MAKING PUBLIC HEALTH PERFORMANCE MEASURES FOR TRANSPORTATION ACCESSIBLE TO PRACTITIONERS

By

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ABSTRACT

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Pollutants emitted into the atmosphere from static and mobile sources pose a threat to human health. The detrimental impact associated with air pollution varies by the type of pollutant, the magnitude, frequency and duration of exposure, and the associated toxicity. While stationary sources play an important role in air pollution, motor vehicle exhaust emissions represent the single largest source of regional air pollution in urban areas. Moreover, outdoor physical activity requires an increased oxygen level with an increase in exercise intensity. Research has shown that both the ventilation and deposition fractions increase significantly during outdoor activities, which may lead to temporary decreases in lung function, increased levels of inflammatory markers in the pulmonary system, reduced vasodilation and impairments in exercise performance. Moreover, studies indicate that populations living, working, or going to school near major roads may be subjected to an increased risk for a number of adverse health effects. The reason behind this increased risk may lay in the presence of elevated concentrations of pollutants emitted directly by motor vehicles. On the other hand, the Environmental Protection Agency's National Ambient Air Quality Standards and Air Quality Index use measurements from fixed monitoring stations, which are usually strategically placed to cover broad regional areas. Evidently, none of these assessment tools exclusively identifies higher levels of acute exposure near urban arterials and intersections due to high concentrations of vehicular movements. Hence, a simple and readily available assessment tool of the air quality near urban arterials and intersections appears important for identifying pedestrian and bicyclist exposure levels, which

will in turn help in encouraging transportation infrastructure investment that fosters physical activity. Furthermore, the inclusion of project-level variables will help identify the changes due to variations in design elements and may eventually help predict network level performance. While the study acknowledges the importance of these issues, it also recognizes that civil engineering students mostly receive exposure to engineering concepts related to motorized travel, and less to concepts related to nonmotorized or active forms of transportation. This study also considers a specific type of learning intervention designed for better learning achievement and proposes a new assessment tool for the evaluation of learning improvement. The sketch planning tools developed in this study does not consider background level pollutants for any particular site, and instead, it focuses on generating the emission concentrations due to only the traffic impacts. Since this generalized version of the arterial air quality risk assessment tool only requires an arterial's speed limit and volume, it can easily be used by practitioners and policymakers for evaluating current and future infrastructure with respect to air quality. The study along an arterial show that the concentration levels at different receptor locations increases with the increase of both volume and speed (except both PM decrease with an increase in speed). The study also identified that the exposure level is higher for children compared to adults. The findings from this study will help decision makers quantify the potential health risk of a pedestrian and bicycle facility along an urban arterial (or corridor) and consider suitable alternatives for better public health.

When similar approach taken for intersection analysis, the study identified that the further the distance from the intersection, the lower the concentration is. The analysis also indicates that the exposure level remains higher closer to the intersection and it changes with speed, volume and intersection geometry. Inclusion of two-fluid model will help decision makers identify potential risk prone intersection and compare that with their model parameters to assess the network performance. Characterizing the transportation related air pollution exposure level at the intersection level with run time and stop time is potentially beneficial for transportation practitioners. Planners can use this two planning tools to include the local air quality needs and impacts in future project-level planning and policy recommendations. While most of the cases, the civil engineering students get less exposure to the concepts of active commuting in class room learning, the assessment of project-based learning intervention using the MAstery Level Achievement method strengthens by specifically identifying the different level of mastery achieved for various categories of the concepts of active commuting. These results improve the overall understanding of the success of a project-based learning intervention from traditional assessment methods. Planners and agencies can use the developed assessment tools to evaluate potential air quality risks along a particular road segment or an intersection which may eventually help assess the network performance.

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DEDICATION

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CHAPTER 1

1.1. INTRODUCTION

Practitioners, policy-makers, researchers, and educators related to the public health sector constantly work to ensure disease-free, prolonged and enhanced human health through coordinated and effective efforts. The multidisciplinary public health system identifies potential health hazards, informs and educates individual and communities and provides remedial solutions to potential concerns. Governmental agencies and public and private organizations, such as local and state public health agencies, law enforcement and public safety agencies, community-based organizations, businesses and individuals, involved in the public health system use various performance measurement standards to ensure health system improvement and accountability. The ultimate goal of a performance measure, such as reduction of the total number of asthma patients or reduction of the total number of deaths due to cardiovascular disease, remains to improve public health and reduce mortality rate. Catastrophes, such as the Donora (1948) and London (1952) air pollution incidents, prompted scientists to investigate the link between air pollution and public health, which led to the establishment of air quality standards in the Clean Air Act Amendment in 1970. While emissions represent the performance measure set by the Environmental Protection Agency (EPA) for monitoring the performance of control strategies of air quality from industries and mobile sources, the duration and frequency of exposure appears to be the key element in monitoring the performance on human health.

1.1.1. Risk associated with air pollution

Pollutants emitted into the atmosphere from static and mobile sources pose a threat to humans and their properties to various extents. The detrimental impact associated with air pollution varies by the type of pollutant, the magnitude, frequency and duration of exposure, and the associated toxicity. Cardiovascular and respiratory diseases (e.g. lung cancer and asthma), chronic obstructive pulmonary diseases (COPD), cancer, birth defects, low-birth weight, inflammation and oxidative stress in the brain and type 2 diabetes represent some of the adverse health impacts associated with air pollution (Wang et al., 2014; Rajagopalan et al., 2012; NIEHS, 2016; Kim, 2009; Brook et al. 2010; Health Effects Institute (HEI) 2010; Stieb et al. 2012; Bos, et al., 2014). In 2012, air pollution contributed to one in eight of the total global deaths and outdoor air pollution in urban and rural areas cause almost 53% (3.7 million) of these deaths (WHO, 2014). Roughly about 800,000 premature deaths per year happen globally due to particulate matters ($PM_{2.5}$, diameter ≤2.5μm).

The Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) for six major criteria pollutants (nitrogen dioxides, carbon monoxide, ozone, sulfur dioxide, lead and large and small particles) for the benefit of public health and the environment. While stationary sources play an important role in air pollution, motor vehicle exhaust emissions (results of incomplete and improper burning of fossil fuel) represent the single largest source of regional air pollution in urban areas (Faiz, 1993; Colvile, et al., 2001). The four major pollutants emitted from mobile sources are carbon monoxide (CO), nitrogen dioxides (NO_2) and particulate matters ($PM_{2.5}$-diameter ≤2.5μm and PM_{10}-diameter ≤ 10μm). The odorless, colorless and tasteless CO impedes the blood's ability to carry oxygen to body tissues and vital organs by producing carboxyhemoglobin, which creates nausea, rapid breathing, weakness, dizziness and even death. While lower resistance to respiratory infection can occur due to the presence of higher levels of NO_2 concentration, inflammation of airways, alveoli and blood stream occurs due to the penetration of particulate matter.

1.1.2. Risks of pedestrians and bicyclists

The effect of air pollutants poses a hazard to human health. 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. Research has shown that both the ventilation and deposition fractions (the fraction of inhaled particles retained in the lungs) increase significantly during outdoor activities (Panis, et al., 2010; Atkinson, 1997; Daigle, et al., 2003; and Londahl, et al., 2007), which may lead to temporary decreases in lung function (Strak, et al., 2010; McCreanor, et al., 2007), increased levels of inflammatory markers in the pulmonary system (Strak, et al., 2010; Chimenti, et al., 2009), reduced vasodilation (Rundell, et al., 2007) and impairments in exercise performance (Marr & Ely, 2010). Exposure to air pollution during physical activity appears greater than static exposure rates; therefore, a proper evaluation of the exposure level along urban arterials and intersections seems important for a more significant health impact assessment.

Moreover, studies indicate that populations living, working, or going to school near major roads may be subjected to an increased risk for a number of adverse health effects (e.g., Pearson et al. 2000; Wilhelm and Ritz 2003; Finkelstein et al. 2004; Gauderman et al. 2005; McConnell et al. 2006; Adar and Kaufman 2007; Samet 2007; Samal et al. 2008). The reason behind this increased risk may lie in the presence of elevated concentrations of pollutants emitted directly by motor vehicles (e.g., Zhu et al. 2002; Harrison et al. 2003; Reponen et al. 2003; Kim et al. 2004; Baldauf et al. 2008a). Research has also shown that a walking or bicycling route closer to a heavy-traffic roadway is associated with symptoms of respiratory dysfunction, cardiopulmonary disease and even mortality from stroke (McConnell, et al., 2006; Tonne, et al., 2007). Studies by MacNaughton et al. (2014), Hatzopoulou et al. (2003), Boogaard et al. (2009) and Kendrick et al. (2011) have shown a direct relation between different types of bike route (i.e. bike path vs. bike lane) and pollutant concentration. Evidently, exposure to traffic-related air pollution depends primarily on meteorological conditions and traffic activity, but what other parameters of the infrastructure have a direct or indirect relation with the exposure level remains unclear. Although, a detailed analysis of the built environment shows that physical barriers such as noise barriers, vegetation, and buildings may have some effect on pollutant concentrations around a structure by blocking the initial dispersion and increasing the turbulence and initial mixing of the emitted pollutants (Al-Dabbous et al. 2014; Bowker et al. 2007; Baldauf et al. 2008b, Heichel and Hankin 1976; Bussotti et al. 1995; and Beckett et al. 2000), the variation and changes of different geometric design features such as left turn lanes, or right turn lanes require further investigation. Inclusion of such project-level variables will help identify the changes due to variations in design elements and may eventually help predict network level performance.

1.1.3. Air Quality Standards

Human exposure to road traffic air pollution has increased tremendously with the increase of pedestrian and bicycle activities near roadways (Morgenstern, et al., 2007). The NAAQS and Air Quality Index (AQI) of EPA use measurements from fixed monitoring stations, which are usually strategically placed to cover broad regional areas. Evidently, none of these aforementioned assessment tools exclusively identifies higher levels of acute exposure near urban arterials and intersections due to high concentrations of vehicular movements. Hence, a finer spatial and temporal resolution to capture short-term and localized exposures that pose acute threats to human health seems necessary.

1.2. PURPOSE OF THE STUDY

MPOs, states, cities and communities increasingly adopt the concept of Complete Streets to ensure the safe, efficient and affordable movement of pedestrians, bicyclists, motorists and transit riders (NCSC, 2016). Complete streets represent one of the major policy concepts considered in making a livable community, and with their growing popularity, physical activity (PA) among residents is also rising. Research has shown that a walking or bicycling route closer to a heavy-traffic roadway is associated with health issues. Hence, a comprehensive assessment of the air quality near urban arterials and intersections appears important for identifying pedestrian and bicyclist exposure levels, which will in turn help in encouraging transportation infrastructure investment that fosters physical activity. Practitioners and advocacy-groups oftentimes design and implement future routes for pedestrians and bicyclists without considering the air quality element. Unfortunately, this lack of an effective sketch planning tool for assessing project-level acute exposure presents a challenge for effective planning, policy and advocacy. This study seeks to develop a sketch planning tool that assesses air quality performance along an arterial and near an intersection. This tool will help decision makers quantify the potential health risk of a pedestrian and bicycle facility and consider suitable alternatives for better public health. While the researcher acknowledges the importance of such an issue, he also recognizes that civil engineering students mostly receive exposure to engineering concepts related to motorized travel, with less attention to concepts related to nonmotorized or active forms of transportation. The proper identification of infrastructure design elements also demands the proper knowledge and education of its users about potential health impacts associated with them. This study also considers a specific type of learning intervention designed for better learning achievement and proposes a new assessment tool for the evaluation of learning improvement along with other more traditional approaches.

1.3. OBJECTIVE

The movement towards a healthier environment depends upon the proper use of air pollution monitoring, forecasting and reporting that exploits increasingly sophisticated information systems. Translating the right systematic indication into a realistic and effective tool has the potential to reduce the costly toll on public health. The location of a travel/jogging route or a walking school bus route, and the proximity of a school or residential areas to a congested arterial predominantly determines the amount of exposure to air pollution and its associated health risk. This dissertation will work towards closing the aforementioned gaps and divide the work into three phases. Each phase and its results and outcomes is then compiled into a manuscript for submission to different journals. To accomplish the overarching objective of making a performance measure for air quality that is accessible to practitioners, the dissertation outlines three broader goals

1) Development of a 2D Project-level Air Quality Assessment Tool for Active Infrastructure
2) Sketch Planning Tool for Intersection Air Quality using Two-fluid Parameters.
3) MAstery Level Achievement (MALA) Method for Assessing a Project-based Learning Approach to Teach Concepts of Active Commuting

While these broader primary goals will help fulfill the overarching objective of the study, several other secondary objectives are also established beforehand. These associated secondary objectives are

a. *Development of a 2D Project-level Air Quality Assessment Tool for Active Infrastructure*

    - Estimate project-level emission rate of CO, NO_2, and PM for various combinations of speed and volume for meteorological condition in selected areas using EPA's Motor Vehicle Emission Simulator (MOVES)

- Compare the exposure level of the three pollutants analyzed from CL4 (a graphical interface for CALINE4) at different receptor locations along an urban arterial with critical and conservative exposure level for any chronic level exposure
- Develop a performance measure assessment tool for each pollutant (CO, NO_2 and PM_{10}/$PM_{2.5}$) connecting speed and traffic volume for practitioners

b. *Sketch Planning Tool for Intersection Air Quality using Two-fluid Parameters.*

- Identify different parameters of a four-legged intersection with i) a left-turn only lane and ii) a left-turn and a right-turn lane on each approach
- Calibrate two-fluid model parameters from vehicle trajectory data
- Estimate emission rate for the network for the selected fleet and volume combination
- Estimate exposure level of CO, NO_2 and $PM_{2.5}$ and PM_{10} at different receptor locations
- Develop regression models to find the correlation among exposure level, volume, speed, stopping time and running time.
- Develop a qualitative performance measure metric for each pollutant (CO, NO_2 and PM_{10}/$PM_{2.5}$) for the practitioners from the projected exposure level

c. *MAstery Level Achievement (MALA) Method for Assessing a Project-based Learning Approach to Teach Concepts of Active Commuting*

- Compare the post-test scores with the pre-test scores and show the improvement is statistically significant for individual questions
- Compare the post-test scores with the pre-test scores to find statistically significant improvement within Bloom's Taxonomy
- Assess the Mastery Level Achievement of individual students on specific learning objectives and compare this with traditional approaches

1.4. METHODOLOGY

Initially, this research seeks to create an air quality performance assessment tool for evaluating the relationship between air quality and the physical characteristics of alternative walking and cycling routes.

This study mainly focuses on monitoring the exposure level at various receptor locations along an urban arterial. At the second stage, the researcher seeks to broaden the overall effect of pollution concentration near an urban intersection. This study will compare the exposure level with the two-fluid model parameters for better understanding of the overall network level condition. At the end, a project-based active learning intervention is undertaken to compare the learning improvement of students with a unique assessment tool. A detailed summary of each stage of this study is given in the following paragraphs.

1.4.1. Stage 1: Assessment tool for arterials

This study supports the development of a tool to better understand and assess the potential near-roadway pollution levels for pedestrians and bicyclists. A project-level performance measure tool will help cardiovascular and respiratory patients decide where to engage in outdoor activity, and help decision makers select more desirable walking and bicycling routes that consider both connectivity and public health by identifying locations with high pollution. For this purpose, the team develops project-level emission rate estimation models using the EPA's Motor Vehicle Emission Simulator (MOVES). The MOVES output (emission rate) serves as an input in CL4 (a graphical interface for CALINE4) to assess the pollutant concentration along an urban arterial. As CALINE only evaluates dispersion due to CO, NO_2 and PM, other pollutants are not considered for evaluation throughout the study. The study identifies critical and conservative exposure values (that can create minor irritation to mortality) and use them as the exposure levels to categorize different potential health impacts. More details of the process and development is given in chapter 2.

1.4.2. Stage 2: Assessment tool for intersections

The magnitude of the role that traffic-related air pollution plays in health outcomes requires further investigation. Geometric features such as dedicated left turn lanes, dedicated right-turn lane, length of turn lanes and traffic conditions such as speed, volume, and signal timing seem to be essential variables for identifying the project-level exposure level of various pollutants. Combining all of these potential effects into a single assessment tool appears to be the best strategy for providing practitioners an easy strategy to identify neighborhoods and subnetworks at risk for high air pollution levels. This study outlines a performance measure assessment framework and proposes a sketch planning tool using the two-fluid parameters to assess the potential near-intersection pollution levels for pedestrians, bicyclists and residents. The two-fluid model by Prigogine and Herman (1971) assumes that vehicular traffic in an urban network can be differentiated as stopped vehicles and running vehicles. Various other studies by Ardekani (1984), Mahmassani et al. (1984), Vo et al. (2007) and Williams et al. (1985) have done extensive researches to evaluate network performance using the two fluid parameters. The study from Ardekani et al. (1992) found both a positive and negative impact of average speed limit, cycle length and signal density on the two-fluid parameters. Another study by Jones et al. (2004) has successfully evaluated the two-fluid model of urban traffic on arterial streets. This study considers two distinct types of stand-alone intersections as a network element and evaluates their performance in terms of exposure level. Intersections represent a critical network element for assessing network performance; therefore, assessing the intersection air quality can enhance the overall knowledge on project-level assessment and can help predict network level air quality. For this purpose, the researchers initially identifies two different types of intersections; one with only a single dedicated left-turn lane and the other with a single left-turn and a single right-turn lanes. Using the geometric dimensions of the two intersection types, the researchers consider high, medium and low approach volumes on the approaches to develop standard urban congestion scenarios. Due to the complexity of the issue and scope of the research, fixed protected only left turns are used for all scenarios. Microscopic simulation is performed using VISSIM for specific scenarios and trajectory data is generated. The rest of the process follows the study protocol of the first study and generates pollutant concentration at various receptor locations near an intersection.

1.4.3. Stage 3: Assessment tool for learning intervention

Engaging students in real world applications of complex engineering concepts will cause higher levels of learning to occur. The purpose of this paper is to present the Mastery level Achievement method for assessing student learning on a project incorporated into a junior-level (third year) transportation engineering course; the project seeks to educate these civil engineering students about the various categories of active commuting and evaluate the effectiveness of such system. A detailed description of the intervention process, its implementation and assessment methods are described in chapter 4.

1.5. ORGANIZATION

The remainder of the dissertation is organized by chronologically placing these three manuscripts at chapters 2, 3 and 4. The final chapter contains a detailed discussion regarding the benefits of the assessment tools and explores possibilities for future implementation.

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CHAPTER 2

DEVELOPMENT OF A 2D PROJECT-LEVEL AIR QUALITY ASSESSMENT TOOL FOR ACTIVE INFRASTRUCTURE

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2.1. INTRODUCTION

A current Federal statute, United States Code, Title 23, Chapter 2, Section 217 (CFR, 2001), mandates that "Bicyclists and pedestrians shall be given due consideration in the comprehensive transportation plans developed by each metropolitan planning organization [MPO] and State…." MPOs, states, cities and communities around the world are increasingly adopting the concept of Complete Streets to ensure the safe, efficient and affordable movement of pedestrians, bicyclists, motorists and transit riders (NCSC, 2016). Complete streets represent one of the major policy concepts considered in making a livable community, and with their growing popularity, physical activity (PA) among residents is also rising. Although this increased level of PA helps to fight obesity and other health issues (NRPA, 2016), exposure to pollutants emitted from motor vehicles may pose significant health hazards (Kampa & Castanas, 2008; Walsh, 2011; Samaranayake, et al., 2014). In 2012, air pollution contributed to one in eight of the total global deaths and outdoor air pollution in urban and rural areas cause almost 53% (3.7 million) of these deaths (WHO, 2014). The Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) provide standards for major criteria pollutants, which consider annual 24-hr or 8-hour average concentration values measured at monitoring stations. The EPA continuously monitors air-quality trends for the six criteria pollutants, and nationally, the concentration for most of the pollutants follows a decreasing trend. While this standard process helps monitor the ambient air quality at the local or regional level, a project-level hot spot corridor analysis plays an important role in the evaluation of pedestrians and bicyclist health. As presence of hot-spots (Samaranayake, et al., 2014; EPA) along an urban arterial may create severe health issues, this research seeks to identify a project-level air quality assessment tool for evaluating the health risks along transportation corridors. The assessment tool will also help decision makers plan for future pedestrian and bicycle facilities and consider public health.

2.2.1. Health Risks Associated with Air Pollution

Any 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, its 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 (Vallero, 2014; Block & Calderon-Garciduenas, 2009). Cardiovascular and respiratory diseases, chronic obstructive pulmonary diseases (COPD), and cancer denote some of the major diseases that may be caused by air pollution (NIEHS, 2016; Kim, 2009). A recent study also found that inflammation and oxidative stress induce cognitive decline and neuropathology in the brain (Bos, et al., 2014). Gasoline and diesel powered motor-vehicles provide a major source of air pollution in urban areas and emit pollutants due to improper and incomplete burning of fossil fuels (Faiz, 1993); (Colvile, et al., 2001). 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 (CDC, 2013). 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 (CDC, 2013). 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 (CDC, 2015). On the other hand, a large 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 vehicle 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 98th 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 standards (EPA, 1995).

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 (Brook, et al., 2004; Brook, et al., 2010; Mills, et al., 2009; Ostro, 2016; and Ezzati, et al., 2004). Aerodynamic diameters are usually used for characterizing coarse particles (PM_{10}, diameter $\leq 10\mu m$), fine particles ($PM_{2.5}$, diameter $\leq 2.5\mu m$) and ultra-fine particles ($PM_{0.1}$, diameter $\leq 0.1\ \mu m$) (Brook, et al., 2010). $PM_{2.5}$ particles largely originate from fossil fuel burning, and they contribute to roughly 800,000 premature deaths per year globally (Pope III & Dockery, 2012). Particulate matter can penetrate deep into the small airways, alveoli, and blood stream and can create inflammation and vasoconstriction (Bos, et al., 2014).

2.2.2. 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 (Panis, et al., 2010; Mills, et al., 2009). Research has shown that both the ventilation and deposition fractions (the fraction of inhaled particles retained in the lungs) increase significantly during outdoor activities (Panis, et al., 2010; Atkinson, 1997; Daigle, et al., 2003; and Londahl, et al., 2007), which may lead to temporary decreases in lung function (Strak, et al., 2010; McCreanor, et al., 2007), increased levels of inflammatory markers in the pulmonary system (Strak, et al., 2010; Chimenti, et al., 2009), reduced vasodilation (Rundell, et al., 2007) and impairments in exercise performance (Marr & Ely, 2010). Although these health issues intensify with the level of activity for recreational users, some utilitarian users may face similar exertion levels. While many researchers (Yu, Wong, & Liu, 2004; Kubesch, et al., 2014; Kubesch, et al., 2015; Wong, et al., 2007; and Andersen, et al., 2015) have found that the benefits of physical activity outweigh the risks due to air pollution exposure, others have shown that the reverse seems true (Giles & Koehle, 2014). Exposure to air pollution during physical activity appears greater due to the increase in activity; therefore, the acute exposure level that creates health issues needs to be considered for the development of the assessment tool.

2.2.3. 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 have increased tremendously with the increasing number of pedestrian and bicyclist activities near roadways (Morgenstern, et al., 2007; Alexander, et al., 2011). Since, research has shown that a walking or bicycling route closer to roadway with heavy traffic is associated with symptoms of respiratory dysfunction, cardiopulmonary disease and even mortality from stroke (McConnell, et al., 2006; Tonne, et al., 2007), a comprehensive assessment of the air quality near arterials 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. (2002), 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 (Nazelle & Rodriguez, 2009; Grivas & Chaloulakou, 2006). Previous studies such as PM hot spot requirements by Patulski (2012) and near road monitoring requirements use representative monitoring stations strategically placed away from the actual arterial in question. Moreover, the amount of pollutant concentration decreases with time and distance as it dilutes with the air. Hence, a finer spatial and temporal resolution for air quality forecasting seems necessary to capture short-term and localized exposures that may pose acute threats to human health (Kloog, et al., 2015; Gold, et al., 2000). 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.

2.2. RESEARCH CONTRIBUTION

This study supports the development of a tool to better understand and assess the potential near-roadway pollution levels for pedestrians and bicyclists. At present, the existing pollution concentration standards do not exclusively consider health hazards associated with acute exposure from mobile sources at project-level scenarios. The EPA NAAQS standards, which use data from fixed monitoring stations located far away from the urban walkways and bicycle lanes, does not consider the uptake of more pollution due to heavy breathing during physical activity. The key requirements from 40CFR Part 58 Appendix E mandate the use of a monitoring distance no greater than 165ft (50m) from the outside nearest edge of traffic lane. Baldauf et al. (2009) in their research suggest the use of station locations 32.8-65.6ft (10-20 m) from the curb-side, but the proper assessment of project level air quality for an arterial needs to address the exposure its users face during their movement along the road. Therefore, fine resolution roadway and traffic specific air pollution data within 10-32.8ft (3-10m) may serve for better understanding the traffic-related pollution (CO, NO_2 and PM_{10}/$PM_{2.5}$) exposure levels for people engaged in outdoor physical activities (Samaranayake, et al., 2014). A project-level performance measure tool will not only help cardiovascular and respiratory patients decide where to engage in outdoor activity, but identifying locations with high pollution can help decision makers select more desirable walking and bicycling routes that optimize both connectivity and public health. For this purpose, the team develops project-level emission rate estimation models using the EPA's Motor Vehicle Emission Simulator (MOVES) and then use the output (emission rate) as an input in CL4 (a graphical interface for CALINE4) to assess the pollutant concentration along an urban arterial. The study identifies critical and conservative exposure values (that can create minor irritation to mortality) and use them as the exposure levels to categorize different potential health impacts. The study later develops a 2D (speed-volume) assessment tool for pollutant concentrations for each of the four pollutants.

The rest of the paper is organized as follows: In section 2, the authors lay out the foundation of the research methodology and discuss the MOVES and CALINE4 modeling in detail. Section 3 discusses the results from both of the modeling platforms, and section 4 provides a detailed discussion of the results and the performance measure tool development. Section 4 also explains the tool's use procedure for practitioners and researchers. Later, in section 5, the research team concludes the study and discusses its potential implications and directions for future research.

2.3. METHODOLOGY

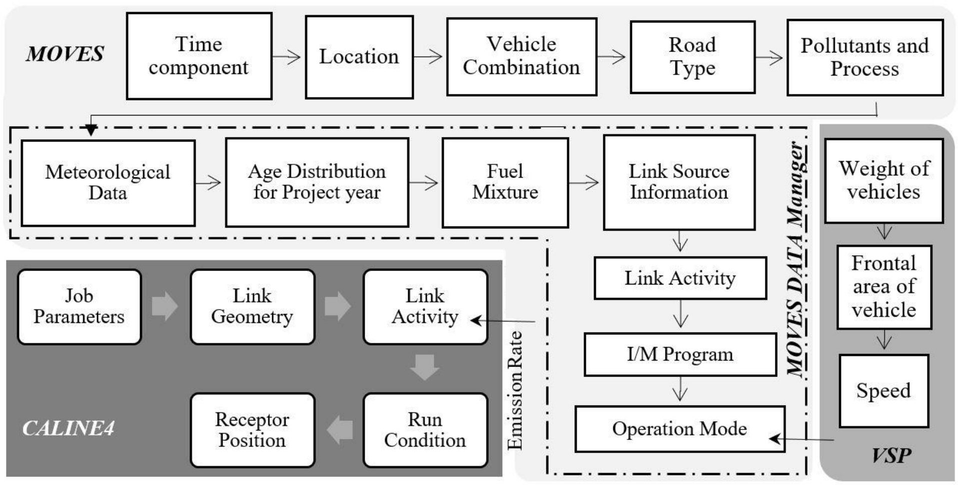

Figure 1 Steps in development of project level performance measure assessment tool for air quality.

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 (Buonocore, et al., 2009). 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 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 of a one-mile long arterial 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.

2.3.1. Project-Level Emission Rate Estimation by MOVES

This study uses the EPA's latest version of motor vehicle emission measurement simulator (MOVES2014a) 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 speeds (30, 35, 40 and 45 mph) for the emission rate calculation. A steady-state traffic condition with constant speed is assumed throughout the study for the arterial. MOVES's default age distribution tool projects the fleet distribution for 2020 which will consider the effect of older fleet and their higher level of emission. Cold temperature and low humidity increases the emission rate (Qiu, et al., 2013); 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 ºF) is higher than that of (19.9 ºF) 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 (1997), which is represented in the following Table 1.

Table 1. Fractions of Hourly Vehicles Present at a One-mile Section

Vehicle source use type ID	Vehicle name	Description[1]	Weight GVWR (lb)	Hour fraction
21	Passenger Car	All Cars	~4,000[2]	0.4245
31	Passenger Truck	Mini-van, pick-up (personal)	0-6,000[3]	0.5085
32	Light Commercial Truck	Mini-van, pick-up (commercial)	0-8,500	0.03
43	School Bus	School and church buses	8,500-10,000	0.007
52	Single Unit Short-Haul Truck	Majority of operation within 200 miles of base	14,001-16,000	0.03

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 conditions. The 'running' mode needs average speed or Vehicle Specific Power (VSP) to be input as the operating mode parameter. A study by (Song, et al., 2012) finds that the mean of the VSP distribution strongly correlates with the VSP value when cruising at the average travel speed. The

[1] Texas Transportation Institute. Characterization of Vehicle Activity and Emissions from Heavy-duty Diesel Vehicles in Texas. Retrieved on 10th of August from https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/mob/5820990400FY1111-20110831-tti-tx_hddv_ei.pdf
[2] List of car weights. Retrieved on 10th of August from http://cars.lovetoknow.com/List_of_Car_Weights
[3] http://www.deq.virginia.gov/Portals/0/DEQ/Air/Assessments/photochemical/MOVES/21-VA_MARAMA_07292014_CRC_A88_part2.pdf

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 (Jimenez, 1999). Table 2 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 2. Calculation of Vehicle Specific Power (VSP) for Different Vehicle Types

	Weight of vehicles (m)		Front Area[4] (A)	Drag Coefficient (Cd)[5]	Speed (V)	Grade (g)	VSP	VSP Bin
Unit	**lb**	**Kg**	**m²**		**(m/s)**		**W/Kg**	
Passenger Car	4000[2]	1814.37	2	0.28	13.41	0	23.614	28
Passenger Truck	6000[3]	2721.55	3.3	0.36	13.41	0	23.800	28
School Bus	10000[3]	4535.92	5	0.7	13.41	0	24.288	28
Light Commercial Truck	8500[3]	3855.54	3.3	0.5	13.41	0	23.788	28
Sing Unit Short-Haul Truck	16000[3]	7257.48	5.2	0.9	13.41	0	24.103	28

2.4.1.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 (Kaur, et al., 2005;

[4] *vehicle frontal area, calculated from http://hpwizard.com/aerodynamics.html*
[5] *vehicle coefficient of drag list. retrieved from* http://ecomodder.com/wiki/index.php/vehicle_coefficient_of_drag_list

Zhao, et al., 2004) and reduces with the downwind distance (Roemer & van Wijnen, 2001). The one-mile road segment (at grade) is a two-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 curb. According to the CALINE4 model, the width of the mixing zone includes the roadway width plus 10ft (~3m) on both sides (Batterman, et al., 2010). 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 (Samaranayake, et al., 2014) in the corridor. The height of the receptor also determines how much dispersion it will measure. Although 40CFR Part 58 Appendix E suggests the use of 6.56 ft (2m) as human height, this study considers both adults (5 feet) and children (3.5 feet) as potential receptors; however, a comparative assessment confirms that children (average 3.5ft of height) 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.

Given the potential variability in meteorological conditions, the sketch planning tool utilizes a worst case scenario approach to identify if a site should consider additional air quality investigation. The settling velocity for particulates at which a particle falls with respect to its immediate surroundings of 0 cm/s and deposition velocity of CO and NO_2 of 0 cm/s represent the rate at which a pollutant can be absorbed for a worst case scenario (Ishaque & Noland, 2008). The study sets the area roughness coefficient to 100 cm (to approximate a suburban area) with a wind speed of 1 m/s and the atmospheric stability class at 1 or A (unstable). The altitude above sea level for Tarrant County is considered 608ft and for Kalamazoo county 700ft. The study assigns standard ambient levels of NO, NO_2 and O_3 at 0.02, 0.10 and 0.20 ppm, respectively, for the sensitivity analysis (Benson, 1984). The study also establishes the photo dissociation rate (KR) at $4 \times 10^{-3}\ s^{-1}$ and the NOx emission factor at 1.0 gm/veh-mi as suggested by (Benson, 1984) for a standard sensitivity run. The study uses wind headings from 0° (due North) and obtains pedestrian exposure for the worst case wind direction conditions (Hanninen, et al., 1999).

2.4. RESULTS

The output results from the MOVES modeling provides emission rates in grams per mile. These results are aggregated based on volume type and speed range and presented in Figure 2. The results suggest that in Kalamazoo, for a speed of 30 mph and traffic volume of 500 veh/hr (V500), the $PM_{2.5}$ emission rate is 0.47 g/mile, which is slightly higher (0.4%) than Tarrant County. In fact, the emission rates from MOVES suggest that relatively insignificant differences between the rates for a change of volume.

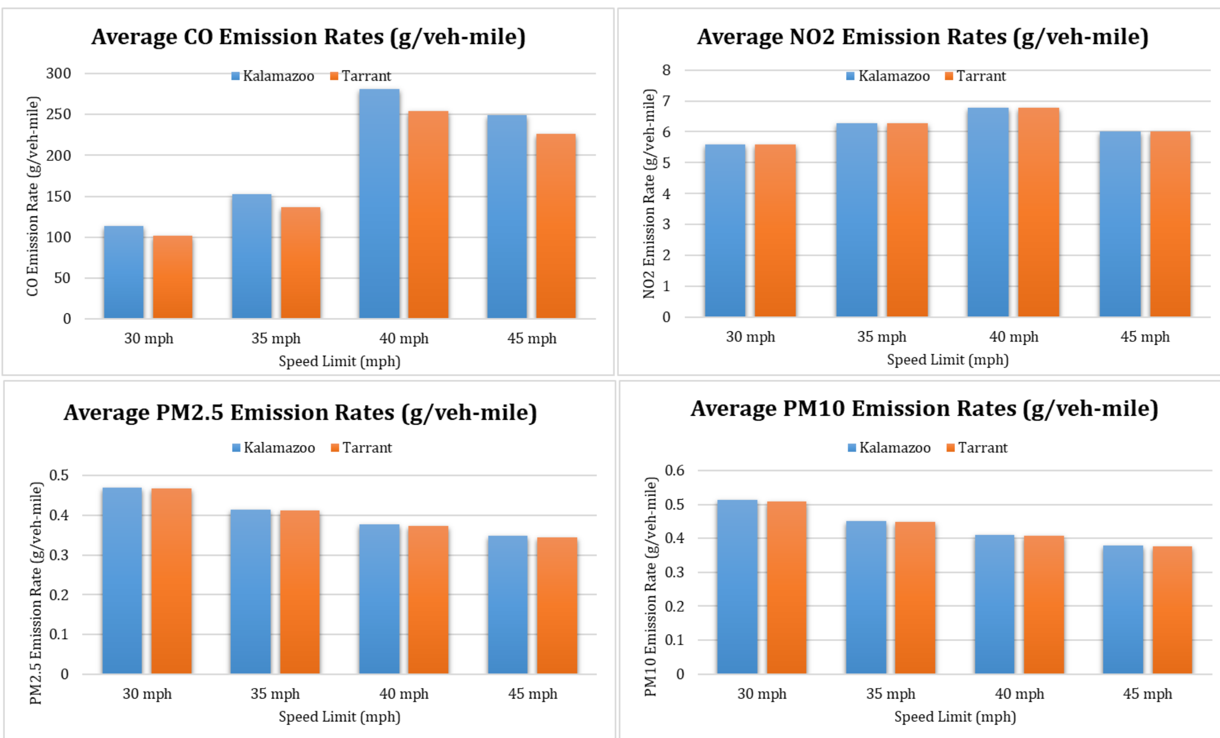

Figure 2 Pollutant emission rates for Kalamazoo (left) and Tarrant (right) county.

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 Panis, et al. (2011). 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 Kenty, et al. (2007). 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.

Table 2 Average 1-hr Pollutant (CO and PM2.5) Concentration at Receptor Locations

CO	**Tarrant County**				**Kalamazoo County**			
	Traffic Volume (veh/hr)				**Traffic Volume (veh/hr)**			
Speed (mph)	50	250	500	750	50	250	500	750
30	4	20	40	59	4	22	45	67
35	5	27	53	80	6	30	60	90
40	10	50	99	149	11	55	110	165
45	9	44	88	132	10	49	98	147

PM2.5	**Tarrant County**				**Kalamazoo County**			
	Traffic Volume (veh/hr)				**Traffic Volume (veh/hr)**			
Speed (mph)	50	250	500	750	50	250	500	750
30	16.5	82.5	164.9	247.3	16.6	83.0	165.9	248.9
35	14.5	72.7	145.5	218.2	14.6	73.3	146.5	219.8
40	13.2	66.0	132.0	198.1	13.3	66.5	133.1	199.7
45	12.2	60.9	121.8	182.7	12.3	61.4	122.9	184.3

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 Table 3 (only CO and $PM_{2.5}$).

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. On the other hand, for $PM_{2.5}$, the minimum and the maximum values are 12.2 μg/m³ and 248.9 μg/m³ respectively with a median value of 102.4 μg/m³.

2.5. DISCUSSION

Studies (Wells, et al., 2012; Wen, et al., 2009; and Semenza, et al., 2008) indicate that a significant number of individuals will change/reduce their outdoor activities based on their perception of air quality or awareness of medical alerts. These findings add to the fact that exposure to outdoor air pollution poses serious health risks. Hence, an arterial air quality tool will help solve this project-level acute exposure issue and help plan future infrastructure investments. When establishing the boundaries for 1-hour pollutant exposure concentrations, the researchers consider both minor and major effects on human health with a focus on risks to children. The standard should capture not only the concentration harmful for susceptible people but also those that can cause mortality. An extensive literature review helps identify these extreme conditions.

2.5.1. Concentration Boundaries

According to National Ambient Air Quality Standards (EPA, n.d.), 1-hr CO concentration is parts per million (ppm) 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 4.

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 4 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 selecting the final category boundary. Table 4 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 4.

TABLE 3 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[6]	0-0.11	0-37.5	0-40	Excellent
35-400	0.11-0.6[7]	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

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) in figure 3. The scale on the right side shows the concentration level for each pollutant. Using the zonal boundaries set before (Table 4), the right-hand side scale is modified to show the average 1-hr concentration. This modification helps identify the health risk boundaries (see Figure 3) 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.

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

[7] *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*

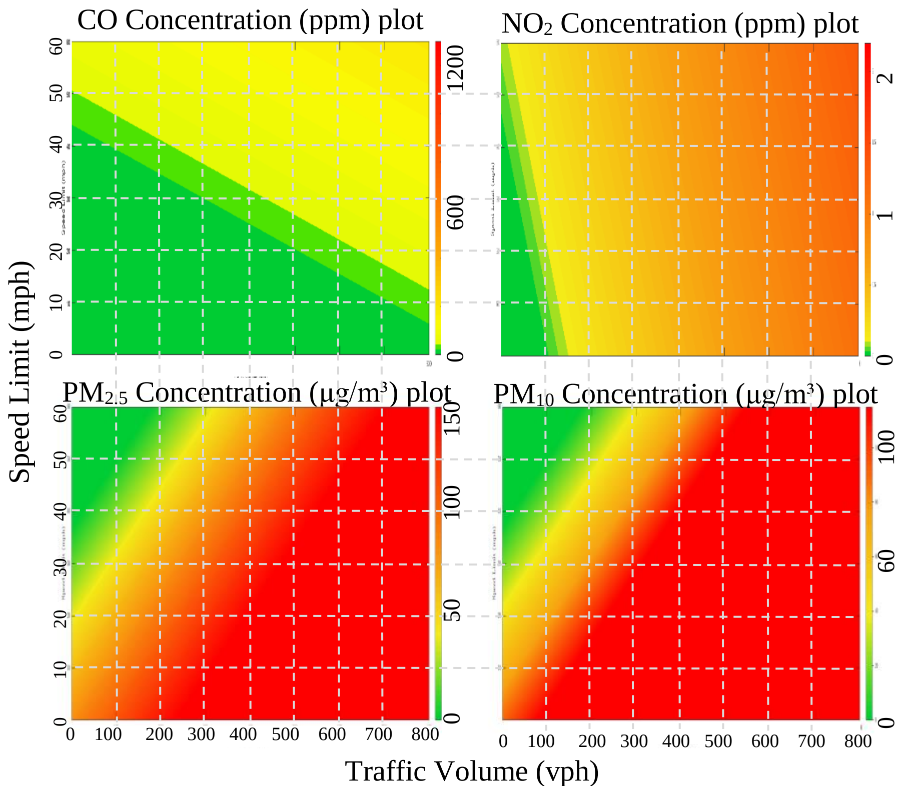

Figure 3. Average 1-hr Pollutant (Clockwise: CO, NO2, PM10 and PM2.5) Concentration Plot.

2.5.2. Application of the Air Quality Performance Measure

Planners and agencies can use these graphs to evaluate potential air quality risks along a particular road segment. The application of this tool requires the traffic volume in veh/hr and speed limit in mph. As an example the study team evaluates the air quality risk near Shackelford Junior High School in Arlington, Texas (Figure 4). This school is located at the intersection of N Fielder Road (40 mph speed limit) and W Lamar Blvd (35 mph speed limit). The peak hour traffic volume for N Fielder is about 675 vph in the SB direction, and EB W Lamar Blvd has a volume of 200 vph. Using Figure 4, the peak hour volume and speed limit specify the air quality for each pollutant. For N Fielder Rd, speed-volume combination falls in the 'good' zone for CO (141 ppm), 'fair' for NO_2 (1.15 ppm) and 'red' zone or the 'poor' zone for both PMs ($PM_{2.5}$ is 178.9 µg/m^3 and PM_{10} is 195.2 µg/m^3). Similarly, for EB W Lamar Blvd, the speed-volume combination shows an 'excellent' condition for CO (22 ppm), 'good' condition for NO_2 (0.32 ppm) and 'fair' condition for both of the PMs ($PM_{2.5}$ is 58.4 µg/m^3 and PM_{10} is 63.6 µg/m^3) . Evidently, the short-term $PM_{2.5}$ and PM_{10} exposure indicates a 'poor' state in the morning peak hour for N Fielder Rd, which

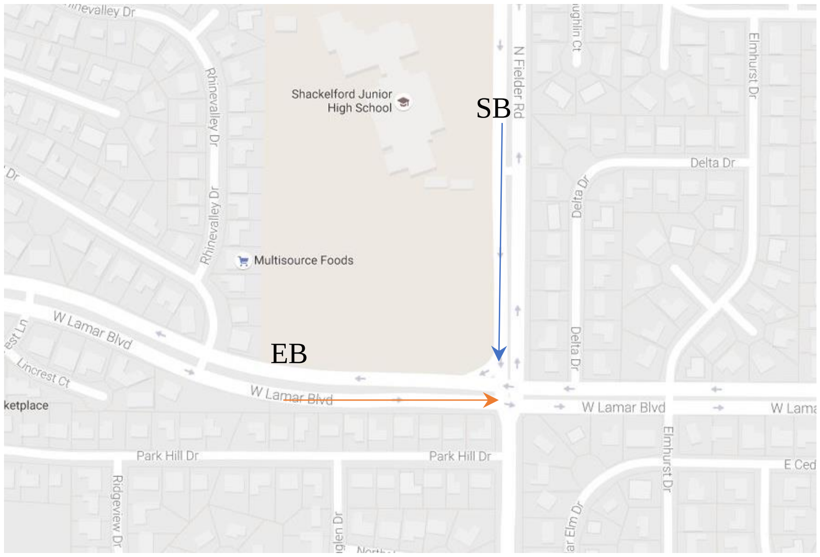

Figure 4 Case study for air quality monitoring (© Google).

requires further investigation to determine if it is safe for physical activity. W Lamar Blvd appears to be an acceptable route for accessing the school bicycling or walking.

2.6. CONCLUSION AND RECOMMENDATIONS

In the absence of any project-level (or corridor analysis) performance measure assessment tool, this proposed tool will help stakeholders such as planners, practitioners and advocacy groups related to active commuting. Instead of using the standards for hot-spot analysis set by EPA, this study uses air quality standards based on various epidemiological studies where a minimum amount of exposure of a specific pollutant creates any type of irritation symptoms among any group of people, specifically vulnerable groups such as children. Not only do children appear to experience more significant risks due to air pollution exposure, but they also risk greater exposure due to higher concentrations at their nose and mouth height. The impact of height can be investigated in greater detail in future studies to determine the most critical combination of concentration and age vulnerability; this study may require more health risk studies to characterize the potential impacts more accurately for different age groups. The assessment tool proposed in this study provides a critical means for evaluating the air quality differences among arterials and other urban streets. While, the tool can be used as a sketch planning tool for identifying future bicycle and pedestrian routes along an arterial, it also helps identify where more detailed hot-spot analysis should occur for future developments.

To help identify when air quality may be a concern, the researchers develop a project-level air quality risk assessment tool. To provide a useful sketch planning tool with generalizable outcomes, the research team makes conservative assumptions for the meteorological conditions. As a result of these and other assumptions, the sketch planning tool does not provide evidence of a definitive health risk; however, it can assess relative health risks and provide an indication that the true health risk may need to be thoroughly modeled. To build this tool, the study only uses two hypothetical sites in two different geographic locations (varying only temperature and humidity); in the future, other sites could be combined with these results to widen the range of potential outcomes. However, as a sketch planning tool, this additional work may not be necessary. The tool does not consider background level pollutants for any particular site, and instead, it focuses on generating the emission concentrations due to the traffic impacts only. Since this generalized version of the arterial air quality risk assessment tool only requires an arterial's speed limit and volume, it can easily be used by practitioners and policymakers for evaluating current and future infrastructure with respect to air quality.

In addition to the previously mentioned limitations, this study may still benefit by relaxing some of the assumptions made in the tool development. For example, the temperature selected for the dispersion modeling should be based on research that indicates likely temperature thresholds for outdoor physical activity and active utilitarian trip making. Although this tool makes generalized assumptions about meteorological conditions, AERMOD can be used instead of CALINE4 for measurement of area specific pollutant concentrations. The tool may benefit from an expansion of the potential volumes and numbers of lanes available to expand the range of arterials covered by it. Additionally, refining wind conditions will likely return much more accurate preliminary assessments of risk; however, this will increase the dimensions required for applying the sketch planning tool. Different receptor placements may be implemented for bicycle and pedestrian facilities to show the potential differences in exposure; furthermore, nearby sensitive facilities such as schools may also be assessed by changing the receptor location. Future studies may also build similar sketch planning instruments for intersections. Planners can use the planning tool to include the local air quality needs and impacts in future project-level planning and policy recommendations.

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CHAPTER 3

Sketch Plan for Intersection Air Quality using Two-fluid Parameters

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3.1. INTRODUCTION

Due to the demand of federal legislation (i.e.; 23 U.S. Code § 217, 2017) and programs (such as Nonmotorized Transportation Pilot Program, Safe Routes to School Program, Transportation Alternative Program, and NHTSA 405) to include nonmotorized, active commuters in transportation facility design, MPOs, states, cities and communities increasingly adopt the concept of Complete Streets to ensure the safe, efficient and affordable movement of pedestrians, bicyclists, motorists and transit riders (NCSC, 2016). Although, a many studies focus on the safety of pedestrians and bicyclists for encouraging more active commuters, less has been done on identifying the air pollution exposure levels of these active mode users. The Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) provide standards for major criteria pollutants, which mostly consider annual 24-hr or 8-hour average concentration values measured at monitoring stations. The Air Quality Index (AQI) developed by the EPA provides an accurate, up-to-date and easily understandable daily level of air pollution. While the NAAQS do not consider the acute exposure to higher concentration levels for all the pollutants, the AQI does not exclusively identify exposure from mobile sources. These factors leave a significant gap, which limits the ability of urban planners and advocacy groups to assess the air pollution exposure level due to transportation activity at any specific location for project-level analysis. Other research (Rahman, 2017) creates a set of assessment tools for practitioners of the public health sector to mitigate these issues and this manuscript specifically focuses on the development of a sketch planning assessment tool for quantifying the potential health risk at an urban intersection to help decision makers plan pedestrian and bicycle facilities while considering public health.

3.1.1. Health Risk

Air pollution has the potential to contribute to many negative health outcomes. The adverse health impact associated with air pollution (Kampa & Castanas, 2008; Walsh, 2011; Samaranayake, et al., 2014) varies depending on the type of pollutant, its magnitude, the exposure duration and frequency, and the associated toxicity. The major air pollutants monitored by the Environmental Protection Agency (EPA) include nitrogen dioxides (NO_2), carbon monoxide (CO), volatile organic compounds (VOC), ozone (O_3), sulfur dioxide (SO_2), and large and small particles. Oxidative stress, inflammation, and genetic defects represent some of the basic mechanisms where the vapor and particulate phases of pollutants induce negative health effects (Vallero, 2014; Block & Calderon-Garciduenas, 2009). Cardiovascular and respiratory diseases (e.g. lung cancer and asthma), chronic obstructive pulmonary diseases (COPD), cancer, and type 2 diabetes (Wang et al., 2014; Rajagopalan et al., 2012) denote some of the major diseases that may be caused by air pollution (NIEHS, 2016; Kim, 2009; Brook et al. 2010; Health Effects Institute (HEI) 2010; Stieb et al. 2012).

3.1.2. Proximity to the Source

While stationary and natural sources play an important role in air pollution, motor vehicle exhaust emissions represent the single largest source of regional air pollution in urban areas and emit pollutants into the air due to an improper and incomplete burning of fossil fuels (Faiz, 1993; Colvile, et al., 2001). Studies indicate that populations living, working, or going to school near major roads may be subjected to an increased risk for a number of adverse health effects such as respiratory, cardiovascular, premature mortality, low birth weight and cancer (e.g., Pearson et al. 2000; Wilhelm and Ritz 2003; Finkelstein et al. 2004; Gauderman et al. 2005; McConnell et al. 2006; Adar and Kaufman 2007; Samet 2007; Samal et al. 2008). Air quality monitoring studies have measured elevated concentrations of pollutants emitted directly by motor vehicles near large roadways—relative to overall urban background concentrations (e.g., Zhu et al. 2002; Harrison et al. 2003; Reponen et al. 2003; Kim et al. 2004; Baldauf et al. 2008a). Studies by MacNaughton et al. (2014), Hatzopoulou et al. (2003), Boogaard et al. (2009) and Kendrick et al. (2011) have shown a direct relation between different types of bike route (i.e. bike path vs. bike lane) and concentration of pollutants.

3.1.3. Variables Associated to Mobile Source

Exposure to traffic-related air pollution depends primarily on meteorological conditions and traffic activity. The number of vehicles, the fleet mix, and vehicle speed/operating pattern represent the major parameters for traffic activity that affect the concentration of near-road pollutants. While geographic locations (state and county) and time span (year, month, day and hour) are examples of required parameters to estimate on-road project-level emission rate in MOtor Vehicle Emission Simulator (MOVES), CALINE4 only requires wind speed and direction, temperature, and atmospheric stability, to describe the dispersion level at locations near roads (Venkatram et al. 2007). A detailed analysis of the built environment shows that physical barriers such as noise barriers, vegetation, and buildings may have some effect on pollutant concentrations around a structure by blocking the initial dispersion and increasing the turbulence and initial mixing of the emitted pollutants (Al-Dabbous et al. 2014; Bowker et al. 2007; Baldauf et al. 2008b, Heichel and Hankin 1976; Bussotti et al. 1995; and Beckett et al. 2000). While the built environment may play a role in controlling the xposure of pollutant concentrations, the traffic and meteorological condition are the dominant factors that contributes towards determining the level of concentrations.

3.1.4. 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 (Panis, et al., 2010; Mills, et al., 2009). Exposure to air pollution during physical activity appears greater than static exposure rates; therefore, the air quality assessment tools need to consider the potential for a more significant health impact.

3.1.5. Assessment tool for project-level analysis

Motor vehicle exhaust emission represents the single largest source of regional air pollution in urban areas. The public’s concern regarding human exposure to near-road traffic-related air pollution has increased tremendously with the increasing number of pedestrian and bicyclist activities near roadways (Morgenstern, et al., 2007; Alexander, et al., 2011). Since, research has shown that a walking or bicycling route closer to a heavy-traffic roadway is associated with health issues, a comprehensive assessment of the air quality appears important for identifying pedestrian and bicyclist exposure levels, which will in turn help in encouraging transportation infrastructure investment that fosters physical activity in a healthy way. The National Collaborating Centre for Environmental Health in their Air Quality Assessment Tools guideline

(Barn et al. 2011) has identified several assessment tools used by practitioners to identify sources contributing to poor air quality, mitigation strategies for the problem and most affected area. This valuable information often times does not seem readily useable to practitioners such as walking/bicycling advocacy groups, urban planners or school principals while considering new infrastructure or a walking or biking route. While the sketch planning tool developed by Kockelman et al. (2010) can be highly cost-effective for budgeting and project targeting decisions by assessing the traffic flow impacts of large scale infrastructure, trip destination pattern, travel mode, route and time of day; the tool is not effective for project-level analysis. The Transportation Air Quality Sketch Planning Tool developed by the Texas Transportation Institute estimates emissions for specific projects for Travel Demand Model (TDM) and non-Travel Demand Model components. While TDM aims at indicating directional changes in emissions for sketch planning purposes, non-TDM provides a starting point for the Community Multiscale Air Quality Modeling System (CMAQ). Neither of these methods focus on identifying the project-level acute exposure level. The lack of an effective sketch planning tool for assessing project-level acute exposure presents a challenge for effective planning, policy and advocacy; this paper seeks to address this gap in previous research.

3.2. RESEARCH CONTRIBUTION

The magnitude of the role that traffic-related air pollution plays in health outcomes requires further investigation. 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. (2002), pollutant concentrations adjacent to and downwind of major traffic routes remain higher than the regional background level. Geometric features such as dedicated left turn lanes, dedicated right-turn lane, length of turn lanes and traffic conditions such as speed, volume, and signal timing seem to be essential variables for identifying the project-level exposure level of various pollutants. Studies from MacNaughton et al. (2014), Jarjour et al. (2013) and Hertel et al. (2008) have shown that the reduction of traffic-volume, an increase of the distance between the pedestrian/bicycle route and the roadway, a vegetation barrier and reduced intersection density appear to decrease air pollution exposure. At the same time, a study by Zhang and Batterman (2013) shows that depending on the type of road, additional traffic can significantly increase the health risks.

This study develops of a sketch planning tool to better understand and assess the potential near-intersection pollution levels for pedestrians and bicyclists. Fine resolution roadway and traffic specific air pollution data may serve for better understanding of traffic-related pollution (CO, NO_2 and $PM_{10}/PM_{2.5}$) exposure levels for people engaged in outdoor physical activities (Samaranayake, et al., 2014). A project-level performance measure tool will help cardiovascular and respiratory patients decide where to engage in outdoor activity and decision makers to identify locations with high pollution while selecting more desirable walking and bicycling routes that optimize both connectivity and public health.

For this purpose, the researcher identifies two different types of intersections approaches; one with a single dedicated left-turn lane and the other with a single left-turn and single right-turn lanes. Using the geometric dimensions of the two intersection types, the researchers consider high, medium and low approach volumes on the major and minor approaches to develop standard urban congestion scenarios. Due to the complexity of the issue and scope of the research, protected only left turn signal is used in all scenarios which makes these two major and minor approaches totally independent of each other. Microscopic simulation is performed using VISSIM for these specific scenarios and trajectory data is generated. The researcher develops project-level emission rate estimation models using the EPA's MOVES for each speed-volume combination; and its output (emission rate) serves as an input in CL4 (a graphical interface for CALINE4) to assess the pollutant concentration near an urban intersection. The study identifies critical and conservative exposure values (that can create minor irritation to mortality) previously identified by Rahman (2017) and uses them as the exposure levels to categorize different potential health impacts.

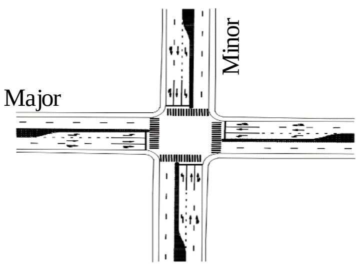
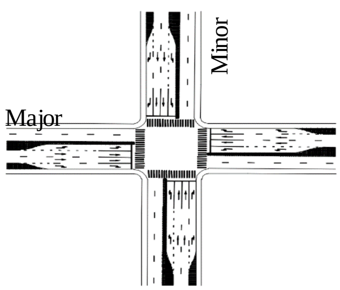
The rest of the paper is organized as follows: In section 3.3, the authors lay out the foundation of the research methodology and discuss the VISSIM, MOVES and CALINE4 modeling in detail. Section 3.4 discusses the results from the modeling platforms, and section 3.5 provides a detailed discussion of the results and advantages and limitation of this study. Later, in section 3.6, the research team concludes the study and discusses its potential implications and directions for future research.

3.3. METHODOLOGY

A proper assessment of the detrimental effect of motor vehicle pollution exposure on people engaged in physical activity requires an estimate of exposure at signalized intersections. The study aims to develop a sketch planning tool to assess and compare air quality conditions at urban intersections. The traffic volume and speed limit represent two major parameters that directly impact emissions of air pollution (Buonocore, et al., 2009). A sketch planning tool that connects the exposure level to key parameters can address potential air quality performance measures at the project-level (at an intersection). Keeping this objective in mind, the research team initially considers a simple urban intersection with a dedicated left-turn lane. The two streets cut at a 90^0 and a curb return of 30ft is used at each approach (TxDOT Manual, 2014) to simulate a pedestrian friendly intersection. The other variables and geometric features such as the acceleration/deceleration lane and storage length of the left-turn lane, right-turn angle, angle of the intersection, total number of lanes are fixed (TxDOT) Roadway Design Manual (2014) and Design Criteria Manual (2003). The research team considers ten speed combinations for major-minor approach with 30, 35, 40 and 45 mph speed limits; however, this paper only considers two speed combinations and six volume combinations for the left and right turn settings because of limited scope of the project (Table 4). After identifying the intersection properties, the researchers perform microscopic simulations for each of the twelve scenarios (Table 5). The approach volumes follow the Highway Capacity Manual exhibits for generalized service volumes for a signalized intersection to simulate three different intersection service condition. The VISSIM model generates link properties and vehicle trajectory files for use in MOVES modeling. At this initial stage, the research team develops a project-level MOVES model for an intersection in Tarrant County in Texas to estimate the emission rate along the intersection 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, vehicle trajectory data from the microscopic simulation model (VISSIM) are used to generate operating mode distributions for different types of vehicles and integrated with MOVES (2014a) using the VIssim Moves Integration Software (VIMIS) developed by Abou-Senna et al. (2013).

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. The overall process of this approach is explained in figure 5.

Table 4 Simulation Scenarios for Experimental Design

Run #		Schematic	Speed		Left Turn Lengths						Right Turn Lengths					
			Major	Minor	Major			Minor			Major			Minor		
					DL	TL	SL	DL	TL	SL	DL	TL	SL	DL	TL	SL
1	Left-turn only		30	30	160	50	100	160	50	100	X	X	X	X	X	X
2			35	30	215	50	100	160	50	100	X	X	X	X	X	X
3			35	35	215	50	100	215	50	100	X	X	X	X	X	X
4			40	30	275	50	100	160	50	100	X	X	X	X	X	X
5			40	35	275	50	100	215	50	100	X	X	X	X	X	X
6			40	40	275	50	100	275	50	100	X	X	X	X	X	X
7			45	30	345	100	100	160	50	100	X	X	X	X	X	X
8			45	35	345	100	100	215	50	100	X	X	X	X	X	X
9			45	40	345	100	100	275	50	100	X	X	X	X	X	X
10			45	45	345	100	100	345	100	100	X	X	X	X	X	X
11	Left and right-turn only		30	30	160	50	250	160	50	250	160	50	50	160	50	50
12			35	30	215	50	250	160	50	250	215	50	100	160	50	50
13			35	35	215	50	250	215	50	250	215	50	100	215	50	100
14			40	30	275	50	250	160	50	250	275	50	175	160	50	50
15			40	35	275	50	250	215	50	250	275	50	175	215	50	100
16			40	40	275	50	250	275	50	250	275	50	175	275	50	175
17			45	30	345	100	250	160	50	250	345	100	250	160	50	50
18			45	35	345	100	250	215	50	250	345	100	250	215	50	100
19			45	40	345	100	250	275	50	250	345	100	250	275	50	175
20			45	45	345	100	250	345	100	250	345	100	250	345	100	250

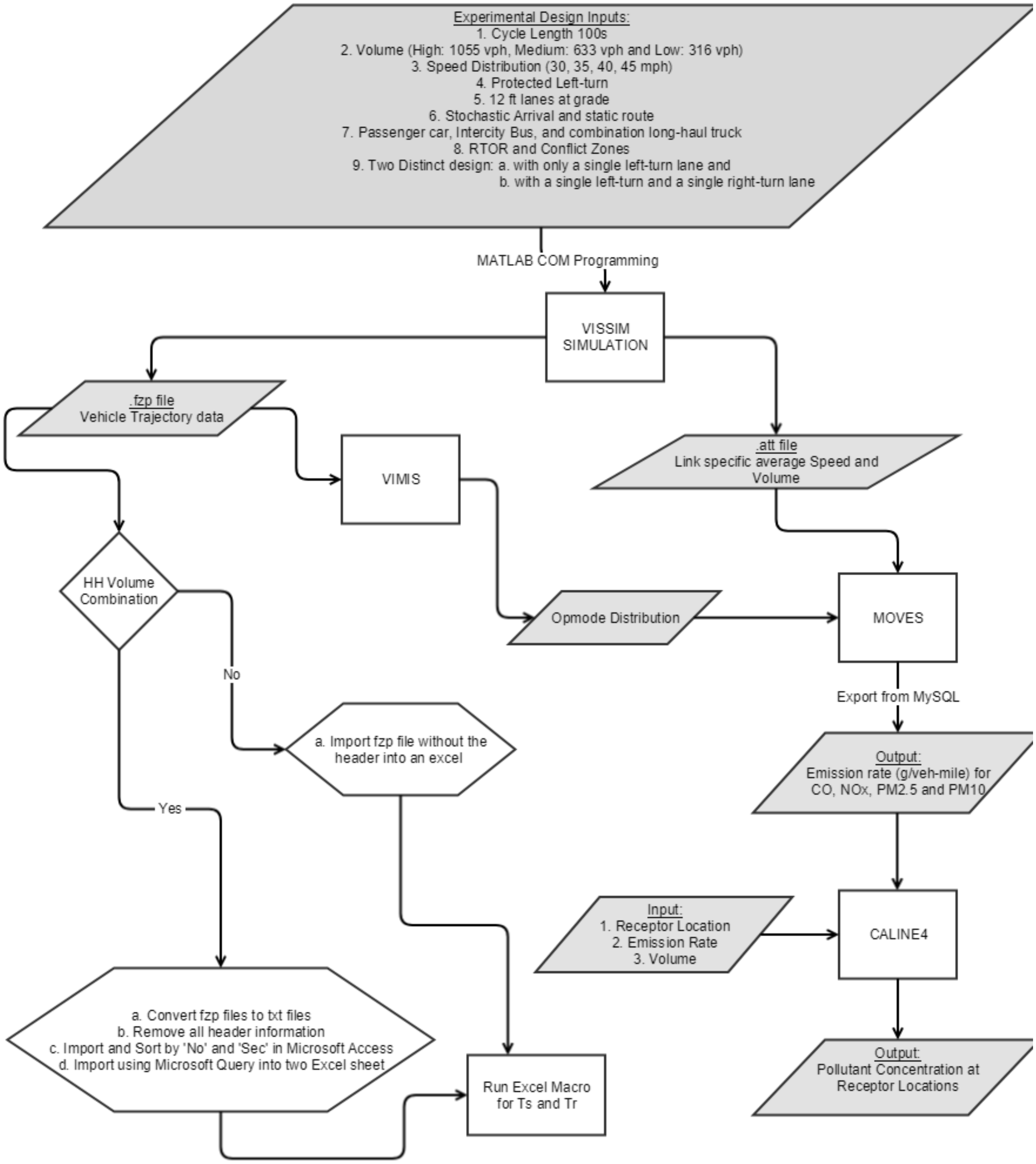


Figure 5 Various stages of the experimental design

3.3.1. Microscopic Simulation in VISSIM

The researchers develop the experimental design to facilitate relationships among variables such as the approach link speed, approach volume, the availability of both dedicated left-turn lanes and left and right turn lanes, and other geometric features. The network in the VISSIM simulator must be based on the intersection dimensions to eliminate any extra length of the network elements to reduce travel time and stop time calculations. The research team calculates the exact length and coordinates of each link and codes it into a VISSIM input file (*.inpx) so that less than one foot of overlap occurs between a connector and a link. Later, the research team calibrates the design speed curve for all combination and also adopts the speed distribution for left-turn and right-turn reduced speed proposed by the Oregon Department of Transportation (ODOT) in their Protocol for VISSIM Simulation (2011).

Every other feature, such as the car following theory and overtaking, uses either the default values or values that reflect the traffic conditions at or around an urban intersection. One major goal for this stage is to make sure the simulator has a sufficient warm-up period to generate traffic and accurately provide consistent results. An initial investigation identifies that with at least 7 runs, the results have less than a 5% error. Moreover, the researchers modified the length of the approach link of the intersection for the worst-case scenario so that the queue created by the signal (100 sec cycle) does not go further than the start point. Due to the scope of the work, a fixed cycle length and splits with only left turn lanes is used for all volume and speed combination for a more signal timing plan is used for the protected left-turn phase, but a more detailed analysis will require the consideration of other signal timing scenarios. As traffic approaches the intersection, 20% turn left and 20% turn right.

After the final calibration of each of the parameters, the research team used Matlab R2016a to do batch run of the simulations. As a single time step is used to check the location of each of the vehicle in the network, the size of the trajectory file for HH volume scenario exceeded the total limit of rows that can be operated in Excel. The research team uses Microsoft Access and Microsoft Query in Excel to split up such big data sets. The researchers evaluated each of the seven simulation runs for accuracy and identified a representative run to be used in MOVES modeling. The researchers used a single signal timing plan (cycle ø100 seconds) with protected only left turn approach for all volume and speed condition.

3.3.2. Project-Level Emission Rate Estimation by MOVES

This study uses the EPA's latest version of MOVES (MOVES2014a) 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 powered vehicles to represent the likely sources of vehicle types (passenger car, intercity bus and combination long-haul truck). The experimental design considers a total of six traffic volume combinations (high-high, high-medium, high-low, medium-medium, medium-low and low-low) and two speed limit combinations (30-30 and 35-30 mph) for major-minor approaches 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 (Qiu, et al., 2013); therefore, to create the worst-case scenario, this study uses an analysis period for weekdays in January 2020 from 8:00 AM-9:00 AM. The MOVES database includes 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 from Tarrant County are collected from the National Oceanic and Atmospheric Administration (NOAA) and Weather Underground website. While the January average low temperature of Tarrant County is 35.5 ºF, the average humidity is about 60%. The different vehicle fractions (93.3% passenger cars, 6% combination long-haul trucks and 0.7% intercity bus) present on a hypothetical urban intersection use the vehicle class percentages found in Hallenbeck et al.'s study (12). The operating mode characterizes the drive cycle into different activities such as idling, running, cruising and braking. The use of VIMIS converts the trajectory file into an operational mode distribution file that identifies the fraction of each vehicle type present for each category of operation.

3.3.3. 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 (Kaur, et al., 2005; Zhao, et al., 2004) and reduces even with the downwind distance (Roemer & van Wijnen, 2001). The generalized intersection has 16 different links where an approach link, a dedicated left turn lane, through lane and a departure lane consist of each leg. Although the approach length of each intersection leg is always 1500ft, the deceleration length and the storage length change based on the speed limit for each approach.

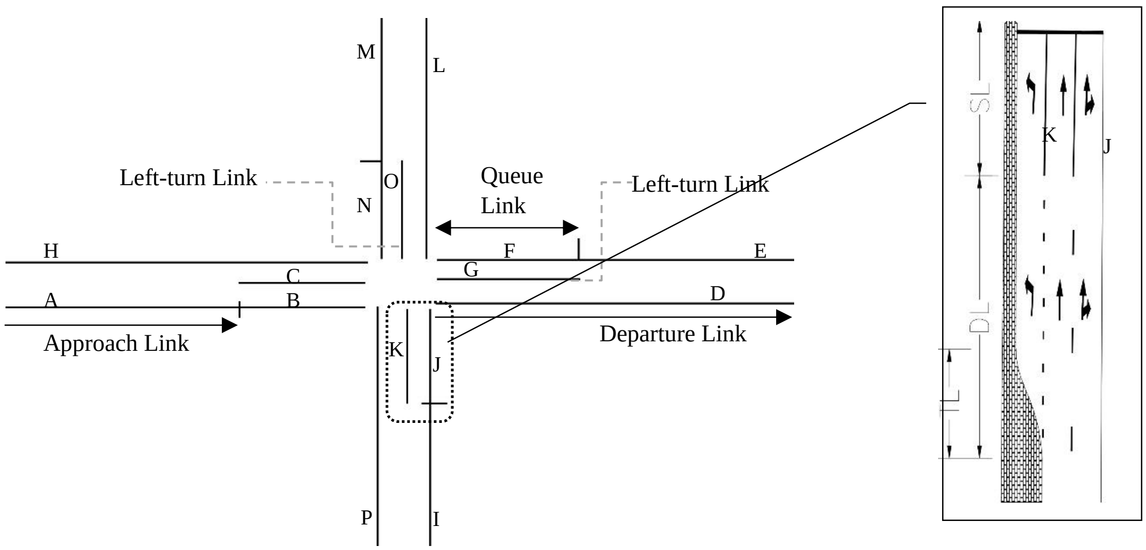


Figure 6 A simplified intersection layout with different links

Receptor placement follows the 1992 Guideline and receptors are located on both sides of the approach roadways. Two receptors are placed at 10ft and 50ft from the curb of the intersection on each approach and a total of eight receptors are placed. To understand the exposure level upstream of an intersection where the queue may reach, the researchers also place a receptor at the middle of each approach link. An additional receptor is placed in each quadrant of the intersection where two receptors are placed 50ft away from the south-west (SW) and north-east (NE) corner diagonally and two others are placed 250ft away from the north-west (NW) and south-east (SE) corner. Mapping of the receptor locations for each intersection is provided in Figure 7. Except for the diagonal receptors, all receptors are 10ft away from the side of the curb. According to the CALINE4 model, the width of the mixing zone includes the roadway width plus 10ft (3m) on both sides (Batterman, et al., 2010). Benson (1984) represents the entire mixing zone at the source and indicates 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 (Samaranayake, et al., 2014). The height of the receptor also determines how much dispersion it will measure. The study by

Rahman (2017) considers both adults (5 ft) and children (3.5 ft) as potential receptors; however, a comparative assessment confirms that children experience a higher concentration. This finding plays a significant role in determining intersection air quality standards because children (average 3.5 ft height) usually experience more health risks when exposed to air pollution; therefore, the standards must reflect these risks. The link geometry and receptor locations change with the change of speed combinations.

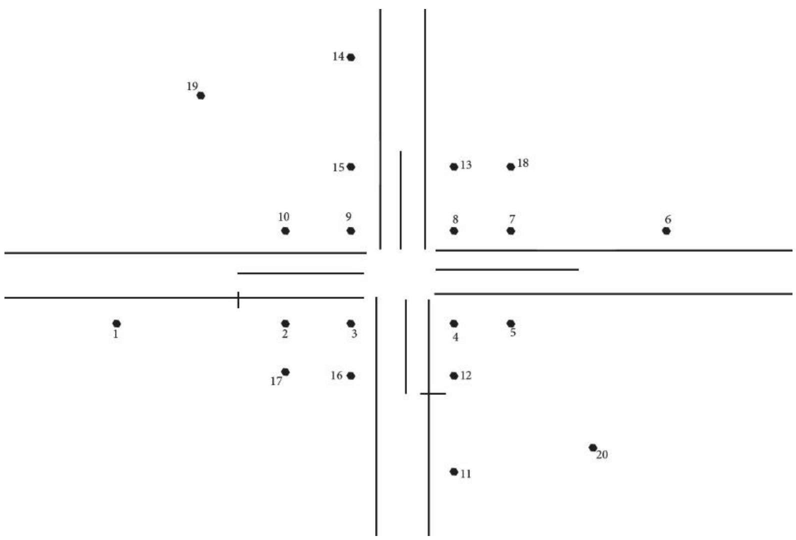


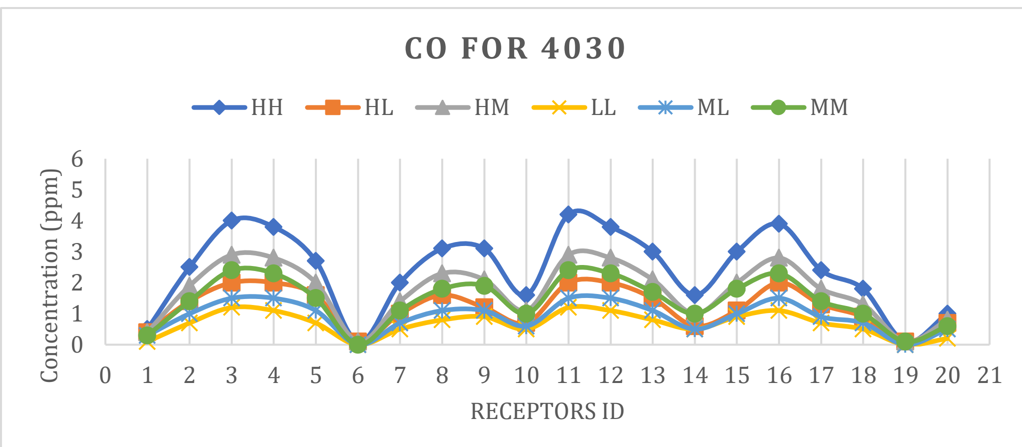
Figure 7 Receptor locations

Given the potential variability in meteorological conditions, the sketch planning tool uses a standard scenario approach to identify if a site should consider additional air quality investigation. The settling velocity for particulates of 0 cm/s is set to reduce the falling rate of particles with respect to its surroundings and deposition velocity for CO and NO_2 is set to 0 cm/s for reduced rate of absorption by the surface represent a worst-case scenario (Ishaque & Noland, 2008). The study sets the area roughness coefficient to 100 cm (to approximate a suburban area) with a wind speed of 1 m/s and the atmospheric stability class at 1 or A (unstable). An elevation of 608ft is assumed for Tarrant County. The study assigns standard ambient levels for NO, NO_2 and O_3 of 0.02, 0.10 and 0.20 ppm, respectively, for the sensitivity analysis (Benson, 1984). The study also establishes the photo dissociation rate (KR) at 4×10^{-3} s^{-1} and the NOx emission factor at 1.0 gm/veh-mi as suggested by Benson (1984) for a standard sensitivity run. The study uses wind headings from 0° (due North) and obtains pedestrian exposure for the worst-case wind direction conditions (Hanninen, et al., 1999).

3.4. RESULTS

The researchers in the experimental design considers a lower or same speed for the minor approach than the major approach speed. For example, if the major approach has a speed of 40mph, then the minor approach can have any of the 30, 35 and 40 mph speed. For each of the simulation runs, 60 seeds are used with a total number of seven runs per combination of speed and volume. A total of 42 simulation outputs are generated for each of the two speed/volume combinations where 6 volume combination considered are high-high (HH), high-medium (HM), high-low(HL), medium-medium(MM), medium-low(ML) and low-low(LL). The initial investigation of the travel time and stop time is used to identify a single representative trajectory file where the total travel time and total stop time is close to the average of all seven runs. These trajectory files are converted to operating mode distributions using VIMIS, which is used by MOVES with the average speed and volume from VISSIM (Figure 5). The output results from the MOVES modeling provides emission rates in grams per hour per mile. The emission rate of the pollutant suggest that emission rate is higher near the intersection compared to approach links and departure links. Through lanes with shared right turns (ie. No right-turn lanes) most of the time faces the major queueing and it shows these links have the highest emissions per mile per hour. The groups with the next highest emission are contains the left turn lanes. A comparison between the emission rate for CO for 35-30 and 30-30 mph speed range identifies that only 41% of the time does the increase of the speeds reduce the emission rate. On the other hand, no change occurs in the PM2.5 and PM10 when comparing for the two different speed ranges. The particulate matter always decreases with an increase in the speed limit, which is consistent with the result of other studies such as (Panis, et al., 2011).

The results from the MOVES analysis are aggregated separately for CO, NO_2, PM2.5 and PM10. The research team aggregated the total concentration of CO for all volume cases for each of the receptor locations and it shows that volume plays an important role in the increase in the pollution exposure at the intersection level. Figure 9 depicts the change of exposure level at various receptor location for 40-30 mph (major street 40 mph and minor street 30 mph) and 45-45 mph speed combination and clearly higher level of traffic has higher concentration level at receptor location closest to the intersections. Receptor 1, 6 and 19 have the lowest level of CO concentration. As the receptor move closer to the intersection, the exposure level increases and because of standard 1-hour average concentration at receptors, the level of concentration is higher at the south side of the intersection as the wind speed and wind direction is assumed 1m/s and north direction, respectively. It is also notable that, receptor 11 has the highest-level concentration. With the increase of the distance from the intersection, receptors such as 17,18 and 19 records lower level of exposure. An increase of exposure level at receptor location 20 suggest the fact that the wind blows at the downwind direction and increases the level of concentration at this neighborhood location.



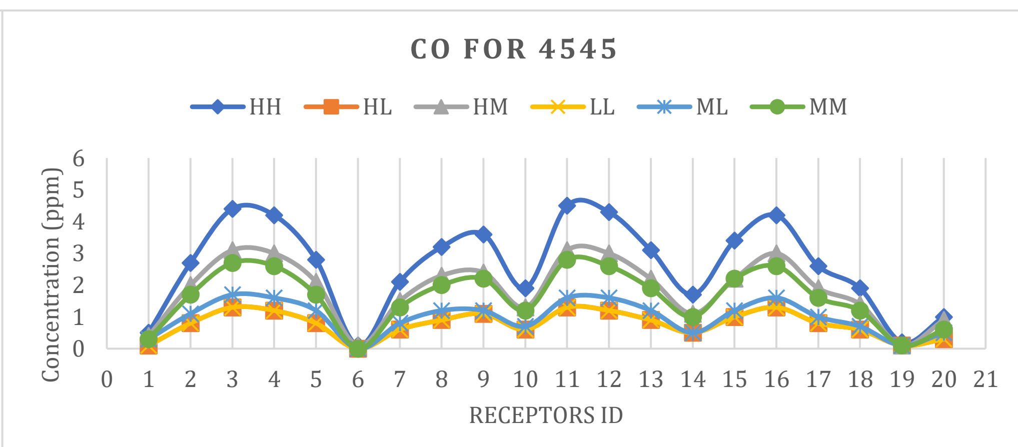


Figure 9 CO concentration at various receptor locations

While receptors 1-5 are located at the EB leg of the intersection, receptors 6-10 are placed along WB leg, receptors 11-12, 4, 8, and 13 are placed on NB and receptors 14-15, 9, 3 and 16 are placed along the SB leg. The higher the speed limit, the higher the CO concentration. Except for the HH case, for almost all of the volume combination, the amount of CO concentration at different receptor locations reduces for the minor speed approach legs. The study also finds consistent result (lower concentration) as found in previous studies at receptors locating at midblock section. A similar trend is observed for the other pollutant concentration measurements (Figure 10). The study by Rahman (2017) has identified from extensive literature review the 1-hr or lower exposure level harmful to any group of people and categorized them in four different severity levels. The CO concentration at different receptor locations does not cross any threshold value of these levels but for PM2.5 the concentration level at receptors close to the intersection falls under the *POOR* category.

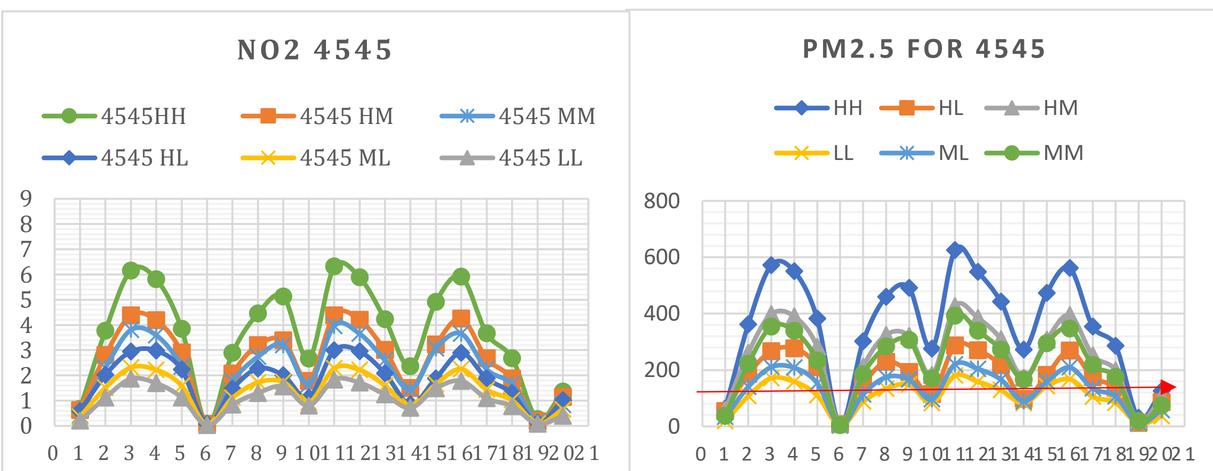


Figure 10 Concentration of NO2 and PM2.5 at various receptor locations

While the initial investigation shows that the stop time is the significant independent variable of pollutant concentration, some other parameters such as speed and volume of the minor road also plays an important role. Unfortunately, the R-square values of these models are below 0.4 which shows poor model performance. Later, the researchers evaluated the pollutant concentrations for worst case scenarios and developed at least 3 models for each of the pollutants. These three models are selected based on the location of different receptors in such a way that, one receptor represents lower concentration and the other higher concentration at or near intersection. The third model is built with the data of a receptor that is located at a neighborhood location away from the intersection. Initially, the researchers considered speed of the major road, speed of the minor road, volume of the major and minor road, directional volume for each approach, and stop time as independent parameters for regression analysis with concentration level for each of the pollutant. Stepwise regression analysis shows that for different pollutant, the independent variables changes. While this is true, stop time is the significant variable for all 12 cases. The researchers regressed the aforementioned independent variables with concentration of CO at receptor 7, 8 and 20.

Table 5 Coefficient of various independent parameter for pollutant concentration

	Receptor	R-square	Intercept	Stop Time fs	Minor Speed	Major Speed	Major Vol.
CO	**7**	0.58832	-1.2311	13.0886	0.00184		
	8	0.57239	-1.1008	12.3732	0.00149645		
	20	0.45652	-0.6763	8.86415			
NO_2	**4**	0.2443	-1.34407	18.6238			
	7	0.6136	16.585	69.0792		-0.7086	-0.00551
	20	0..6445	21.024	105.98		-0.9638	-0.00872
PM2.5	**2**	0.5733	13.6952	3557.73	-12.3605		
	9	0.5439	32.109	3279.67	-11.465		
	20	0.5069	23.05	1511.13	5.1564		
PM0	**2**	0.5735	12.9186	3873.65	-13.4276		
	9	0.5441	33.3167	3570.59	-12.457		
	20	0.5074	23.923	1646.21	-5.599		

The researchers developed 3 different models for each pollutant for an α-value of 0.05 at 3 different receptor locations. It shows that, with the increase of stop time, CO concentration increases tremendously. Though the R-square values of the models are not very high, it is enough to show that there is a strong relationship between stop time and pollutant concentration. The other regression models for other three pollutants are given in table 5. It is evident form the study that stop time is a significant independent parameter for estimating pollutant concentration at receptor location closest to the intersection and farthest from the intersection. This ensures the universal properties of the models. Furthermore, in minor approach speed is also seemed to be important. With the increase of the minor speed, the queued vehicles dissipate fast which eventually reduces the exposure concentration. The researchers also calibrated the two-fluid model parameters for both type of intersection geometry and it is clear that the performance of the network is poor considered to the performance of a regular network performance. The negative value of n indicates the geometric characteristics of the intersection inversely proportional to the concentration of pollutants. Table 6 shows the two-fluid model parameters calibrated from trajectory data.

	Left-turn only	Left-right turn
n	-4.0573933	-2.29975
Tm	7.08503845	4.484409

3.5. DISCUSSION

Studies (Wells, et al., 2012; Wen, et al., 2009; and Semenza, et al., 2008) indicate that a significant number of individuals will change/reduce their outdoor activities based on their perception of air quality or awareness of medical alerts. These findings add to the fact that exposure to outdoor air pollution poses serious health risks. Hence, an air quality assessment tool will help solve this project-level acute exposure issue and help plan future infrastructure investments. The analysis indicates that the exposure level remains higher closer to the intersection and it changes with speed, volume and intersection geometry. This preliminary framework lays the foundation of the development of a project-level air quality assessment tool but various other scenarios with speed-volume combination along with geometric features need to be considered.

3.5.1. **Sample Application**

An example of project-level assessment tool for arterials can be found in a set of exposure graphs for CO, NO_2, PM2.5 and PM10 by the research team in their previous work. These graphs 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. The development of such project-level assessment tool can help planners and agency personnel use the previously developed zonal boundary guidelines (Rahman, 2017) to appropriately identify the severity level of an intersection close to a future walking or bicycle route. The tool will be a single or series of graphs connecting the speed limit, volume, geometric characteristics and other features. So when a planner wants to check the condition of an intersection in close proximity of a future Walking School Bus route, the user needs to find the intersecting point of their variables and that will identify which criteria it falls in.

3.6. CONCLUSION AND RECOMMENDATIONS

In the absence of any tool, the short-term exposure levels of pedestrians and bicyclists do not receive enough attention and this new approach helps utilitarian and recreational pedestrians and bicyclists. This study proposes the development of an intersection air quality assessment tool back by previously identified standards based on human health risks for children. Not only do children appear to experience more significant risks due to air pollution exposure, but they also risk greater exposure due to higher concentrations at their nose and mouth height. The impact of an intersection is crucial in assessing the air quality not just for the users of the nearby walking or biking route, this project-level assessment can help better understand overall network level performance.

To help identify when air quality may be a concern, the researchers compare the project-level air quality and its significance in developing a risk assessment tool. The sketch planning tool does not provide a definitive health risk; however, it can assess relative health risks and provide an indication that the true health risk may need to be thoroughly modeled. The tool does not consider background level pollutants for any particular site, and instead, it focuses on generating the emission concentrations due to only the traffic impacts. Since this generalized version of the intersection air quality risk tool only requires an intersection's speed limit, volume and geometric dimensions, it can easily be used by practitioners and policymakers for evaluating current and future infrastructure with respect to air quality.

3.6.1. Future research

Even though the exposure level changes with the geometry of the intersection for different volume and speed range, a significant number of other variables need to be added for a complete picture. The addition of a dedicated right-turn lane can identify a different scenario than a shared right-turn lane. A speed limit of 40 and 45 mph along with 30 and 35 mph can be combined with the six volume ranges for a total of 120 different scenarios. Due to the limited scope of the work, only three different vehicle types are used, but to duplicate an urban intersection scenario, more detailed composition of vehicles should be considered.

Traditional air quality impact assessment methods are either a. macroscopic traffic assignment models (average vehicle speeds on individual links and/or for entire journeys) or b. average emission factors (fuel consumption and vehicle emissions, for each vehicle type). 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. The Two Fluid Model developed by (Herman & Prigogine, 1979) has been successfully used for evaluating the quality of traffic in a urban street network. This model assumes that vehicular traffic in an urban network can be understood as consisting of stopped vehicles and running vehicles. Characterizing the transportation related air pollution exposure level at the intersection level with run time and stop time is potentially beneficial for transportation practitioners. The continual work of the research team includes the development of a relationship across randomized intersection characteristics and their two fluid model parameters with the exposure level at different receptor locations. This can not only characterize the intersection but can serve as an overall network level air quality performance measure.

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CHAPTER 4

MAstery Level Achievement (MALA) Method for Assessing a Project-based Learning Approach to Teach Concepts of Active Commuting

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4.1. 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 and analysis 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 (i.e.; (23 U.S. Code § 217, 2017) and programs (such as Nonmotorized Transportation Pilot Program, Safe Routes to School Program, Transportation Alternative Program, NHTSA 405) emphasize the inclusion of nonmotorized, active modes in transportation facility design. MPOs, states, cities, and communities around the world are increasingly adopting policy concepts such as Complete Streets to ensure the safe, efficient, environmental friendly and affordable movement of pedestrians, bicyclists, motorists and transit riders (NCSC, 2016). Hence, all of the stakeholders including civil engineers must understand the impact of infrastructure elements on active commuting. This paper develops a unique assessment method and evaluates the learning outcomes of one active-based learning intervention incorporated into a junior-level (third year) transportation engineering course to educate these civil engineering students about the active commuting.

This analysis implements a unique assessment tool designed for project-based active learning or other modular interventions. The learning intervention exposes students to two distinct concepts, encouraging physical activity and providing safety, identified as critical to active commuting. The research team initially adopts a traditional single group pre-posttest design to compare the degree of change resulting from the learning intervention. The authors evaluate the project-based learning impact in two different ways: overall question-based improvement and level of learning improvement. Blooms' Taxonomy is used to classify questions into levels of learning ranging from remember to analyze. Though the pre-posttest approach is a concise and effective direct measure of the students' learning improvement from project-based learning intervention, it does not directly capture the level of mastery achieved for different concepts. At the same time, the project report will not be captured in a traditional pre-posttest assessment. But with this unique approach, the authors evaluate the report based on the students' performance in understanding infrastructure problems and recommending improvements. Based on all the posttest and report scores, the researchers determine each student's achieved level of mastery. So, this study evaluates the project-based learning intervention using the unique overall MAstery Level Achievement (MALA) method on various categories and total percent of students achieving mastery.

4.2. LITERATURE REVIEW

2.1.1. Active Based Learning

One goal of undergraduate civil engineering education is to prepare students with the professional problem-solving skills necessary to tackle complex engineering projects. Students must be able to apply fundamental theories and techniques of learned knowledge to identify solutions to transportation and other infrastructure challenges. For educators, the challenge remains to identify and implement efficient and effective learning strategies that facilitate this goal. Active based learning strategies such as project-based learning have demonstrated success because they stress students' active involvement in their own learning (Hall et al., 2002) and commonly emphasize higher order thinking and group work (Bonwell and Eison, 1991). 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 (Freeman et al., 2014).

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. Robust literature demonstrates a number of improved student learning outcomes when using active based learning techniques (Freeman et al., 2014; Lorenzo et al., 2006; Haak et al., 2011; and Huang & Levinson, 2012). Active learning strategies can also yield disproportionate benefits for students from disadvantaged populations and for female students in male-dominated fields (Lorenzo et al., 2006; and Haak et al., 2011). 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: 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 (Freeman et al., 2014).

However, at the same time, active learning strategies can be highly variable and range in intensity and duration. Thus, a need remains for more empirical evidence to identify that active learning strategies achieve their goals and yield improved learning outcomes. This paper will enhance this knowledge gap by assessing the learning outcomes associated with one particular type of active learning intervention, a project-based learning (PBL) intervention using a unique assessment tool. PBL involves students in solving or analyzing challenging authentic and curriculum-based problems (Mills and Treagust, 2003). PBL requires students to use problem-solving, metacognition, and self-motivation to be successful in (Farrell, 2010). Students who undergo a PBL intervention should

a. gain longer retention and deeper understanding of learned content (Penuel & Means, 2000; and Stepien et al., 1993);

b. acquire better problem-solving skills compared to traditional classes which, helps in career exploration, technology use, student engagement, community connections, and content relevancy (Blumenfeld et al., 1991; and Ravitz et al., 2012);

c. show improved engagement, self-reliance, and attendance (Thomas & Mergendoller, 2000; Walker & Leary, 2009); and

d. develop social, collaboration, and conflict resolution skills. (ChanLin, 2008; Belland et al., 2006; Lightner et al., 2007; and Krishnan et al., 2011).

Due to these enormous benefits, project-based instruction has rapidly gained acceptance by the educational community and is now being applied to a wide spectrum of engineering disciplines, at various types of academic institutions and throughout the different phases of the educational programs (Esche & Hadim, 2002).

4.2.2. **Project Based Learning to Teach Concepts of Active Commuting**

Increasingly, federal agencies such as the U.S. Department of Transportation (USDOT) and the Department of Health and Human Services (DHHS) have identified joint objectives to improve the health of the American population. Increasing active commuting represents one area that addresses the goals of both the USDOT and the DHHS. The immediate outputs of increased active commuting include increased physical activity, and decreased car dependency and congestion, which may lead to improvements in longer term outcomes such as reduced obesity and other health conditions associated with physical activity, air quality, mobility and quality of life. While the behavior and attitudes of individuals can 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 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 (PA) and active commuting (Addy et al., 2004; Agrawal & Schimek, 2007; Ahlport et al., 2008; Babey et al., 2009; Berke et al., 2007; Boehmer et al., 2007; Boone-Heinonen et al., 2010; and Brownson et al., 2001). Although the increased level of PA helps to fight obesity and other health issues (NRPA, 2016), exposure to pollutants emitted from motor vehicles may pose significant health hazards (Kampa & Castanas, 2008; Walsh, 2011; and Samaranayake, et al., 2014). Research has shown that a walking or bicycling route closer to a heavy-traffic roadway is associated with symptoms of respiratory dysfunction, cardiopulmonary disease and even mortality from stroke (McConnell, et al., 2006; and Tonne, et al., 2007). Pollutant concentrations adjacent to and downwind of major traffic routes directly or indirectly depend on the built and natural environment and other temporal and spatial conditions. Measures to improve and increase PA require addressing these issues properly.

The second is through transportation facilities that improve pedestrian or cyclist safety. Features of the built environment that address perceived safety have a dual effect of promoting physical activity and active commuting. For example, sidewalks, street connectivity, traffic, crosswalk improvements, street lighting and the presence of crossing guards represent factors associated with perceived safety (Addy et al., 2004; Boehmer et al., 2007; and Brownson et al., 2001). 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 a greater emphasis on vehicular and motorized travel, and as such, students receive less exposure to transportation facility analysis and 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 active transportation modes into the curriculum becomes important. A PBL intervention aligned with the course objectives represents one way to accomplish this. Furthermore, PBL also has the benefit of enhancing student learning in areas where they have less exposure. However, the conventional assessment methods do not consider the extent and level of concept mastery. Previous literature demonstrates the effectiveness of the Mastery Learning Approach (MLA) in classroom settings where students move on to the higher level of a unit after they successfully master the lower level unit (Fehlen, 1976; Mevarech, 1985; Davis & Sorrell, 1995; Guskey, 2005; and Jazayeri, 2015). Traditional MLA fails to assess concept clusters from PBL intervention. This paper seeks to compare the learning improvement using traditional methods and introduce MAstery Level Achievement (MALA) as a new strategy to assess PBL interventions.

4.3. METHODOLOGY

4.3.1. Intervention Details

The research team introduced the intervention to junior-level (third year) civil engineering students in the Introduction to Transportation Engineering course during four different semesters. Traffic Flow Theory, Highway Design, Transportation Demand Modeling, Safety and Pavement Design represent some of the fundamental theories and skills taught in this class. Prior to the PBL intervention, the instructor allocated a single lecture to nonmotorized forms of transportation in a 15-week semester. Due to the limited instructional time, available for active transportation, no lecture time accompanied the intervention; therefore, the project emphasizes individual and group self-directed learning combined with occasional review meetings with the course conveners. The circumstances prompted the research team to prepare detailed observational manuals to introduce students to different infrastructure elements related to physical activity and safety factors and provide students with detailed instructional material and data collection forms for the project. This application of the project investigates the major intersections and road segments in neighborhoods near twenty-six elementary schools in Arlington, TX, by randomly assigning teams of at least two students to each location. This intervention (class project) includes three phases. In phase one, each group collects inventory data of transportation infrastructure elements related to active commuting by either field observation or electronic map (Google/Bing) inspection. In phase two, students identify the busiest intersection and/or segments for pedestrian or bicycle activity during the morning peak hours and collect conflict data using the Android based app “Safe Activity” at these locations for a minimum of four hours. In the last phase of the project, students submit a project report where they identify problems they have found in their study area and recommend solutions. All students received a brief project description and introduction to the project materials prior to starting the project and research team members are available on an ongoing manner for any queries. The overall process of this PBL intervention can be expressed in the flow chart in Figure 11.

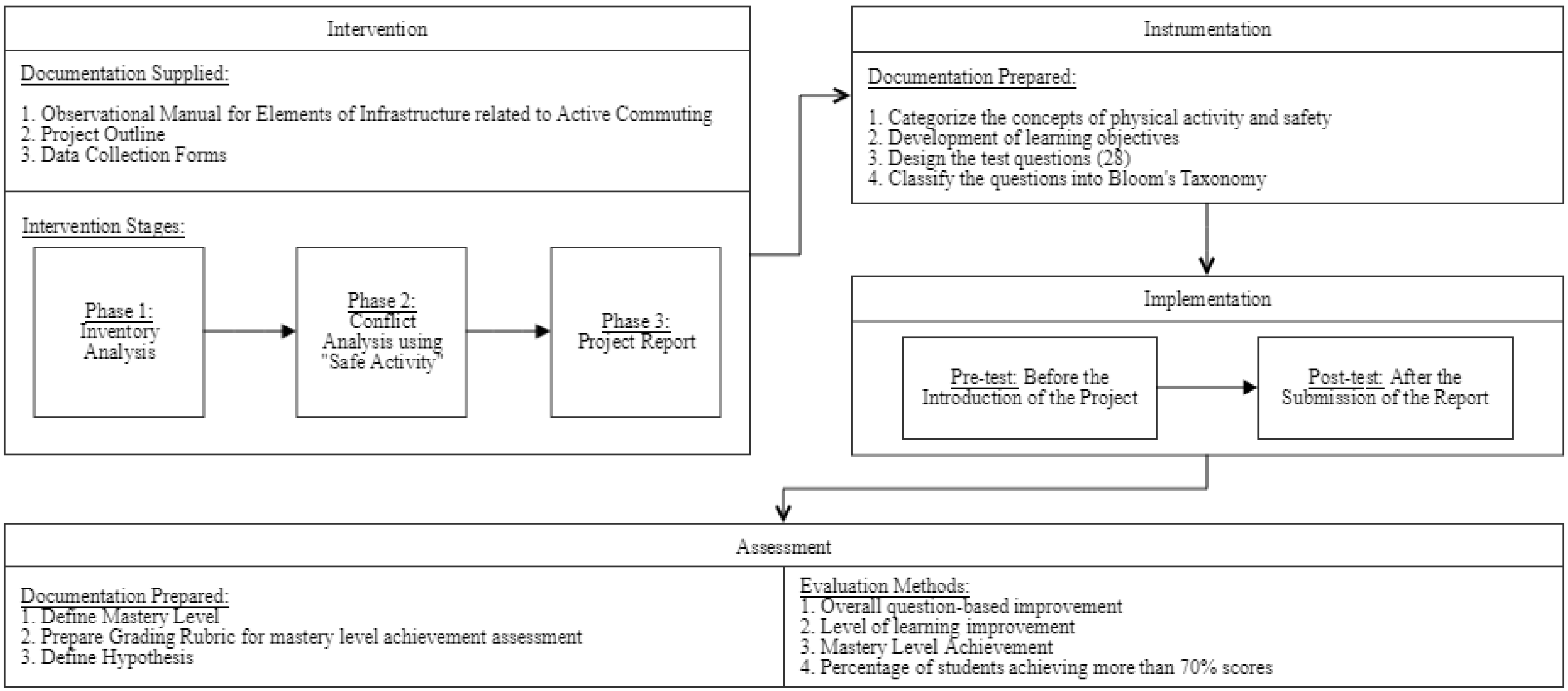

Figure 11 Overall process of the project-based learning intervention

4.3.2. **In**strumentation

The project's main learning goal seeks to introduce students to the infrastructure elements and performance that support active transportation. Due to the relatively small class size each semester, formation of a control group remains difficult; therefore, the evaluation uses a single group pretest-posttest design to compare the change in learning. The first 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 (introduction of the class project) and the posttest measurement made at a point in time reasonably afterward (after the end of class project). The MALA assessment of the report using analytical rubrics represents the second definitive characteristic of the research design.

To develop the testing instrument, the research team combines traffic control devices (TCD), infrastructure elements (PB), network and connectivity issues (N), and air quality factors (AQ) associated with pedestrian and bicycle movement into broad categories of physical activity and safety concepts and create a series of objectives related to the course. The objectives mainly focus on identifying the infrastructure features associated with physical activity and safety, recognizing what the measure or element aims to accomplish, selecting among competing alternatives and describing a performance measure and its purpose. The learning objectives of the course inform the development of the pre/posttest instruments. The course objectives and test questions are available online in the ASCE Library (ascelibrary.org). 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 set for students by educators into cognitive, affective, and psychomotor domains (Bloom et al., 1956; and Flinders et al., 1996). The present study classifies questions into four of the five categories of Bloom's modified Taxonomy (Anderson et al., 2001), remember, understand, apply and analyze, ranging from low to higher levels of learning. Questions associated with the remember category 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.

The final test instrument consists of 28 questions; fourteen address measures and elements associated with physical activity and the other fourteen address safety. Specifically, the Physical Activity (PA) module consists of eight multiple choice questions, three short answer questions, two problem identification questions and ten *matching* 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), all 14 questions are multiple choice questions. Table 6 illustrates the linkages between the questions and the assessment categories.

Table 6. Distribution of questions into 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)*

4.3.3. Implementation

Prior to the delivery of the curriculum and materials, the research team administered the pretest to the classes, and a total of 153 of the 170 students completed it. At the end, 156 students took the posttest (a repeat of the pretest). Thus, complete assessment data was available for 145 students. Of the 170 students enrolled in the class over the four semesters, the gender representation skewed towards males (n=111). In terms of race and ethnicity, almost 47% of the students were white, about 32 % were Hispanic and about 21% were black or others. At the end of the semester, students were also required to submit their project report. The research team only had two semesters of data to analyze MALA; hence, the MALA analysis only included about 82 students.

4.3.4. **Assessment**

While the quantitative comparison between the pretest and posttest help evaluate individual question-based improvement and the level of learning improvement on Bloom's Taxonomy, summative assessment at the end of a course or educational lesson represents the key to assessing student mastery on a particular competency. Performance-based assessment, which is different from traditional course grading, serves as an assessment tool for mastery level of certain types of cognitive competency on different skill sets. In the early 1960s, Carroll presented the idea that the longer the classroom learning time is, the higher the rate of learning would be (Carroll, 1963). Bloom (1976) expanded this definition by stating that 95% students provided with learning opportunity and quality instruction will reach mastery level (Bloom, 1976). Bloom also explained that mastery learning not only helps students master specific knowledge but also represents an effective way to improve student attitudes and interest toward learning (Özden, 2008; and Kazu et al. 2005). The basic theoretical assumption of mastery learning is that a student must have or acquire a predetermined set of skills and knowledge to master specific learning objectives (Guskey, 2007; Schellhase 2008; and Zimmerman & Dibenedetto, 2008). Researchers have shown that students in well-implemented mastery learning classes consistently reach higher levels of achievement and develop greater confidence in their ability to learn and in themselves as learners (Anderson, 1994; Guskey & Pigott, 1988; and Kulik et al., 1990). In the mastery learning technique, a teacher defines the objectives for student learning and students need to demonstrate their improvement. While practitioners use a wide variety of Mastery Learning strategies, this study specifically adopts a modified version called 'MAstery Level Achievement' and evaluates MALA at different cognitive domains for specific types of transportation infrastructure related to active commuting. The research team categorizes and defines four mastery levels (Table 7).

Table 7. Definition of Mastery Levels

Level Hierarchy	Mastery Level	Definition
1	Unsatisfactory	Student demonstrates minimal to no knowledge on the elements of a specific category
2	Marginal	Student demonstrates knowledge on some of the elements of a specific category
3	Proficient	Student demonstrates knowledge on all of the elements of a specific category
4	Advanced	Student meets level 3 and demonstrates knowledge on elements of a particular category that he/she was not exposed to

Assessing the mastery levels described in Table 7 requires a reliable and standard scoring method. The 'grading rubrics', often time used by teaching and learning practitioners represent a reliable example of such a scoring system. The word 'rubric' "connote[s] a simple assessment tool that describes levels of performance on a particular task and is used to assess outcomes in a variety of performance-based contexts from kindergarten through college (K-16) education" (Hafner & Hafner, 2003). Rubrics usually include criteria for rating important categories of performance and act as a guideline for the instructor to assess student development toward achieving course learning outcomes relevant to particular student work. While holistic scoring rubrics make an overall judgment about the quality of performance, analytic scoring rubrics provide diagnostic information to the teacher about each category of the assessment. Moreover, as topic-specific rubrics seem likely to produce more generalizable and dependable scores than generic rubrics (DeRemer, 1998; and Marzano, 2002), the research team develops four different scoring rubrics for the four broader objectives. A generalized concise version of the scoring rubric with the definition of each level for MALA is given in Table 8. The accurate use of the rubric for grading the report remains essential for evaluating MALA; therefore, the authors provide an example for the best use of the scoring rubric. The students must evaluate the bicycle and pedestrian infrastructure in

Table 8. Grading Rubric for the evaluation of MAstery Level Achievement

		Mastery Level			
		Level 1: Unsatisfactory	**Level 2: Marginal**	**Level 3: Sufficient**	**Level 4: Advanced**
Bloom's Taxonomy	**Remember**	Can remember minimum to none PB[1]/TCD[2]/N[3]/AQ[4]	Can remember some PB[1]/TCD[2]/N[3]/AQ[4]	Can remember all fundamental PB[1]/TCD[2]/N[3]/AQ[4]	Can remember advanced level PB[1]/TCD[2]/N[3]/AQ[4]
	Understand	Understand the functionality of minimum to zero PB[1]/TCD[2]/N[3]/AQ[4]	Understand the principles of some PB[1]/TCD[2]/N[3]/AQ[4]	Can understand the objective and functionality of all basic PB[1]/TCD[2]/N[3]/AQ[4]	Can understand the objective and functionality of advanced level PB[1]/TCD[2]/N[3]/AQ[4]
	Apply	Can apply minimum to none PB[1]/TCD[2]/N[3]/AQ[4] according to their principle	Can apply some of the PB[1]/TCD[2]/N[3]/AQ[4] based on their principle	Can apply all fundamental level of PB[1]/TCD[2]/N[3]/AQ[4] to appropriate location	Can apply advanced level of PB[1]/TCD[2]/N[3]/AQ[4] to appropriate location based on principle
	Analysis	Can evaluate none to zero PB[1]/TCD[2]/N[3]/AQ[4] based on their functional requirements and can identify and solve problems	Can evaluate some PB[1]/TCD[2]/N[3]/AQ[4] based on their functional requirements and can identify and solve problems	Can evaluate all basic PB[1]/TCD[2]/N[3]/AQ[4] based on functional requirements and can identify and solve problems	Can evaluate advanced level of PB[1]/TCD[2]/N[3]/AQ[4] based on functional requirements and can identify and solve problems

[1]PB-Pedestrian and Bicycle related infrastructure elements, [2]TCD-Traffic Control Devices, [3]N-Network and connectivity, [4]AQ-Air Quality

their study area, identify problems and provide appropriate solutions. One group suggests that the crosswalk on a busy segment does not provide enough safety for pedestrians. The group also indicates that one side of the segment lacks a sidewalk. The students recommend the installation of a HAWK signal at the crossing location and paved sidewalk in adjacent locations. In this case, the students have shown the *advanced* level of learning achievement for the *Analyze* level taxonomy for *safety* concepts related to traffic control devices (TCDs). On the other hand, the group also demonstrates that they have *proficient* knowledge of *infrastructure elements* (PB) as they can *remember* and *understand* the function of a sidewalk for *physical activity* concepts.

4.3.5. **Hypothesis testing**

The research team establishes four hypotheses for each category of active commuting under investigation to assess the overall question-based improvement, level of learning improvement on Bloom's taxonomy, MALA and achieving *sufficient* or *advanced* mastery level. The hypotheses investigate active learning strategies for increasing overall learning and facilitating 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.

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

H_3: Mastery Level will be achieved at the end of the project on specific cognitive skill sets

H_4: The number of students achieving *sufficient* MALA is higher in posttest/report than the pretest.

Safety Concepts:

H_5: Posttest scores will be higher than pretest scores for each individual question.

H_6: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth at the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy.

H_7: Mastery Level will be achieved at the end of the project on specific cognitive skill sets.

H_8: The number of students achieving *sufficient* MALA is higher in posttest/report than the pretest.

The assessment uses a one-tailed paired t-test to examine the improvement at a 0.05 significance level (marginally or approaching) and 0.01 (significant) significance level, because each subject has two related observations (pretest and posttest/ report). The null hypothesis assumes no improvement after the learning intervention. To analyze the data, the pre- and posttest questions and the final project report may receive a maximum score of five points. For the multiple-choice questions, the scores may only be zero or five. For the short answer questions, the given points vary 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). Finally, the authors grade the report using the aforementioned MALA rubric.

4.4. RESULTS

4.4.2. Physical Activity Learning Objectives

This section discusses both the quantitative and qualitative assessment of the learning objectives associated with physical activity, considers each of the hypotheses and develops a summary of the overall PA results. Figure 12 illustrates the distribution of the pre- and posttest scores (out of 80 points) for physical activity concepts. The posttest scores (M=47.04, SD =10.42) improve over the pretest scores (M=41.35, SD=9.04); based on the paired t-test, the students show a significant improvement (p-value $5.08x^{-10}$) on the physical activity material. Though the overall performance for physical activity remains low with only twenty-eight students scoring over seventy percent on the posttest (56 out of 80), the student cohort performs better on the posttest than the pretest (9 in pretest compared to 28 students in posttest scored at or above 70 percent).

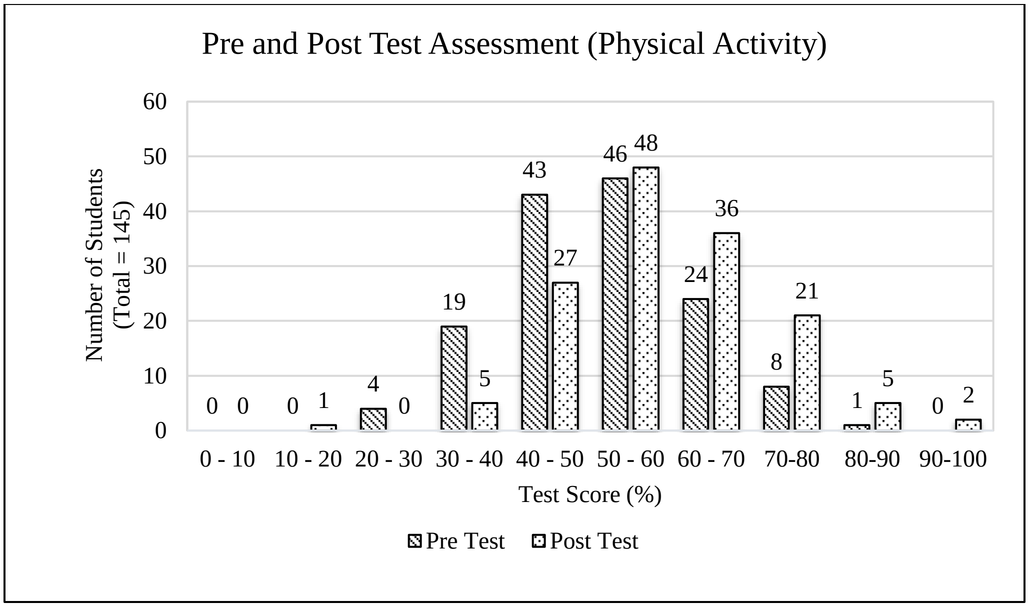

Figure 12 Distribution of pre-and posttest scores for physical activity concepts.

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, enough evidence exists to show significant improvement across the student cohort. Figure 13 illustrates the pre- and posttest scores by question for the PA concepts. Questions 1, 3, 4, 5, 7, 8, 12, and 13 require a moderate level of learning (Execute and Implement), questions 2, 6, 9, 10 and 14 require the lowest/a low level of learning (Ability to Recall or Recognize) and 11 requires the highest level of learning. The poor performance of the student cohort on questions 2, 6, and 11 may either lay in the fact that the student group lacks exposure to those specific infrastructure elements and concepts. Although the student cohort performs worst on question 6, they still experience a significant improvement ($t(df=144) =-2.9$, $p=0.002$) in the post test compared to the pretest at both 0.05 and 0.01 significance level. For question 2, the overall performance of the student cohort remains below 2.0, but the students experience a significant improvement ($t(df=144)=-2.29$, $p=0.012$) for a 0.05 significance level. Question 9 also shows a significant improvement for the 0.05 significance level but fails at the 0.01 significance level. The student cohort not only performs particularly poorly on questions

7, 8 and 11, but the posttest scores also decrease compared to the pretest. These questions address more complex concepts that may not connect as well with the activities in the project as the researchers initially anticipated.

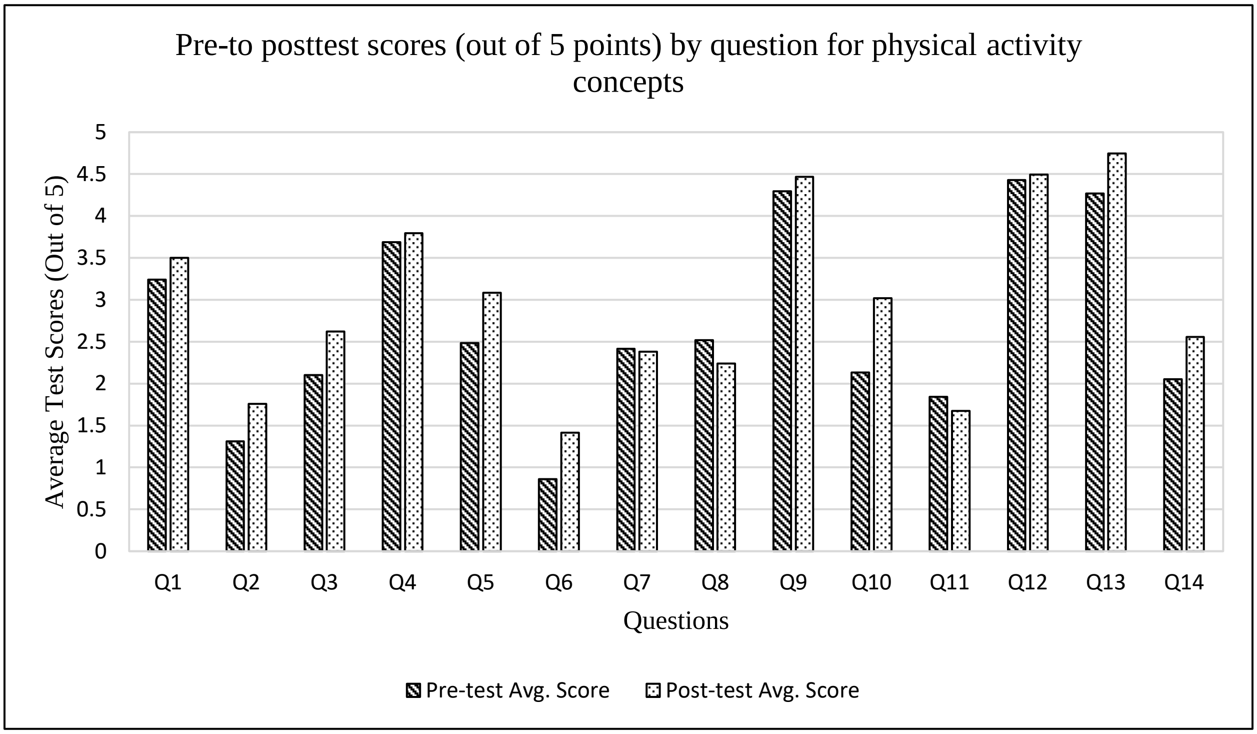

Figure 13 Pre- to posttest scores (out of 5 points) by question for physical activity concepts.

From the remaining nine questions, the student cohort shows a significant improvement for six different questions; where for four of these questions (question 5, 10, 13 and 14), the improvement appears significant for both the 0.05 and 0.01 significance levels. Question 5 asks the student to calculate the travel time of pedestrians on a crosswalk (t(df=144) = -2.73, p=0.0035). Question 10 asks students to define and identify traffic calming devices used in transportation infrastructure (t(df=144) = -5.55, *p*=0.0000). Question 13, which asks students to identify design flaws, shows significant improvement with a p-value of $2.06x^{-06}$. Finally, Question 14 asks students matching questions (t(df=144) = -6.05, p=$5.9x^{-09}$). Question 3 asks the students about the purpose of a wide median for a pedestrian and sees significant improvement with a p-value of 0.012 for a 0.05 significance level, which fails to satisfy the 0.01 significance level.

Although, the student cohort demonstrates strong performance (scores above 4) on question 9, the improvement of the scores from the pretest to posttest remains insignificant. The students have a generalized knowledge of the benefits of light along a sidewalk/intersection, which may not allow much room for improvement. Questions 1 and 12 appear to demonstrate the same pattern where students achieve high scores on both the pre-and posttest, which allows limited opportunity for significant improvement.

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

This hypothesis also achieves a mixed result (Figure 14). While the analysis questions show a decline in scores, the lower levels of *remember*, *understand* and *apply* show significant improvement. The test scores show significant improvement for the remembering (t (df=144) =-6.73, p=0.000), understanding (t(df=144) = -7.32, p=0.000) and applying (t(df=144) = -3.0, p=0.001) categories. The decline of scores on the *analysis* question appears to occur because only question 11 falls under this category and students received little exposure to this learning concept. Regardless, this result indicates a failure in the test to appropriately assess the analysis category or a failure in the project to achieve improvement in higher order thinking.

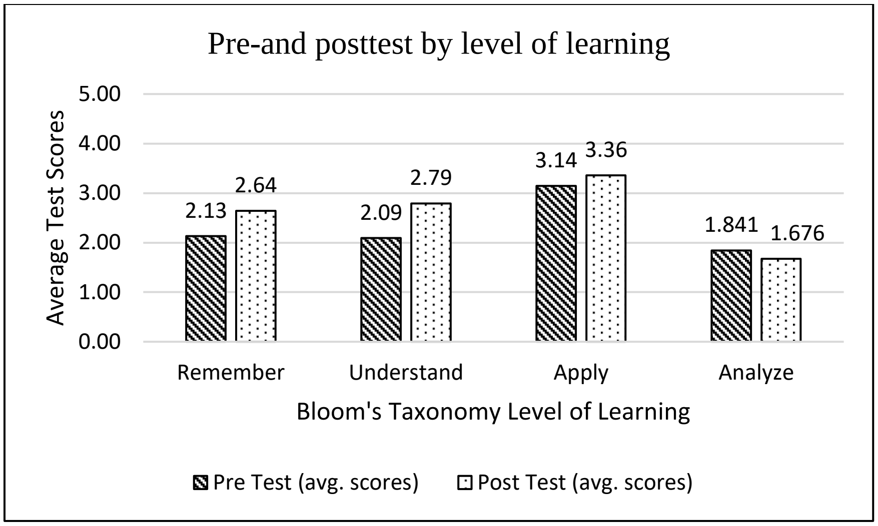

Figure 14. Pre- and posttest scores by level of learning for physical activity concepts.

H_3: Mastery Level will be achieved at the end of the project on specific cognitive skill sets for physical activity concepts

From the previous two hypothesis tests, students perform significantly better on questions 2,3,5,6,9,10,13 and 14 where 2 and 6 are remember questions, 10 and 14 are both remember and understand questions and 5 and 13 are application questions. While traditional PBL interventions adopt pre-posttest scores to evaluate the learning outcomes (Gallagher et al., 1995; and Bayer, 2016), this study additionally assesses the MALA on different categories of physical activity concepts at various levels of Bloom's taxonomy. The MALA method uses the mastery level grading rubric to evaluate student performance on the project reports; compares the higher of the posttest and report achievement with the pretest scores for each category of physical activity concepts at different taxonomy levels.

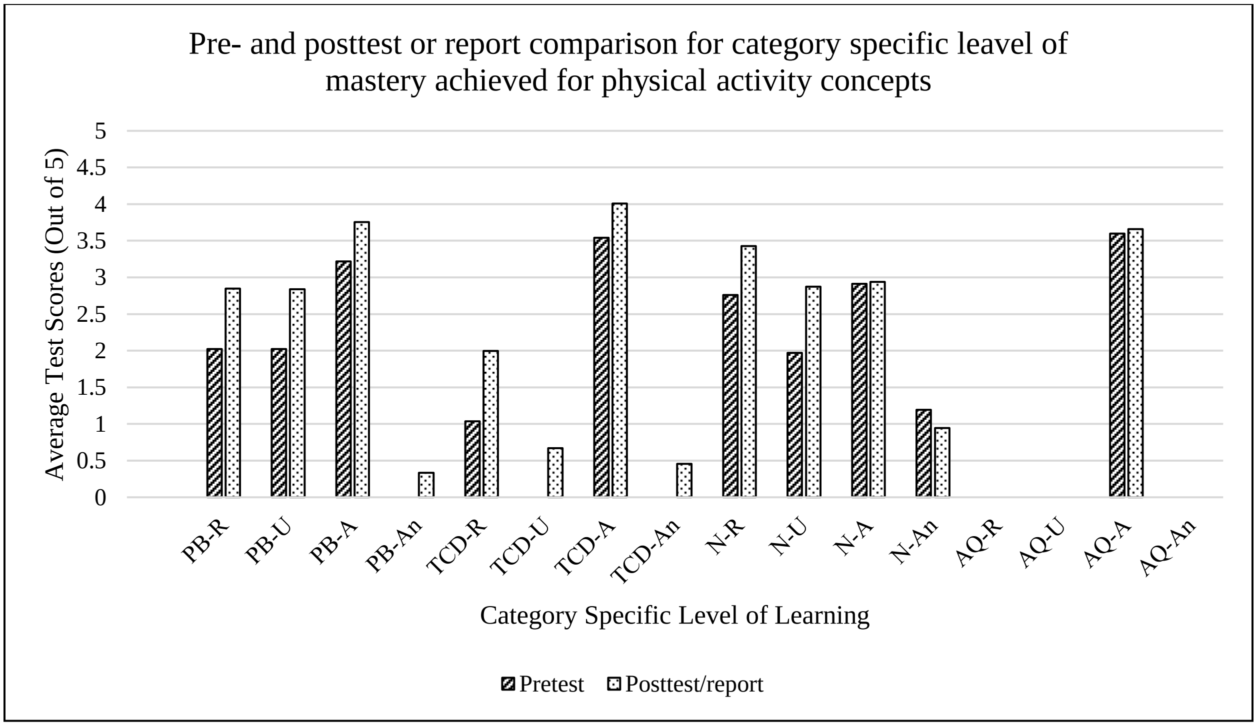

Figure 15 MAstery Level Achievement comparison between qualitative report/posttest and pretest for physical activity concepts

Figure 15 illustrates the student cohort's achieved mastery level for categories of physical activity concepts. The four levels of the taxonomy associated with the design objectives (*remember, understand, apply* and *analyze)* and four physical activity concept categories (infrastructure elements, traffic control device, for network and connectivity, and air quality) create a set of 16 different combinations of mastery level achievement to consider for this particular hypothesis. The student cohort performs well across all four taxonomy levels of infrastructure elements (PB) that encourage or discourage physical activity. The cohort achieves at least *marginal* mastery level for the PB category. The mastery level improvement achieved by the student cohort for the *remember*, *understand* and *apply* taxonomies of the PB category appear statistically significant for both the 0.05 and 0.01 significance levels. Although, the overall average test scores of the student cohort appear poor for the traffic control device (TCD) category (*remember* achieved marginal, *understand* achieved unsatisfactory, *apply* achieved sufficient and *analyze* achieved unsatisfactory), the MALA improvement seems statistically significant for all four taxonomies. While, the student cohort demonstrates overall higher scores for network and connectivity (N) than TCDs and AQ (*remember, understand* and *apply* achieved *sufficient* mastery whereas *analyze* achieved an *unsatisfactory* level), only the *remember* (t(df=81) =-6.74, p=0.000) and *understand* (t(df=81) =-6.59, p=0.000) taxonomies show statistically significant MALA improvement.

H_4: The number of students achieving sufficient MALA is higher in posttest/report than the pretest for physical activity concepts.

This hypothesis specifically tests if the total percentage of students achieving a masterly level 3 or higher (*sufficient* or *advanced*) increases after the intervention. The *remember* (39 vs 18 students), *understand* (32 vs 18 students) and *apply* (72 vs 59 students) levels of learning for infrastructure elements (PB) show that the total percentage of students achieving at least *sufficient* mastery level significantly increases for both significance levels after the intervention. Similarly, for the traffic control device (TCD) category (23 vs 3 students) and network and connectivity (N) category (61 vs 42 students), the *remember* and *understand* levels of learning have shown a significant improvement in the students achieving at least *sufficient* mastery level.

In summary, the analysis suggests that the PBL intervention results in the following impacts on the students' grasp of physical activity concepts. While the overall scores of the student cohort for the physical activity concepts remain rather low, the student cohort experiences a significant improvement in the overall test score for the questions related to physical activity. The three questions where the student cohort averages a score lower than 2, all deal with a rather specific walkability or bikability topic. In question 2, students must identify all traffic control devices that may be used for pedestrians at an intersection, but they may be confused by the signal heads normally used for vehicular movement. The students also have likely never encountered a HAWK (High-intensity Activated crosswalk) beacon signal head for pedestrian crossing, which must be successfully identified in question 6. Due to very limited bicycle activity around the study area, students remain less exposed to the opportunities and factors that increase utilitarian biking presented in question 11. These questions may need to be revised for future educational outcome assessments. The project-based intervention and supporting training materials appear to be well structured to encourage growth throughout Bloom's Taxonomy except at the higher level (analysis). The MALA assessment for different physical activity concept categories and levels of learning proves to be a key contribution beyond traditional pre-posttest comparisons. Overall, this new approach not only identifies specific skills (concept categories) mastered by the students but also validates the results achieved through pre-posttest. For example, while the student cohort shows significant improvement in *remember*, *understand* and *apply* levels of learning from the traditional approach, the MALA method specifically shows the level of mastery (*marginal* or *sufficient* or *advanced*) they have achieved on different categories of the PA concepts. The study also shows that the total percentage of students achieving at least *sufficient* mastery level significantly increases after the intervention. The limited student background in the factors affecting physical activity makes this comprehensive growth critical.

4.4.3. **Safety Learning Objectives**

This section focuses on the intervention's effect on the safety-based learning objectives. Figure 16 illustrates the pre- and posttest scores for safety concepts. While little improvement occurs between the pretest (M=48.8, SD=9.39) and the posttest (M=51.96, SD =8.03), students perform more strongly 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. The improvement in the safety material appears statistically significant (t(df=144) =-3.87, p=0.000) for 0.05 significance level.

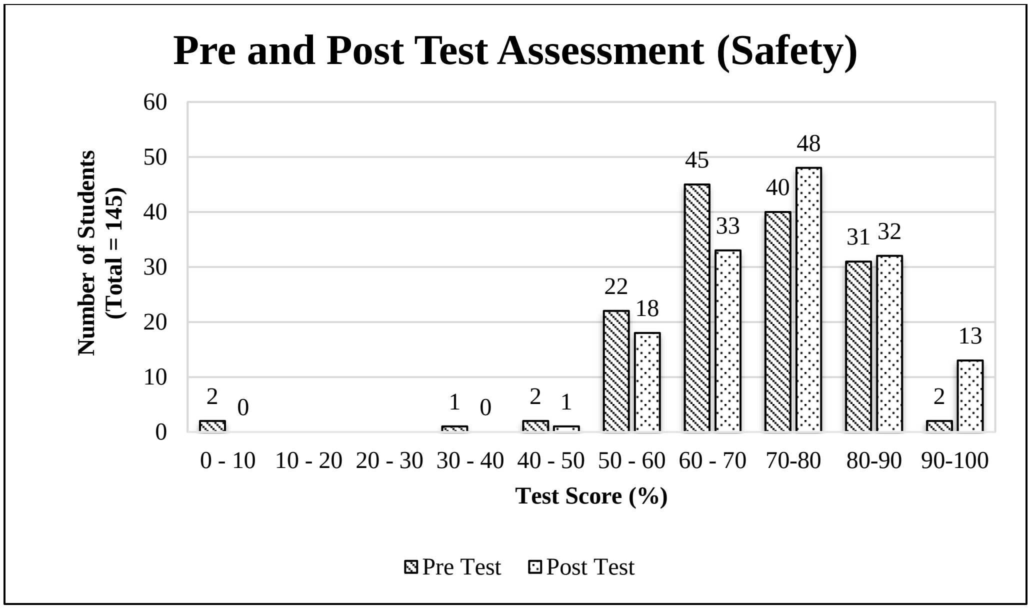

Figure 16. Distribution of questionnaire questions, learning objective and levels of learning.

H_5: Posttest scores will be higher than pretest scores for each individual question related to safety concepts.

The individual question growth appears limited (see Figure 17), and most questions with the exception of questions 15 and 22 experience no change or an increase in cohort performance. Students appear to be experiencing a challenging time understanding the regulatory signs for pedestrian safety (Q25), which received the lowest amount of correct responses. The student cohort demonstrates a stronger overall performance over safety concepts than physical activity concepts; the average scores are 3.6 for safety compared to 2.8 for physical activity. The student cohort performs well on the question related to bicycle boxes, which is a new topic, and achieves a significant improvement (p= 0.0064). For question 24, a remember question, which asks students to identify pedestrian pavement markings and signs, the learning gains appear significant (p=0.000). The difference in test scores shows the highest gain or improvement of 19 percent for question 24. Finally, Question 26, an apply question, asks students to apply different sidewalk designs to improve safety for active commuting (p=0.0075) and question 28, a remember question asks the students about a pedestrian buffer zone (p=0.0007). Question 20, which asks the students about bike lanes, shows significant improvement for a significance level of 0.05 but fails at 0.01. Question 21, an understand question, asks students to demonstrate an understanding of the influence parking restrictions can have on the safety of active commuters, which appears significant for a 0.05 significance level. For questions 15, 16, 17, 18, 22, 23, 25 and 27, the improvement does not approach significance.

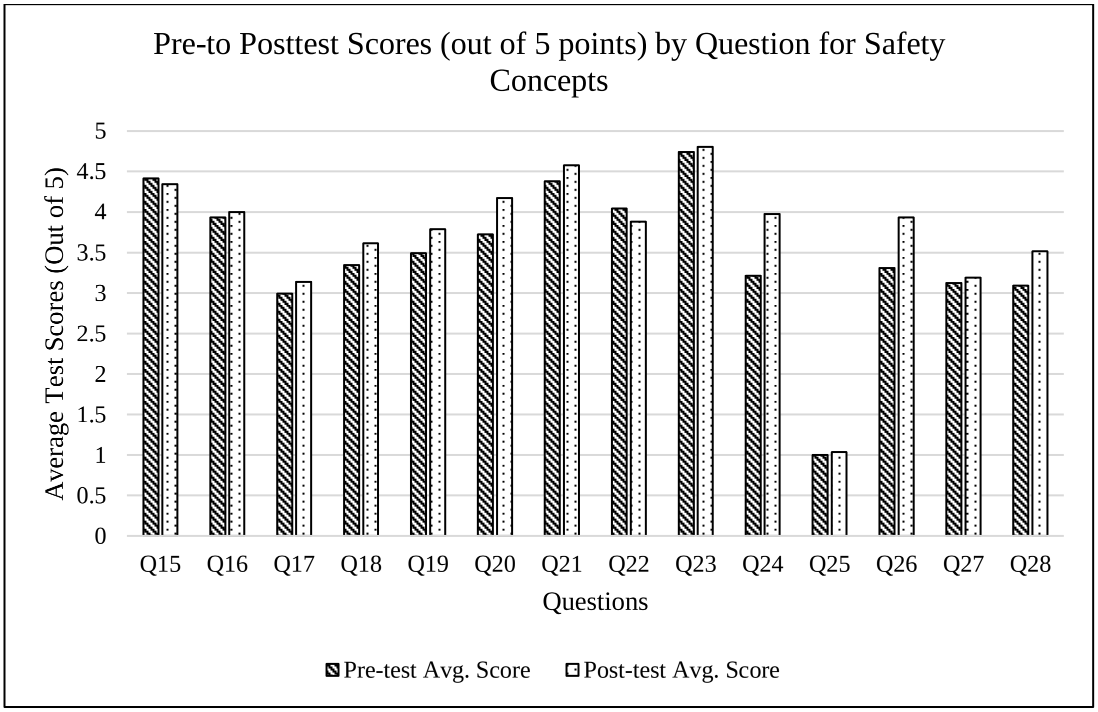

Figure 17. Pre/posttest scores by level of learning for safety concepts

H_6: Posttest scores will vary based on the categories of Bloom's Taxonomy. Specifically, the intervention encourages more growth at the higher levels of learning categories (i.e. apply and analyze) within Bloom's Taxonomy for safety concepts.

Figure 18 and the supporting analysis indicate that statistical evidence for this hypothesis exists. The test scores improve for the *remember*, *understand*, *apply*, and *analyze* questions, but the improvements remain statistically insignificant for the *analyze* questions. Overall, the students' performance increases the most for application questions.

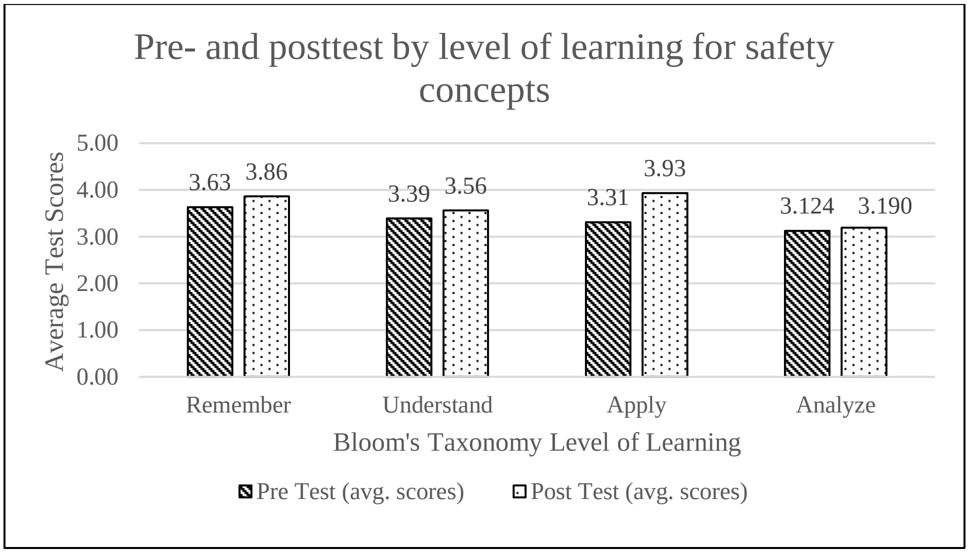

Figure 18 Distribution of questionnaire questions, learning objective and levels of learning.

H_7: Mastery Level will be achieved at the end of the project on specific cognitive skill set for various categories of safety concepts

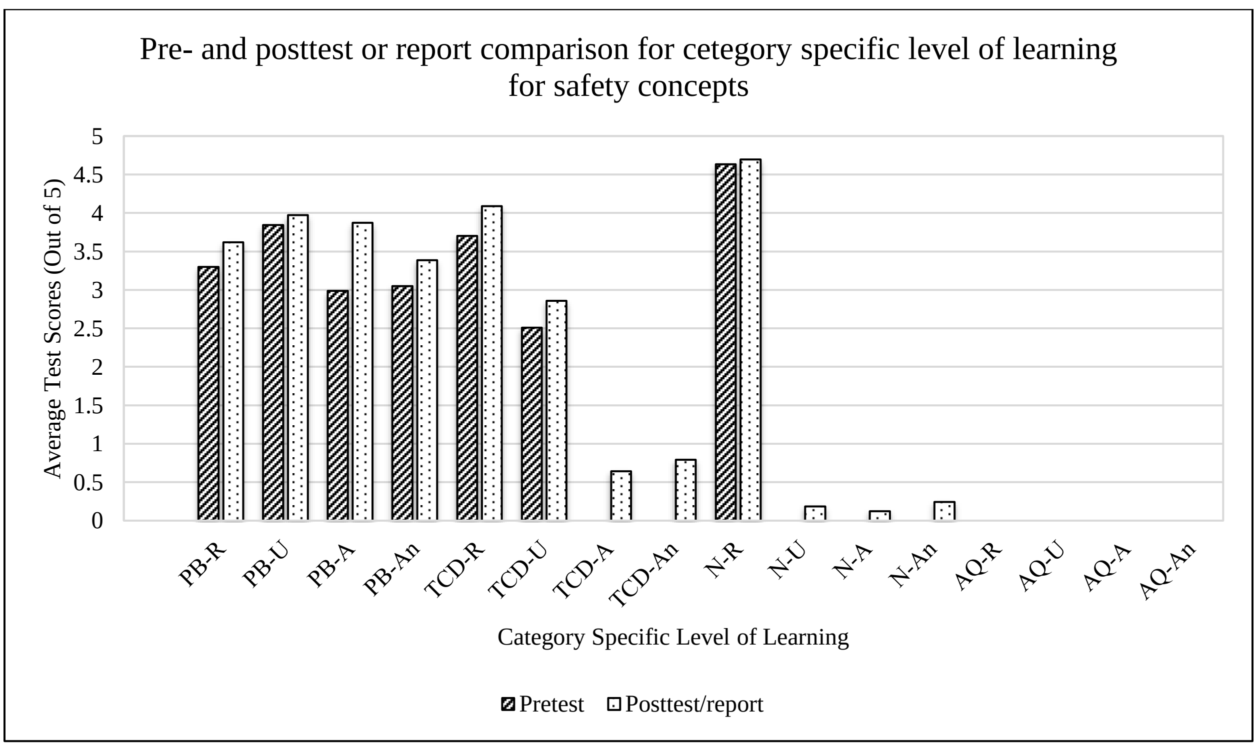

Figure 19 MAstery Level Achievement comparison between qualitative report/posttest and pretest for physical activity concepts

The student cohort performs well for all four infrastructure element (PB) levels but only achieves statistically significant mastery level improvement for the *remember* and *apply* taxonomies with a significance of (p=0.0014) and (p=0.0065). The performance of the student cohort on TCD-R and TCD-U at least achieve a *marginal* improvement in mastery level with a significance of (p=0.0009) and (p=0.0025). The student cohort also achieves *advanced* level mastery for the *remember* level of the network and connectivity category. For the rest of the categories from Figure 19, the TCD-A, TCD-An, N-U, N-A and N-An, the student cohort remains below an unsatisfactory level of mastery, but some growth appears in these categories, which indicates isolated success of the PBL across the cohort.

H_8: The number of students achieving sufficient MALA is higher in posttest/report than the pretest for safety concepts.

Based on the mastery level achieved in the previous hypothesis testing, this hypothesis assesses if the total percent of students achieving at least a *sufficient* mastery level increases after the intervention. The analysis shows that *apply* taxonomy for the PB category and the *understand* and *apply* taxonomies for TCD category have achieved an improvement in the number of students with *sufficient* mastery level with a significance level of 0.05. A total of 61 students achieve *sufficient* mastery level at the end of the project whereas only 49 students achieved that on the pretest. Similarly, 22 students in understanding and 6 students in applying achieve a sufficient mastery level at the end whereas only 11 and zero students initially achieve it.

In summary, the analysis suggests that the PBL intervention results in the following impacts on the students' grasp of the safety concepts. The overall cohort performance appears stronger for safety than physical activity. The students perform particularly poorly on one question related to a midblock crossing that may need to be revised for greater clarity in future educational assessments. The cohort achieves a significant improvement for four test questions related to bicycle box, crosswalk, sidewalk and buffer zones and marginal improvement on bike lane and street parking related questions. While the intervention stimulates improvement in the higher order domains of Bloom's Taxonomy, the *analyze* level does not have any significant improvement. Overall, almost all of the categories that have test questions achieve at least a *sufficient* mastery level. The rest of the categories at least have seen some significant improvement in the mastery level. Furthermore, the MALA method also shows the level of skills mastered on various categories of safety concepts. Furthermore, the total percentage of students achieving at least *sufficient* mastery level remains higher than that of pretest scores. The absence of questions related to TCDs and Ns for higher levels of Bloom's Taxonomy makes the MALA assessment more important.

4.5. DISCUSSION AND CONCLUSION

The inability of the conventional approach to clearly define the level of mastery on a particular objective or subject matter compelled the research team to adopt a more robust assessment method for clear delineation of mastered physical activity and safety concepts. The students show a significant level of improvement in the MAstery Level Achievement (MALA) for the infrastructure elements (PB) and traffic control device (TCDs) categories at all four-taxonomy levels for physical activity concepts. The student cohort also achieves mastery on the network and connectivity (N) category for *remember* and *understand* level of taxonomy for the same concept. On the other hand, students achieved mastery for TCDs at all four taxonomy levels, for PB at only the *remember* and *apply* levels and for N at the *understand* and *analyze* levels. Overall, the total percentage of students achieving at least *sufficient* mastery level increases after the intervention. These results improve the overall understanding of the success of a PBL or other modular intervention from traditional assessment methods. The student cohort shows significant improvement in posttest scores for both physical activity and safety concepts. Furthermore, students have shown significant improvement for the *remember*, *understand*, and *apply* taxonomies for both physical activity and safety concepts, but failed to show any on the higher order *analyze* taxonomy. Hence, the MALA method clearly strengthens the assessment of the PBL approach by specifically identifying the level of mastery achieved for different categories of active commuting concepts.

The report's MALA evaluation also reveals 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, by the end of the project, students 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 study 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 getting more information related to field problems.

Overall, the assessment of the project reports suggests that the students' perception towards active transportation seems to be favorable upon completion of the PBL intervention. 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.

1. 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 categories that among those scoring the lowest on the pretest, improvement did occur in both safety and physical activity.
2. The concepts and a student's initial level of exposure to those concepts influence 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. 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
    - 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 categories.

3. However, the evaluation of the reports indicates a higher level of learning. Since the research team designs the project rather than the students, so they may remain less engaged directly with higher conceptual challenges.

4.5.2. **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 assessment methods for comparing the mastery level achievement appear important, too. The introduction of MALA to evaluate the intervention for different learning concepts adds a new dimension to the conventional pre-posttest comparison. Furthermore, the research team recognizes that the assessment tool and grading rubric need additional validation across more classroom settings and contexts. So, the authors recommend future research on project-based learning intervention in collaboration with other transportation classes. 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 the 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.

4.5.3. **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 (Esche & Hadim, 2002) and that the learning styles of the students must also be taken into consideration (Huang & Levinson, 2012). 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 appear more pronounced for the physical activity concepts, those with 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. Additionally, the results from the MALA method show that students have gained higher level skills not presented in the course. So, a standalone PBL intervention not specific to the course content can even be considered due to the structure of the grading rubric and MALA method. Finally, instructors must ensure that students receive adequate exposure to all course concepts through the project.

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SUPPLEMENTAL DATA

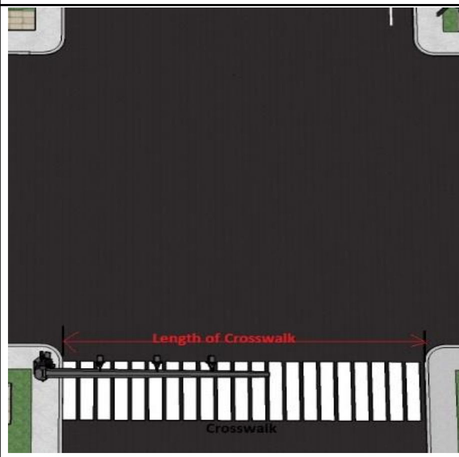
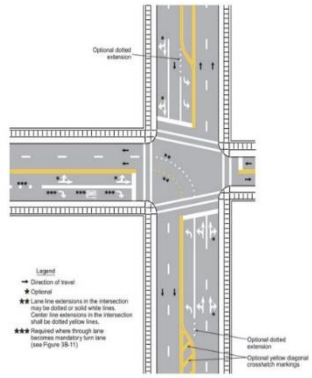
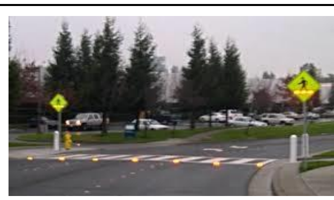
Learning Objectives

1.	Explain the importance of crosswalk at intersections and midblock crossings.
2.	Identify different types of traffic control devices for pedestrian/bicyclists.
3.	Explain the importance of lighting for sidewalks and intersections.
4.	Explain and discuss various types of traffic calming devices for intersections and roadway segments.
5.	Assess intersections and sidewalks for ADA compliance.
6.	Discuss importance of ADA compliance for intersections and sidewalks
7.	Identify various elements/aspects of sidewalk facilities that have positive/negative impact on walking/biking
8.	Explain and discuss the impact of number of lanes on walkability and bikeability
9.	Describe the role of trails and sidewalk facilities for physical activity
10.	Explain the purpose of sidewalk
11.	List components of a sidewalk that influence walkability/bikeability
12.	Describe the importance of buffer zone for public health
13.	Define and discuss the impact of driveways for a walkable / bikeable route
14.	List various types of median
15.	Explain the importance of a median for a walkable/bikeable route
16.	Identify different types of traffic controls at midblock crossings that affect the perceived safety of a walking route
17.	Explain the effects of air quality on choosing a walking/biking route
18.	List at least five meteorological elements that affect the air quality
19.	Identify different types of sources/origins that create pollution along a walking/biking route
20.	Explain how land use affects non-vehicular travel behavior and physical activity
21.	List a number of factors that influence recreational walking/biking
22.	List a number of factors that influence utilitarian walking/biking
23.	Explain why a continuous walking path is necessary in a neighborhood for increasing physical activity
24.	Short list different types of infrastructure elements that influence in the decision making process of choosing a walking/biking route.
25.	*Explain the importance of a complete street.*
26.	*Recommend infrastructure improvement, program or policy that could be implemented near a school or similar community location to reduce childhood obesity.*
27.	*Explain how poorly maintained infrastructure hampers physical activity*
28.	*Explain the role design elements play in the walkability of a sidewalk*
29.	*Design traffic control devices and signs for pedestrian and bicyclists*
30.	*Identify various types of intersection present in a transportation network*
31.	*List various innovative measures for increasing walkability/bike ability*
32.	*Discuss about innovative ideas that may help increase physical activity*
33.	*Identify conflict points present at different types of transportation facility*

Test Questions

Q1		Which factor/factors deters/deter pedestrians from using a sidewalk facility		
	a.	Trees along the sidewalk	b.	Trashbins
	c.	Street Furniture	d.	Dark Alley
	e.	b & d	f.	None of the above
Q2		Which is/are used as a/ control device/es for pedestrians at the intersection		
	a.		b.	
	c.		d.	
	e.	All of the above		
Q3		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		
Q4		Where does bad air quality matter for pedestrians?		
	a.	Parking lot	b.	Sidewalk
	c.	Driveway	d.	Intersection
	e.	All of the above		

Test Questions Cont'd

Q5		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 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
Q6		Which is a HAWK(High-intensity Activated crosswalk) beacon
	a.	
	c.	
	b.	
	d.	
	e.	All the above

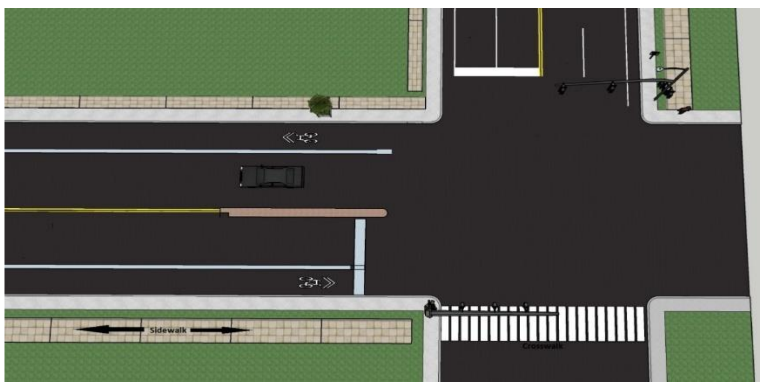
Test Questions Cont'd

Q7	**a**	Which facility does **NOT** look safe		
	a.		c.	
	b.		d.	
	e.	All the above		
Q8	**a**	**The paths of any two road users (**vehicles, pedestrians and bicyclists) while turning, diverging or merging cross each other creates a conflict point. In the folowing figure, identify the total number of pedestrian –vehicle conflict points		
				
	a.	12	b.	18
	c.	21	d.	24
Q9		List three reasons for inlcuding lighting along sidewalk/intersections.		
Q10		Define with examples some traffic calming device and identify three reasons to use a traffic calming		
Q11		What are some of th reasons that increase utilitarian biking		

Test Questions Cont'd

Q12 Identify three things wrong in the folowing scenario.

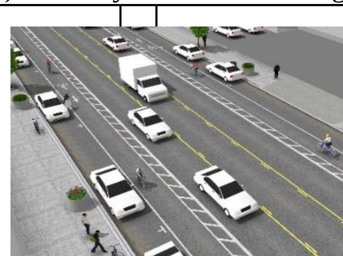
Q13 What is wrong in the following scenario? Please identify and mark on the picture.



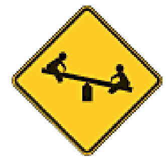
Q14 Please match table A with table B and write on the left most column

	Table A		Table B	
	a	Raised median	i	Utilitarian Usage of Sidewalk
	b	Dark Alley	ii	Active Kids
	c	Historical place	iii	Length of crosswalk
	d	Higher AADT	iv	Higher walking rate
	e	Number of Lanes	v	Low Walkability
	f	Shopping Mall	vi	Increase Conflict Points
	g	Complete Street	vii	Less Perceived Safety for kids/Daytime trips
	h	Driveways	viii	Less Physical Activity
	i	Obesity	ix	Recreational biking
	j	Safe Route to School	x	Separate opposing traffic

Test Questions Cont'd

Q15		What are some of the benefits of bicycling and walking?		
	a	Transportation, Environment, and Health	b	Transportation, Environment, Quality of life, Health, and Economy
	c	Environment, Quality of life, Health, and Economy	d	Transportation, Environment, Quality of life, and Health
Q16		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
Q17		Mark (X) locations where midblock crossings are used		
	_	Long block lengths between intersections	_	Schools
	_	Hospitals	_	High pedestrian activity locations
Q18		Mark TRUE (T) / FALSE (F) for each statement about curb extensions. Curb		
	_	shorten pedestrian crossing distance.	_	shorten pedestrian signal phase.
	_	allow pedestrians to see the traffic better.	_	allow traffic to see the pedestrians.
Q19		Mark TRUE (T) / FALSE (F) for each statement about bicycle boxes at an intersection. Bicycle Box		
	a	Increases visibility of bicyclists	b	Reduces signal delay for bicyclists
	c	Provides priority for bicyclists at signalized intersection		
	d	Groups bicyclists together to clear an intersection quickly and minimize impediment to other traffic		
Q20		Which sequence (a, b, c, or d) correctly identifies the images of bike lanes presented		
		  		
	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		

Test Questions Cont'd

Q21		Indicate whether the following statements are true (T) or false (F) about parking		
	_	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		
Q22		Match the following warning signs		
	1	Pedestrian crossing	a	
	2	Advanced pedestrian crossing	b	
	3	Playground	c	
	4	School bus stop	d	
	5	School crossing	e	
	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		

Test Questions Cont’d

Q23		Complete the following sentences related to pedestrian intersection design principles.		
	1	Encourage crossing at intersection ______		
	2	Make pedestrians ________to traffic		
	3	Minimize ________ distance		
	4	Make vehicular traffic visible to ________		
	a	crossing	b	pedestrians
	c	visible	d	corners
Q24		Match the following Crosswalk Markings		
	1	Standard	_	
	2	Continental	_	
	3	Zebra	_	
	4	Ladder	_	

Test Questions Cont'd

Q25		Indicate which of the Regulatory Signs below are related to pedestrians.		
	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
Q26		Which of the following are important sidewalk design elements?		
	1	1. Sidewalk width	2	2. Buffer areas
	3	3. Cross-slope	4	Sight Distances
	5	Continuity		
	a	1, 4 and 5	1, 2 and 4	
	c	3, 4 and 5	d	All of the above
Q27		Compare and contrast dedicated and shared bike lanes.		
Q28		Define Pedestrian Buffer zone.		

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CHAPTER 5

5.1. CONCLUSION AND DISCUSSION

Due to increasing efforts by planners and public health officials, more and more people have started walking and biking for recreational and utilitarian purposes. Planners and policy-makers have been working constantly to ensure the safety of pedestrians and bicyclists, but less has been done to ensure the environmental quality that also may encourage or discourage physical activity. The tools and techniques present for air quality evaluation do not identify exposure level exclusively due to mobile sources. Moreover, the current standards are based on records at fixed monitoring stations mostly placed more than 32.8ft away from the curb-side of the roads. Furthermore, the tools do not act as a readily available tool for planners or practitioners as they do not specifically connect speed and volume in the severity criteria. This study addresses this issue in three stages

a. The first study identifies critical and conservative exposure values (that can create minor irritation to mortality) and use them as the exposure levels to categorize different potential health impacts. This study develops a project-level tool to better understand and assess the potential near-roadway pollution levels for pedestrians and bicyclists. The tool will not only help cardiovascular and respiratory patients decide where to engage in outdoor activity, but identifying locations with high pollution can help decision makers select more desirable walking and bicycling routes that optimize both connectivity and public health. The study develops a 2D (speed-volume) assessment tool for pollutant concentrations for each of the four pollutants.

b. The research team acknowledges that the arterial air quality assessment tool helps practitioners identify hot-spot areas for different locations just using the speed and volume of a specific arterial. This leads to the need to investigate intersection related air pollution. While arterials may be reduced to only two dimensions, intersections have three or more approaches with potentially different speeds and volumes and a variety of traffic signal control strategies. Therefore, the author explores the potential of using two-fluid parameters to capture differences in intersection emissions related exposure.

c. This analysis investigates the performance of a unique assessment tool designed for a project-based active learning intervention. The traditional pre-posttest rarely directly captures the level of mastery achieved for different concepts. The researcher identifies that educating students about active commuting remains important for the future. This study evaluates the project-based learning intervention using the unique overall MAstery Level Achievement (MALA) method on various categories and total percent of students achieving mastery.

5.1.1. Conclusion

The results from MOVES 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 (Panis, et al., 2011). 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). For each of the pollutants, the research team calculates the average 1-hr concentration and plots it against Speed (Y-axis) and Volume (X-Axis) graph. This graph can be used as a tool to identify the potential pollutant concentration at a height of 3.5 feet for different volume and speed combinations. The tool does not consider background level pollutants for any particular site, and instead, it focuses on generating the emission concentrations due to only the traffic impacts. Since this generalized version of the arterial air quality risk assessment tool only requires an arterial's speed limit and volume, it can easily be used by practitioners and policymakers for evaluating current and future infrastructure with respect to air quality. Additionally, refining wind conditions will likely return much more accurate preliminary assessments of risk; however, this will increase the dimensions required for applying the sketch planning tool. Different receptor placements may be implemented for bicycle and pedestrian facilities to show the potential differences in exposure; furthermore, nearby sensitive facilities like schools may also be assessed by changing the receptor location. Future studies may also build similar sketch planning instruments for intersections. Planners can use the planning tool to include the local air quality needs and impacts in future project-level planning and policy recommendations.

The results from the second paper are aggregated separately for CO, NO_2, PM2.5 and PM10. The research team aggregated the total concentration of CO for HH and LL cases for each of the receptor locations and it shows that volume plays an important role in the increase in the pollution exposure at the intersection level. The CO or NO_2 concentration decreases as the receptor locations move further from the intersection. When a receptor is located at the midblock segment of the approach length, it measures lower concentrations than the receptors located closer to the intersection. The analysis indicates that the exposure level remains higher closer to the intersection and it changes with speed, volume and intersection geometry. The sketch planning tool does not provide a definitive health risk; however, it can assess relative health risks and provide an indication that the true health risk. Inclusion of two-fluid model will help decision makers identify potential risk prone intersection and compare that with their model parameters to assess the network performance. Characterizing the transportation related air pollution exposure level at the intersection level with run time and stop time is potentially beneficial for transportation practitioners. The continual work of the research team includes the development of a relationship across randomized intersection characteristics and their two fluid model parameters with the exposure level at different receptor locations. This can not only characterize the intersection but can serve as an overall network level air quality performance measure.

Placeholder: (This section will have elaborated discussion on exposure and two-fluid model before 17th of August)

The students show significant level of improvement at the MAstery Level Achievement (MALA) for infrastructure elements (PB) and traffic control device (TCDs) categories at all four-taxonomy levels for physical activity concepts. The student cohort also achieved mastery on network and connectivity (N) category for the *remember* and *understand* level of taxonomies for the same concept. On the other hand, students achieved mastery for TCDs at all four taxonomy levels, for PB at only the *remember* and *apply* levels and for N at the *understand* and *analyze* levels. Overall, the total percentage of students achieving at least *sufficient* mastery level increases after the intervention. These results improve the overall understanding of the success of a project-based learning intervention from traditional assessment methods. The student cohort shows significant improvement in posttest scores for both physical activity and safety concepts. Furthermore, students have shown significant improvement for the *remember*, *understand*, and *apply* taxonomies for both physical activity and safety concepts, but failed to show any on the higher order *analyze* taxonomy. Hence, the MAstery Level Achievement method clearly strengthens the assessment of the project-based learning approach by specifically identifying the different level of mastery achieved for different active commuting concepts.

5.1.2. Limitations

To provide a useful sketch planning tool with generalizable outcomes, the research team makes conservative assumptions for the meteorological conditions. The sketch planning tool does not provide a definitive health risk; however, it can assess relative health risks and provide an indication that the true health risk may need to be thoroughly modeled. In addition to the previously mentioned limitations, this study may still benefit by relaxing some of the assumptions made in the tool development. For example, the temperature selected for the dispersion modeling should be based on research that indicates likely temperature thresholds for outdoor physical activity and active utilitarian trip making.

5.1.3. Research Implication

Planners and agencies can use the developed 2D assessment tool (speed vs volume graphs for pollutant concentration) to evaluate potential air quality risks along a particular road segment. The severity level of the pollutant concentration used in the graph can be a guideline for the practitioners to show any minor irritation or symptom on human health.

The sketch planning tool uses VSP for emission rate calculation, which may not exactly represent the traffic in question. Future studies can build a small network of intersection and segment and do the same study for more accurate traffic representation.

The composition of traffic in intersection study only comprised of passenger car, intercity bus and combination long-haul truck which does not exactly represent regular urban traffic. Researchers are encouraged to gather area specific traffic composition and use that for more representative analysis.

Due to the scope of the work, pedestrian and bicycle traffic are not consider here. A robust future study may include a typical urban busy intersection with high, medium and low volume of pedestrians and evaluates the exposure levels.

Space holder for two-fluid model research implication

The limitations in the third 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. The introduction of MALA to evaluate the intervention for different learning concepts adds a new dimension to the conventional pre-posttest comparison. Furthermore, the research team recognizes that the assessment tool and grading rubric need additional validation across additional classroom settings and contexts. So, the author recommends future research on project-based learning intervention in collaboration with other transportation classes. 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 concepts. Steps can also be taken to modify the intervention and vary it based on the 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.

5.1.4. **Educational Implications**

For educators, the findings from the third paper 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. 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 seem more pronounced for the physical activity concepts with 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.

AUTHOR'S CONTRIBUTION

The authors of this study have contributed to various extent in each of the manuscript. In the second paper, Dr. Abou-Senna from University of Central Florida helped Mr. Rahman in converting trajectory files to Opmode distribution file using his VIMIS. In the third manuscript, Dr. Madanu helped in the project-based learning intervention development process, specifically all materials related to safety concept. The other manuscript authors are PhD committee members.