^3	.5*ρ*B1*D1	E1/m	g*Cr	g*Grade	1.1*a	VSP	VSP Bin
21	Passenger Car	0.56	20.1	8144.87	2752.64	1.645	0.1324	0	1.595	36.401	30
31	Passenger Truck	1.19	20.1	8144.87	5839.53	1.287	0.1324	0	1.595	36.043	
32	School Bus	3.50	20.1	8144.87	17203.99	1.459	0.1324	0	1.595	36.215	
43	Light Commercial Truck	1.65	20.1	8144.87	8110.45	1.277	0.1324	0	1.595	36.033	
52	Sing Unit Short	4.68	20.1	8144.87	23004.20	0.792	0.1324	0	1.595	35.548	

After proper VSP bin selection for each of the pollutant type for ‘crankcase running’ and ‘running’ process, operating modes are identified. A total of 16 simulations are performed for each county based on speed and traffic volume. The output from the MOVES modeling provides emission rates in gram per mile. These emission rates for different speed and volume range are accumulated and presented in Tables 5.5, 5.6, 5.7 and 5.8.

Table 5.5 CO Emission Rates (g/mile) for Tarrant and Kalamazoo County

	30 mph	35 mph	40 mph	45 mph
Kalamazoo V50	113.932	152.491	280.766	249.5697
Tarrant V50	101.6	136.491	254.022	225.797
Kalamazoo V250	113.932	152.491	280.766	249.5697
Tarrant V250	101.6	136.491	254.022	225.797
Kalamazoo V500	113.932	152.491	280.766	249.5697
Tarrant V500	101.6	136.491	254.022	225.797
Kalamazoo V750	113.932	152.491	280.766	249.5697
Tarrant V750	101.6	136.491	254.022	225.797

Table 5.6 NO_2 Emission Rates (g/mile) for Speed and Volume Combinations

	30 mph	35 mph	40 mph	45 mph
Kalamazoo V50	5.5886	6.288772	6.771968	6.019638
Tarrant V50	5.585526	6.283772	6.76597	6.01464
Kalamazoo V250	5.5886	6.288772	6.771968	6.019638
Tarrant V250	5.585526	6.283772	6.76597	6.01464
Kalamazoo V500	5.5886	6.288772	6.771968	6.019638
Tarrant V500	5.585526	6.283772	6.76597	6.01464
Kalamazoo V750	5.5886	6.288772	6.771968	6.019638
Tarrant V750	5.585526	6.283772	6.76597	6.01464

Table 5.7 PM_{10} emission rates (g/mile)for speed and volume combinations

	30 mph	35 mph	40 mph	45 mph
Kalamazoo V50	0.513	0.452	0.411	0.38
Tarrant V50	0.509	0.449	0.408	0.376
Kalamazoo V250	0.513	0.452	0.411	0.38
Tarrant V250	0.509	0.449	0.408	0.376
Kalamazoo V500	0.513	0.452	0.411	0.38
Tarrant V500	0.509	0.449	0.408	0.376
Kalamazoo V750	0.513	0.452	0.411	0.38
Tarrant V750	0.509	0.449	0.408	0.376

Table 5.8 $PM_{2.5}$ emission rates (g/mile) for speed and volume combinations

	30 mph	35 mph	40 mph	45 mph
Kalamazoo V50	0.47	0.415	0.377	0.348
Tarrant V50	0.467	0.412	0.374	0.345
Kalamazoo V250	0.47	0.415	0.377	0.348
Tarrant V250	0.467	0.412	0.374	0.345
Kalamazoo V500	0.47	0.415	0.377	0.348
Tarrant V500	0.467	0.412	0.374	0.345
Kalamazoo V750	0.47	0.415	0.377	0.348
Tarrant V750	0.467	0.412	0.374	0.345

The results are aggregated based on volume type and speed range. Particulate matters are separated based on their size in order to use them separately in CALINE4. For example, in Kalamazoo, for a speed of 30 mph and traffic volume of 500 veh/hr (V500), $PM_{2.5}$ emission rate is 0.47 g/mile. The results from MOVES also show that, for both CO and NO_2, the emission rate increases with an increase of speed up to 40 mph and then it starts to decrease. The particulate matter always decreases with an increase in the speed limit, which is consistent with the result of other studies such as (46). Weather appears to affect the emission rate of CO, as the results show a difference in CO emission rates between Tarrant County and Kalamazoo County. Kalamazoo County has a lower temperature and higher humidity. CO has almost a 5.3% higher emission rate in Kalamazoo County than Tarrant County and NO_2 has almost similar emission rate (~0.04%) for both counties.

PM_{10} concentrations are higher than $PM_{2.5}$ concentrations, and with an increase of speed the emission rate reduces for both, but the difference between them remains small when compared to the impact of temperature or humidity changes. The NO_2 concentration appears relatively unaffected by speed or volume this could be due to the assumptions imbedded in the model as identified by (47). The CO emission rate seems to be greatly impacted by lower temperature and higher humidity. These emission rates are later used in CALINE4 for dispersion modeling.

5.4.2. Dispersion Modeling

CALINE4 predicts the concentration level at specific receptor (pedestrian or bicyclist) locations. Research has shown that pollutant concentrations are significantly higher at sidewalk locations (48,49) and reduces with the downwind distance (50). The one-mile road segment (at grade) is a one-lane two-way directional arterial road with 12 ft width (suburban) lanes where the receptors are placed at an equal distance (1320ft) from each other and 10 ft away from the side of the curb. According to the CALINE4 model, the width of the mixing zone includes the roadway width plus 3m(~10ft) on both sides (51). Benson (1984) in his research the entire mixing zone represents the source and measuring as close to the outer border of the source gives the worst-case concentration. These receptors provide a proxy for bicyclist and pedestrian activity (53) in the corridor. The height of the receptor also determines how much dispersion it will measure. Initially, the study considers both adults (5 feet) and children (3.5 feet) as potential receptors; however, a comparative assessment confirms that children experience a higher concentration.

This finding plays a significant role in determining arterial air quality standards because children usually experience more health risks when exposed to air pollution; therefore, the standards must reflect these risks. The link geometry and receptor locations remain fixed for all facility and air pollution scenarios. Figure 5.2 below shows a plan view of the link geometry and receptor locations. Receptors are marked from A to J and are shown in pentagons.

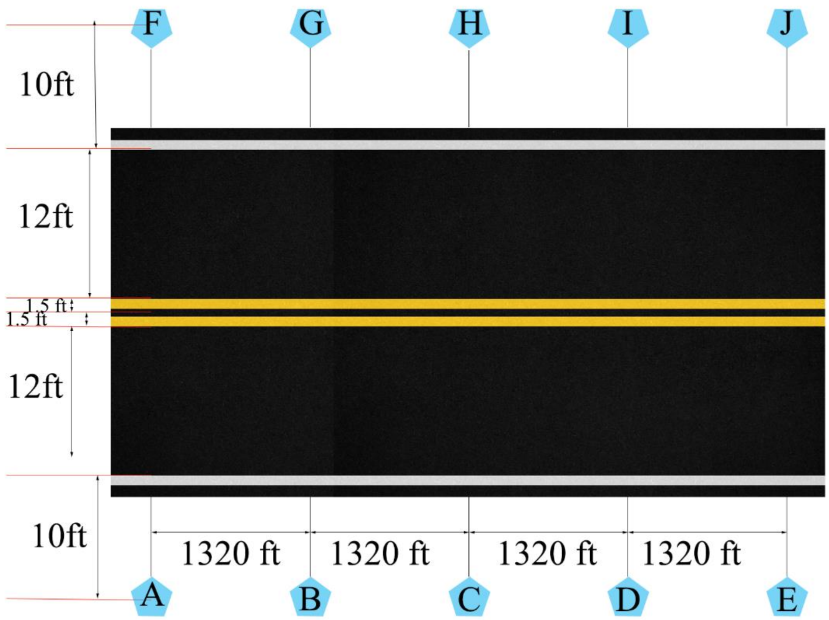

Figure 5.2 Link Geometry and Receptor Locations (plan not drawn in scale)

Different types of assumptions are made based on conservative values suggested by CALINE4. These assumptions are listed in Table 5.9.

Table 5.9 Base Condition Variable Inputs

Variable	Base/Conservative value
Settling velocity	0 for PM
Deposition Velocity	0 for CO and NO_2
Aerodynamic Roughness Coefficient	Suburban (100cm)
Mixing Zone Width	Width+2*3m
Atmospheric Stability Class	1
Altitude above sea level	608 ft (Tarrant), 700 ft (Kalamazoo)
Traffic Volume(vehicle/hour)	50, 250, 500, 750

Ambient levels of NO, $N0_2$ and O3 must be specified. These were assigned standard values of 0.02, 0.10 and 0.20 ppm, respectively, for the sensitivity analysis. Also, a photo dissociation rate (KR) and a NOx emission factor are needed. Values of 4 x 10-3 s-1 for KR and 1.0 gm/veh-mi for the NOx emission factor as suggested by Benson (1984) for a standard sensitivity run. Table 5.10 presents the run conditions for all three pollutants.

Table 5.10 Run Conditions for CALINE4 ('X' represents not used/required)

Conditions	CO	PM	NO2
Wind Speed (≥0.5 m/sec)	1	1	1
Wind Direction (0-360°)	0	0	0
Wind Direction Std. Dev. (5-60°)	15	15	15
Atmospheric Stability Class (1-7)	1	1	1
Mixing Height (≥5m)	5	5	5
Ambient Temperature (°C)	5	5	5
Ambient CO Concentration (≥ppm)	0	X	X
NO2 Photolysis Rate Constant (per sec)	X	0.004	X
NO2/NOx Ratio (0-1)	X	1	X
Ambient PM Concentration (µg/m^3)	X	X	0

Estimating pollutant concentration at a receptor location requires two major variables as an input; a) traffic volume (vehicle per hour), and b) Emission factors from MOVES (g/mile). A conservative condition is assumed for predicting the concentration at 10 different receptor locations identified along the urban unrestricted roadway. Atmospheric Stability Class is a measure of turbulence of the atmosphere so a minimum stability class is entered to depict minimum wind turbulence. This will create a situation where the receptors get as much pollutant concentration as possible (worst case scenario). After a series of CALINE4 model run (4*4) for each of the pollutants (CO, NO_2, PM_{10} and $PM_{2.5}$), the research team accumulated concentration data for each of the Tarrant County and Kalamazoo County. A series of results are attached in Appendix 5B.

The concentration levels at different receptor locations from the CALINE4 show that concentration level increases with the increase of both volume and speed (except both PM decrease with an increase in speed); and concentration in Kalamazoo County appears slightly higher than Tarrant County. The average concentrations from all ten receptors for each volume and speed combination are shown in the following tables (11-14). The maximum CO concentrations for all speed and volume combination for Tarrant County range between 4 ppm and 149 ppm and have a median value of 47 ppm whereas for Kalamazoo County the upper range is 165 ppm and the median is 52 ppm. For $PM_{2.5}$, the values ranged between 12.2 µg/m^3 and 248.9 µg/m^3 with a median value of 102.4 µg/m^3. The following tables show the averaged 1-hr pollutant concentration for CO, NO2, PM_{10} and $PM_{2.5}$.

Table 5.11 CO 1-hr Average Concentration

Tarrant County					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	3.98	19.84	39.66	59.48
	35	5.32	26.64	53.34	79.9
	40	9.92	49.58	99.16	148.72
	45	8.8	44.08	88.12	132.2

Kalamazoo County					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	4.48	22.32	44.64	66.96
	35	6	29.88	59.74	89.58
	40	11	54.98	109.98	164.96
	45	9.76	48.88	97.76	146.62

Table 5.12 NO2 1-hr Average Concentration

Tarrant County					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	0.07	0.3525	0.7025	1.055
	35	0.0775	0.4	0.79	1.19
	40	0.0875	0.4275	0.85	1.2775
	45	0.0775	0.38	0.76	1.1325

Kalamazoo County					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	0.07	0.3525	0.7025	1.0625
	35	0.0775	0.4	0.7925	1.19
	40	0.0875	0.43	0.8575	1.2875
	45	0.0775	0.38	0.76	1.1425

Table 5.13 PM_{10} 1-hr Concentration

Tarrant County					
		Traffic Volume (veh/hr)			
		50	**250**	**50**	**750**
Speed (mph)	**30**	17.971	89.843	179.686	269.557
	35	15.843	79.271	158.529	237.8
	40	14.4	72	144.043	216.086
	45	13.257	66.343	132.757	199.1

Kalamazoo Country					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	18.1	90.53	181.114	271.657
	35	15.94	79.79	159.557	239.371
	40	14.5	72.56	145.1	217.657
	45	13.43	67.09	134.143	201.243

Table 5.14 $PM_{2.5}$ 1-hr average concentration

Tarrant County					
	Traffic Volume (veh/hr)				
		50	**250**	**500**	**750**
Speed (mph	**30**	16.5	82.457	164.886	247.314
	35	14.5429	72.714	145.471	218.186
	40	13.2	66.043	132.043	198.071
	45	12.157	60.9	121.8	182.7

Kalamazoo County					
		Traffic Volume (veh/hr)			
		50	**250**	**500**	**750**
Speed (mph)	**30**	16.6	82.971	165.9	248.9
	35	14.643	73.271	146.5	219.786
	40	13.3	66.529	133.114	199.657
	45	12.257	61.429	122.857	184.3

5.5 Field Data Collection

The values above were used to represent the present base case scenario of an urban one-lane two-way segment. A comprehensive literature review unveiled different types of standards for short-term pollutant exposure. Based on this review, the research team developed a colored based zonal boundary where green means excellent and red means not acceptable to human health. Practitioners, policy makers, can use the colored-based map and community volunteers to find out the base condition given by only the speed limit (mph) and traffic volume (veh/hr). The advantage of the colored map is that the user does not need to use any software for identifying health hazards. The color-coded map and details about its usage is provided in Chapter 7.

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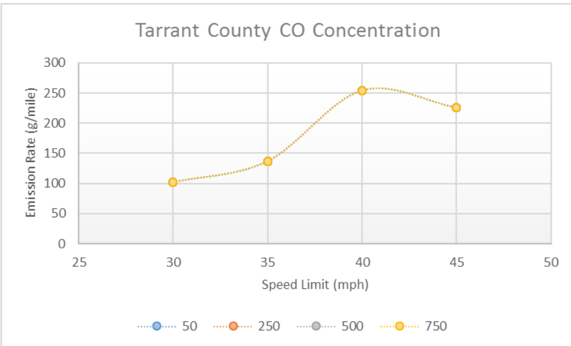
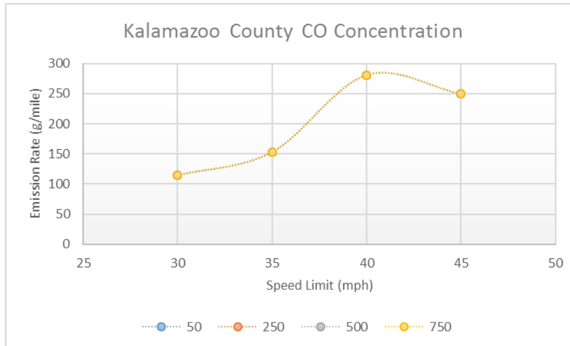
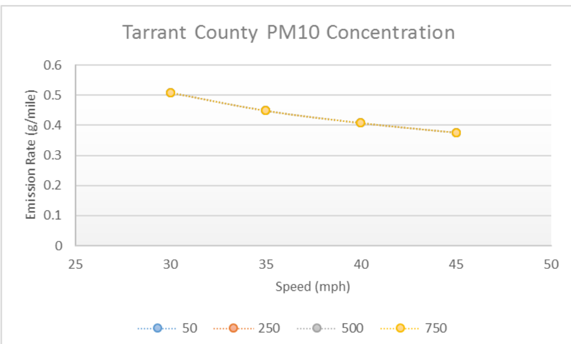
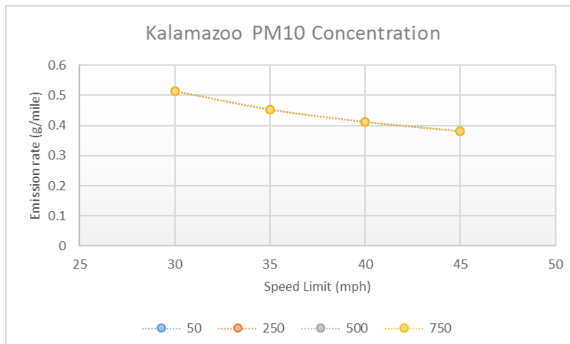
Appendix 5A: Emissions and County Relationships

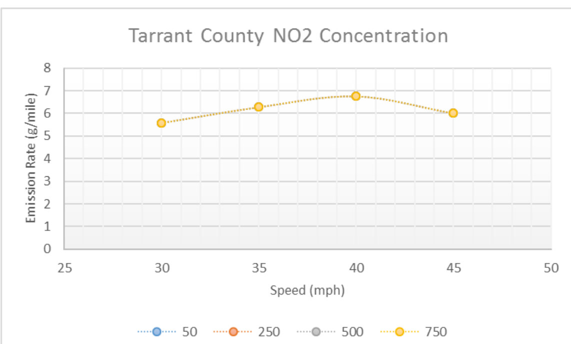
The following figures show the relationships between emissions by County.

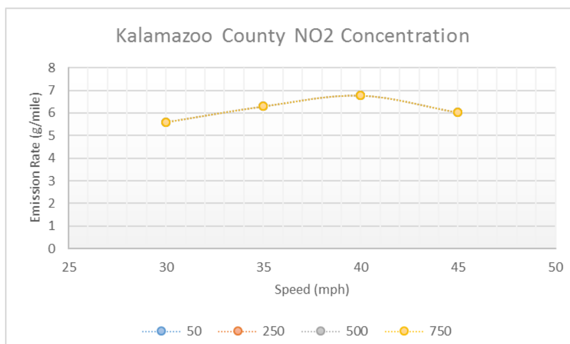


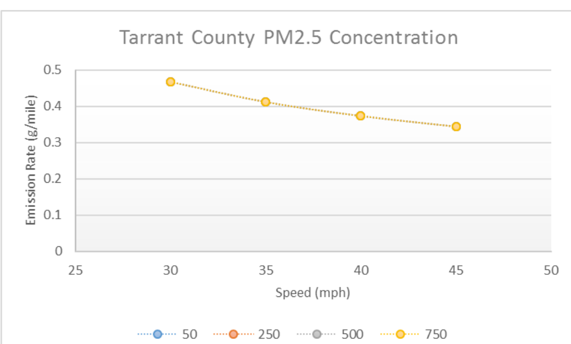


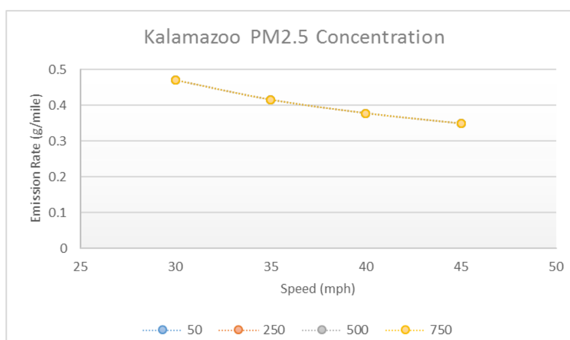












APPENDIX 5B: Emissions and Speed Limit Relationships

Table 5.B.1 CO Emission and Speed Limit by County

		CO (ppm) 30 mph				CO (ppm) 35 mph				CO (ppm) 40 mph				CO (ppm) 45 mph			
	Receptor	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**
Tarrant County	**A**	4.1	20.6	41.1	61.7	5.5	27.6	55.3	82.8	10.3	51.4	102.8	154.1	9.1	45.7	91.3	137
	B	4	19.8	39.6	59.3	5.3	26.6	53.2	79.7	9.9	49.5	98.9	148.4	8.8	44	87.9	131.9
	C	3.6	18.2	36.5	54.7	4.9	24.5	49.1	73.5	9.1	45.6	91.2	136.9	8.1	40.6	81.1	121.7
	D	4	19.8	39.5	59.3	5.3	26.6	53.2	79.7	9.9	49.4	98.9	148.3	8.8	43.9	87.9	131.8
	E	4.2	20.8	41.6	62.4	5.6	27.9	55.9	83.8	10.4	52	104	155.9	9.2	46.2	92.4	138.6
	F	4.1	20.6	41.1	61.7	5.5	27.6	55.3	82.8	10.3	51.4	102.8	154.1	9.1	45.7	91.3	137
	G	4	19.8	39.6	59.3	5.3	26.6	53.2	79.7	9.9	49.5	98.9	148.4	8.8	44	87.9	131.9
	H	3.6	18.2	36.5	54.7	4.9	24.5	49.1	73.5	9.1	45.6	91.2	136.9	8.1	40.6	81.1	121.7
	I	4	19.8	39.5	59.3	5.3	26.6	53.2	79.7	9.9	49.4	98.9	148.3	8.8	43.9	87.9	131.8
	J	4.2	20.8	41.6	62.4	5.6	27.9	55.9	83.8	10.4	52	104	155.9	9.2	46.2	92.4	138.6
Kalamazoo County	**A**	4.6	23.1	46.3	69.4	6.2	31	61.9	92.9	11.4	57	114	171	10.1	50.7	101.3	152
	B	4.5	22.3	44.5	66.8	6	29.8	59.6	89.4	11	54.8	109.7	164.5	9.8	48.8	97.5	146.3
	C	4.1	20.5	41.1	61.6	5.5	27.5	55	82.4	10.1	50.6	101.2	151.8	9	45	90	134.9
	D	4.5	22.3	44.5	66.8	6	29.8	59.6	89.3	11	54.8	109.7	164.5	9.7	48.7	97.5	146.2
	E	4.7	23.4	46.8	70.2	6.3	31.3	62.6	93.9	11.5	57.7	115.3	173	10.2	51.2	102.5	153.7
	F	4.6	23.1	46.3	69.4	6.2	31	61.9	92.9	11.4	57	114	171	10.1	50.7	101.3	152
	G	4.5	22.3	44.5	66.8	6	29.8	59.6	89.4	11	54.8	109.7	164.5	9.8	48.8	97.5	146.3
	H	4.1	20.5	41.1	61.6	5.5	27.5	55	82.4	10.1	50.6	101.2	151.8	9	45	90	134.9
	I	4.5	22.3	44.5	66.8	6	29.8	59.6	89.3	11	54.8	109.7	164.5	9.7	48.7	97.5	146.2
	J	4.7	23.4	46.8	70.2	6.3	31.3	62.6	93.9	11.5	57.7	115.3	173	10.2	51.2	102.5	153.7

Table 5.B.2 NO2 Emission and Speed Limit by County

		NO2 (ppm) 30 mph				NO2 (ppm) 35 mph				NO2 (ppm) 40 mph				NO2 (ppm) 45 mph			
	Receptor	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**
Tarrant County	**A**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0.07	0.36	0.72	1.08	0.08	0.41	0.81	1.22	0.09	0.44	0.87	1.31	0.08	0.39	0.78	1.16
	C	0.07	0.36	0.72	1.08	0.08	0.41	0.81	1.22	0.09	0.44	0.87	1.31	0.08	0.39	0.78	1.16
	D	0.07	0.36	0.72	1.08	0.08	0.41	0.81	1.22	0.09	0.44	0.87	1.31	0.08	0.39	0.78	1.16
	E	0.07	0.33	0.65	0.98	0.07	0.37	0.73	1.1	0.08	0.39	0.79	1.18	0.07	0.35	0.7	1.05
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.68	0.05	0.25	0.49	0.74	0.04	0.22	0.44	0.65
	H	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.68	0.05	0.25	0.49	0.74	0.04	0.22	0.44	0.65
	I	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.68	0.05	0.25	0.4	0.74	0.04	0.22	0.44	0.65
	J	0.04	0.2	0.4	0.6	0.05	0.23	0.45	0.68	0.05	0.24	0.48	0.73	0.04	0.22	0.43	0.65
Kalamazoo County	**A**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0.07	0.36	0.72	1.09	0.08	0.41	0.81	1.22	0.09	0.44	0.88	1.32	0.08	0.39	0.78	1.17
	C	0.07	0.36	0.72	1.09	0.08	0.41	0.81	1.22	0.09	0.44	0.88	1.32	0.08	0.39	0.78	1.17
	D	0.07	0.36	0.72	1.09	0.08	0.41	0.81	1.22	0.09	0.44	0.88	1.32	0.08	0.39	0.78	1.17
	E	0.07	0.33	0.65	0.98	0.07	0.37	0.74	1.1	0.08	0.4	0.79	1.19	0.07	0.35	0.7	1.06
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.69	0.05	0.25	0.49	0.74	0.04	0.22	0.44	0.66
	H	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.69	0.05	0.25	0.49	0.74	0.04	0.22	0.44	0.66
	I	0.04	0.2	0.41	0.61	0.05	0.23	0.46	0.69	0.05	0.25	0.49	0.74	0.04	0.22	0.44	0.66
	J	0.04	0.2	0.4	0.6	0.05	0.23	0.45	0.68	0.05	0.24	0.49	0.73	0.04	0.22	0.43	0.65

Table 5.B.3 PM10 Emission by County

		PM10(µg/m3) 30 mph				PM10 (µg/m3) 35 mph				PM10 (µg/m3) 40 mph				PM10 (µg/m3) 45 mph			
	Receptor	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**
Tarrant County	**A**	19.4	96.8	193.7	290.5	17.1	85.4	170.9	256.3	15.5	77.6	155.3	232.9	14.3	71.5	143.1	214.6
	B	18	90.2	180.4	270.7	15.9	79.6	159.2	238.8	14.5	72.3	144.6	217	13.3	66.6	133.3	199.9
	C	16	80.1	160.2	240.3	14.1	70.7	141.3	212	12.8	64.2	128.4	192.6	11.8	59.2	118.3	177.5
	D	18	90.2	180.4	270.7	15.9	79.6	159.2	238.8	14.5	72.3	144.6	217	13.3	66.6	133.3	199.9
	E	19.4	96.8	193.7	290.5	17.1	85.4	170.9	256.3	15.5	77.6	155.3	232.9	14.3	71.5	143.1	214.6
	F	19.4	96.8	193.7	290.5	17.1	85.4	170.9	256.3	15.5	77.6	155.3	232.9	14.3	71.5	143.1	214.6
	G	18	90.2	180.4	270.7	15.9	79.6	159.2	238.8	14.5	72.3	144.6	217	13.3	66.6	133.3	199.9
	H	16	80.1	160.2	240.3	14.1	70.7	141.3	212	12.8	64.2	128.4	192.6	11.8	59.2	118.3	177.5
	I	18	90.2	180.4	270.7	15.9	79.6	159.2	238.8	14.5	72.3	144.6	217	13.3	66.6	133.3	199.9
	J	19.4	96.8	193.7	290.5	17.1	85.4	170.9	256.3	15.5	77.6	155.3	232.9	14.3	71.5	143.1	214.6
Kalamazoo Country	**A**	19.5	97.6	195.2	292.8	17.2	86	172	258	15.6	78.2	156.4	234.6	14.5	72.3	144.6	216.9
	B	18.2	90.9	181.9	272.8	16	80.1	160.2	240.4	14.6	72.9	145.7	218.6	13.5	67.4	134.7	202.1
	C	16.1	80.7	161.4	242.2	14.2	71.1	142.2	213.4	12.9	64.7	129.3	194	12	59.8	119.6	179.4
	D	18.2	90.9	181.9	272.8	16	80.1	160.2	240.4	14.6	72.9	145.7	218.6	13.5	67.4	134.7	202.1
	E	19.5	97.6	195.2	292.8	17.2	86	172	258	15.6	78.2	156.4	234.6	14.5	72.3	144.6	216.9
	F	19.5	97.6	195.2	292.8	17.2	86	172	258	15.6	78.2	156.4	234.6	14.5	72.3	144.6	216.9
	G	18.2	90.9	181.9	272.8	16	80.1	160.2	240.4	14.6	72.9	145.7	218.6	13.5	67.4	134.7	202.1
	H	16.1	80.7	161.4	242.2	14.2	71.1	142.2	213.4	12.9	64.7	129.3	194	12	59.8	119.6	179.4
	I	18.2	90.9	181.9	272.8	16	80.1	160.2	240.4	14.6	72.9	145.7	218.6	13.5	67.4	134.7	202.1
	J	19.5	97.6	195.2	292.8	17.2	86	172	258	15.6	78.2	156.4	234.6	14.5	72.3	144.6	216.9

Table 5.B.4 PM2.5 Emission by County

		$PM_{2.5}$ ($\mu g/m^3$) 30 mph				$PM_{2.5}$ ($\mu g/m^3$) 35 mph				$PM_{2.5}$ ($\mu g/m^3$) 40 mph				$PM_{2.5}$ ($\mu g/m^3$) 45 mph			
	Receptor	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**	**V 50**	**V 250**	**V 500**	**V 750**
Tarrant County	**A**	17.8	88.9	177.7	266.6	15.7	78.4	156.8	235.2	14.2	71.2	142.3	213.5	13.1	65.6	131.3	196.9
	B	16.6	82.8	165.6	248.3	14.6	73	146.1	219.1	13.3	66.3	132.6	198.9	12.2	61.2	122.3	183.5
	C	14.7	73.5	147	220.5	13	64.8	129.7	194.5	11.8	58.9	117.7	176.6	10.9	54.3	108.6	162.9
	D	16.6	82.8	165.6	248.3	14.6	73	146.1	219.1	13.3	66.3	132.6	198.9	12.2	61.2	122.3	183.5
	E	17.8	88.9	177.7	266.6	15.7	78.4	156.8	235.2	14.2	71.2	142.3	213.5	13.1	65.6	131.3	196.9
	F	17.8	88.9	177.7	266.6	15.7	78.4	156.8	235.2	14.2	71.2	142.3	213.5	13.1	65.6	131.3	196.9
	G	16.6	82.8	165.6	248.3	14.6	73	146.1	219.1	13.3	66.3	132.6	198.9	12.2	61.2	122.3	183.5
	H	14.7	73.5	147	220.5	13	64.8	129.7	194.5	11.8	58.9	117.7	176.6	10.9	54.3	108.6	162.9
	I	16.6	82.8	165.6	248.3	14.6	73	146.1	219.1	13.3	66.3	132.6	198.9	12.2	61.2	122.3	183.5
	J	17.8	88.9	177.7	266.6	15.7	78.4	156.8	235.2	14.2	71.2	142.3	213.5	13.1	65.6	131.3	196.9
Kalamazoo County	**A**	17.9	89.4	178.8	268.3	15.8	79	157.9	236.9	14.3	71.7	143.5	215.2	13.2	66.2	132.4	198.6
	B	16.7	83.3	166.6	249.9	14.7	73.6	147.1	220.7	13.4	66.8	133.7	200.5	12.3	61.7	123.4	185.1
	C	14.8	74	147.9	221.9	13.1	65.3	130.6	195.9	11.9	59.3	118.6	178	11	54.8	109.5	164.3
	D	16.7	83.3	166.6	249.9	14.7	73.6	147.1	220.7	13.4	66.8	133.7	200.5	12.3	61.7	123.4	185.1
	E	17.9	89.4	178.8	268.3	15.8	79	157.9	236.9	14.3	71.7	143.5	215.2	13.2	66.2	132.4	198.6
	F	17.9	89.4	178.8	268.3	15.8	79	157.9	236.9	14.3	71.7	143.5	215.2	13.2	66.2	132.4	198.6
	G	16.7	83.3	166.6	249.9	14.7	73.6	147.1	220.7	13.4	66.8	133.7	200.5	12.3	61.7	123.4	185.1
	H	14.8	74	147.9	221.9	13.1	65.3	130.6	195.9	11.9	59.3	118.6	178	11	54.8	109.5	164.3
	I	16.7	83.3	166.6	249.9	14.7	73.6	147.1	220.7	13.4	66.8	133.7	200.5	12.3	61.7	123.4	185.1
	J	17.9	89.4	178.8	268.3	15.8	79	157.9	236.9	14.3	71.7	143.5	215.2	13.2	66.2	132.4	198.6

Chapter 6. Project Based Learning: A Field Data Collection Opportunity

The development and piloting of the inventories used for the indices and analyses were accomplished by incorporating it as a component of a junior-level engineering class. The results of that initiative are discussed in this chapter, as well as the value of the inclusion of active commuting concepts in university level civil engineering course. Furthermore, decision makers interested in improving the transportation infrastructure in their community or at their site are encouraged to partner with universities or other civil engineering courses to use these inventories to collect the data.

6.1 Introduction

The use of active-based learning techniques in classroom instruction can be an effective pedagogical strategy to facilitate student learning. This approach assumes that engaging students in real world applications of complex engineering terms and concepts will cause higher levels of learning to occur. One complex engineering task is the design of infrastructure to support active modes of transportation or active commuting, defined as the types of transportation modes that are powered by human energy; including examples such as walking, biking, skating and use of a wheel chair. Due to pressures to ensure that students meet the demands of the professional engineering exams, students often receive greater exposure to engineering concepts related to motorized travel, and less to concepts related to nonmotorized or active forms of transportation. Yet, at the same time, federal legislation and programs emphasize the inclusion of the needs of nonmotorized, active commuters in transportation facility design. The purpose of this paper is to present the results of one active-based learning intervention incorporated into a junior-level (third year) transportation engineering course to balance these demands.

This analysis investigates a project-based active learning intervention, which is designed to expose students to two distinct concepts identified as critical to active commuting. The two concepts of interest are physical activity and safety. The research adopts a single group pre-posttest design to compare the degree of change resulting from the learning intervention. Learning is evaluated in two primary ways: overall question based learning and level of learning. Blooms' Taxonomy is used to classify questions into levels of learning ranging from remember to analyze. Students also submit a qualitative project report evaluating project sites in terms of promoting or encouraging active commuting and recommend infrastructure-level measures of improvement. T-tests evaluate the quantitative change in learning. The qualitative report is evaluated based on the level of understanding demonstrated through students' fieldwork performance, research team discussions and written recommendations.

The results suggest that students demonstrate an overall lower level of knowledge of physical activity than safety concepts at the beginning of the course. However, students perform significantly better in the posttest on individual physical activity concepts and in learning domains. On concepts related to safety, students showed an overall higher level of knowledge and demonstrated some learning gains across levels of learning, but statistical significant results were minimal. The higher knowledge of safety concepts at the onset of the course is to be expected as students are often exposed to safety concepts through the traditional curriculum and these are emphasized to a greater degree than physical activity in the course. The findings suggest that the project-learning based approach has a stronger effect on the concepts to which students receive less exposure. The paper concludes with a discussion of implications and future research needs to enhance the generalizability of the study.

6.2 Literature Review

Active Based Learning. One goal of undergraduate civil engineering education is to prepare students with the professional problem-solving skills necessary to tackle complex transportation engineering projects. Students must be able to apply fundamental theories and techniques of learned knowledge to identify solutions to transportation infrastructure challenges. For educators, the challenge remains identifying and implementing efficient and effective learning strategies that facilitate this goal. Active based learning strategies such as project-based learning have demonstrated success. Active learning strategies stress students' active involvement in their own learning (1) and commonly emphasize higher order thinking and group work (2). However, while the research suggests such strategies can be successful, a need for "a second generation of research" geared towards understanding what particular conditions and elements facilitate successful learning outcomes exists (3).

The call for a second wave of research surrounding active learning strategies is informed by a recent study published in the National Academy of Sciences (NAS) that suggests a reframing of the debate over traditional versus active based learning strategies towards understanding what elements of active based learning strategies work, to what ends, and under what conditions. A robust literature demonstrates a number of improved student learning outcomes when using active based learning techniques (3, 4, 5, 6). Active learning strategies can also yield disproportionate benefits for students from *disadvantaged populations* and for *female students* in male-dominated fields (4, 5). Furthermore, a meta-analysis of active learning versus traditional lectures (n=225) in STEM (Science, Technology, Engineering and Math) undergraduate courses found that on average (3): Student performance increased by 0.47 SDs under active learning (n=158); average exam scores improved by about 6% in active learning sections; students in traditional lecturing courses were 1.5 times more likely to fail; and found these effects to be robust across the STEM Disciplines.

However, at the same time, active learning strategies can be highly variable and range in intensity and duration. Thus, there remains a need for more empirical evidence as to what active learning strategies yield improved learning outcomes. Such information can help educators design more effective courses. The purpose of this paper is to contribute to this knowledge gap by assessing the learning outcomes associated with one particular type of active learning intervention, a project-based learning (PBL) intervention. PBL is a focused pedagogical approach that involves students in solving or analyzing challenging authentic and curriculum-based problems (7). Problem solving ability, metacognition, self-motivation are some of the important skills necessary to be successful in PBL (8). Students are encouraged to assume responsibility for their learning experience and to shift from passive to more active learning patterns (9). Project-based instruction has rapidly gained acceptance by the educational community and is now being applied in a wide spectrum of engineering disciplines, at various types of academic institutions and throughout the different phases of educational programs (10).

Project Based Learning to Teach Concepts of Active Commuting. Increasingly, federal agencies such as the U.S. Department of Transportation (DOT) and the Department of Health and Human Services (DHHS) have identified joint objectives to improve the health of the American population. Increasing active commuting is one area that addresses the goals of both the DOT and the DHHS. The immediate outputs of increased active commuting include increased physical activity, decreased car dependency and congestion, which in turn may lead to improvements of longer term outcomes such as reduced obesity and other health conditions associated with physical activity, improved air quality, improved mobility and more generally, improved quality of life. While obviously the behavior and attitudes of individuals can also affect the increased likelihood of active commuting, substantial research suggests that engineering measures can also have an impact.

Transportation facilities can positively impact the likelihood of increased active commuting in two primary ways. The first is via transportation facilities that include measures or elements associated with the features of the built environment that are correlated with increased physical activity. Good lighting, access to 'adequate' sidewalks, street connectivity; distance or proximity to a destination, flat, straight terrain and traffic volume have been identified as factors that promote physical activity and active commuting (11, 12, 13, 14, 15,16, 17, 18).

The second is through transportation facilities that improve safety for pedestrians or cyclists. Features of the built environment that address overall perceived safety have a dual effect of promoting physical activity and active commuting. For example, sidewalks, street connectivity, traffic, presence of crossing guards and crosswalk improvements and street lighting are factors that are associated with perceived safety (11, 16, 18). Measures to increase perceived safety include the implementation of traffic calming and control mechanisms; improved collection of and access to data on incident locations and outcomes; increased public safety and awareness programs; and enhanced construction and inspection methods of pedestrian and bicycle facilities.

Traditional engineering curriculum often places greater emphasis on vehicular and motorized travel, and as such, students receive less exposure to transportation facility design concepts related to active commuting. Nonetheless, as this becomes an increased priority for regional, state and federal transportation and public health agencies, finding ways to effectively and efficiently incorporate it into the curriculum becomes important. A project-based learning intervention aligned with the course objectives represents one way to accomplish this. Furthermore, a project-based learning project also has the benefit of enhancing student learning in areas where they have less exposure. The question is, what learning gains emerge?

6.3 Methodology

Intervention Details. The research team introduced the intervention to junior-level (third year) civil engineering students in the Introduction to Transportation Engineering course in the Spring semester of 2015 at the University of Texas at Arlington. This course introduces students to the following topics: Traffic Flow Theory, Transportation Demand Modeling, Highway Design, Intersection Safety, and Pavement Design. Typically, the instructor allocates a single lecture to nonmotorized forms of transportation in a 15 weeks' semester. Of the 36 students enrolled in the class, the gender representation skewed towards males (n=28). In terms of race and ethnicity, the majority identified as white (n=32). The instructor teaches this course once every year, which makes formation of a control group difficult; as a result, the research team adopted a single group intervention. Due to limited instructional time available for active transportation, no lecture time accompanied the intervention and the emphasis was placed on individual and group self-directed learning along with occasional review meeting with the course convener. The research team prepared detailed manuals related to physical activity and safety factors associated with active commuting. This intervention (class project) is divided in two phases. In phase one, the student groups are required to collect inventory data (initial location survey) at eleven different locations by either going to the field or observing electronic map (Google/Bing) for key features of transportation facilities along the dimensions of physical activity and safety. The research team also provided observational manuals and example inventories. The observational manuals introduced students to different elements of the infrastructure associated with active commuting and also explain how to collect information. Based on information gathered in phase one, the course convener selected four locations that may have major infrastructure related issues for active commuting. In phase two, students are assigned to four locations where they collect information on conflicts, gather data on queue and analyze the data and generate recommendations for improvements. All students received materials prior to entering into the field and research team members were available in an ongoing manner for questions and queries.

Instrumentation. The project's main learning goal is to introduce students to the elements and measures of transportation infrastructure that support active transportation. A single group pretest-posttest design compares the degree of change in learning. The definitive characteristic of the research design is that (at least) two measurements are made on the same experimental unit: the pretest measurement made prior to the administration of a treatment or intervention and the posttest measurement made at a point in time afterward.

To develop the testing instrument, the research team creates a series of objectives related to the course. The objectives include those that focus on whether or not students can identify the features associated with physical activity and safety, recognize what the measure or element aims to accomplish, select among competing alternatives or describe a particular type of measure and what it aims to accomplish. The learning objectives of the course inform the development of the pre/posttest instruments. With framed objectives as a reference, the research team designs the questions for the test (Appendix 6A). Most of the test questions are a direct interpretation of a learning objective. A list of learning objectives and associated questions are listed in Table 6.1. Finally, the team analyzes and links the questionnaire to various categories of Bloom's Taxonomy in order to evaluate the level of learning that occurs.

Bloom's Taxonomy classifies different learning objectives into cognitive, affective, and psychomotor domains (19, 20). The present study classifies questions into four of the five categories of Bloom's modified Taxonomy (21), remember, understand, apply and analyze, ranging from low to higher levels of learning. Questions that are associated with the remember category are those that ask students to list or recall information. Questions that require students to restate, identify, summarize or infer information link to the understand category. The apply category captures questions related to interpret and implementation. Finally, questions linked to the analyze category require students to differentiate or structure knowledge in new ways to generate a response.

Table 6.1 List of Objectives with Associated Questions

Obj. No	Objectives	Q No	Questions
1	Explain the importance of crosswalk at intersections and midblock crossings.	5	Calculate Crosswalk crossing time
		13	Importance of Crosswalk, sidewalk and connectivity
2	Identify different types of traffic control devices for pedestrian/bicyclists.	2	Which is/are used as a/ control device/es for pedestrians at the intersection
		16	Which of the following intersection features affect pedestrian safety?
3	Explain the importance of lighting for sidewalks and intersections.	9	List three reasons for including lighting along sidewalk/intersections
		18	Mark True/False for each statement about curb extensions
		19	Mark True/False for each statement about bicycle boxes
10	Explain the purpose of sidewalk	13	Importance of Crosswalk, sidewalk and connectivity
11	List components of a sidewalk that influence walkability/bikeability	1	Which factor/factors deters/deter pedestrians from using a sidewalk facility
15	Explain the importance of a median for a walkable/bikeable route	3	How can a wider median help Pedestrians
16	Identify different types of traffic controls at midblock crossings that affect the perceived safety of a walking route	6	Which is a HAWK(High-intensity Activated crosswalk) beacon
		12	Identify missing traffic control devices at midblock crossings.
19	Identify different types of sources/origins that create pollution along a walking/biking route	4	Where does bad air quality matter for pedestrians?
22	List a number of factors that influence utilitarian walking/biking	11	What are some of the reasons that increase utilitarian biking?
23	Explain why a continuous walking path is necessary in a neighborhood for increasing physical activity	13	Importance of Crosswalk, sidewalk and connectivity
33	Identify conflict points present at different types of transportation facility	7	Which facility does NOT look safe at shared lanes
		8	Identify total number of vehicle-pedestrian conflict points in the figure.

The final test instrument consists of 28 questions total and is provided in Appendix 6A. Fourteen are applicable to measures and elements associated with physical activity and 14 are associated with safety. Specifically, the Physical Activity (PA) module consists of eight multiple choice questions, three short answers questions, two problem identification questions and ten pairs of matched pair questions. The questions cover nineteen objectives related to identifying, applying, analyzing or selecting midblock/intersection features that affect physical activity. For the Safety Module (S), the first 12 questions are multiple choice questions and the last two are short answer questions. Table 6.2 illustrates the linkages and distribution between the questions and the assessment categories of interest.

Table 6.2 Distribution of Question Types, by Bloom's Taxonomy and Levels of Learning

Expected Level of Learning	***Bloom's Taxonomy***	***Question Codes***
Lowest--Ability to Recall or Recognize	*Remember*	*12 (2, 6, 9, 10, 14, 15, 16, 17, 20, 22, 24, 28)*
Low--Ability to interpret or summarize	*Understand*	*7 (10, 14, 18, 19, 21, 23, 25)*
Moderate--Execute and Implement	*Apply*	*9 (1, 3, 4, 5, 7, 8, 12, 13, 26)*
Highest -- Structure Knowledge in New Ways	*Analyze*	*2 (11, 27)*

Hypotheses and Data Analysis. The research team establishes two hypotheses for each dimension of active commuting under investigation to assess the learning intervention. The hypotheses are informed by the general review of literature on active based learning, which generally supports that active learning strategies not only increase overall learning but also facilitate higher levels of learning. The research team anticipates learning improvements in the following areas:

Physical Activity Concepts

H_1: Posttest scores will be higher than pretest scores for each individual question related to physical activity concepts.

H_2: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth on the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy for physical activity concepts.

Safety Concepts

H_3: Posttest scores will be higher than pretest scores for each individual question related to safety concepts.

H_4: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth on the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy for safety concepts.

A one-tailed paired t-test is conducted to assess the improvement at a 5% (significant) and 10% (marginally or approaching) significance level. A paired t-test is used because each subject has two related observations (pretest and posttest). The null hypothesis assumes that there is no improvement after the learning intervention. To analyze the data, the pre- and posttest questions and the final project report are scored. For multiple-choice questions, the answers are scored correct or incorrect. The researchers score each on a five-point scale. For the short answer questions, the given points vary depending on the result, and are qualitatively scored based on a student's ability to demonstrate a particular level of knowledge about the key concepts (could the student move from simple remembering to applying or analyzing situations). In order to address the potential limitations that a structured questionnaire provides to analyze higher levels of learning, student-research team meetings and the postproject assessment are also analyzed for qualitative themes. Each student produces a final written report documenting their observations from the fieldwork and learning materials. The students also have the opportunity to provide their qualitative feedback about the project through individual meetings with the research team.

Implementation. Prior to the delivery of the curriculum and materials, the research team administered the pretest to the class, and 28 of the 36 students completed it. At the end of the semester, 32 students took the posttest (a repeat of the pretest). Thus, complete assessment data were available for 27 students. The majority of the 27 were male (n=22) and identified as white (n=23). At the end of the semester, students were also required to submit their project report.

6.4 Results

Physical Activity Learning Objectives. This section discusses the quantitative assessment, which omits the short answer questions, of the physical activity learning objectives. This section considers each of the hypotheses and develops a summary of the overall results. Figure 6.1 illustrates the distribution of the pre- and posttest scores (out of 80 points) for physical activity concepts. The posttest scores (M=41.2, SD =8.17) improve over the pretest scores (M=38.1, SD=6.77); based on the paired t-test, the students show a significant improvement (p= 0.043) on the physical activity material. The overall performance for physical activity remains low with only six students scoring over seventy percent on the posttest, which is 56 out of 80.

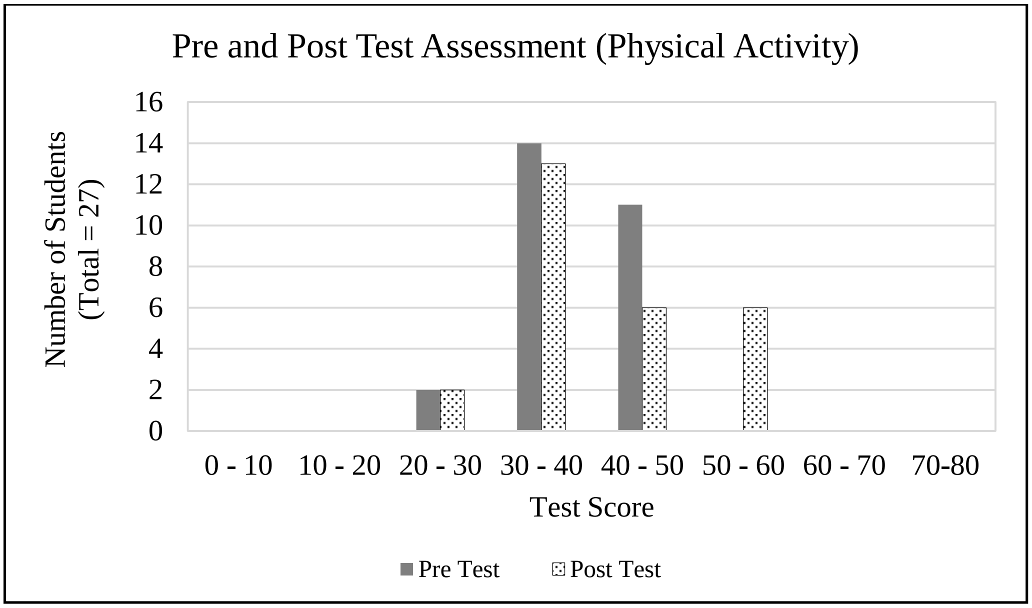


Figure 6.1 Distribution of pre-and post-test scores for physical activity concepts

H_1: Posttest scores will be higher than pretest scores for each individual question related to physical activity concepts.

While not every question shows significant improvement, some of the questions show significant improvement across the student cohort. Figure 6.2 illustrates the pre- and posttest scores by question for physical activity concepts. The student cohort performs particularly poorly on questions 1 and 6, questions that require Moderate Level of learning (Execute and Implement) or Lowest Level of learning (Ability to Recall or Recognize). The reason behind this performance on 1 and 6 may be attributed to the fact that the student group had lower exposure to all possible types of nonmotorized infrastructure facilities in the field. For nine of the other questions, the cohort average increases from the pretest to posttest; for four of these questions, 10, 11, 12 and 14, the improvement appears significant. Question 10 asks students to define and identify traffic calming devices used in transportation infrastructure (t(df=26) = 3.39, p=0.001). Question 10, on traffic calming, the cohort receives a moderate average score on the pretest, but improved by 34.5 points in the posttest. Question 11 asks students to name different criteria for increasing utilitarian biking (t= (df=26) = 1.71, p=0.049). Question 12 asks students to identify different laws and regulations of traffic rules and regulation (t(df=26) = 2.18, p=0.019). Question 14 asks students to match different types of simple paired match questions (t(df=26) = 3.24, p=0.002). Finally, Question 13, which asks students to identify design flaws, shows a nearly significant improvement with a p-value of 0.056. Questions 10-14 vary in Bloom's Taxonomy classification, ranging from Lowest to Highest Level of learning.

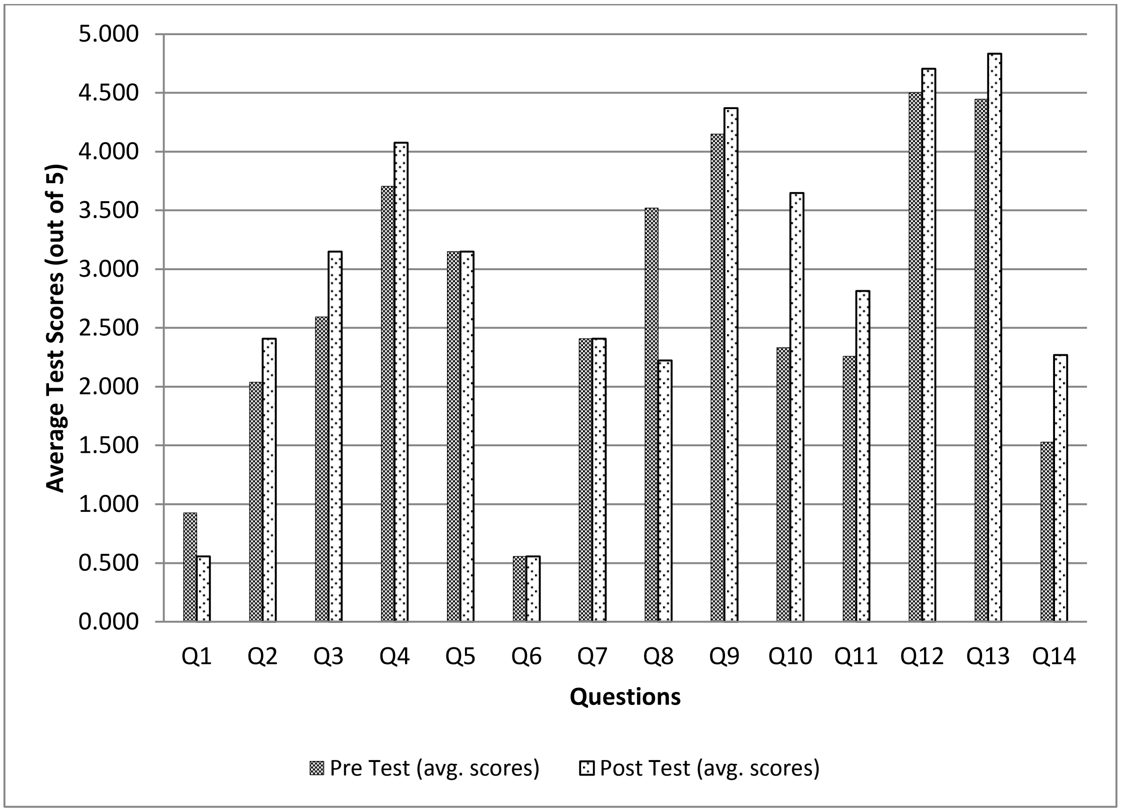


Figure 6.2 Pre- to post-test scores (out of 5 points) by question for physical activity concepts

H_2: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth on the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy for physical activity concepts.

This hypothesis also achieves mixed results; the analysis questions show significant improvements, but the lower levels of remember and understand show even larger growth. Figure 6.3 presents the results. The analysis questions show significant improvement ($t(df=26) = 1.71$, $p=0.049$) while the apply category remains virtually unchanged. The test scores show significant improvement for both the remembering ($t\ (df=26) = 4.52$, $p=0.000$) and understanding ($t(df=26) = 4.98$, $p=0.000$) question categories.

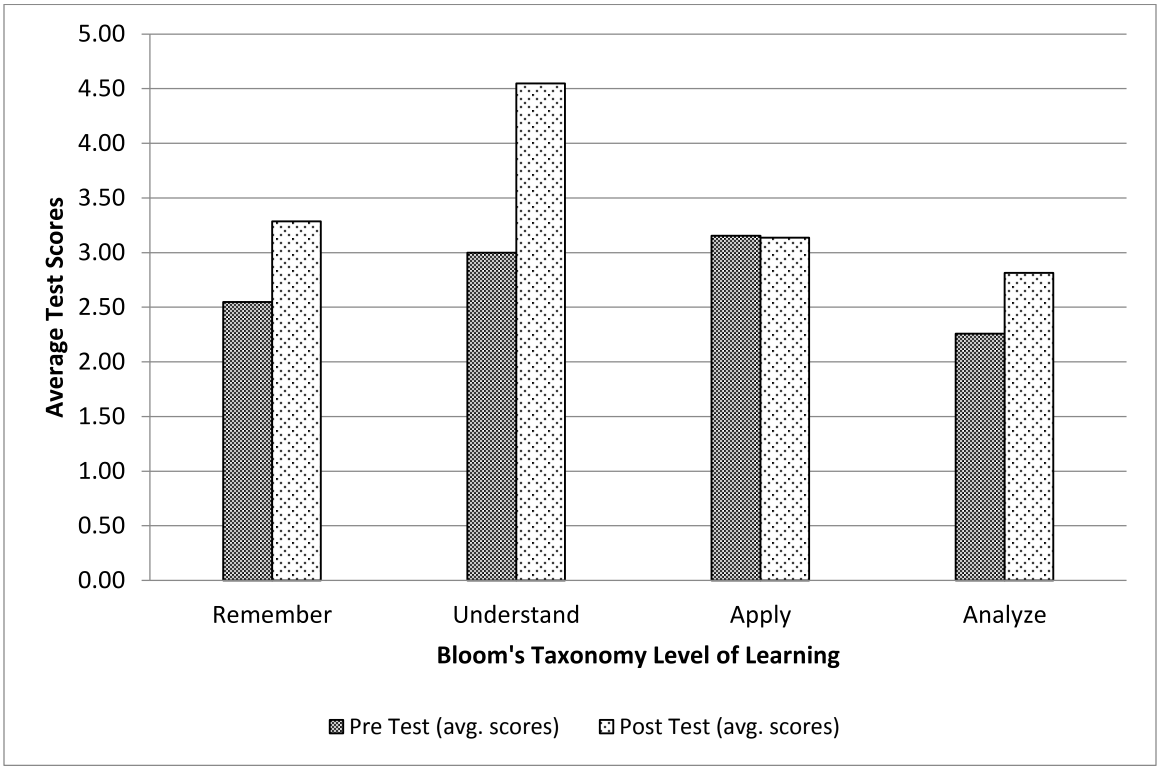


Figure 6.3 Pre- and post-test scores by level of learning for physical activity concepts

In summary, the analysis suggests that the project-based learning intervention does have an impact on the students' grasp of the physical activity concepts. While the overall scores for the physical activity learning objectives remain rather low, the student cohort experiences a significant improvement in the overall test score for the questions related to physical activity. The two questions where the student cohort average is less than 1 both deal with rather specific walkability topics. In question 1, students must identify a factor that may discourage walking, but they do not experience this particular situation during their project nor do they encounter a HAWK (High-intensity Activated crosswalk) beacon signal head for pedestrian crossing, which must be successfully identified in question 6. These questions will likely need to be revised for future educational outcome assessments. During the posttest, four questions show significant improvement and two of these and three additional questions have over seventy percent of the cohort answering correctly. The two questions showing significant growth and strong performance: defining and identifying traffic calming devices, which is a new concept for students (Remember/Understand) and identifying cases where violations of laws and regulations related to biking and walking appear (Application). The other three strong performing questions include identifying locations of concern for air quality (Application), explaining the importance of lighting for sidewalks and intersections (Remember), and identifying pedestrian and bicycle-related design flaws (Application). The project-based intervention and supporting training materials appear to be well structured to encourage growth throughout Bloom's Taxonomy. The limited student background in the factors affecting active transportation makes this comprehensive growth critical.

Safety Learning Objectives. This section focuses on the intervention's quantitative effect on the safety-based learning objectives. Figure 6.4 illustrates the pre- and posttest scores for safety concepts. While almost no improvement occurs between the pretest (M=48.3, SD=5.9) and the posttest (M=48.5, SD =6.5), students perform better on the safety material with the cohort mean approaching seventy percent. This appears to indicate that the knowledge of safety factors related to bicycling and walking may already exist for many junior civil engineering students. Furthermore, the course where the intervention occurs emphasizes safety as a broad and critical concept that they must seek to achieve and exposure is increased. The 12 students that scored less than the cohort average in the pretest show a nine percent improvement in the posttest; however, those cohort members scoring above average on the pretest experience a 6.5 percent decrease from the pre- to post-test.

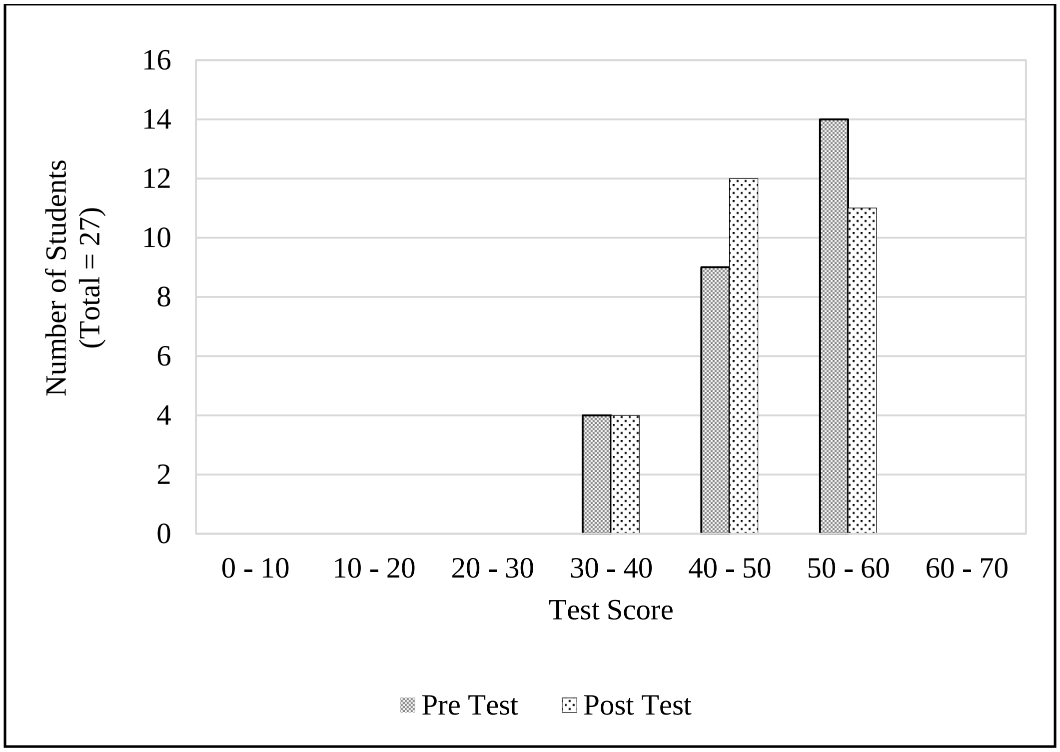


Figure 6.4 Distribution of questionnaire questions, learning objective and levels of learning

H_3: Posttest scores will be higher than pretest scores for each individual question related to safety concepts.

As seen in the analysis of the physical activity concepts, the growth for individual questions appears limited (see Figure 6.5). The majority of questions indicate no change or a decrease in cohort performance, with the exception of questions 4, 7, 9, 10, and 12. Students appear to have a more challenging time understanding the regulatory signs that relate to pedestrian safety (Q11), as it shows the highest decrease, 29%, and the lowest amount of correct responses on the pretest. For question 4, an understand level question that asks students to demonstrate an understanding of how curb cuts influence safety, learning gains appear significant (p=0.01). The difference in test scores shows the highest gain or improvement of 19 percent for question 4. Question 7, an understand question, asks students to demonstrate an understanding of how parking restrictions can influence the safety of active commuters, but this is not significant nor does it approach significance (p=0.33). Question 9, an understand level question, asks students to identify midblock/intersection features and how they relate to safety for active commuting and the change approaches significance (p= 0.08). Questions 10 and 12 do not approach significance. Question 10, a remember question, asks students to identify pedestrian pavement markings and signs (p=0.16). Finally, Question 12, an apply question, asks students to apply different sidewalk designs to improve safety for active commuting (p=0.13).

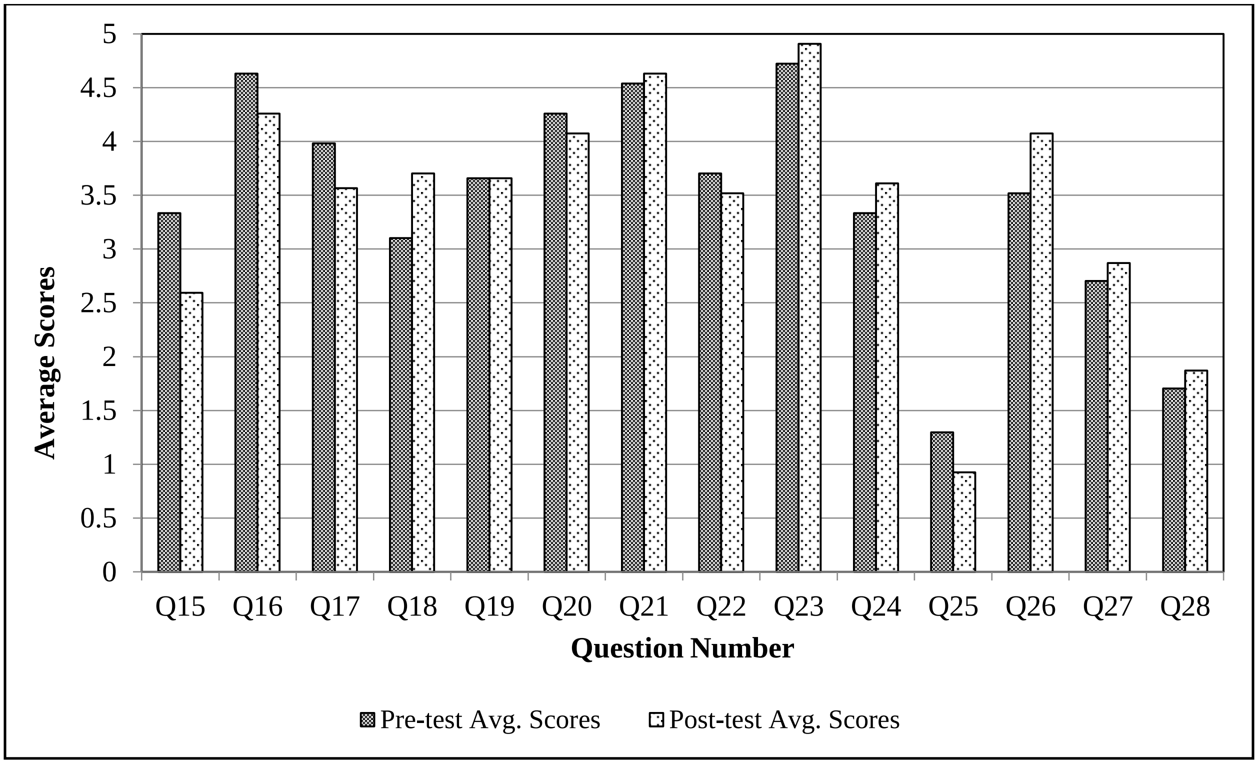


Figure 6.5 Pre/posttest scores by level of learning for safety concepts

H_4: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth on the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy for safety concepts.

Figure 6.6 and the supporting analysis indicate an upward effect, but it is not statistically significant. Although the test scores improved for the understand, apply, and analyze type questions, the improvements remain statistically insignificant. The cohort's growth on the application questions comes the closest to achieving statistical significance with a p-value of 0.132. Overall, students performed well on analyze and application type questions compared to remembering type questions.

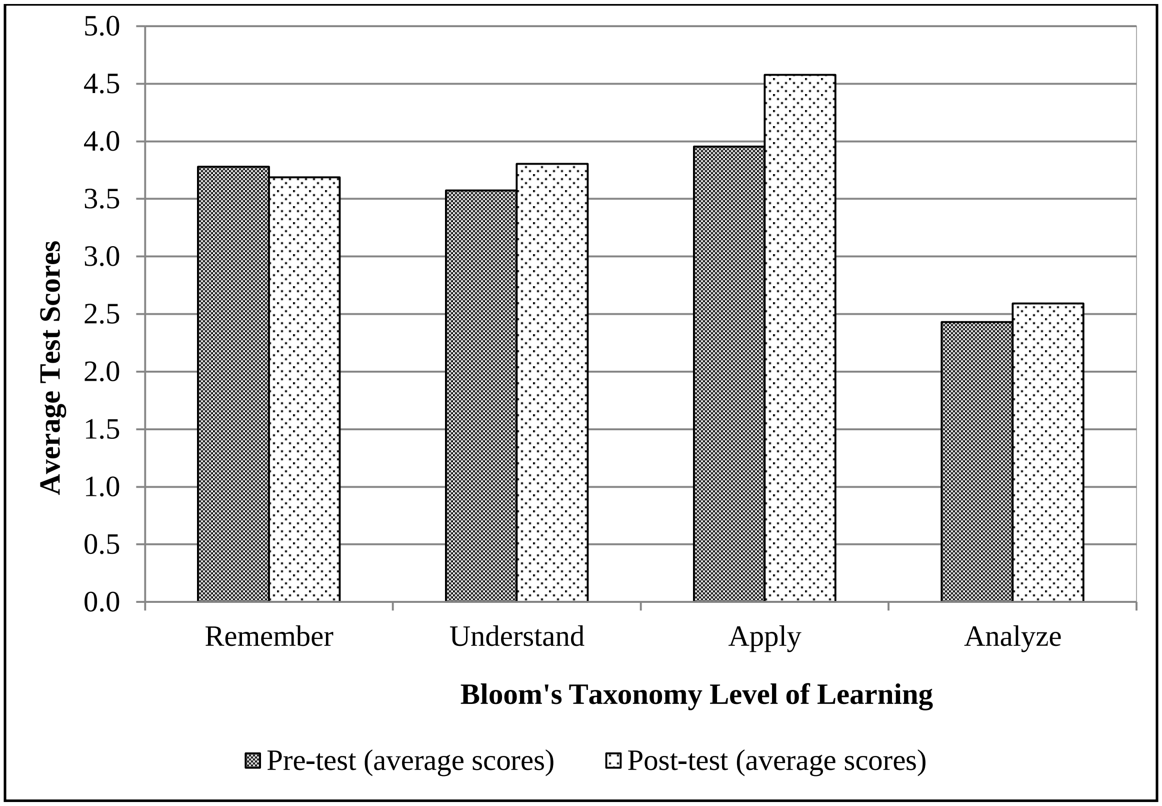


Figure 6.6 Distribution of questionnaire questions, learning objective and levels of learning

In summary, the analysis suggests that the project-based learning intervention has some impact on the students' grasp of the safety concepts but it is not significant. While no significant improvement occurs, the overall cohort performance appears stronger for safety than physical activity. For ten of the fourteen questions, over seventy percent of the cohort selects the correct response. The students perform particularly poorly on one question related to midblock crossing that may need to be revised for greater clarity in future educational assessments. The cohort achieves significant improvement for two learning objectives: (1) compare and contrast dedicated and shared bike lanes and (2) define pedestrian buffer zone. While the intervention stimulates improvement in the higher order domains of Bloom's Taxonomy, these improvements remain insignificant.

Qualitative Analysis. The analysis of the qualitative data provides supplemental information on the patterns of student learning. For example, the students' comprehension of conflict analysis related to the safety module (a qualitative assessment) appears strong because the cohort scores an average of 74 percent. In addition, the students score a 75 percent average score on identification, discussion, and provision of recommendations related to active transportation at the data collection sites. Particularly, data obtained through the instructor/student sessions, open-ended questions and the research team's evaluation of the written report reveal the following general themes:

- The articulation of an awareness of active transportation and infrastructure concerns and the co-existence of active transportation with motorized transportation on community roadways. For instance, students state that they would not have put emphasis on non-motorized transportation features when designing street segments; however, by the end of the project,

they have a better understanding of active transportation elements and its co-existence with motorized traffic.
- A demonstration of the ability to draw upon experiences at the data collection sites to identify, discuss and provide recommendations and improvements in transportation facilities to meet active transportation needs.
- The ability to design data collection schemes for gathering more data and information to solve field problems.

Overall, the individual discussions with students and the assessment of their project reports suggest that the students' perception towards active transportation seems to be favorable upon completion of the project based learning intervention.

6.5 Discussion and Conclusion

Overall, the intervention only achieves partial success across the hypotheses; however, this limited success indicates a continued need for additional research around what active learning strategies work and why. Failure to find full support for all hypotheses suggests that the initial level of exposure students may have to certain concepts has an impact on the associated learning that occurs with active-learning based techniques. Secondly, despite statistical support across all questions and learning domains, the qualitative assessment suggests that such fieldwork may improve student knowledge about active commuting and transportation infrastructure to support its positive public health effects. Exposure in the field led students to identify additional innovations and needs. This research builds on existing work to identify some points that need to be considered in the development and integration of active learning strategies into the classroom environment.

Individuals with lower levels of understanding of active commuting may benefit the most from an active learning intervention. This is evidenced by the pattern in the pretests across the safety and physical activity dimensions that among those scoring the lowest on the pretest, improvement did occur in both safety and physical activity.

1. The concepts and a student's initial level of exposure to those concepts influences learning outcomes. The analysis conducted here suggests that active learning outcomes vary by course objective, specific questions, and desired level of learning and course concepts.

2. The analysis also suggests that project-based learning carries a risk that students will not be equally exposed to all concepts during the fieldwork, which is evidenced by the following results: Statistical significance appears *unique* to particular questions or course objectives and significance of improvement also varies by *concept exposure*. For example, significant improvements were found in levels of learning for physical activity concepts but not for safety improvements. This appears to occur because the students begin the intervention with a higher knowledge of some concepts than others and fieldwork may not expose them to new dimensions.

3. Finally, the study fails to find consistent quantitative statistical evidence of higher levels of learning across all concepts as a result of the intervention. However, the qualitative reports and evaluation of descriptive questions indicates a higher level of understanding. Two plausible explanations for this exist. First, the research team designed the project rather than the students so the student participants are less engaged directly with higher conceptual challenges.

Secondly, the pre- and posttest structured, forced-choice questionnaires alone may not sufficiently enable researchers to assess higher levels of learning.

The findings have implications for researchers and educators interested in teaching students to recognize the demands active commuting poses on transportation infrastructure.

6.6 Research Implications

The limitations in this study remain important for researchers interested in assessing learning strategies and outcomes. Specific recommendations include the following related to instrumentation, research design and variability in the intervention. In regards to research design, pre- and posttests represent a simple and cost-effective instrument to assess the intervention, but other options such as pre- and post scenario exposures should be considered and validated. Furthermore, the research team recognizes that the assessment tool needs additional validation across additional classroom settings and contexts. The other tools that exist are not suitable for studying learning concepts related to active commuting, as they largely focus on traditional engineering concepts. Other ways to enhance the rigor of the assessment include adding a control group, devising a long term research design to address both short-term and long-term learning and retention of the concepts, enlarging the sample size, and controlling for previous student exposure to active commuting ideas and concepts. Steps can also be taken to modify the intervention and vary it based on instructor and learning conditions. This intervention includes limited instructor time, and this is one variable that can be altered to see how more or less involvement in instruction influences the levels of learning. Finally, the intervention is administered in a class that is predominantly nonminority and male. As mentioned earlier, active learning strategies have been found to have a significant learning effect on underrepresented groups in science and engineering fields, and thus a research design that includes a larger sample of underrepresented populations would be valuable.

6.7 Educational Implications

For educators, the findings augment existing literature and suggest that the level of exposure students have to particular concepts at the onset of the course and the manner in which project-based learning is introduced into a course may influence learning outcomes. Previous research suggests that project-based learning improves the ease with which student learning occurs (10) and that the learning styles of the students must also be taken into consideration (6). This analysis suggests that preexisting student knowledge and curricular emphasis on particular concepts may also influence learning outcomes. For example, the students entered the course with higher exposure and knowledge of safety concepts and lower exposure and knowledge of physical activity concepts. However, learning gains are more pronounced for the physical activity concepts, those for which there was less a priori knowledge. Thus, instructors may wish to design project-based learning in a way to ensure that it effectively challenges students' preexisting knowledge. Finally, instructors must ensure that students receive adequate exposure to all course concepts through the project.

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Appendix 6A: Test Questions

SET I

Part I: Multiple Choice Questions

[Circle or indicate the correct answer/answers in the following multiple choice questions.

Each question is worth 5 points]

1) ____ Which factor/factors discourage pedestrians from using a sidewalk facility

a. Trees along the sidewalk
b. Clean trashbins
c. Street Furniture (sitting benches)
d. Poorly lit sidewalk
e. b & d
f. None of the above

2) ____ Which is/are used as a/ control device/es for pedestrians at an intersection?

a. 

b. 

c. 

d. 

e. All of the above

3) ____ How can a wider median help pedestrians?

a. Divide opposite traffic
b. Reduce head-on collision
c. Help in land development
d. Act as a Refuge Island
e. All of the above

4) ____ Where does bad air quality matter for pedestrians?

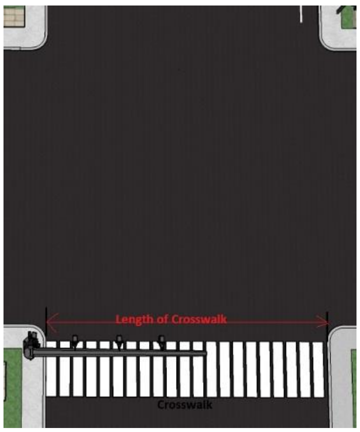
a. Parking lot
b. Sidewalk

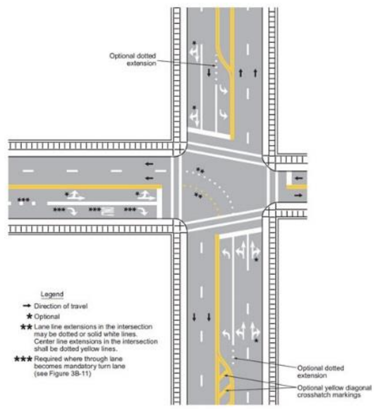
c. Driveway

d. Intersection

e. All the above

5) ____ Length of a crosswalk is measured from one side of the curb to the other side as shown in the picture. Which one is true for the next picture if the lane width is 12 ft and walking speed is 4.5 ft per second?





a. N/S Crossing time 12 sec and 7 sec

b. E/W crossing time is 10 sec and 10 sec

c. E/W crossing times is 14 sec and 14 sec

d. N/S crossing time is 14 sec and 6 sec

6) ____ Which is a HAWK (High-intensity Activated crosswalk) beacon?

a.

c.

b. 

d. 

e. All the above

7) ______ Which facility does **NOT** look safe ?

a. 

c. 

b. 

d. 

e. All the above

f. None of the above

8) ______ The paths of any two road users (vehicles, pedestrians and bicyclists) while turning, diverging or merging across each other creates a conflict point. In the following figure, identify the total number of pedestrian –vehicle conflict points

a. 12

b. 18

c. 21

d. 24

Part II: Short Questions.

[Answer the following short questions. Each is worth 5 points.]

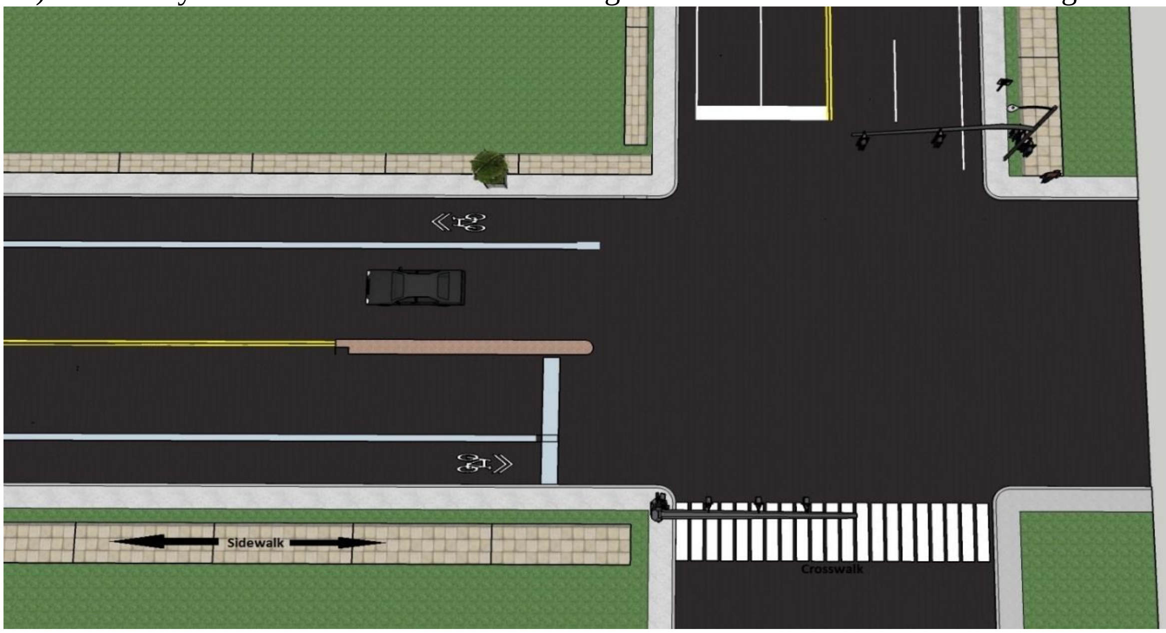
9) List three reasons for including lighting along sidewalks/intersections.

10) Define traffic calming devices (with examples) and identify three reasons to use a traffic calming.

11) What are some of the reasons that increase utilitarian biking?

12) Identify three things wrong in the following scenario.

13) Identify and mark three design flaws in the following scenario.



Part III: Matching (15 points)

[Please match table A with table B and write on the left most Column. Each weighs 1.5 points.]

		Table A		Table B
____	A	Raised median	i	Utilitarian Usage of Sidewalk
____	B	Uneven or deteriorating sidewalk	ii	Active Kids
____	C	Trails through parks	iii	Length of Crosswalk (exposure time when crossing)
____	D	Higher AADT	iv	Consideration of all Modes
____	E	Number of Lanes	v	Low Walkability
____	F	High density development	vi	Increase Conflict Points
____	G	Complete Street	vii	Less Perceived Safety especially when Biking
____	H	Driveways	viii	Less Physical Activity
____	I	Obesity	ix	Recreational Biking
			x	Physical Barrier between Opposing Traffic on Urban Streets
____	J	Safe Route to School		

Pedestrian and Bicycle Safety Questions

Either fill/circle the option, mark X, or choose between YES/NO or TRUE (T)/FALSE (F) when answering. Each question is worth FIVE (5) points.

1) _____ **What are some of the benefits of bicycling and walking?**

_____

a. Transportation and Environment

b. Transportation, Environment, Quality of life, Health, and Economy

c. Environment and Economy

d. Transportation, Health, and Quality of life

2) _____ **Which of the following intersection features affect pedestrian safety?**

a. Length of turning lanes

b. Material of signal mast arm

c. Crosswalks and No Right Turn on Red (RTOR) restrictions

d. None of the above

3) **Mark (X) locations where midblock crossings are used**

[ ] Long block lengths between intersections

[ ] Schools

[ ] Hospitals

[ ] High pedestrian activity locations

4) **Mark TRUE (T) / FALSE (F) for each statement about curb extensions. Curb Extensions are used to**

_________________ shorten pedestrian crossing distance.

_________________ shorten pedestrian signal phase.

_________________ allow pedestrians to see the traffic better.

_________________ allow traffic to see the pedestrians.

5) **Mark TRUE (T) / FALSE (F) for each statement about bicycle boxes at an intersection. Bicycle Box**

____________ Increases visibility of bicyclists

____________ Reduces signal delay for bicyclists

____________ Provides priority for bicyclists at signalized intersection

____________ Groups bicyclists together to clear an intersection quickly and minimize impediment to other traffic

6) **Which sequence (a, b, c, or d) correctly identifies the images of bike lanes presented below?**

_____

http://nacto.org

(1) (2) (3)

a. 1 - Buffered Bike Lane; 2 - Conventional Bike Lane; 3 - Shared Bike Lane

b. 1 - Conventional Bike Lane; 2 - Buffered Bike Lane; 3 - Shared Bike Lane

c. 1 - Shared Bike Lane; 2 - Conventional Bike Lane; 3 - Buffered Bike Lane

d. 1 - Conventional Bike Lane; 2 - Shared Bike Lane; 3 - Buffered Bike Lane

7) **Indicate whether the following statements are true (T) or false (F) about parking restrictions near schools.**

_____ Parking restrictions are needed to regulate parent parking

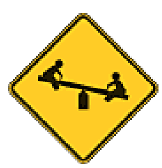
_____ Strictly push parent motorists into adjacent neighborhoods of school

_____ Deny parents appropriate and adequate space for parking and drop- off activities

_____ Curb paint and signs can be used individually or together to help convey messages regarding parking restrictions

8) **Match the following warning signs**

_____

1. Pedestrian crossing [ ] a. 

2. Advance pedestrian crossing [ ] b. 

3. Playground [ ] c. 

4. School bus stop [ ] d. 

5. School crossing [ ] e. 

Source: MUTCD, http://mutcd.fhwa.dot.gov

a. 1 - b, 2 – e, 3 – a, 4 – d, 5 - c

b. 1 - e, 2 – c, 3 – a, 4 – b, 5 – d

c. 1 - c, 2 – e, 3 – a, 4 – b, 5 – d

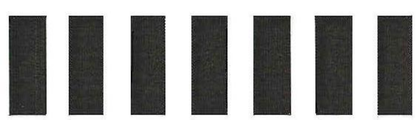
d. 1 - d, 2 – e, 3 – a, 4 – b, 5 – c

9) **Complete the following sentences related to pedestrian intersection design principles.**

1. Encourage crossing at intersection _____	[ ]	a. crossing
2. Make pedestrians _______to traffic	[ ]	b. pedestrians
3. Minimize _______ distance	[ ]	c. visible
4. Make vehicular traffic visible to _______	[ ]	d. corners

10) **Match the following Crosswalk Markings**

_____

1. Standard [ ] a. 

2. Continental [ ] b. 

3. Zebra [ ] c. 

4. Ladder [ ] d. 

Source: http://www.fhwa.dot.gov/publications/research/safety/pedbike/05085/

11) **Indicate which of the Regulatory Signs below are related to pedestrians.**


Source: *MUTCD*, http://mutcd.fhwa.dot.gov

(1) (2) (3) (4) (5)

a. 1, 2, 3 and 4

b. 1, 3 and 4

c. 1,3, 4 and 5

d. All of the above

12) ____ **Which of the following are important sidewalk design elements?**

1. Sidewalk width
2. Buffer areas
3. Cross-slope
4. Sight distances
5. Continuity

a. 1, 4 and 5

b. 1, 2, and 4

c. 3, 4, and 5

d. All of the Above

13) ________ **Which of the following are true about dedicated and shared bike lanes?**

1. Dedicated bike lanes are on-street separated travel facilities for bicyclists. In shared bike lanes, all roadways, except where prohibited by law, are shared by bicycles and motor vehicles.
2. Dedicated bike lanes can provide safety benefits to road users though separate operational space for safe motorist overtaking of bicyclists.
3. Shared bike lane presence visually narrows the roadway or motor vehicle travel lanes to encourage lower motor vehicle speeds.
4. Dedicated bike lanes enable bicyclists to travel at their preferred speed.
5. Shared bike lanes facilitate predictable behavior and movements between bicyclists and motorists.
6. Shared bike lanes can also serve pedestrians.
7. Shared bike lane markings should not be placed on roadways that have a speed limit above 35mph.
8. Shared lane markings are particularly useful when marked bike lanes are not an option due to street width or other factors.

a. 1, 2, 3, 5, and 8

b. 1, 3, 5, 6 and 7

c. 1, 2, 4, 7, and 8

d. 1, 2, 5, 6, and 8

14) **Mark TRUE (T) / FALSE (F) for each statement about Pedestrian Buffer zone.**

__________ Space between the sidewalk and closest lane of moving vehicles

__________ Buffer zone may include bicycle lane or parked cars

__________ Type of buffer zone includes planting strip of grass and trees

__________ Street furniture including benches, newspaper boxes, street lighting, and public art may act as a buffer zone

Chapter 7. Green Means GO: A Decision Making Tool for Measuring the Public Health Performance of Transportation Infrastructure

7.1 Research Objectives

To develop tools that empower policy makers to evaluate the multiple public health concerns in transportation infrastructure investments.

7.2 Performance Measures Plot – Safety and Physical Activity

A two-dimensional performance measure plot was created that allows decision makers to measure the transportation infrastructure against a single public health objective, such as safety or physical activity, or against both objectives. The zones were created using the data obtained from the creation of the physical activity and safety indices, detailed in previous chapters. A separate plot was developed for each mode (pedestrian and bicyclist) and location (segment and intersection). The plot designates index zones that satisfy both safety and physical activity levels. The study assigns four color codes for safety zones and physical activity levels (see Table 7.1). If an agency wants to evaluate the transportation infrastructure against multiple (both safety and physical activity measures) objectives, the designated zones or levels should be combined.

Table 7.1 Safety Zones and Physical Activity Levels Color Coding Scheme

Safety Impact	Color Code	Walkability and/or Bikeability
Negative Impact on Safety		Discourages
Negative – Minimal Impact on Safety		Discourages - Neutral Effect
Minimal - Positive Impact on Safety		Neutral Effect - Definitely Improves
Positive Impact on Safety		Definitely Improves

Decision makers can use Figures 7.1 – 7.4 to evaluate transportation infrastructure against both safety and physical activity objectives. Decision makers use the tool after field data has been collected, using the forms and worksheets provided in the previous chapters. Data from the Pedestrian Safety Assessment Index (PSAI) and the Bicyclist Safety Assessment Index (BSAI) are used to measure the transportation infrastructure against the public health objective of safety. Data from the Walkability Assessment Index (WAI) and the Bikeability Assessment Index (BAI) are used to measure the transportation infrastructure against the public health objective of physical activity. The plot allows a decision maker to determine if the particular transportation infrastructure encourages both safety and physical activity objectives, or if the objectives are in conflict. The plot between the safety and physical activity index, for a given mode and location, shows zones where both safety and physical activity follow the same definition of color coded zones (see right diagonal of Figure 7.1). When safety and walkability values in are in the green area, it suggests that this infrastructure investment has a positive impact on safety and improves walkability. Higher values indicate positive impacts. For example, using Figure 7.1, if the safety index is below a .16 and the walkability index is below .10, both public health objectives are not achieved. However, a given facility may have conditions that positively impact safety, but may have neutral effect on walkability or bikeability (non-diagonal elements). For example, using Figure 7.1 again, if the safety index value was below .16 and the walkability index was greater than .32, the plot suggests that the infrastructure has a negative impact on safety, but has a positive impact on physical activity, as measured by walkability. The same logic applies to Figures 7.2-7.4, but these account for different modes and intersections versus segments, and these have different index values. However, higher values still indicate a positive impact.

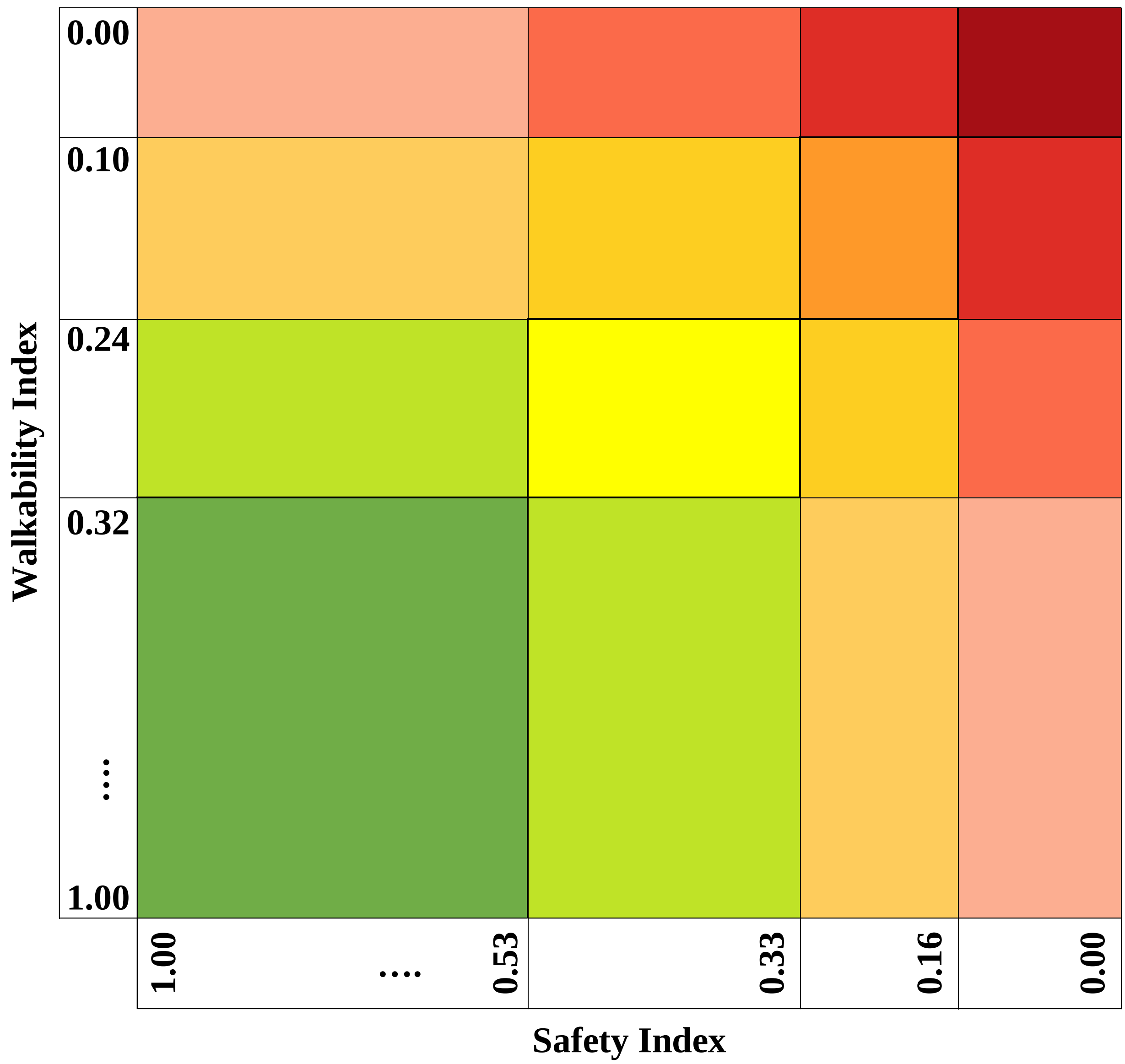


Figure 7.1 Safety and Walkability Segment Plot

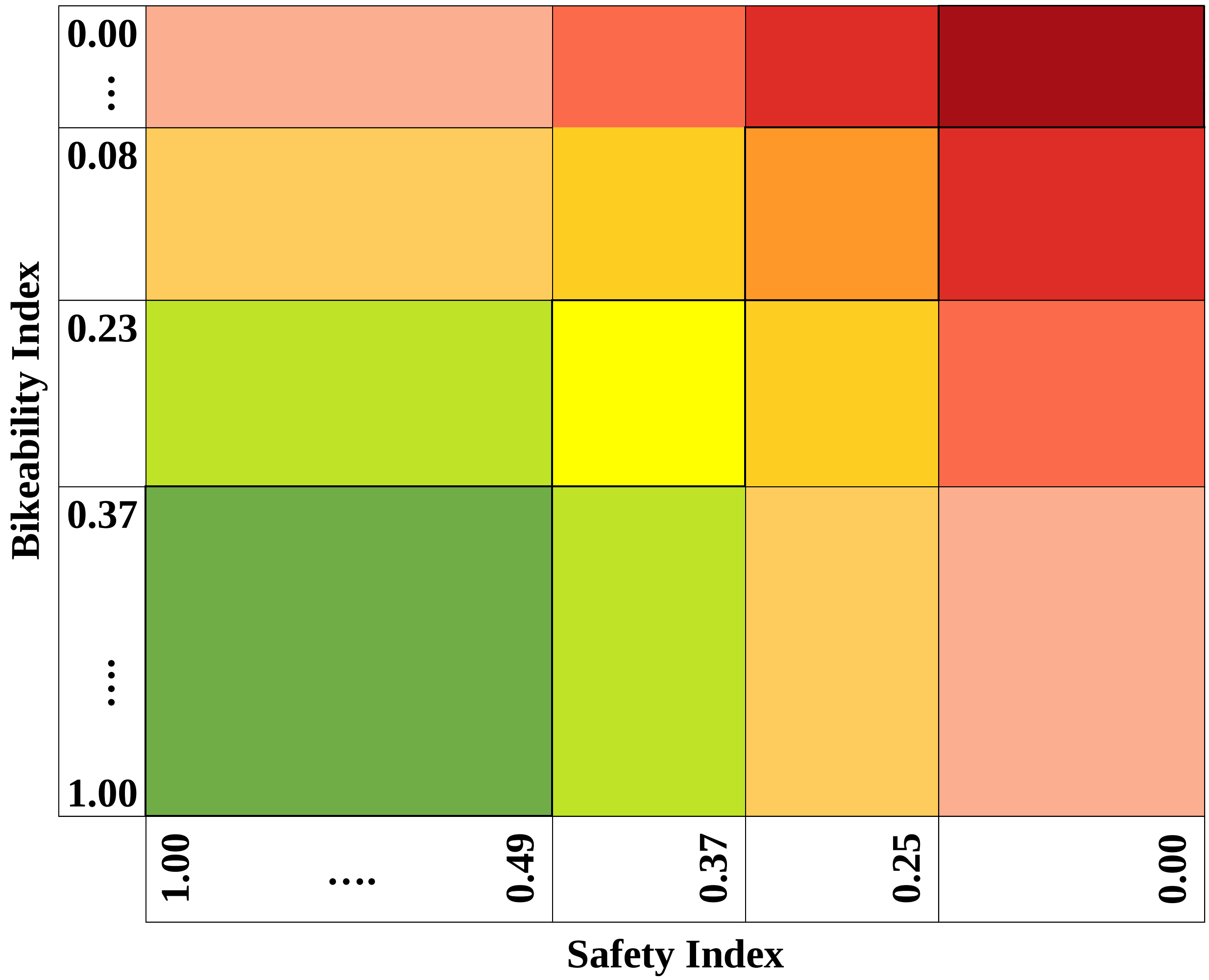


Figure 7.2 Safety and Bikeability Segment Plot

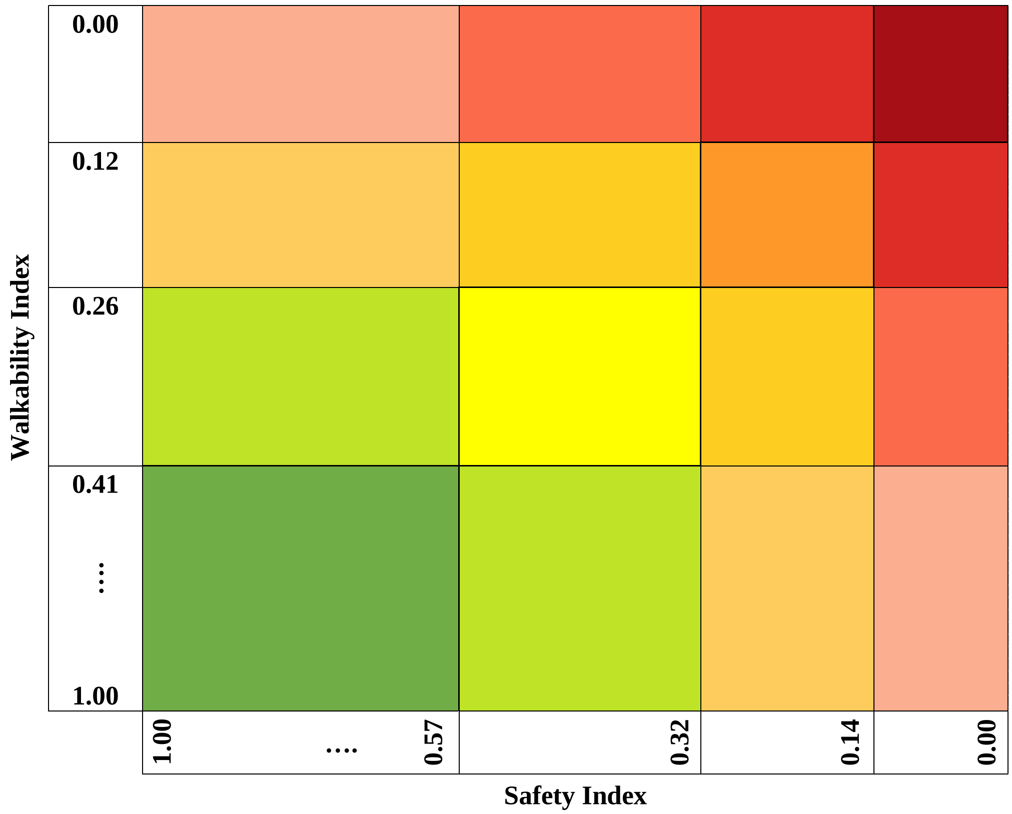


Figure 7.3 Safety and Walkability Intersection Plot

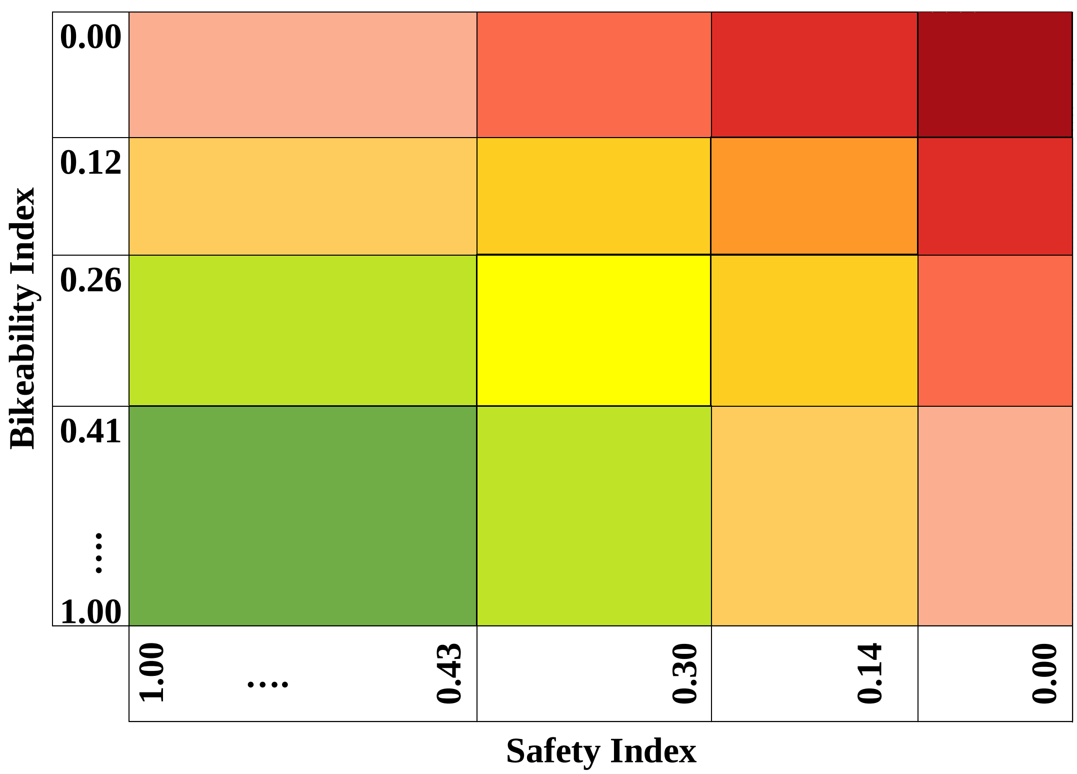


Figure 7.4 Safety and Bikeability Intersection Plot

7.3 Example Implementation Case

Dr. Smith is a principal of a school and is very interested in working with his regional Metropolitan Planning Organization (MPO) to improve the safety of the transportation infrastructure around his school, in hopes that it enables more students to walk or bike to school. Improving the minutes of physical activity students receive daily is of major importance to the school, as new evidence suggests a relationship between school performance and physical activity. However, Dr. Smith is also aware that safety is important, so she wants to better understand the best options. The tools developed through this project can help Dr. Smith work with her regional MPO to identify the preferred infrastructure investments that would achieve multiple public health objectives.

The first step is for Dr. Smith to identify and recruit data collectors. Field data is necessary to calculate the safety indices, the Pedestrian Safety Assessment Index (PSAI) and the Bicyclist Safety Assessment Index (BSAI), and the physical activity indices, the Walkability Assessment Index (WAI) and the Bikeability Assessment Index (BAI). If Dr. Smith has a partnership with a university or a high school or other nonprofit organization, she is encouraged to draw upon volunteers or students to conduct the inventory and collect the data necessary to perform the analysis. If she does not have such a partnership, she could work with the teachers and parents in the school to collect the necessary data. Involvement of others in the process of evaluation and inventory is valuable as it can raise broader community awareness of the relationship between transportation and public health.

Next, a training session needs to be designed to prepare the data collectors to inventory the transportation infrastructure around the school. The data collection teams enter the field to collect data after completing the training. After all the necessary data is collected, it must be entered into the appropriate Excel spreadsheets for analysis (in the appendix of this chapter and available on the website of the Transportation Research Center for Livable Communities). The Excel spreadsheets include the appropriate weights for each transportation element and elemental option so an overall index number can be calculated. Entering the data into the Excel spreadsheet produces scores that can be plotted in the Performance Measures Plots, to determine how the existing transportation facility affects public health objectives. Each step in the process is elaborated below.

Step 1. After the data collection team has been recruited, the team would attend a 60-minute training session to prepare them for data collection in the field. Training manuals are provided in the appendix of this chapter for the training session (Appendix 7A-PA Inventory Manual and Appendix 7B-Safety Inventory Manual). Two manuals are prepared to educate data collection volunteers on the different elements of the infrastructure for the assessment of safety, air quality and physical activity. The first manual covers ***physical activity*** and the second manual covers ***safety***. The manuals ***are divided into subsections: Intersection and Segment for Pedestrians and Bicyclists.*** Survey forms are prepared for each of these modules and sections. Students (or community volunteers) can use these inventory forms for collecting data on transportation infrastructure elements data in the field or virtually (online using google earth). Each manual discusses the different types of infrastructure elements and definitions that the data collectors need to know before collecting data related to the selected public health objectives. Visual aids are also included to illustrate possible infrastructure elements and options. The visual aids will help data collectors identify the elements of the transportation infrastructure in their area of study. At the end of the training, the data collection team should be required to evaluate one road segment and one intersection using each inventory to make sure all data collectors are using the materials correctly.

Step 2. After successfully completing training, two-person teams should be assigned to collect data on the road segments and intersections surrounding the location, in this case the school. Each road segment and intersection should be assigned a segment or intersection number for data entry purposes. Assigning duplicate teams to the same segment or intersection can enhance the reliability of the data collection as it allows one to check for inter-rater reliability. Division of labor can be based upon the number of volunteers. The forms that match the data collection responsibilities of the two-person teams are listed in Table 7.2.

Table 7.2 Team Data Collection Responsibilities and Required Forms

Team Number	**Infrastructure**	**Public Health Objective**	**Mode Type**	**Form**
1	Segment	Safety	Bicyclist	Bike Safety Segment
1	Intersection	Safety	Bicyclist	Bike Safety Intersection
2	Segment	Safety	Pedestrian	Ped Safety Segment
2	Intersection	Safety	Pedestrian	Ped Safety Intersection
3	Segment	Physical Activity	Bicyclist	PA Bike Segment
3	Intersection	Physical Activity	Bicyclist	PA Intersection
4	Segment	Physical Activity	Pedestrian	PA Walk Segment
4	Intersection	Physical Activity	Pedestrian	PA Intersection

Step 3. The teams are sent into the field to inventory the infrastructure. The inventory is a survey that contains a checklist of questions with close-ended options. It is relatively simple to complete while in the field.

Step 4. After collecting the data, the teams should submit the data collection to one team or assigned individual, which would be responsible for entering the data entry into the respective Microsoft Excel sheet for the necessary analysis. After the data is entered into a database, responses are converted into binary responses and then index values are calculated (Excel formulas are pre-programmed into the workbook). An example is provided in the first column of each Excel spreadsheet. Table 7.3 presents a list of the Excel sheets and numbers that correspond to the different field inventories.

Table 7.3 Crosswalk Between Excel Spreadsheets and Field Inventories

Team Number	**Inventory Form**	**Excel Spreadsheet**
1	Bike Safety Segment	5. Bike Seg Safety
1	Bike Safety Intersection	3. Bike Int Safety
2	Ped Safety Segment	4. Ped Seg Safety
2	Ped Safety Intersection	2. Ped Int Safety
3	PA Bike Segment	6. PA Seg Bike
3	PA Intersection	1. PA Int Walk/Bike
4	PA Walk Segment	7. PA Seg Walk
4	PA Intersection	1. PA Int Walk/Bike

Step 5. The Excel spreadsheet is formatted to calculate a value for each segment and intersection in each direction (East Bound/North Bound or West Bound/South Bound). The overall score will be calculated and appear at the end of each column. This score can then be located in the appropriate Performance Measures Plot to determine its overall impact on public health.

For example, consider the segment scores provide in the Excel spreadsheets for the hypothetical segment, Segment 101. If Dr. Smith is interested in knowing how Segment 101 influences the public health dimensions of physical activity and safety, she looks up the scores calculated in Spreadsheet #7, PA Segment Walk, and Spreadsheet #4, Ped Seg Safety. Spreadsheet #7 provides two scores, .36 (EB/NB) and .34 (WB/SB), one for each direction. Spreadsheet #4 also provides two scores for each direction, .43 and .42. These values can then be plotted in the Safety and Walkability Segment Plot, Figure 7.1 above. The plot location suggests this is a segment that is relatively safe and walkable as all scores fall into the green areas. Dr. Smith could also use the spreadsheets to determine how the safety or walkability of this segment could change if certain elements are added or different options are considered. Table 7.4 presents the crosswalk between the Excel Spreadsheets and the Performance Measures Plots.

Table 7.4 Crosswalk between Excel Spreadsheets and Performance Measures Plot

Public Health Objective	**Scores to Consider**	**Excel Spreadsheet**	**Performance Measures Plot**
Safety	Bicyclists-Segment	5. Bike Seg Safety	Safety and Bikeability Segment Plot
	Bicyclists-Intersection	3. Bike Int Safety	Safety and Bikeability Intersection Plot
	Pedestrian-Segment	4. Ped Seg Safety	Safety and Walkability Segment Plot
	Pedestrian-Segment	2. Ped Int Safety	Safety and Walkability Intersection Plot
Physical Activity	Bikeability-Segment	6. PA Seg Bike	Safety and Bikeability Segment Plot
	Walkability and Bikeability-Intersection	1. PA Int Walk/Bike	Safety and Bikeability Intersection Plot and Safety and Walkability Intersection Plot
	Walkability-Segment	7. PA Seg Walk	Safety and Walkability Segment Plot

As mentioned previously, the index scores and plots presented here do not account for traffic or other social or behavioral characteristics of the population that may influence public health outcomes. Therefore, Dr. Smith is advised to use these tools as a way to quantify the performance of the transportation infrastructure; however, final decisions must also take into consideration other features that are unique to the particular context.

7.4 Air Quality Performance Measures

In this section, the method used to create the air quality performance measures and how to use the measures are discussed.

Concentration of 1-hr pollutant exposure for zonal boundaries:

According to National Ambient Air Quality Standards (EPA), 1-hr CO concentration in parts per million is 35. According to the National Institute for Occupational Safety and Health (NIOSH), Emergency Exposure Guidance Levels (EEGLs) and Immediately Dangerous to Life or Health Concentrations (IDLH) for 1-hr exposure are 400 ppm and 1200 ppm respectively (CDC, 2014). Based on these values, the research team develops the zonal boundaries in Table 7.5.

Experimental studies suggest that nitrogen dioxide (NO_2) can have a significant, negative health impact when its 1-hr concentration exceeds 200 µg/m^3 (WHO, 2005). Hesterberg, et al., (2009) found that 0.6 ppm of NO_2 exposure for 1-hr is harmful for the asthmatic population. Table 7.5 shows 1-hr exposure concentration for NO_2, their sources and impacts.

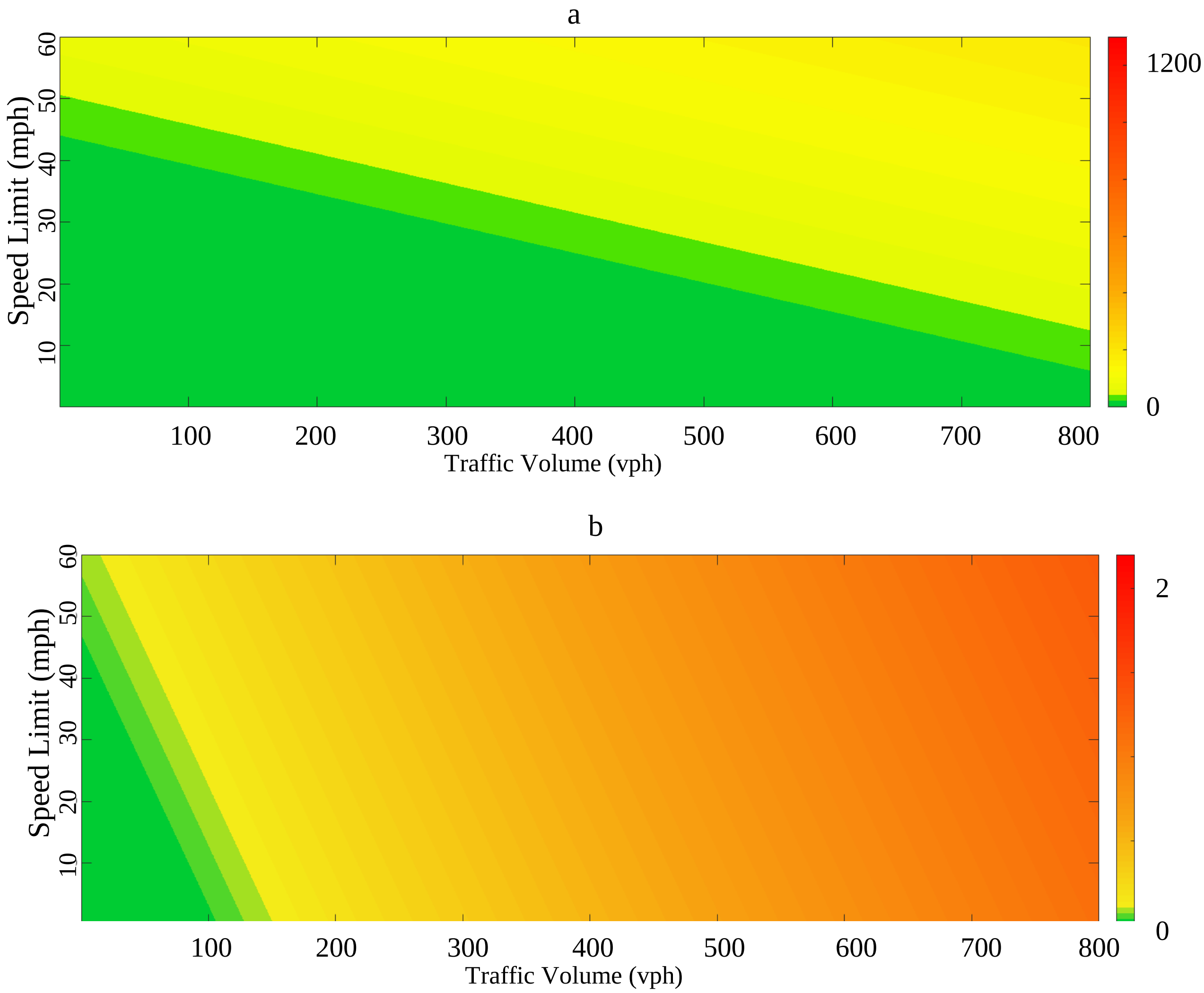
Researchers at the University of Alberta used a location specific parameter based equation and converted 24-hour $PM_{2.5}$ concentrations of 30 µg/m^3 to 1-hour concentrations of 80 µg/m^3. According to the Alberta Index of the Quality of the Air (IQUA) the breakpoint 1-hour concentration for $PM_{2.5}$ is 40 µg/m^3 for a good rating, and then less than or equal to 80 µg/m^3 is fair and above that is poor (Fu, et al., 2016). The research team uses these values directly with a minor modification (linear interpolation) for getting the final category boundary. Table 7.5 shows 1-hr $PM_{2.5}$ concentrations with their health categories.

A 10 µg/m^3 increase in daily PM_{10} is associated with a 0.43% increase in mortality due to all natural causes (Qian, et al., 2010). A 10 µg/m^3 increase in daily PM_{10} is associated with a 0.75% increase in mortality due to all natural causes among the elderly in Italy (Forastiere, et al., 2008). A concentration of 25 µg/m^3 represents the breakpoint between good and fair air quality and 50 µg/m^3 represents the breakpoint between fair and poor air quality based on the 24-hour rolling average PM_{10} concentration in City of Montreal, British Columbia and the Greater Vancouver Regional District (Fu, et al., 2016). On the other hand, a 10µg/m^3 increase in the 24-hour exposure corresponds to approximately a 15µg/m^3 increase in the 1-hour max (EPA, 1995). Son & Bell, (2013) show in their research that an increase in 10µg/m^3 in 1-hr maximum PM_{10} is associated with a 0.10% increase in total mortality. A comparison between different exposure metrics shows that a 1-hr average PM_{10} concentration (94.1 µg/m^3) is significantly higher than the other exposure metrics. Based on this information, the research team interpolated the 1-hr (short-term) PM_{10} Concentration in Table 7.5.

For each of the pollutants, the research team calculates the average 1-hr concentration from both counties and plots it against Speed (Y-axis) and Volume (X-Axis) graph. The scale on the right side shows the concentration level for each pollutant. Using the zonal boundaries set before (Table 7.5), the right-hand side scale is modified to show the average 1-hr concentration. This modification helps identify the health risk boundaries (see Figure 7.4 a-d) for different combinations of speed and volume. This graph can be used as a tool to identify the potential pollutant concentration at a height of 3.5 ft. for different volume and speed combinations.

TABLE 7.5 1-hr Concentration (ppm) of Pollutants and their Zonal Boundaries

CO (ppm)	NO_2 (ppm)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	Criteria
0-35[7]	0-0.11	0-37.5	0-40	Excellent
35-400	0.11-0.6[8]	37.5-75.0	40-80	Good
400-1200	0.6-2	75.0-112.5	80-120	Fair
>1200	>2	>112.5	>120	Poor



[7] *CO concentration from CDC. retrieved from www.cdc.gov/niosh/idlh/630080.html*

[8] *Hesterberg, et al., (2009). critical review of the human data on short-term nitrogen dioxide (no2) exposures: evidence for no2 no-effect levels. critical review in toxicology, 743-81*

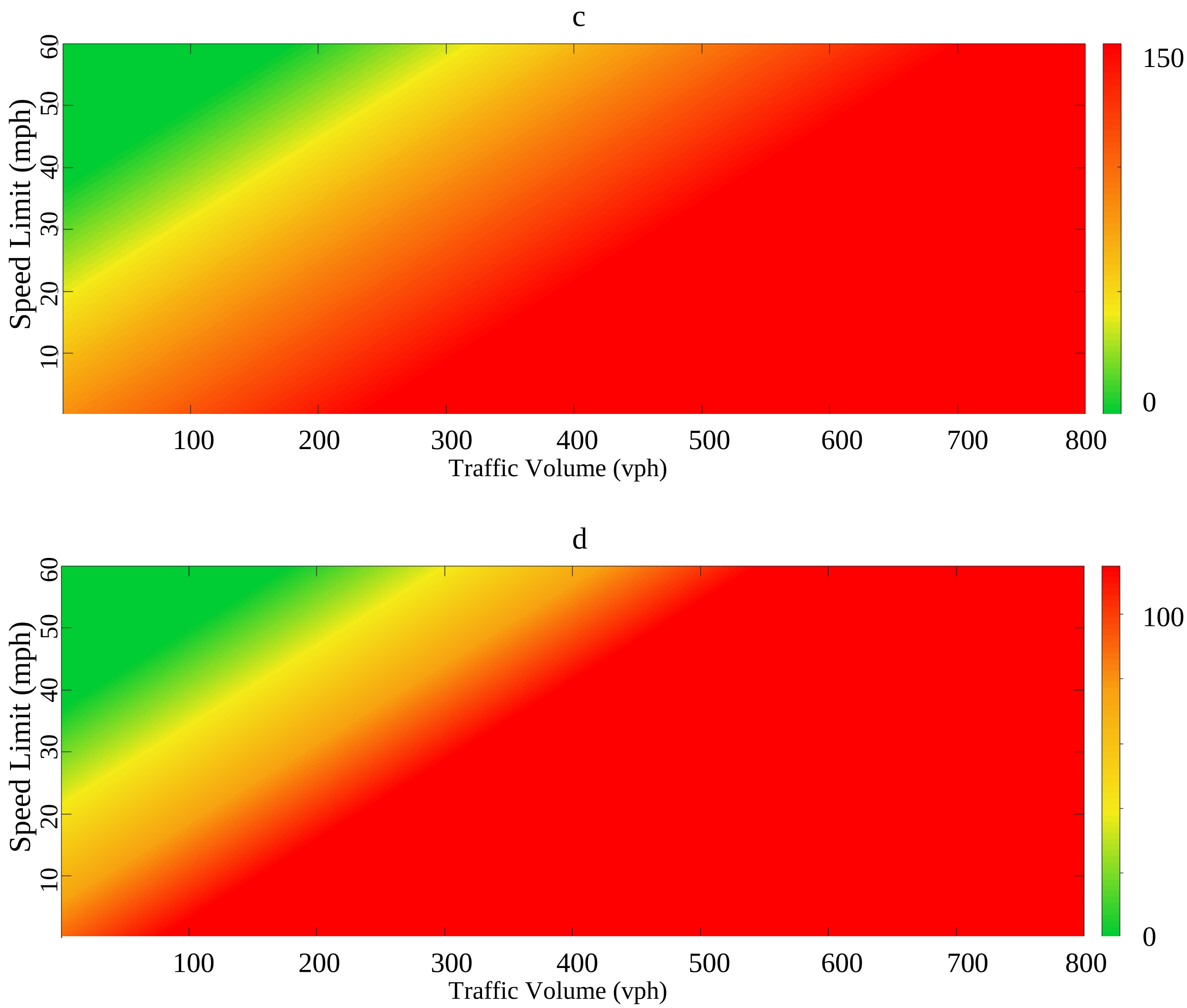


Figure 7.3 a) 1-hr CO concentration; b)1-hr NO_2 concentration; c) 1-hr $PM_{2.5}$ Concentration; and d) 1-hr PM_{10} concentration

7.5 Example Implementation Case of Using the Air Quality Graphs

Dr. Smith has completed collection of the information on physical activity and safety, but now wishes to evaluate the potential impacts of air quality along a particular road segment. The major data she needs to collect in the field is traffic volume in veh/hr and speed limit in (mph). With these two variables and the modelled graphs provided above she can easily find out the exact condition of the road segment. She does this by mapping the traffic volume on the x- axis, and the speed limit on the y-axis. The color coding indicates the health rating of the intersection of these two points. For example, if Dr. Smith wants to check $PM_{2.5}$ concentrations (Figure 7.5), along a road segment with a volume of 500 vehicles per hour, regardless of the speed limit of the road, the designated zonal boundaries could be either ‘Fair’ or ‘Poor’. This is because the entire bar is colored red to orange at any speed. Thus, the $PM_{2.5}$ concentrations for short-term exposure is not healthy and hence, this may discourage physical activity and may conflict with public health objectives of walking or bicycling. On the other hand, for a road segment with 200 vehicle/hr traffic and a speed limit of 40 mph, the $PM_{2.5}$ concentration is in excellent condition.

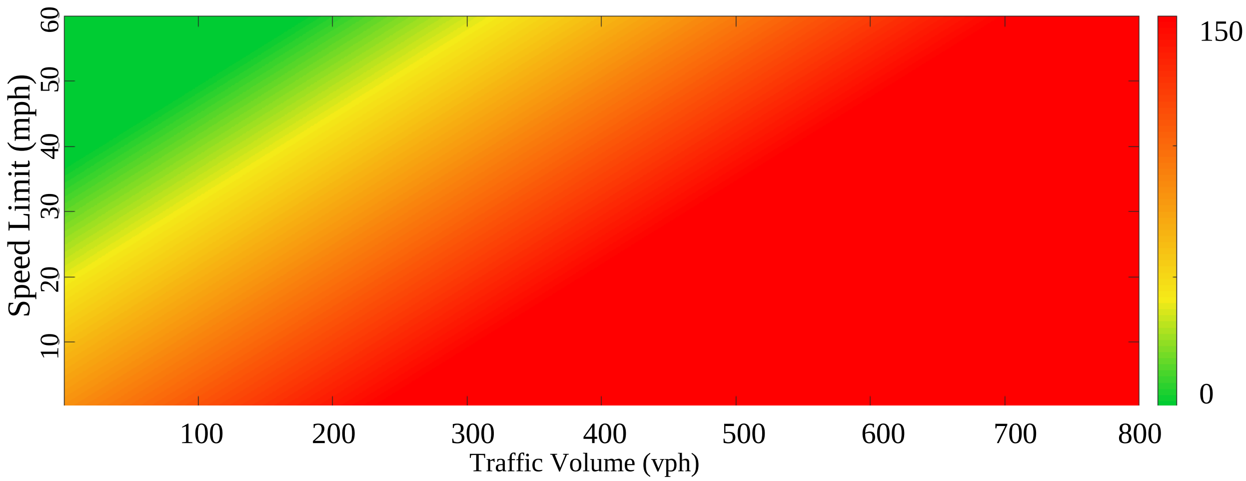


Figure 7.4 1-hr PM2.5 concentration

The research team uses base case scenarios for developing the zonal map for the pollutants, so decision makers should keep in mind that the graphs are based on only two different sites. However, the graphs still do provide an indication to decision makers of the potential presence of pollutants to which adults and kids may be exposed when engaging in physical activity along a particular route. If any agency wants to identify area specific concentration of pollutants, AERMOD should be used instead of CALINE4, which gives more flexibility in defining a location and its meteorological conditions.

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Appendix 7A: PA Inventory Manual

Physical Activity Assessment – Observers' Manual

This manual provides information on collecting transportation elements and elemental options that relate to physical activity at both intersections and segments.

Table of Contents

Table of Figures

1. Intersection Elements

1.1. Intersection types

According to MUTCD, an intersection is the area within the crosswalks and/or beyond the stop lines or yield lines and is controlled by traffic control signals. Different types of intersection are available. Some intersection even might not have a traffic signal system because of not meeting the requirements of Signal Warrant.

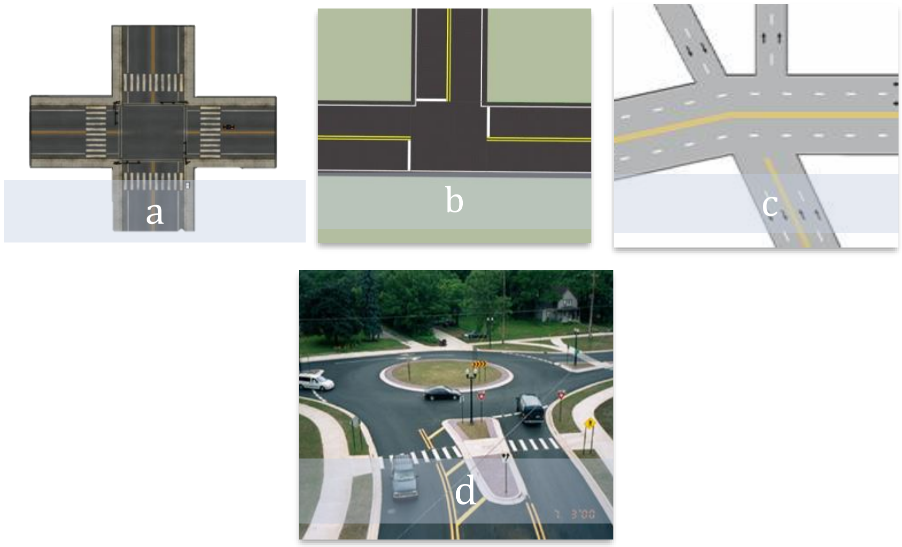

Figure 2 Types of Intersection; a. 4-way[1], b. 3-way[2], c. multi-leg[3], d. traffic circle[4]

1.2. Crosswalk

A crosswalk is the place where pedestrians and bicyclist safely cross the street across the flow of traffic and it is either at an intersection or at a midblock segment placed at the right angle of the centerline of the roadway. Crosswalks by themselves do not provide safety but at least it alerts drivers about the presence of cyclists and pedestrians.

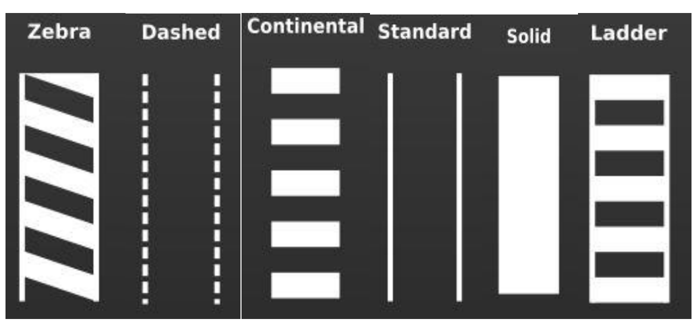

Figure 3 Different types of crosswalk markings[5]

All approach of an intersection should have crosswalk markings but due to wear and tear and improper maintenance, it might not be present at all locations. Different cities and MPOs use different combinations and approaches when it comes to placing crosswalk. The length of a crosswalk mainly depends on the number of through lanes present at that direction plus the turning lanes. The standard lane width range is 9ft-12ft.

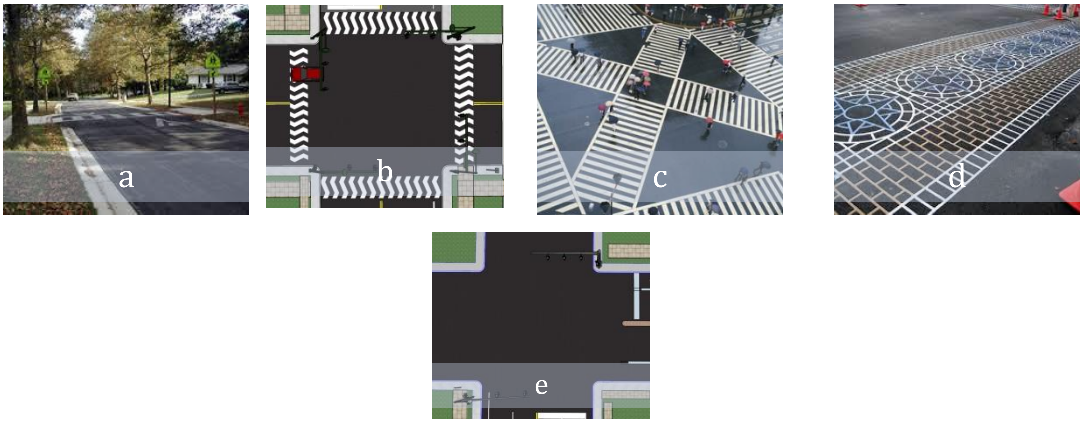

Figure 4 Use of Crosswalks; a. Raised[6], b. all approach[7], c. scrabble[8], d. textured[9], e. no markings

1.3. Traffic Control Devices

Different types of traffic control devices are used at an intersection. Standard most common devices are shown in figure 4.

a b c

Figure 5 Types of traffic Control Devices; a. Traffic Signal [10], b. Yield Sign[11], c. Stop Sign[12]

1.4. Pedestrian/bike crossing signals

A single device or a combination of devices and/or technologies should be present at the location of a pedestrian or bike crossing. Some examples are shown in figure 5.

a b c d

Figure 6 Pedestrian Crossing Control Devices; a. alphabetic walk sign[13], b. walk/do not walk sign[14], c. walk sign with counter[15], d. audible counter signal[16]

1.5. Pedestrian/bike crossing sign

Different types of pedestrian crossing warning signs are used for alerting drivers.

a b c d e

Figure 7 Pedestrian cross sign; a. Yield for pedestrian[17]., b. Stop for Pedestrian[18]., c. Crosswalk 1[19], d. crosswalk 2[19], e. Pedestrian/bike Crossing[19]

1.6. Intersection Lighting

Proper lighting at the intersection is important for safe movement of traffic. It helps driver identify movements of pedestrians and bicycles. A minimum of two light standards are required at a 4-way intersection. Different measuring tools can be used to measure the amount present at certain location. Shailesh *et al.* (2014) used LuxMeter (an Iphone app) for a visibility based path finding methodology for selecting bike path and walk path [20].

> (*Time rate flow of light is measured in lumens (lm). One lumen is the amount of light which falls on an area of one square foot, every point of which is one foot from the source of one candela. One foot candle is the illumination of a surface one square foot in area on which there is a uniformly distributed luminous flux of one lumen. One foot candle is 10.76 lux*)[21]

According to WSDOT, the standard design guideline for light level are shown in the following table:

Table 9 Light level Standard chart[21]

Light Level and Uniformity Ratio Chart					
Highway Design Class	Minimum Average Maintained Horizontal Light Level[2]			Maximum Uniformity Ratio[5]	Maximum Veiling Luminance Ratio[6]
	Pedestrian/Area Classification				
	High (footcandles)	Medium (footcandles)	Low (footcandles)		
Highways With Full Access Control[1][8]					
Main Line	0.6	0.6	0.6	4:1	0.3:1
Ramps	0.6	0.6	0.6	4:1	0.3:1
Crossroads	0.6	0.6	0.6	4:1	0.3:1
Ramp Intersections	0.9	0.9	0.9	4:1	0.3:1
Highways Without Full Access Control[3][8]					
Main Line	1.2	0.9	0.6	4:1	0.3:1
Intersections	1.2	0.9	0.9	4:1	0.3:1
Other Illuminated Features					
Construction Lanes and Detours	1.0	1.0	1.0	4:1	0.3:1
Major Parking Lots/Rest Areas	0.8	0.8	0.8	4:1	0.3:1
Vehicle Inspection Areas	2.0	2.0	2.0	4:1	0.3:1
Sidewalks, Walkways & Shared Use Paths	0.8	0.8	0.8	4:1	0.3:1
Weigh Scales	0.8	0.8	0.8	4:1	0.3:1
Transit Stops[4]	2.0	2.0	2.0	NA[7]	0.3:1
Midblock Ped X-ing	2.0	2.0	2.0	4:1	0.3:1

1.7. Traffic Calming

Different types of traffic calming techniques are used by cities and MPOs. These are mainly used to reduce speed along the neighborhood, which in turn also ensures safety of pedestrians and bicyclists.

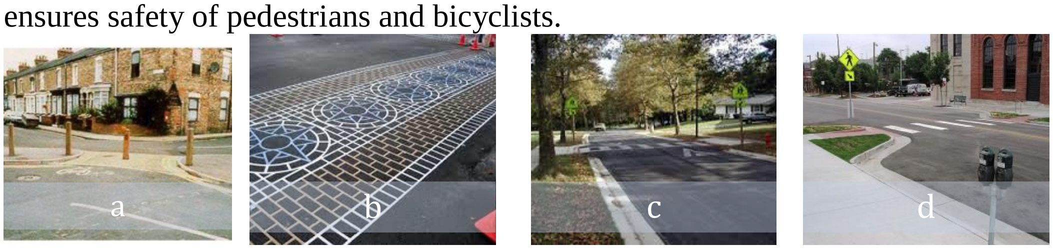

Figure 8 Examples of Intersection Calming Techniques; a. diagonal diverter[22], b. textured-crosswalk[9], c. raised[6], d. bulb-out[23]

1.8. ADA Compliance

All design of the intersection element should follow American Disability Act. As for intersection, curb ramp should be present at all crossing providing ample area for wheelchair or motorized wheelchair to steer clearly. Some examples of curb ramp are given in the pictures.

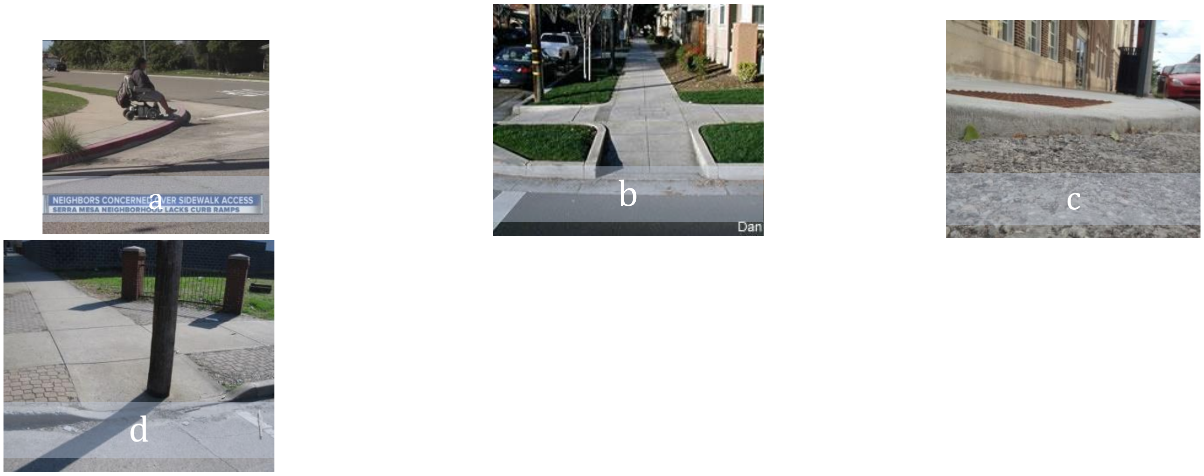

Figure 9 Curb Ramp; a. No ramp[24], b. 100%useable[25], c. not useable[27], d. <50% useable[27]

1.9. High-intensity Activated crossWalK (HAWK) becon

HAWK beacon (**H**igh-Intensity **A**ctivated cross**W**al**K** beacon) is a traffic control device used to stop road traffic and allow pedestrians to cross safely. It is officially known as a **Pedestrian Hybrid Beacon** (**PHB**). The purpose of a HAWK beacon is to allow protected pedestrian crossings, stopping road traffic only as needed. Where standard traffic signal 'warrants' prevent the installation of standard three-color traffic signals, the HAWK beacon provides an alternative. [68]

Figure 9 HAWK becon[69]

1.10. Other important factors

Factors such as presence of refuge island, advanced stop line, advanced yield sign, right turn red light are some important techniques, which increases the safety of pedestrians.

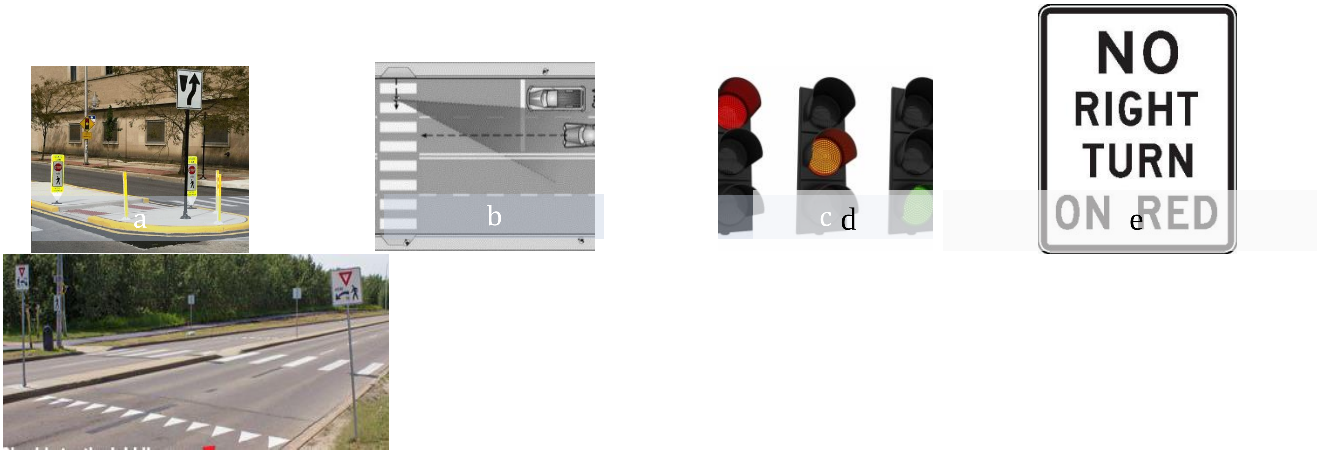

Figure 10 Other advantageous factors for pedestrians and bicyclists; a. refuge island28, b. Advanced Stop Line29, c. Cycle length10, d. No Turn on red and31 e. Advanced Yield line30

2. Segment Elements

2.1. Number of lanes

An intersection can have different combinations of lane numbers depending upon the presence of major and minor arterials. The total number of lanes of the major arterial going towards NB/SB/EB/WB direction is important if there is a midblock crossing present. When counting number of lanes, turning lanes are not considered (MUTCD-2009).

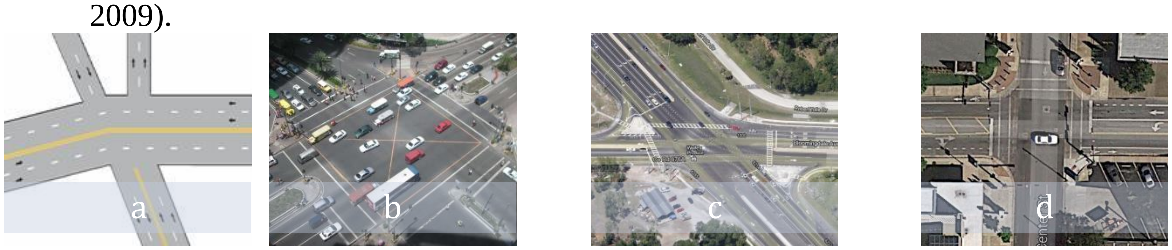

Figure 11 Different combinations of intersection lanes; a. two-lane two-way [3], b. three lane[32], c. two lane and one lane[33], d. one lane all direction[34]

2.2. Speed Limit

Speed limit is assigned for reducing accidents. Posted speed limit is lower than the design speed for safety reasons.

2.3. Traffic Calming

Different types of traffic calming techniques are used by cities and MPOs. These are primarily used to reduce speed along the neighborhood and in turn also improves safety of pedestrians and bicyclists. Traffic calming devices used for road segments are as follows:

Figure 12 Traffic Calming techniques for road segment; (clockwise from top left) a. Speed enforcement[37], b. speed bump[38], c. roundabout[4], d. chicane [39], e. median [40]

2.4. Midblock crossing

Midblock crossing are required when there are a lot of pedestrian movement near school, shopping and restaurant areas (41). When there is a midblock crossing a number of control measures should be taken to prevent any types of accidents.

2.5. ADA compliance

When designing pedestrian right of way, it is regulatory to follow ADA standards. A minimum of 36 inch is required for wheelchair usage with a grade of not more than 14 percent (42). Sidewalks become unusable for wheelchair for almost the same reason they become unusable at the intersections.

2.6. Sidewalk

A sidewalk is a designated space along the side of the road separated by a curb. Sidewalk can be present along all sides of major and minor arterials in pedestrian friendly design. However, in poor designed areas, sidewalks can be absent in one or both side of the road. In cases, it is also seen that sidewalk started at the intersection and after some distance disappeared. A continuous paved sidewalk separated from vehicle traffic by curb and buffer or curb with buffer provides a safe place for kids to walk to school and/or bike (43). Sidewalks should also follow ADA design standards. Things to consider for sidewalk are discussed in the following literature.

2.6.1. Continuity: The continuity of a sidewalk is very important for the safety of pedestrians and bicyclists (43, 44). Discontinuous sidewalks force pedestrian and bicyclists to cross the road and move to the other side of the arterial and then cross back again to get to the designated desired place. Sometimes, absence of sidewalks lead to walking on the street.

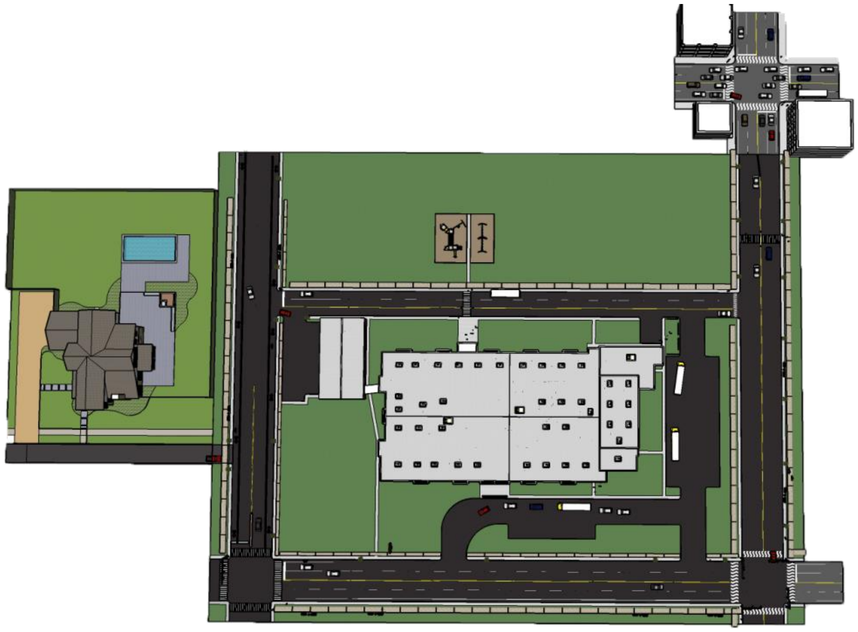

Figure 13 Continuity of sidewalk[45]

2.6.2. Width of sidewalk: A proper sidewalk should have a minimum of five to six feet of sidewalk width depending upon the presence of pedestrian usage (43, 46). Near shopping area, schools, parks and restaurants a minimum of eight feet sidewalk is required (46).

Figure 14 Width of sidewalk; a. pedestrian only[44], b. shared[47]

2.6.3. Sidewalk surface condition: It should be firm, stable and slip –resistant (43). Due to improper maintenance, earth movement and some other conditions, sidewalks become less useable.

Figure 15 Percent of Sidewalk Usability; (clockwise from top left) a. Unpaved[48], b. <25%[49], c. <50%[50], d. <75%[51], e. 100%[52]

2.6.4. Obstruction: Sidewalk obstruction mostly can occur due to misplacement of construction materials, signposts, utility poles, parked cars, trashcans and fire hydrants (51, 52, 54). Several situations are shown in the following figures.

Figure 16 Sidewalk obstruction; (clockwise from top left a. 100% blocked[53], b. >75% blocked[54], c. >50% blocked[55], d. 0% blocked[45], e. >25% blocked[56]

2.6.5. Sidewalk Buffer: A sidewalk buffer is the space between rightmost traffic lane and the sidewalk. Four types of sidewalk buffers can be present. They are planting strips of grass and trees, bicycle lanes, parallel parked cars and street enhancement fixed objects (light poles, benches) (43). A combination of these four types of buffers can also be found in the field.

Figure 17 Sidewalk Buffer; (clockwise from top left) a. no buffer, b. parallel parking[58], c. bicycle lane[59], d. Street furniture[60], e. Parallel parking and bicycle lane[61]

2.6.6. Sidewalk Lighting: Pedestrian visibility and personal security plays an important role when choosing a walking or bike route for both recreational and utilitarian use. Light level for the road segment from Table 1 should be used.

2.6.7. Presence of Driveways: Driveways should be designed such a way that it does not hamper the regular movement of regular pedestrians, pedestrians with disabilities and bicyclist. Drivers should be continuously cautioned about the presence of pedestrians and bicyclists. Fewer driveways and narrower driveway crossings are safer for school area (43).

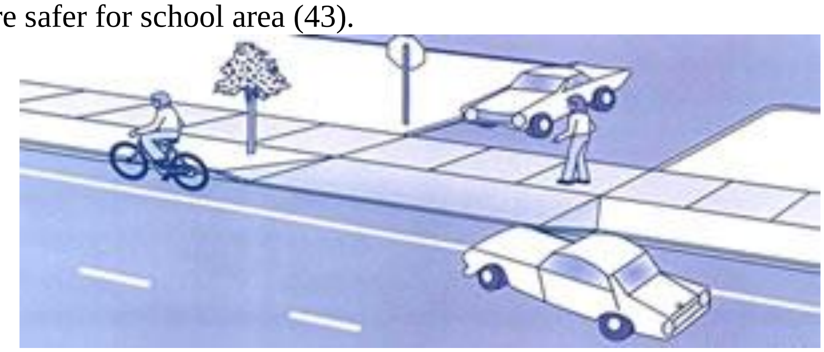

Figure 18 Wing type driveway[43]

2.6.8. Aesthetics and perceived safety: Presence of illegal wall graffiti, littering, overflown trash, abandoned houses and parking lots are examples of negative features of a sidewalk that deter people from walking or biking along it. On the other hand, proper illuminated seating areas, flashing reduced speed sign, school crossing guards are some features that enhance the perceived safety of pedestrian especially in the school zone.

2.6.9. Median: Medians divide the travel way at the center to separate the traffic from opposing directions. Raised medians act as a safety refuge and can accommodate pedestrian and bicyclists. Presence of a refuge island is one of the pre-requisites for a complete street (62). Different types of medians can be present which may or may not serve the purpose of a refuge island. According to TXDOT design standards, for pedestrian movement, at least a 5ft x 5ft refuge island must be provided for safety (63).

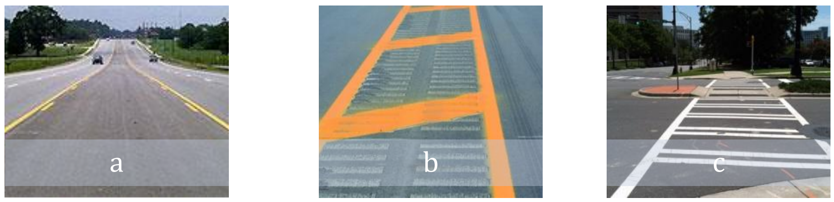

Figure 19 Medians; a. Two-way Turning Lanes[64], b. Rumble Strip Median[65], c. Raised Median[67]

3. Meteorological Information

Air quality plays an important role while choosing a walking route or a biking route. Presence of high volume traffic in hot summer afternoon may pose severe environmental threats for pedestrians and cyclists. Different types of vehicles emit various levels of emissions at different temperature. In school areas, parents also create pockets of bad air while stalling in the parking lot to drop off kids for school. Road type, vehicle type, aerodynamic roughness coefficient, altitude, wind speed, temperature, CO emission factor are variables that control the quality of air near school zone or any type of walking or biking route along a major arterial. Only diesel and gasoline engine vehicles are considered in air quality measurement. For simplicity, only vehicles and trucks will be used. Altitude, wind speed, and temperature of the study area control the rate of plume spreading. Widths of the roadway and traffic volume are required for analysis in CALINE for predicting air pollutant concentration near roadways. Preexisting CO concentration has to be identified from EPA website for analysis.

3.1.1. Aerodynamic roughness coefficient

It determines the amount of total local air turbulence that affects plume spreading.

Table 2. Aerodynamic Roughness Coefficient defined for various types of landscapes[68]

Roughness Coefficient (cm)	Landscape Type
0.002	Sea, paved areas, snow-covered flat plain, tide flat, smooth desert
0.5	Beaches, pack ice, morass, snow-covered fields
3	Grass prairie or farm fields, tundra, airports, heather
10	Cultivated areas with low crops and occasional obstacles (such as bushes)
25	High crops, crops with varied height, scattered obstacles (such as trees or hedgerows), ineyards
50	Mixed far fields and forest clumps, orchards, scattered buildings
100	Regular coverage with large obstacles, open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests
≥200	Centers of large towns or cities, irregular forests with scattered clearings

4.1.1. Road Type

Arterials are considered as restricted road and freeways are considered as unrestricted roads.

4. Land Use and Social Behavior

Different types of land usage influence walking and cycling. Presence of shopping mall, parks, historical sites, restaurants have positive impact on deciding whether or not to walk/bike. The total number of people using the walking path or bike path or both for recreational purpose is also important for increasing physical activity. For further analysis, data needs to be collected to identify gender variation, age variation, and purpose of the use.

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Appendix 7B: Safety Inventory Manual

Safety Assessment - Observers' Manual

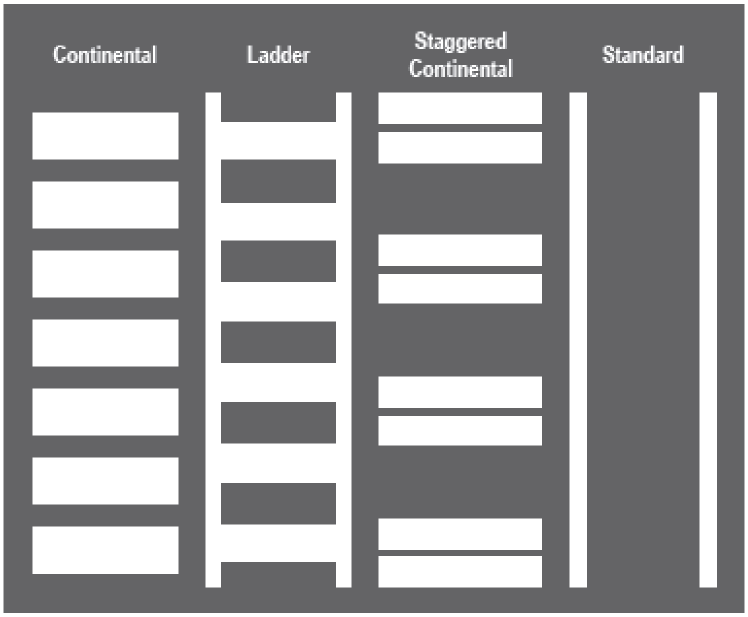
This manual provides information on collecting pedestrian and bicyclist safety features data at both intersections and segments.

Table of Contents

Pedestrian - Intersection - Safety Assessment

Crosswalks

Following are the types of crosswalk that may present at an intersection.



Types of Crosswalk[1]

Count directions that the crosswalks are present at the intersection. For instance, the figure shows continental crosswalks in four directions.

Continental Crosswalks[2]

Pedestrian Count Signal

Count the number of crosswalks that have pedestrian signals with countdown timers and with NO countdown timers.

Pedestrian Signal with Time Counters[3]

a[4] *b*[5]

Pedestrian Signal without Time Counters

No Right Turn on Red (RTOR) Sign Restrictions
Count the number of directions where a “No Turn on Red” restriction sign is present.

No Turn on Red Restriction Sign[6]

Signage
Look for signs that warn vehicular traffic about pedestrian crossings.

a[7]

b[3]

Warning Signage

Pedestrian - Segment - Safety Assessment

Pavement Markings

Look for marking at mid-block pedestrian crossings. If present, mark as 'adequate' unless otherwise.

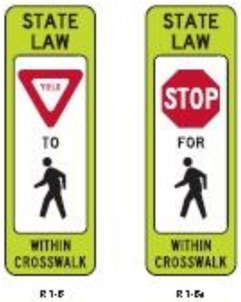
a[8]

b[3]

Markings at Mid-block Pedestrian Crossings

Signs for Pedestrians

Observe for presence of adequate signage.



Pedestrian Signage[3]

Raised Median Island / Presence of Median

Observe whether a pedestrian can take refuge, if needed, in the median while crossing the street.

a[9]

b[3]

Road Median Types

Pedestrian Beacon / Presence of Hawk Signal
These are the pedestrian signals present at midblock.

a[10]

b[11]

c[12]

d[13]

Pedestrian Signals at Midblock

Traffic Calming Features

Traffic calming features are physical features that reduce the negative impact of motor vehicles by slowing their speed. Observe all traffic calming features present. A few examples are shown below:

Curb Extensions/Bulb outs

Mini-Circles

Partial Closures

Roundabouts

Speed Humps

Speed Tables

Chicane

Rumble Strips

Speed Enforcements

Traffic Calming Features[14]

Sight Distance

See if the line of sight for a pedestrian crossing the street is restricted due to presence of curves, objects like buildings, or other objects.

Location with Limited Sight Distance[15]

Driveways

Count the number of driveway or minor streets cuts along the street segment. A parking garage should count as two drive-way cuts. Both sides of the street should be rated.

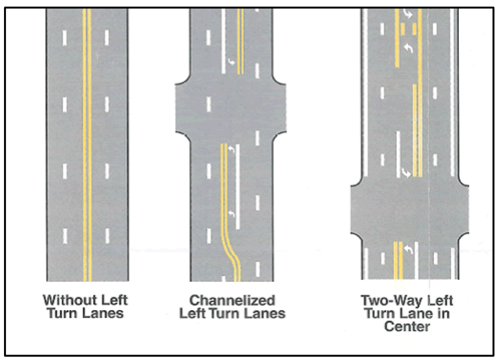
Driveway

Parking Garage

Sample Driveway Locations on a Street Segment[14]

Number of Traffic Lanes to Cross

Count the number of lanes. Do not count two-way left turn lane or bike lanes. For example, the lane configurations illustrated below have four lanes.



Traffic Lane Configurations[16]

Presence of Curb

Curb Location on a Street Segment[17]

Commercial Land use

Label the land use as commercial if there is a majority of businesses, stores, markets, restaurants, salons, etc., are present on any side of the segment.

Width of Sidewalk

Use tape measurement to obtain width of sidewalk. In urban settings, measure sidewalk width from curb to building line or landscaped area. Do not measure sidewalk width at locations like a bulb out or curb extension. If sidewalk width along a segment varies, then take multiple measurements and calculated weighted (length based) width of sidewalk.

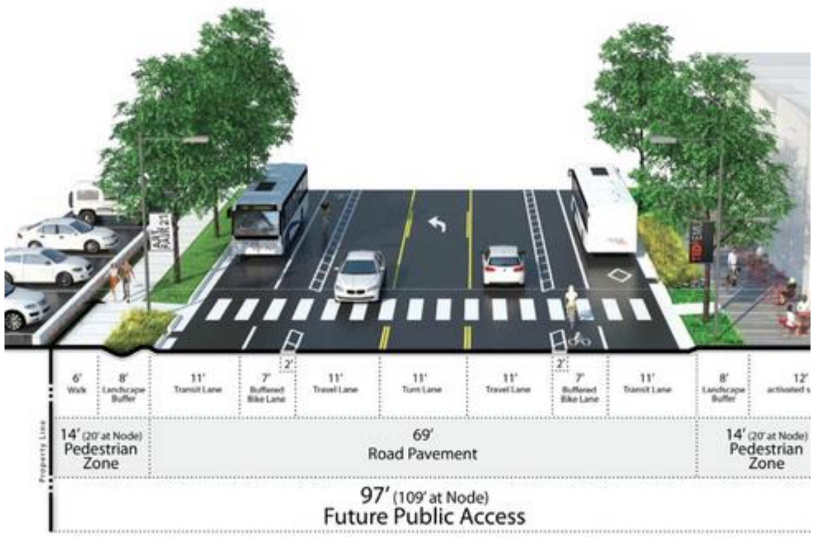
Sidewalk Cross Slope

Visually assess cross sectional slope of sidewalk (slope across the sidewalk, but not longitudinal)

Measuring Cross Slope[3]

Buffer Zone

Check for the presence of buffer zone that can protect pedestrians from street traffic (A separate bike lane or on-street parking can act as a buffer). Rate both sides of the street. Measure the space between the curb, or curb line, to the near edge of pedestrian sidewalk. If on-street parking or bike lanes separate the sidewalk, mark first option under buffer zone. For instance, the example street below has an 8 inch buffer zone on both sides.



Sample Buffer Zone[18]

Condition of Sidewalk

Surface quality of a sidewalk may be good, fair, and bad. A *good quality* sidewalk has very small and occasional surface impediments. A *fair quality* has some cracking, buckling, and erosions, but does not pose significant hazard conditions for walking. *Bad quality* surface has significant cracking, patching, buckling, weathering, holes, tree root intrusion, vegetative encroachment, standing water or cracks raised a few inches above surface level that can be detrimental to pedestrian safety. Measurement should be done at both sides.

Good Quality

Fair Quality

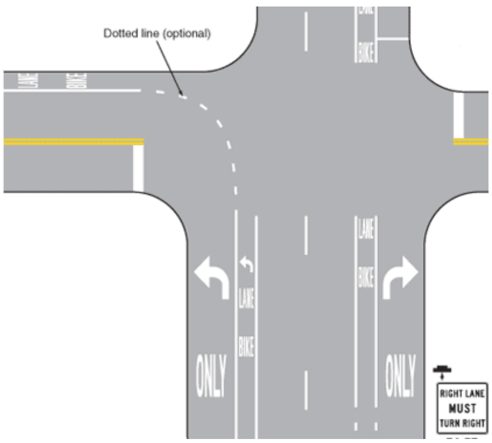
Poor Quality

Sidewalk Conditions[1]

Bicyclist Intersection Safety Assessment

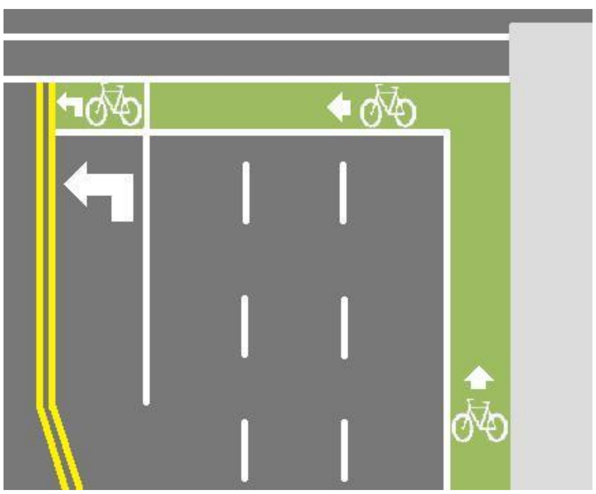
Presence of Left Turn Bicycle Lane /Bicycle Boxes at Left Turn Lanes

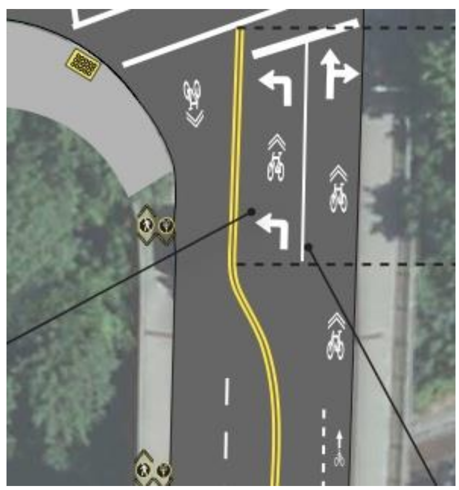
Presence of a standard width bike lane adjacent to a left turn lane reduces conflicts and enhances safety for intersection turning bicyclists. According to the City of Portland Office of Transportation: "*Bike Boxes are a roadway engineering treatment to improve bike safety at intersections. They are intended to improve awareness and visibility of cyclists and to help prevent dangerous "right-hook" collisions." (19)* Count how many left turn bike lanes or bike boxes are present at the intersection. Example left turn bike lanes and bike boxes are presented below.



Left Turn Bike Lane[16]

Bike Box[20]


Bike Box[21]


Share Bike Lane[22]

Intersection Bicycle Lanes / Bicycle Boxes
Look for a bike lane or bike boxes at an intersection that facilitates passage of bicycles to an upstream approach.

Intersection Bicycle Lanes[23]

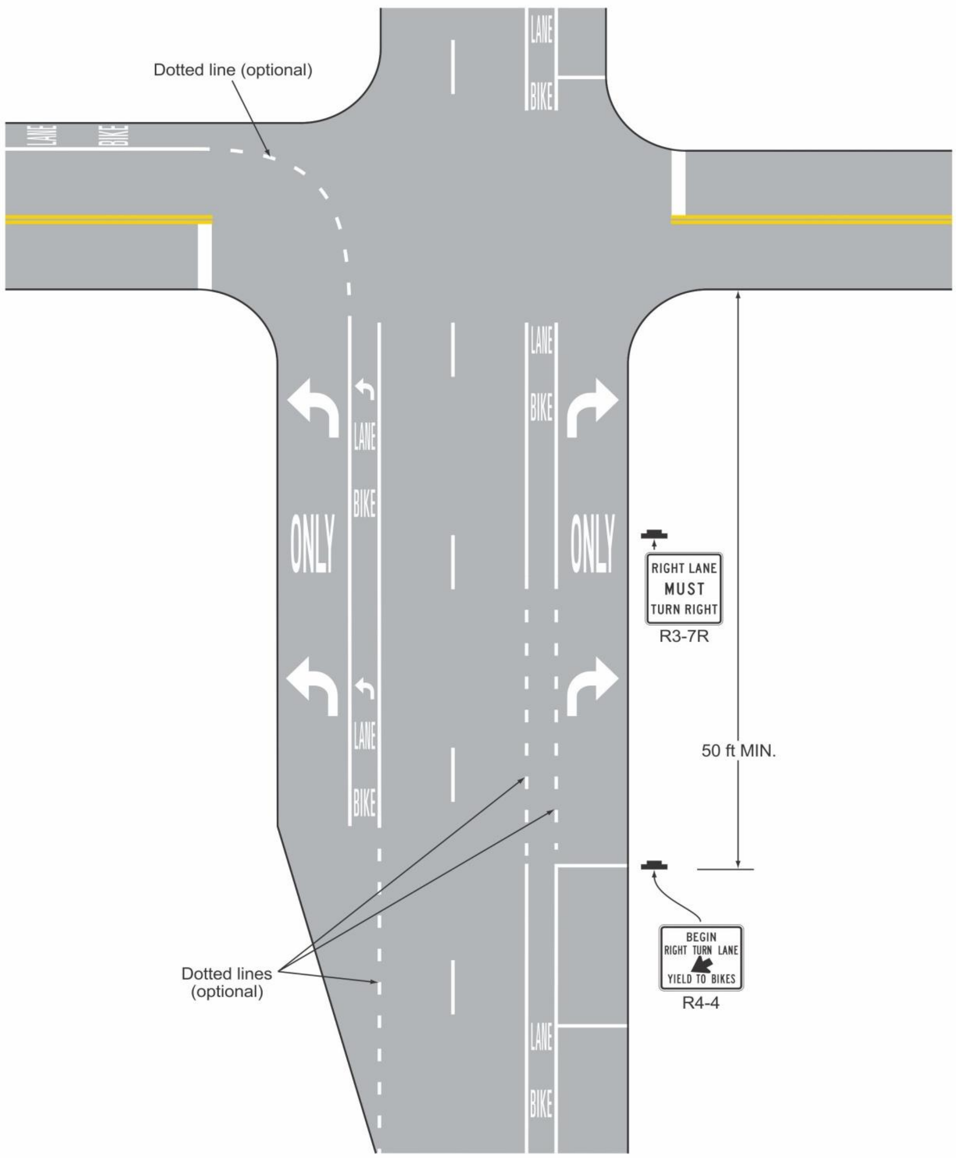
Signs
Look for bike signs (examples of bike facility signs are shown below)

Bike Signs[24]

No Right Turn on Red (RTOR) Sign Restrictions
Count the number of directions where a "No Turn on Red" restriction sign is present.

No Turn on Red Restriction Sign[6]

Markings
Mark the option ‘adequate’, if bicycle related pavement markings are present on a given section of road or at an intersection.



Bike Lane Markings[16]

Bicyclist Segment Safety Assessment

Markings

Mark the option 'adequate', if bicycle related pavement markings are present on a given section of road or at an intersection.

a[25]

b[26]

Markings of Bike Lane on a Road Segment

Signs

Look for bike signs (examples of bike facility signs are shown below)

a[27]

b[28]

Bike Lane Signs

Traffic Calming Features

Traffic calming features are physical features that reduce the negative impact of motor vehicles use by slowing their speed. Observe for all traffic calming features present. A few examples are shown below:

Curb Extensions/Bulb outs

Mini-Circles

Partial Closures

Roundabouts

Speed Humps

Speed Tables

Chicane

Rumble Strips

Speed Enforcements

Traffic Calming Features[14]

Driveways

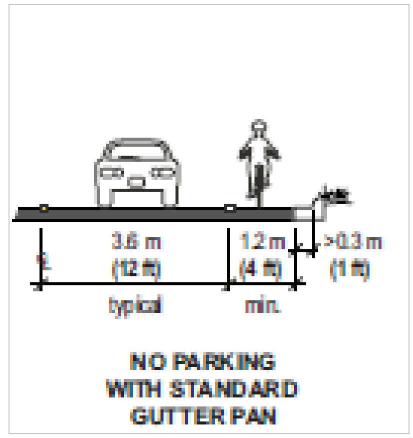
Count the number of driveway or minor streets cuts along the street segment. A parking garage should count as two drive-way cuts. Both sides of the street should be rated.

Driveway *Parking Garage*

Sample Driveway Locations on a Street Segment[14]

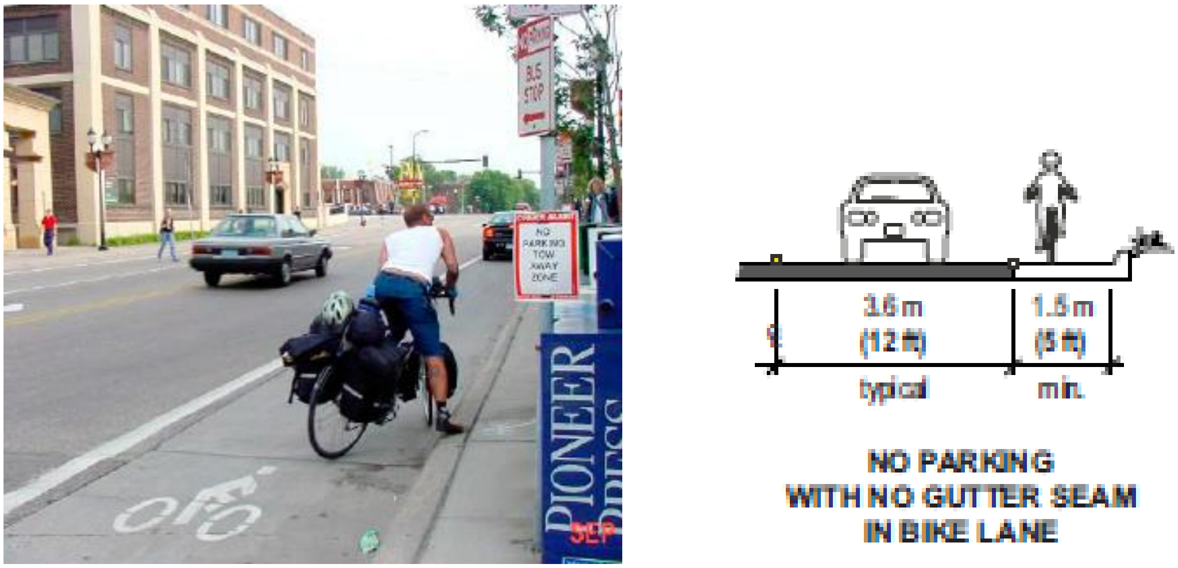
Roadway Surface Condition (Shared Bike Lane)
See the description in the *Condition of Bike Lane* section. Rate the condition of wide outside lane (i.e. shared bike lane) with respect to safety and riding quality for bicyclists. For instance, if the pavement surface offers unsafe and poor riding quality for the bicyclists it can be rated as poor.

Bike Lane Width
According to Minnesota DOT Bikeway Facility Design Manual: "*A typical bicycle lane is a portion of a roadway designated by striping, signing, and pavement markings for the preferential or exclusive use of bicycles" (29)*. Measure marked bike lanes width for a standard bicycle lane type (Figure a). In some cases, a bike lane may be present on a roadway with a curb but without a gutter (Figure b). In those cases, just measure marked bike lane width. If a gutter is used as a bike lane (with no on-street parking), the distance between the bike lanes marking to the edge of curb becomes bike lane width (Figure c). Paved shoulders of appropriate width can also accommodate bicycles, but unpaved shoulders do not accommodate bicycles (Figure d). Width of paved shoulder becomes bike lane width. However, if right shoulder is equipped with a rumble strip, then measure bikeway width from the right edge of rumble strip to either curb line or landscape line. Traffic barrier protected bike lanes separate the travel lanes from bike lanes (Figure e). Shared bike lanes on wide outside lanes share the road right-of-way with vehicular traffic. Consider lane width of wide outside lane as bike lane width (Figure f).

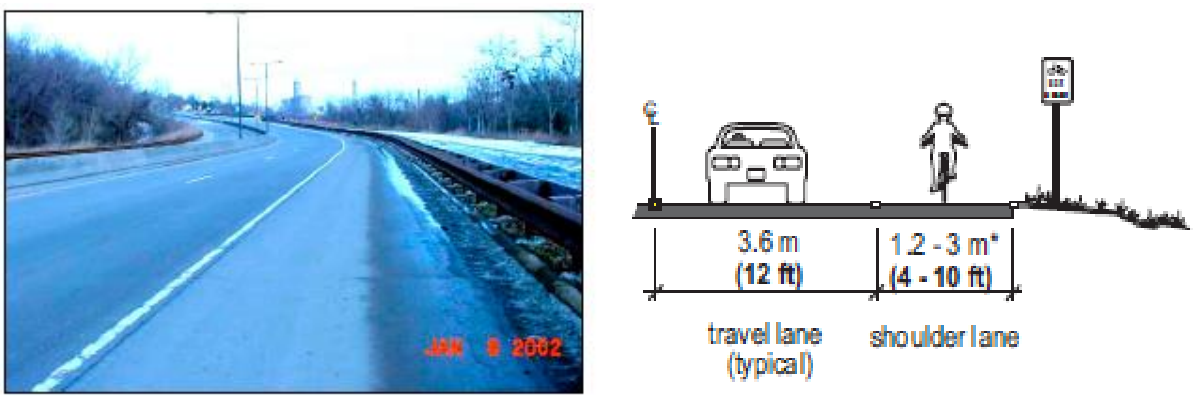


(a) Typical Bike Lane[29]

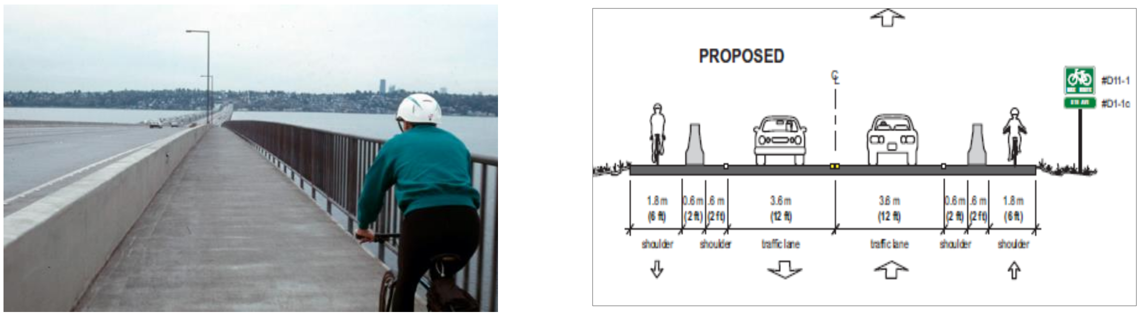
(b) Bike Lane on a Road with Curb but no Gutter[29]



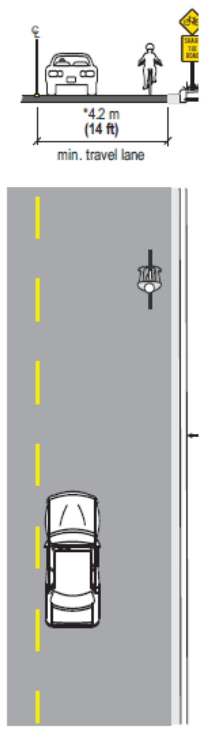
(c) Bike Lane with Gutter and Curb[29]



(d) Bike Lane on Road Shoulder[29]



(e) Traffic Barrier Protected Bike Lanes[29]



(f) Shared Bike Lane[29]

Type of Bike Lane in Road Right-of-Way

Mark first option for roadway sections matching at least one of the layouts shown in above Figures (a) to (f).

Condition of Bike Lane

A good condition bike lane has very few minor surface quality problems and does not significantly hamper the riding quality. A bike lane with a fair conditioned surface has major cracks, minor holes, and minor bumps. Though riders may feel some discomfort, the bike lane does not pose significant safety concerns. In contrast, poor quality surface has visible cracks, potholes, undulated surfaces and drainage problems that are detrimental to both safety and riding the facility. Some example surface conditions are shown below.

Good Conditioned Bike Lane[30]

Fair Conditioned Bike Lane[31]

Bad Conditioned Bike Lanes[31]

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Appendix 7C: Excel File for Data Analysis

Appendix 1.X: Experts' Feedback Survey

Survey: Active Commuting and Road Infrastructure

Thank you for your willingness to participate in this survey. This project is supported by the Transportation Research Center for Livable Communities (TRCLC), a University Transportation Center (UTC) supported by the US Department of Transportation (DOT). The purpose of the survey is to collect data on the factors that influence pedestrian and bicycle safety. You have been selected to participate in the survey given your professional role, experience and knowledge in this area. The information that you provide will be used in the creation of performance measures to better evaluate the performance of different types of transportation investments on pedestrian and bicycle safety. If you have any questions, or would like to see the results of the analysis, please contact Dr. Colleen Casey at colleenc@uta.edu.

Due to the need for more in-depth insights into the wide array of road elements characteristics, the survey will take approximately 30-60 minutes to complete. Your response will remain anonymous. There are no perceived risks as well as direct benefits to you as a participant in this study. Participation is voluntary, refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled, and you may discontinue participation at any time without penalty or loss of benefits. If you have questions about your rights as a research subjects, you may contact UTA Regulatory Services at regulatoryservices@uta.edu or call 817-272-3723.

By clicking "NEXT" below, you confirm that you are 18 years of age or older and have read or had this document read to you. You have been informed about this study's purpose, procedures, possible benefits and risks, and you may print a copy of this form using the "Print" function in your browser. You have been given the opportunity to ask questions before you make a decision regarding your participation, and you have been told that you can ask other questions at any time.

You voluntarily agree to participate in this study. By clicking "NEXT" below, you are not waiving any of your legal rights. Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Thank you for participating in our survey. Your feedback is important.

Survey: Active Commuting and Road Infrastructure

1. Please select the choice that best reflect your area of expertise.

- ◯ Pedestrian and bicycle safety as well as walkability and/or bikeability
- ◯ Pedestrian and bicycle safety
- ◯ Walkability and/or bikeability

Survey: Active Commuting and Road Infrastructure

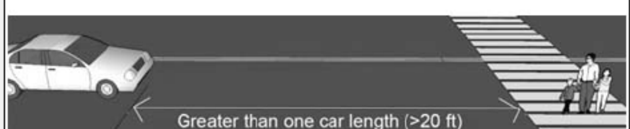
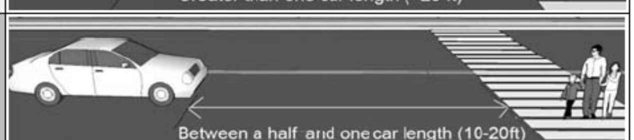
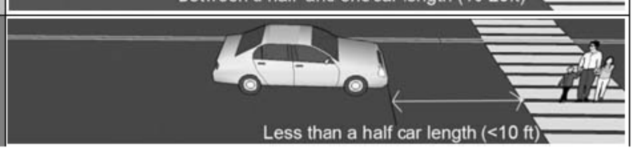
Safety Section 1: Vehicle - Pedestrian Conflicts

The risk of collision between vehicles and pedestrians are often a function of the distance between both parties and the evasive action that each party takes to avoid collision. This section asks you to rate the risk of collision between vehicles and pedestrians based on these 2 factors: *separation distance between vehicle and pedestrian* and *severity of evasive action*. The tables below describe each factor.

Factor 1: Severity of Evasive Action

Risk level	Vehicle Action	Pedestrian Action
Light	A controlled deceleration or acceleration of vehicles.	A change from a walk to stop.
Medium	A moderate but controlled deceleration or acceleration.	A change from a walk to jog.
Heavy	A sharp, less controlled deceleration or acceleration (for instance, abruptly changing direction of vehicle with less control to avoid a collision with the pedestrian).	A change into a sprint. This is likely combined with a change of course after the deceleration or acceleration.
Emergency	A sudden, uncontrolled deceleration or acceleration.	Take emergency action such as jumping out of the street and may be coupled with a fast, sporadic change of course.

Factor 2: Separation Distance between vehicle and pedestrian (when the conflicting road users begin to take an action to avoid the collision)

Distance	Between Vehicle and Pedestrian
Far	
Medium	
Close	

1. Using the definitions provided above, please indicate the safety risk based on the relationship of the *severity of evasive action* and *separation distance between vehicles and pedestrians* (Category A, B, C, D). The categories range from Category A as a "serious safety situation" to Category D as presenting "no immediate safety concern".

Category A	a serious incident in which a collision is narrowly avoided.
Category B	an incident with significant potential for collision where distance decreases and a time critical response is necessary to avoid a collision.
Category C	an incident characterized by moderate time and/or distance to avoid a collision.
Category D	an incident with no immediate safety concerns, but a conflict occurs by encroachment of the space/area of a roadway surface designated for a single vehicle/person.

For example, if you think that when the separation distance between a vehicle and pedestrian is "far" and the severity of evasive actions taken by both the vehicle and the pedestrian are "light", a situation of "no immediate safety concern" results, please mark "D".

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Pedestrian, Far (>20 ft)				
Separation Distance Vehicle-Pedestrian, Medium (10-20 ft)				
Separation Distance Vehicle-Pedestrian, Short (<10 ft)				

Other (please specify)

2. Finally, use the same factors, *separation distance between vehicle and pedestrian* and *severity of evasive action,* to categorize the type of safety situation it creates, **safe** (no likelihood of collision), **moderately safe** (low likelihood of collision) or **not safe** (high likelihood of collision).

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Pedestrian, Far (>20 ft)				
Separation Distance Vehicle-Pedestrian, Medium (10-20 ft)				
Separation Distance Vehicle-Pedestrian, Short (<10 ft)				

Other (please specify)

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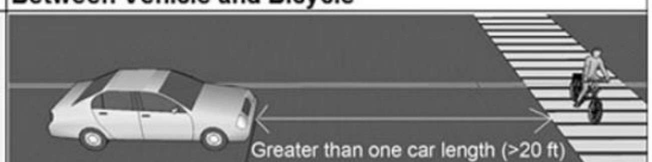
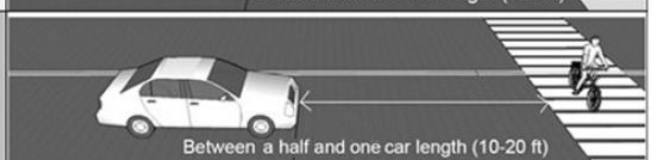
Safety Section 2: Vehicle - Bicyclist Conflicts

The following section asks you to apply the same logic in the previous section to rate the risk of collision between vehicles and bicyclists. Please consider the following 2 factors as a function of collision: *separation distance between vehicle and bicyclist*and *severity of evasive action*. The tables below describe each factor.

Factor 1: Severity of Evasive Action

Risk level	Vehicle Action	Bicyclist Action
Light	A controlled deceleration or acceleration of vehicles.	A slight change in speed and no change in direction.
Medium	A moderate but controlled deceleration or acceleration.	A normal stop or moderate change in speed and no change in direction.
Heavy	A sharp, less controlled deceleration or acceleration (for instance, abruptly changing direction of vehicle with less control to avoid a collision with the bicyclist).	A hard stop or controlled change in direction.
Emergency	A sudden, uncontrolled deceleration or acceleration.	An abrupt, uncontrolled change in direction.

Factor 2. Separation Distance between Vehicle and Bicycle (when the conflicting road users begin to take an action to avoid the collision)

Distance	Between Vehicle and Bicycle
Far	
Medium	
Close	

1. Using the definitions provided above, please indicate the safety risk based on the relationship of the *separation distance between vehicle* and *bicyclist* and the *severity of evasive action* factors. Same as the previous section, the categories range from Category A as a "serious safety situation" to Category D as presenting "no immediate safety concern" (Click for Category A, B, C, D).

For example, if you think that when the separation distance between a vehicle and bicyclist is "far" and the severity of evasive actions taken by both the vehicle and the bicyclist are "light", a situation of "no immediate safety concern" results, please mark "D".

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Bicyclist, Far (>20ft)				
Separation Distance Vehicle-Bicyclist, Medium (10-20 ft)				
Separation Distance Vehicle-Bicyclist, Short (<10 ft)				

Other (please specify)

2. Finally, use the same factors, *separation distance between vehicle and bicyclist* and *severity of evasive action,* to categorize the type of safety situation it creates, **safe** (no likelihood of collision), **moderately safe** (low likelihood of collision) or **not safe** (high likelihood of collision).

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Vehicle-Bicyclist, Far (>20 ft)				
Separation Distance Vehicle-Bicyclist, Medium (10-20 ft)				
Separation Distance Vehicle-Bicyclist, Short (<10 ft)				

Other (please specify)

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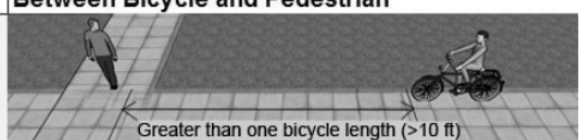
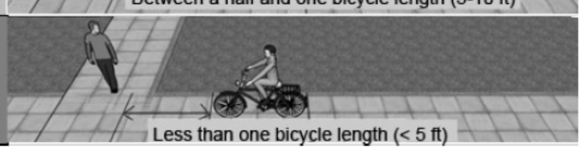
Safety Section 3: Bicycle - Pedestrian Conflicts

In this section, you are asked to apply the same logic to rate the risk of collision betweenbicycles and pedestrians. Please rate the risk of collision using the same 2 factors:*separation distance between bicycle and pedestrian* and *severity of evasive action*. The tables below describe each factor.

Factor 1: Severity of Evasive Action		
Risk level	**Bicycle Action**	**Pedestrian Action**
Light	Cruising away from pedestrian with a change of direction.	A change from a walk to stop.
Medium	A moderate but controlled deceleration and likely combined with a change of direction.	A change from a walk to jog.
Heavy	A sharp, less controlled deceleration and no change of direction.	A change into a sprint. This is likely combined with a change of course after the deceleration or acceleration.
Emergency	A sudden, uncontrolled deceleration or no change of direction.	Take emergency action such as jumping out of the street and may be coupled with a fast, sporadic change of course.

Factor 2 Separation Distance between Bicycle and Pedestrian (when the conflicting road users begin to take an action to avoid the collision)

Distance	Between Bicycle and Pedestrian
Far	
Medium	
Close	

8

1. Using the definitions provided above, please indicate the safety risk created based on the relationship of the *separation distance between bicycle* and *pedestrian* and the *severity of evasive action* factors. Same as the previous section, the categories range from Category A as a "serious safety situation" to Category D as presenting "no immediate safety concern" (Click for Category A, B, C, D).

For example, if you think that when the separation distance between a bicycle and pedestrian is "far" and the severity of evasive actions taken by both the bicycle and the pedestrian are "light", a situation of "no immediate safety concern" results, please mark "D".

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Bicycle-Pedestrian, Far (>10 ft)				
Separation Distance Bicycle-Pedestrian, Medium (5-10 ft)				
Separation Distance Bicycle-Pedestrian, Short (<5 ft)				

Other (please specify)

2. Finally, use the same factors, *separation distance between bicycle and pedestrian* and *severity of evasive action*, and categorize the type of safety situation it creates, **safe** (no likelihood of collision), **moderately safe** (low likelihood of collision) or **not safe** (high likelihood of collision).

	Evasive Action, Light	Evasive Action, Medium	Evasive Action, Heavy	Evasive Action, Emergency
Separation Distance Bicycle-Pedestrian, Far (> 10 ft)				
Separation Distance Bicycle-Pedestrian, Medium (5-10 ft)				
Separation Distance Bicycle-Pedestrian, Short (<5 ft)				

Other (please specify)

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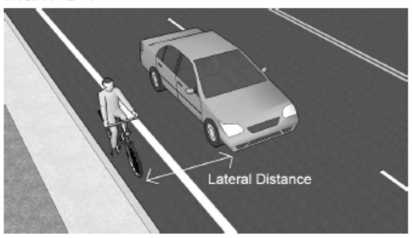
Safety Section 4: Vehicle - Bicyclist Overtaking Methodology

Using the same logic, this section asks you to consider the risk of collision that occurs when bicyclists are overtaken by vehicles as a function of 2 factors, distance and speed. The following section asks you to rate the risk of conflict created by vehicle overtaking of bicyclists based on two factors: *lateral distance* and *speed.*

1. Using the definitions above, please indicate the safety risk created based on the relationship between the *lateral distance between the vehicle and bicyclist* and *speed of the passing vehicle*. Same as the previous section, the categories range from Category A as a "serious safety situation" to Category D as presenting "no immediate safety concern" (Click for Category A, B, C, D).

For example, if you think that when the *lateral distance between a vehicle and bicyclist* is "> 3ft" and the *speed of the passing vehicle* is "<= 10 mph", a situation of "no immediate safety concern" results, please mark "D".



	Vehicle Speed, Slow (<= 10 mph)	Vehicle Speed, Average (10-20 mph)	Vehicle Speed, Moderate (21-40 mph)	Vehicle Speed, Fast (40+ mph)
Lateral Distance Vehicle - Bicyclist, Close (<=3 ft)				
Lateral Distance Vehicle - Bicyclist, Far (>3 ft)				

Other (please specify)

2. Finally, use the same factors, *lateral distance between vehicle and bicyclist* and *speed of passing vehicle,* to categorize the type of safety situation it creates, **safe** (no likelihood of collision), **moderately safe** (low likelihood of collision) or **not safe** (high likelihood of collision).

	Vehicle Speed, Slow (<= 10 mph)	Vehicle Speed, Average (10-20 mph)	Vehicle Speed, Moderate (21-40 mph)	Vehicle Speed, Fast (40+ mph)
Lateral Distance, Close (<= 3 ft)				
Lateral Distance, Far (>3 ft)				

Other (please specify)

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Safety Section 5: Bicycle - Pedestrian Overtaking Methodology

Overtaking presents a serious safety concern for pedestrians and bicyclists and can be a function of distance and speed. The following section asks you to rate the risk of collision created by bicyclist overtaking of pedestrians based on two factors: *lateral distance* and *speed*.

1. Using the definitions provided above, please indicate the safety risk created based on the relationship of the lateral distance between the bicycle and pedestrian and speed of the passing bicycle (Category A, B, C, D). Choose Category A if you think it is a "serious safety situation" or the subsequent category B, C, and D as the likelihood of collision decreases to D being "no immediate safety concern".

Category A	a serious incident in which a collision is narrowly avoided.
Category B	an incident with significant potential for collision where distance decreases and a time critical response is necessary to avoid a collision.
Category C	an incident characterized by moderate time and/or distance to avoid a collision.
Category D	an incident with no immediate safety concerns, but a conflict occurs by encroachment of the space/area of a roadway surface designated for a single bicycle/person.

For example, if you think that when the *lateral distance between a bicycle and pedestrian* is "> 3ft" and the *speed of the passing bicycle* is "<= 10 mph", a situation of "no immediate safety concern" results, please mark "D".

	Bicycle Speed, Slow (<= 10 mph)	Bicycle Speed, Average (10-20 mph)	Bicycle Speed, Fast (20+ mph)
Lateral Distance Bicycle - Pedestrian, Close (<=3 ft)			
Lateral Distance Bicycle - Pedestrian, Far (>3 ft)			

Other (please specify)

2. Finally, use the same factors, *lateral distance between bicycle and pedestrian* and *speed of passing bicycle*, to categorize the type of safety situation it creates, **safe** (no likelihood of collision), **moderately safe** (low likelihood of collision) or **not safe** (high likelihood of collision).

	Bicycle Speed, Slow (<= 10 mph)	Bicycle Speed, Average (10-20 mph)	Bicycle Speed, Fast (20+ mph)
Lateral Distance, Close (<= 3 ft)			
Lateral Distance, Far (>3 ft)			

Other (please specify)

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Safety Section 6: Pedestrian - Segment Safety

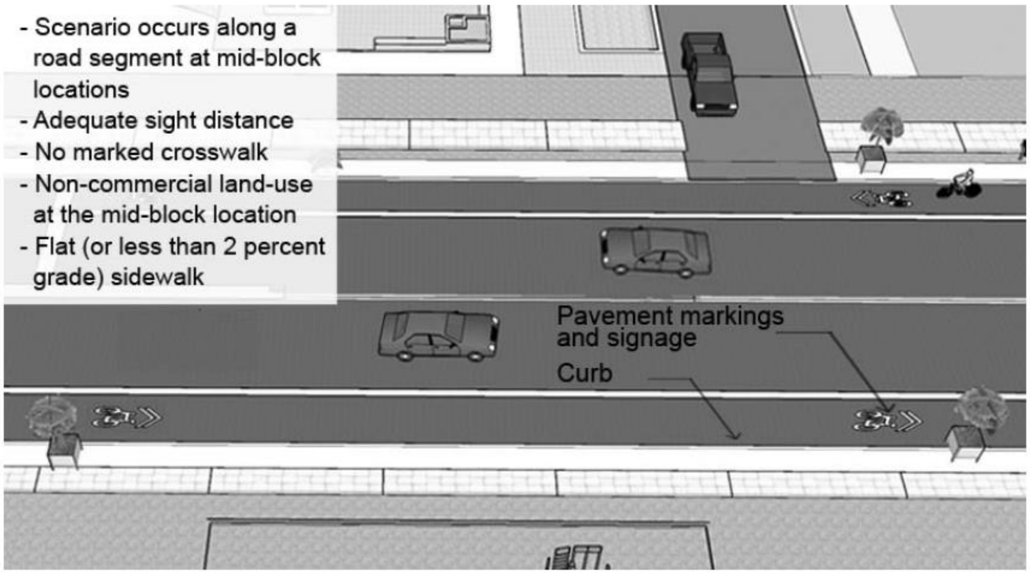
This section consists of questions about elements that may influence pedestrian safety along the road segment. A combination of these elements can make up a variety of street characteristics scenarios. First, you are asked to rate the importance of each road segment element in providing a safe pedestrian environment. Second, you are asked to consider how an adjustment of an element alters the pedestrian safety along a road segment.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, in providing a safe pedestrian environment.

	Least Important	Moderately Important	Important	Most Important
Number of Traffic Lanes to Cross	○	○	○	○
Speed Limit	○	○	○	○
Driveways	○	○	○	○
Sidewalk Width	○	○	○	○
Sidewalk Continuous along Entire Segment	○	○	○	○
Buffer Zone	○	○	○	○
Parking Restrictions near Crosswalk Area	○	○	○	○
Sidewalk Street Lighting	○	○	○	○
Sidewalk Surface Condition	○	○	○	○

Next, evaluate the safety impact of a change in each of the above elements on the scenario described below. Indicate if a change **negatively impacts safety** (demands immediate action to improve condition), **minimally impacts safety** (action necessary to improve the condition), or **positively impacts safety** (no immediate action to improve the condition).

The image below illustrates base conditions of the road segment characteristics.



2. Please consider how an adjustment in **number of traffic lanes to cross** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
2 Lanes			
4 Lanes			
4+ Lanes			

3. Please consider how an adjustment in **speed limit** impacts safety of pedestrians ((in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
<= 20 mph			
21 - 30 mph			
31 - 40 mph			
> 40 mph			

4. Please consider how an adjustment in the**number of driveways** per block along a street segment impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
None	◯	◯	◯
Less than 5 driveways	◯	◯	◯
5 - 10 driveways	◯	◯	◯
More than 10 driveways	◯	◯	◯

5. Please consider how an adjustment in**sidewalk width** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
More than or equal 5 feet	◯	◯	◯
Less than 5 feet	◯	◯	◯

6. Please consider how an adjustment in**sidewalk connectivity** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Continuous Sidewalk	◯	◯	◯
Disconnected Sidewalk	◯	◯	◯

7. Please consider how an adjustment in the**buffer zone** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Presence of 4-6 ft Buffer Zone from Curb Line to Sidewalk's Near Edge/Presence of Either On-Street Parking/Presence of Bike Lanes.	◯	◯	◯
No Buffer Zone	◯	◯	◯

8. Please consider how an adjustment in **parking restrictions near crosswalk area** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Parking restricted within 30 foot distance in advance of crosswalk marking	◯	◯	◯
No parking restrictions near crosswalk	◯	◯	◯

9. Please consider how an adjustment in **street lighting** conditions impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	◯	◯	◯
Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	◯	◯	◯
Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	◯	◯	◯

10. Please consider how **sidewalk surface conditions** impact the safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
 More than 75% in Good Condition			
 70-50% in Good Condition			
 50-25% in Good Condition			
 Less than 25% in Good Condition			

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Safety Section 7: Pedestrian - Signalized Intersection Safety

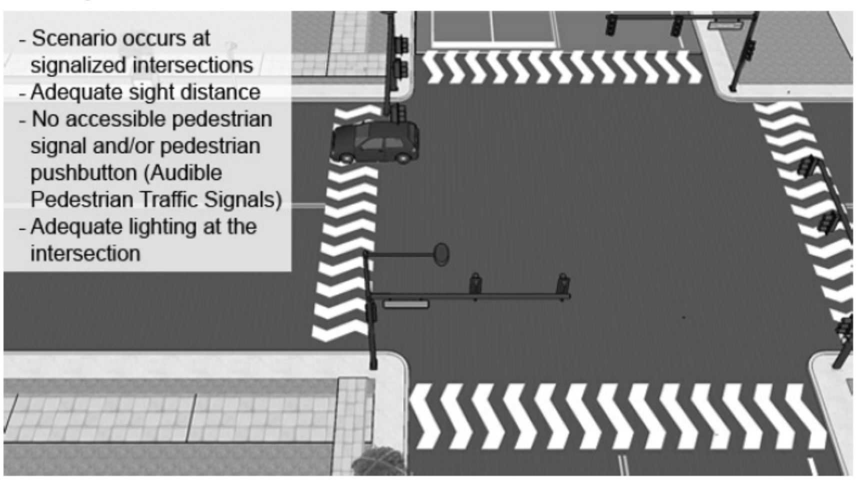
This section consists of questions about elements that may influence pedestrian safety at an intersection. A combination of these elements can make up a variety of street characteristics scenarios. First, you are asked to rate the importance of each road segment element in providing a safe pedestrian environment. Second, you are asked to consider how an adjustment of an element alters the pedestrian safety at an intersection.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, in providing a safe pedestrian environment.

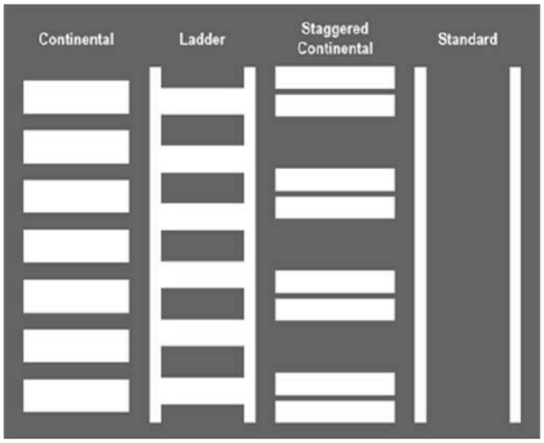
	Least Important	Moderately Important	Important	Most Important
Presence of Crosswalks	○	○	○	○
Pedestrian Time Counters	○	○	○	○
No Right-Turn-On-Red (RTOR)	○	○	○	○

Next, evaluate the safety impact of a change in each of the above elements on the scenario described below. Indicate if a change **negatively impacts safety** (demands immediate action to improve condition), **minimally impacts safety** (action necessary to improve the condition), or**positively impacts safety** (no immediate action to improve the condition).

The image below illustrates base conditions of the intersection characteristics.



2. Please consider how an adjustment in **type of crosswalks** (see image below) impacts safety of pedestrians (in addition to base conditions).



	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Continental/Ladder/Staggered Continental Type on All Directions	○	○	○
Standard/Parallel Type on All Directions	○	○	○
None	○	○	○

3. Please consider how an adjustment in **pedestrian time counters** at an intersection impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
All Directions with Counters	○	○	○
Two Directions (on Major/Minor Road) with Counters	○	○	○
No Counters	○	○	○
No Pedestrian Phase	○	○	○

4. Please consider how presence of **No Right-Turn-On-Red (RTOR)** at an intersection impacts safety of pedestrians (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
No Right-Turn-On-Red on All Directions	○	○	○
No Right-Turn-On-Red on Two Directions (on Major/Minor Road)	○	○	○
Not Present	○	○	○

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Safety Section 8: Bicycle - Segment Safety

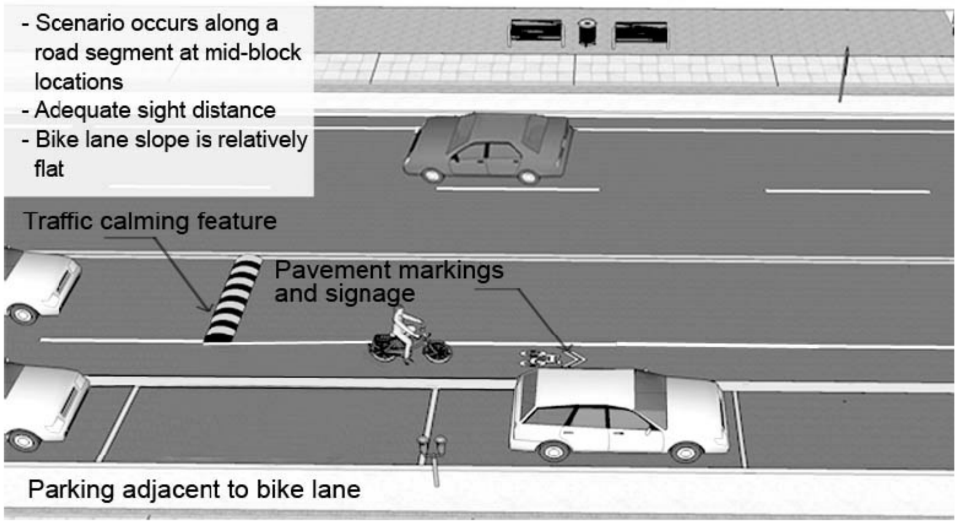
This section consists of questions about elements that may influence bicycle safety along the road segment. A combination of these elements can make up a variety of street characteristics scenarios. First, you are asked to rate the importance of each road segment element in providing a safe bicycle environment. Second, you are asked to consider how an adjustment of an element alters the bicycle safety along a road segment.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, in providing a safe bicycle environment.

	Least Important	Moderately Important	Important	Most Important
Number of Driveways per Block	○	○	○	○
Speed Limit	○	○	○	○
Type of Bike Lane in the Street Segment Right-of-Way	○	○	○	○
Bike Lane Continuous along the Street Segment	○	○	○	○
Street Lighting Conditions	○	○	○	○
Presence of Commercial Land Use/Places	○	○	○	○

Next, evaluate the safety impact of a change in each of the above elements on the scenario described below. Indicate if a change **negatively impacts safety** (demands immediate action to improve condition), **minimally impacts safety** (action necessary to improve the condition), or **positively impacts safety** (no immediate action to improve the condition).

The picture below illustrates base conditions of the road segment characteristics.



2. Please consider how an adjustment in **number of driveways per block** impacts safety of bicyclists (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
None	○	○	○
Fewer than 5 on Each Direction of Segment per Block	○	○	○
5 or More on Each Direction of Segment per Block	○	○	○

3. Please consider how an adjustment in **speed limit** impacts safety of bicyclists (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
<= 20 mph	○	○	○
21 - 30 mph	○	○	○
31 - 40 mph	○	○	○
> 40 mph	○	○	○

4. Please consider how an adjustment in **type of bike lane in the Street Segment Right-of-Way** impacts safety of bicyclists (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
Bike Lane Adjacent to Vehicular Travel Lane	◯	◯	◯
Shared Bike Lane with Vehicular Travel Lane	◯	◯	◯

5. Please consider how an adjustment in the presence of **continuous bike lane along the street segment** impacts safety of bicyclists (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
Yes	◯	◯	◯
No	◯	◯	◯

6. Please consider how an adjustment in **street lighting** conditions impacts safety of bicyclists (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	◯	◯	◯
Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	◯	◯	◯
Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	◯	◯	◯

7. Please consider how the **presence of commercial land use** impacts safety of pedestrians (in addition to base conditions).

	Negatively Impact Safety	Minimally Impact Safety	Positively Impact Safety
Yes	◯	◯	◯
No	◯	◯	◯

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Safety Section 9: Bicycle - Signalized Intersection Safety

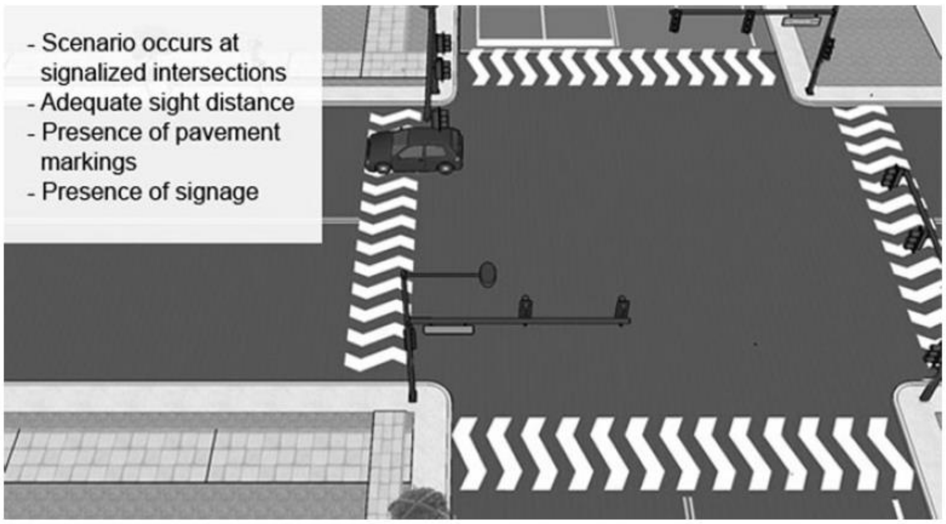
This section consists of questions about elements that may influence bicycle safety at an intersection. A combination of these elements can make up a variety of street characteristics scenarios. First, you are asked to rate the importance of each road segment element in providing a safe bicycle environment. Second, you are asked to consider how an adjustment of an element alters the bicyclist safety at an intersection.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, in providing a safe pedestrian environment.

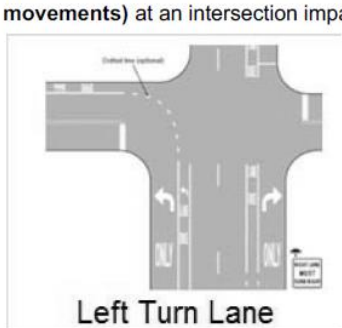
	Least Important	Moderately Important	Important	Most Important
Presence of Bicycle Lane or Bicycle Boxes at Left Turn Lanes (For Turning Bicyclist Movements)	○	○	○	○
Presence of Bicycle Lanes or Bicycle Boxes (For Non-Turning Bicyclist Movements)	○	○	○	○
No Right-Turn-On-Red (RTOR)	○	○	○	○
Street Lighting at the Intersection	○	○	○	○
Pavement Markings for Bicylists	○	○	○	○

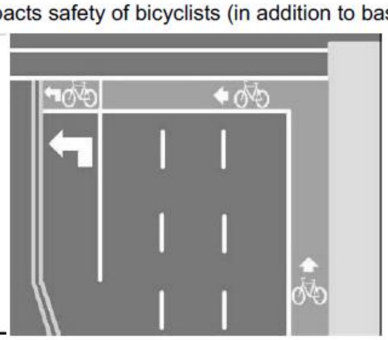
Next, evaluate the safety impact of a change in each of the above elements on the scenario described below. Indicate if a change **negatively impacts safety** (demands immediate action to improve condition), **minimally impacts safety** (action necessary to improve the condition), or**positively impacts safety** (no immediate action to improve the condition).

The image below illustrates base conditions of the intersection characteristics.



2. Please consider how **presence of left turn bicycle lane or bike boxes (for turning bicycle movements)** at an intersection impacts safety of bicyclists (in addition to base conditions).





Example of a Left Turn Bike Lane   Example of a Bike Box

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Present on All Directions	○	○	○
Present on Two Directions (On Major/Minor Road)	○	○	○
Shared Lanes on All Directions	○	○	○

3. Please consider how **presence of bicycle lanes and bicycle boxes (for non-turning movements)** at an intersection impacts safety of bicyclists (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Present on All Directions	◯	◯	◯
Present on Two Directions (On Major/Minor Road)	◯	◯	◯
Shared Lanes on All Directions	◯	◯	◯
None	◯	◯	◯

4. Please consider an how an adjustment in **Right-Turn-On-Red (RTOR) restrictions** at an intersection impacts safety of bicyclists (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
No Right-Turn-On-Red on All Directions	◯	◯	◯
No Right-Turn-On-Red on All Directions on Two Directions (On Major/Minor Road)	◯	◯	◯
Right-Turn-On-Red Allowed on All Directions	◯	◯	◯

5. Please consider how an adjustment in **street lighting** at an intersection impacts safety of bicyclists (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	◯	◯	◯
Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	◯	◯	◯
Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	◯	◯	◯

6. Please consider how **pavement markings** at an intersection impact safety of bicyclists (in addition to base conditions).

	Negatively Impacts Safety	Minimally Impacts Safety	Positively Impacts Safety
Adequate	○	○	○
None	○	○	○

Survey: Active Commuting and Road Infrastructure

Physical Activity Section 1: Road Segment Elements that Influence Walkability

This section asks you to consider a set of questions about road segment elements that influence walkability. A combination of these elements can make up a variety of street characteristics scenarios. First, you are asked to rate these elements based on its importance to road segment walkability. Second, you are asked to consider how an adjustment of an element alters the walkability along a road segment.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, for walkability in a street segment.

	Least Important	Moderately Important	Important	Most Important
Speed (mph)	◯	◯	◯	◯
Buffer Zone	◯	◯	◯	◯
Street Lighting Conditions	◯	◯	◯	◯
Number of Driveways along Road Segment per Block	◯	◯	◯	◯
Sidewalks Free of Obstructions	◯	◯	◯	◯
Tidiness of Surrounding Environment	◯	◯	◯	◯
Traffic Calming Features	◯	◯	◯	◯
Traffic Signals	◯	◯	◯	◯
Sidewalk Width	◯	◯	◯	◯
Surface Condition	◯	◯	◯	◯
ADA Compliant	◯	◯	◯	◯
Median Type	◯	◯	◯	◯
Connectivity to Activities Center	◯	◯	◯	◯

Next, consider how a change in each of the above element alters the walkability of the road segment, with all other elements remain unchanged at base conditions listed in the table below. Indicate if a change in each element either **definitely improves walkability**, has **neutral effect on walkability**, or **discourages walkability**.

Road Segment Elements	Base Conditions
Speed	30 mph
Buffer Zone	Parallel Parking
Street Lighting (Visibility from a distance of 13 feet)	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment
Driveways	None
Obstructions on Sidewalk	None
Tidiness	Clean and Uncluttered
Traffic Calming Devices	Present
Traffic Signals	HAWK
Sidewalk Width	5 feet
Surface Condition	Paved and Level
ADA Compliant	Yes
Median Type	Yes, Greater than 6 feet Raised
Connectivity	All Major and Minor Arterials from Local/Collector Streets Connect to Most Activity Centers

2. Please consider how an adjustment in**speed limit** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
20 miles per hour	○	○	○
30 miles per hour	○	○	○
35 miles per hour	○	○	○
Greater than 40 miles per hour	○	○	○

3. Please consider how each type of **buffer zone** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 Landscaping and Parallel Parking	○	○	○
 Parallel Parking and Bike Lane	○	○	○
 Parallel Parking	○	○	○
 Dedicated Bike Lane	○	○	○

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4. Please consider how an adjustment in **street lighting** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment	○	○	○
Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road Segment	○	○	○
Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment	○	○	○

5. Please consider how an adjustment in **number of driveways** per block along street segment alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
None	○	○	○
Less than 5 driveways	○	○	○
5-10 driveways	○	○	○
More than 10 driveways	○	○	○

6. Please consider the extent of **obstructions on sidewalks** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 None			
 More than 75 %			
 25%-50%			
 Less than 25%			

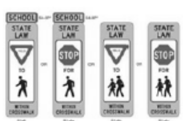
7. Please consider how **tidiness** of surrounding environments alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 Clean	○	○	○
 Illegal Grafitti	○	○	○
 Littering and Trash Overflow	○	○	○
 Vacant Building	○	○	○

8. Please consider how each type of**traffic calming device** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 Raised Median and Crosswalk	○	○	○
 Speed Bump	○	○	○
 Roundabout	○	○	○
 Speed Enforcement	○	○	○

9. Please consider how each type of**traffic signal** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 HAWK	◯	◯	◯
 In Pavement Flashing Light and/or Walk Sign with Flashing Beacon	◯	◯	◯
 On Pavement Warning Sign	◯	◯	◯
 Crosswalk Markings (without any Pedestrian walk sign)	◯	◯	◯

10. Please consider how an adjustment in**width of sidewalks** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
3 feet	◯	◯	◯
5 feet	◯	◯	◯
8 feet	◯	◯	◯
12 feet	◯	◯	◯

11. Please consider how **surface conditions** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 More than 75% in Good Condition	○	○	○
 70-50% in Good Condition	○	○	○
 50-25% in Good Condition	○	○	○
 Less than 25% in Good Condition	○	○	○

12. Please consider how **compliance to ADA standards** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
 ADA Compliant			
 Unpaved Sidewalk			
 Accesible Ramp partially blocked			
 Uneven Ramp Slope			

13. Please consider how an adjustment in **median type** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
			
			
			
			

14. Please consider how **connectivity between activity centers** alters the walkability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities			
Minor Arterials from Locals and Collectors Street Connect to Some Activities			
Individual Links with No System Level Connection with Activities			

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Physical Activity Section 2: Road Segment Elements that Influence Bicycle Activity

This section asks you to consider a set of questions about road segment elements that influence bikeability. A combination of these road segment elements can make up a variety of street characteristics scenarios. First, you are asked to rate these elements based on its importance to road segment bikeability. Second, you are asked to consider how an adjustment of an element alters the bikeability along a road segment.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, for bikeability in a street segment.

	Least Important	Moderately Important	Important	Most Important
Number of Vehicle Lanes	○	○	○	○
Speed Limit (mph)	○	○	○	○
Bicycle Lane Types	○	○	○	○
Bicycle Lane Width (Without a Buffer Zone)	○	○	○	○
Tidiness of Surrounding Environment	○	○	○	○
Street Lighting Conditions	○	○	○	○
Number of Driveways along Road Segment per Block	○	○	○	○
Connectivity to Activities Center	○	○	○	○

Next, consider how a change in each of the above element alters the bikeability of the road segment, with all other elements remain unchanged at base conditions listed in the table below. Indicate if a change in each element either **definitely improves bikeability**, has **neutral effect on bikeability**, or **discourages bikeability**.

Road Segment Elements	Base Conditions
Number of Lanes	One
Speed Limit (mph)	Less or Equal 20 mph
Bicycle Lane Type	Curbside Colored and Parallel Car Buffer
Bicycle Lane Width (Excluding Buffer)	12 feet
Tidiness	Clean and Uncluttered
Street Lighting (Visibility from a distance of 13 feet)	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment
Driveways	None
Connectivity/Continuity	All Major and Minor Arterials from Local/Collector Streets Connect to Most Activity Centers

2. Please consider how an **upward adjustment** in **number of vehicle lanes** alters the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
One Lane	○	○	○
Two Lanes	○	○	○
Three Lanes	○	○	○
More than Four Lanes	○	○	○

3. Please consider how an adjustment in**speed limit** alters the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
Less than or equal 20 mph	○	○	○
30 mph	○	○	○
35 mph	○	○	○
More than 40 mph	○	○	○

4. Please consider consider **how different bicycle lane types** alter the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
 Curbside with Colored Parked Car Buffer			
 Curbside with Protection by Flexposts			
 Raised Curb Barrier			
 Curbside with Colored Buffer			

5. Please consider how an adjustment in **bicycle lane width** (without a buffer zone) alters the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
12 feet			
8 feet			
6 feet			
Equal or less than 4 feet			

6. Please consider how **tidiness** of surrounding environments alters the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
 Clean			
 Illegal Grafitti			
 Littering and Trash Overflow			
 Vacant Building			

7. Please consider how an adjustment in **street lighting** alters the bikeability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
Excellent Visibility of Approaching Figures without Dark Spaces Along the Road Segment			
Moderate Visibility of Approaching Figures with Some Dark Spaces Along the Road Segment			
Poor Visibility of Approaching Figures with Long Dark Spaces Along the Road Segment			

8. Please consider how an adjustment in the**number of driveways per block** along a street segment alters the bikeability of the street segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
None	◯	◯	◯
Less than 5 driveways	◯	◯	◯
5 - 10 driveways	◯	◯	◯
More than 10 driveways	◯	◯	◯

9. Please consider how **connectivity between activity centers** alters the bikeability of the segment (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
All Major and Minor Arterials from Local and Collector Streets Connect to Most Activities	◯	◯	◯
Minor Arterials from Locals and Collectors Street Connect to Some Activities	◯	◯	◯
Individual Links with No System Level Connection with Activities	◯	◯	◯

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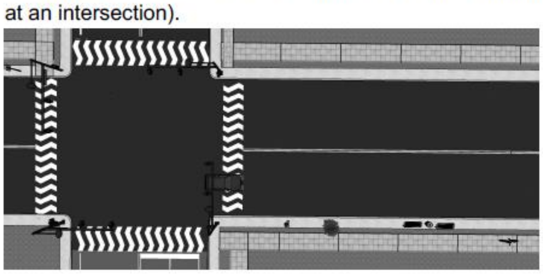
Physical Activity Section 3: Intersections, Walkability and Bicycle Activity

This section asks you to consider a set of questions about road segment elements that influence walkability and/or bikeability at an intersection. A combination of these elements can make up a variety of scenarios. Assume that these scenarios occur at a four-legged intersection (four road segments converged at an intersection).



First, you are asked to rate road segment elements based on its importance to road segment walkability and/or bikeability. Second, you are asked to consider how an adjustment of an element alters the walkability and/or bikeability of the road segment at an intersection.

1. Rate the importance of each road segment element, INDEPENDENT OF EACH OTHER, for walkability and/or bikeability **at an intersection.**

	Least Important	Moderately Important	Important	Most Important
Presence of Crosswalk	○	○	○	○
Crosswalk Length (Number of Traffic Lanes to Cross)	○	○	○	○
Intersection Pavement Treatments	○	○	○	○
Compliance to ADA Standards	○	○	○	○
Presence of a Left Turn Bike Lane	○	○	○	○
Presence of a Bike Box	○	○	○	○
Street Lighting Conditions	○	○	○	○
Advanced STOP/YIELD Sign	○	○	○	○
No Right Turn on Red (RTOR) Sign	○	○	○	○

Next, consider how a change in each of the above element alters the walkability and/or bikeability of the road segment, with all other elements remain unchanged at base conditions listed in the table below. Indicate if a change in each element either **definitely improves walkability and/or bikeability**, has **neutral effect on walkability and/or bikeability**, or **discourages walkability and/or bikeability**.

Road Segment Elements	Base Conditions
Presence of Crosswalk	All Four Legs
Crosswalk Length	1 Lane/Direction
Intersection Pavement Treatments	Raised Intersection with Crosswalk
Left Turn Bike Lane	Present
Bike Box	Present
Street Lighting (Visibility from a Distance of 13 feet)	Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment
ADA Compliant	Yes
Advanced Stop or Yield Sign	Present
No Right Turn On Red (RTOR)	Present

2. Please consider how the **presence of a crosswalk** alters walkability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability	Neutral effect on walkability	Discourages walkability
All Four Legs	◯	◯	◯
Only at Two Legs	◯	◯	◯
None	◯	◯	◯

3. Please consider how an adjustment in **crosswalk length** (the number of traffic lanes to cross) alters walkability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability and/or bikeability	Neutral effect on walkability and/or bikeability	Discourages walkability and/or bikeability
1 Lane/Direction	◯	◯	◯
2 Lanes/Direction	◯	◯	◯
3 Lanes/Direction	◯	◯	◯
4 Lanes/Direction	◯	◯	◯

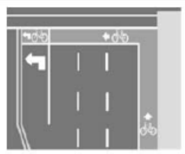
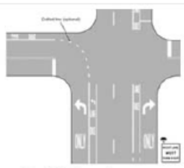
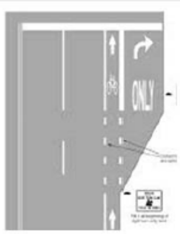
4. Please consider how an adjustment in**pavement treatment** alters walkability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability and/or bikeability	Neutral effect on walkability and/or bikeability	Discourages walkability and/or bikeability
 Raised Intersection with Crosswalk			
 Intersection Treatment Not Raised			
 Only Crosswalk Raised			
 No Treatment			

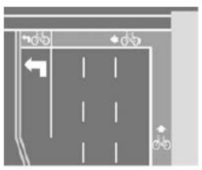
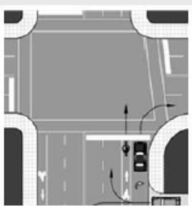
5. Please consider how **compliance to ADA standards** alters accessibility at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves accessibility	Neutral effect on accessibility	Discourages accessibility
 All Direction, Slope <1:12	○	○	○
 Presence of Grates	○	○	○
 No Curb Ramp	○	○	○

6. Please consider how each **type of left turn for bike lanes** alters bikeability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
 Bike Box			
 Left Turn Lane			
 Only Through			

7. Please consider how each **type of bike box** alters bikeability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves bikeability	Neutral effect on bikeability	Discourages bikeability
 Bike Box	○	○	○
 Two Stage Turn Queue	○	○	○
 None	○	○	○

8. Please consider how an adjustment in **street lighting** conditions (at all four legs of the the intersection) alters walkability and bikeability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability & bikeability	Neutral effect on walkability & bikeability	Discourages walkability & bikeability
Excellent Visibility of Approaching Figures without Dark Spaces along the Road Segment	○	○	○
Moderate Visibility of Approaching Figures with Some Dark Spaces along the Road Segment	○	○	○
Poor Visibility of Approaching Figures with Dark Spaces Present along the Road Segment	○	○	○

9. Please consider how an adjustment in **presence of an advanced STOP or YIELD sign** alters walkability and bikeability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability & bikeability	Neutral effect on walkability & bikeability	Discourages walkability & bikeability
In All Directions	◯	◯	◯
In Two Directions	◯	◯	◯
None	◯	◯	◯

10. Please consider how an adjustment in **Right-Turn-On-Red (RTOR) restrictions** alters walkability and bikeability at an intersection (all other elements remain unchanged at base conditions).

	Definitely improves walkability & bikeability	Neutral effect on walkability & bikeability	Discourages walkability & bikeability
No Right-Turn-On-Red in All Directions	◯	◯	◯
No Right-Turn-On-Red in Two Directions	◯	◯	◯
Right-Turn-On-Red Allowed in All Directions	◯	◯	◯

Survey: Active Commuting and Road Infrastructure

Background Information (Optional)

1. What is your current Job title?

2. About how long have you been in your current position?

- < 1 year
- 1 - 3 years
- 3 - 5 years
- 5 - 10 years
- 10+ years

3. Gender

- Male
- Female
- Different Identity

Please state

4. Age

- <18
- 18 - 29
- 30 - 44
- 45 - 59
- 60+

5. What is the highest level of school you have completed or the highest degree you have received?

- High school degree or equivalent (e.g., GED)
- Some college but no degree
- Associate degree
- Bachelor degree
- Masters degree
- Doctorate

Name of the highest degree (please specify)