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Development of Performance Measures for Non-Motorized Dynamics

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16. Abstract

This report recommends performance measures for non-motorized (pedestrian and bicyclists) traffic safety for Michigan cities. Based on the data collected from four Michigan cities, Ann Arbor, East Lansing, Flint, and Grand Rapids, the research team analyzed non-motorized safety at three levels (city level, census tract level, and corridor level). The census tract-level analysis revealed that the number of access points, higher population with lower education, and higher exposure measures tended to increase non-motorized crashes. Through detailed corridor-level analyses, safety performance functions (SPF) for intersections and mid-blocks were developed. The intersection SPFs showed that higher average daily traffic (ADT), more number of bars, less number of lanes on minor approaches were associated with higher pedestrian crashes while intersections with right turn lane and bus stops exhibited relatively high number of bicycle crashes. Midblock SPFs also revealed that ADT, the number of access points, and the number of bus stops were factors leading to more non-motorized crashes. This research also presents results of before-and-after studies for non-motorized improvements and how performance measures are used when determining countermeasures.

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Executive Summary

Due to an increase in traffic congestion and concerns on human health and environmental issues, non-motorized modes (walking and cycling) have been encouraged as alternative modes of transportation to motor vehicle. Ensuring safety of pedestrians and bicyclists is among the crucial tasks of any jurisdiction attempting to promote non-motorized modes. Although the statistics have shown a declining trend, pedestrian and bicyclists fatalities are still one of the significant contributors to deaths resulting from traffic crashes. In Michigan alone, there were 141 pedestrian and 24 bicyclist fatalities, accounting for 18.7% of total fatalities resulting from crashes in 2011 (Michigan Office of Highway Safety Planning, 2013). Except for the Detroit area, both pedestrian and bicycle crashes are randomly distributed rather than concentrated at particular locations. This random nature of crashes makes it difficult to apply crash countermeasures when scoping transportation projects. This study was a result of efforts by the Michigan Department of Transportation (MDOT) to develop a systematic approach to determine performance measures for non-motorized safety and to identify the need for countermeasures when designing facilities. The research had six specific objectives:

1. Building an inventory database for non-motorized safety analysis and providing a guideline for data collection, storage, and management;
2. Conducting detailed analysis of high crash and low crash communities to identify factors affecting crashes involving pedestrians and bicyclists and to develop applicable performance measures;
3. Evaluating performances of recent pedestrian and bicycle improvement projects through before and after studies and cost-benefit analyses to quantity their effectiveness;
4. Identifying cultural issues associated with pedestrian incidents, and determining what issues can and cannot be addressed by engineering solutions;
5. Developing systematic guidance for adjusting performance measurements by comparing the nationwide non-motorized performance measurements and analysis results; and
6. Developing a user guide for using performance measures and determining the need for non-motorized countermeasures.

An extensive literature review was conducted to identify documented factors causing non-motorized crashes. The literature indicated that influential factors can be classified into following groups:

- Demographics
- Socio-Economics
- Land-use
- Facility (Speed, Volume, etc.)
- Transit and Travel mode
- Geometry and Design
- Other Factors (Environmental, Seasonal, Educational, Cultural, etc.)

With regard to demographics, much of the research agreed that young people are more at risk to be involved with non-motorized crashes, while the elderly experience more severe crashes. Also, males are more likely to be involved in a crash as opposed to females. Concerning socio-economics, as affluence level increases in an area/household, the less likely crashes are to occur. Land usage also affects non-motorized crash frequency/severity. Due to the nature of commercial/industrial areas (which are often characterized with higher density of trip generators/terminators), crash rates tend to be higher in these locations compared to residential areas. With regard to transportation facilities, as the density of facilities increases, the number of both motorized and non-motorized crashes tends to decrease. The impact of travel volumes on these facilities has also been investigated, with most research finding a positive relationship between volume (exposure) and crash frequency. The geometry and design of transportation facilities also shows a significant impact on non-motorized safety, with non-motorized crashes most commonly resulting from inadequate lighting conditions. In addition to factors described above, there are numerous other factors (e.g., individual behavior, temperature, weather, road condition, vehicles, cultural issues, etc.) that could contribute to non-motorized crashes.

Many agencies and organizations have developed their own performance measures according to their priorities, to evaluate performance in terms of improving the safety of non-motorized transportation. In this study, efforts made by others to develop performance measures were reviewed to evaluate their benefits, improve them and/or propose new performance measures fitting our study. According to the existing literature, safety performance measures could be categorized in the following groups:

1. Crash frequency of special types of crashes
2. Different rates of pedestrian/bike crashes
3. Facilities
4. Investment & achieved benefits
5. Enforcement
6. Cultural issues and their effects
7. Cost of crashes
8. Others

Literature showed that the various performance measures concerning crash quantity or crash rate are currently the most utilized measures by state DOTs. This is likely due to the ability of such a performance measure to aggregate the performance of all other supplementary groups into one statistic. However, crash frequency performance does not tell the whole story. Agencies wishing to determine the root cause behind higher than expected crash frequency should strive to dig a little deeper and investigate some of the other performance groups within their jurisdiction, such as infrastructure, exposure, enforcement/education, and other similar measures.

Data Collection

To accomplish the objectives of this study, data were collected in four Michigan cities: Ann Arbor, East Lansing, Flint and Grand Rapids. The data collected were categorized into the following groups:

- Non-motorized crash data
- Pedestrian and bicycle volume as exposure measures
- Non-motorized facility inventory

- Non-motorized improvement projects
- Activity locations
- Socioeconomic and demographic data
- Crime rates
- Land use data
- Traffic volume data (for corridor level analysis)

As this study dealt with a large amount of data, it was important to develop a good data management system. The research team employed ESRI® ArcGIS 10.0 and compiled all data in the GIS database. The GIS database enabled the research team to process the data in an analyzable format. In this study, performance measures were evaluated at three levels: – the city level, census tract level, and corridor level. Accordingly, the data collected had to be processed in these three levels. As this study used a modeling approach in estimating pedestrian and bicycle volumes, all necessary data including socio-economic data had to be processed for individual intersections. The census-tract level analysis also required to process all necessary data for each census tract. The corridor level analysis required more detailed data processing efforts.

Non-Motorized Volume Model

Pedestrian and bicyclist exposures are defined as the rate of pedestrian or bicyclist's contact with motorized traffic. Higher exposure results in more crashes involving non-motorized traffic. Even though pedestrian and bicycle volumes are essential for safety performance analysis and planning non-motorized facilities, there have been very limited efforts to collect and archive data, mainly due to the lack of reliable and economic data collection means. In order to efficiently measure non-motorized volumes, there have been efforts to develop sensors for detecting, counting, and classifying pedestrians and bicycles. This study employed two types of pedestrian and bicycle volume collection approaches. The first type was to collect 12 hour data at selected locations using automated pedestrian and bicycle sensors, and the second type was to collect data manually for one hour at coverage locations. The counts from locations for the first type were used to identify a time-of-day non-motorized traffic pattern representing the area, which could be used to extrapolate the one hour counts from coverage locations. For each city, three locations were determined for this type, and commercially available video image sensors from Miovision were installed for data collection. In order to select data collection sites, first, pedestrian and bicycle crashes from 2004 to 2012 were mapped using ArcGIS. Then, sites were selected using multiple criteria such as crash density, activity at locations (schools, non-motorized facilities, etc.), land use characteristics (using Google Map), and geographical distribution, and locations proposed by local transportation planning agencies. As a result, one sensor was installed in a busy downtown intersection in each city while the other two sensors were located in less crowded areas with different types of land-use. Manual data collection was conducted at 20 locations for each city by five trained students. The criteria for site selection was having at least one crash during the study timeframe, although the majority of sites chosen experienced a considerable number of non-motorized crashes during the analysis period.

In order to estimate pedestrian and bicycle volumes at signalized intersections where data was not collected, individual models were developed. Data from 91 signalized intersections in four Michigan cities (i.e., Ann Arbor, East Lansing, Flint and Grand Rapids) were processed, which included facility, geometry/design, land-use, demographic and socioeconomic data. In addition to the processed pedestrian and bicycle volume data, land use, demographic and other intersection characteristics within both 1/4-mile and 1/2-mile buffers were also processed from the GIS database. Non-motorized exposures at intersections were estimated using the volume models developed in this study. Validity of the models was checked through bootstrapping – a statistical approach in which properties of an estimator (e.g., the variance) are estimated through resampling techniques. Understandably, the observed exposure measures are desirable, but the non-motorized volume models developed in this study can provide rough estimates for the intersections where non-motorized volume data are unavailable. For more accurate models, extensive data collection efforts are needed. The models were applied to all signalized intersections in the four cities. Although the exposures were limited only to signalized intersections, the average value for a given area can represent overall pedestrian or bicyclist exposure.

Crash Analysis

This study analyzed crash data associated with socio-economic, demographic, exposure and physical feature variables. The analyses were conducted in three levels- city-wide, census tract, and corridor level. While analysis of crash data at the city level and the census tract level may explain the effects of significant characteristics on crashes, corridor-level analysis helps to identify factors causing non-motorized crashes, such as non-motorized facility features and traffic characteristics. Since corridors consist of two components (intersection and midblock), the corridor-level analyses evaluated each of these components separately. A midblock was defined as the length of roadway segment between two intersections. For each component, traffic and other physical features which may impact crash frequency and severity (such as geometry, presence of bike lanes, access points, etc.) were investigated to develop safety performance functions (SPFs). SPFs predict the number of crashes expected at a particular level of analysis based on a statistical analysis of the relationship between various factors on observed crash frequencies. The study fitted several negative binomial and Poisson regression models. The resulting intersection and midblock SPFs for pedestrian and bicycle crashes are as follows:

$$N_{Pedestrian\ Crash\ No.@\ Intersection} = \exp(-.043449\ NLN_{minor\ road} + .000018\ ADT + .000056\ Pedestrian\ Volume + .0455736\ Number\ of\ Bars - .0035416\ Grad\ Degree + .043991)$$

$$N_{Bike\ Crash\ No.@\ Intersection} = exp(.26783\ D_{Major\ Right\ Lane\ No} - .0913841\ NLN_{minor\ road} + .0000211\ ADT + .0006378\ Bike\ Vol\ ume + .6660973\ Dum_{Bus\ Stop} + .5015012\ Dum_{Business\ Landuse} - 0.4236471)$$

where

$N_{Pedestrian\ Crash\ No.@\ Intersection}$ = the number of pedestrian crashes at intersections

$N_{Bike\ Crash\ No.@\ Intersection}$ = the number of bicycle crashes at intersections

$NLN_{minor\ road}$ = the total number of lanes on minor roads

ADT = average daily traffic approaching to the intersection

$Pedestrian\ Volume$= the number of pedestrian crossing the intersection

$Bike\ Vol\ ume$ = the number of pedestrian crossing the intersection

$Number\ of\ Bars$ = the number of bars

$Number\ of\ Grad\ Degree$ = the number of people who have graduate degree with ¼ mile

$Dum_{Bus\ Stop}$ = 1 if a bus stop exist; 0 otherwise

$Dum_{Business\ Landuse}$ = 1 if business area; 0 otherwise

$$N_{Pedesrian\ Crash\ @\ midblock} = exp(.017 * Access\_points + 0.00004 * ADT + 0.00005 * Ped\_Vol - 0.105 * Speed\_Limit + 0.76 * Length\_Corridor + 2.04)$$

$$N_{bike\ crashes\ @\ midblock} = \exp(.00006 * ADT + 0.011 * Bike\_vol - 0.117 * Speed\_limit + 0.073 * No\_BusStop + 0.026 * Bike\_Commuter - 0.31 * D\_Bike\_Ln + 0.72 * Length\_Corridor + 2.03)$$

where,

$N_{Pedesrian\ Crash\ @\ midblock}$ = the number of pedestrian crashes at midblock

$N_{bike\ crashes\ @\ midblock}$ = the number of bicycle crashes at midblock

$Access\_points$ = the number of access points

ADT= average daily traffic of two ends

Ped_Vol = average of pedestrian volumes

$Bike\_vol$= average of bicycle volumes

$Speed\_Limit$ = speed limit of the arterial

$No\_BusStop$ = the number of bus stops along the corridor

$Bike\_Commuter$ = the number of employees commuting by bicycle

D_Bike_Ln = 1 if bicycle lanes exist; 0 otherwise

$Length\_Corridor$= the length of corridor

Findings from these models are summarized as follows:

1) Based on the fitted model, pedestrian intersection crashes increased with vehicle ADT, pedestrian volume, and the number of bars in the vicinity of the signalized intersections.
2) The increase in the number of people with graduate degrees corresponded (statistically significant) to a decrease in the number of pedestrian intersection crashes. Minor roads with many lanes (at major-minor intersections) were associated with less number of pedestrian intersection crashes perhaps due to the fact that pedestrians are more cautious when crossing wide minor roads.
3) Increases in vehicle ADT, bicycle volume, the presence of bus stops and business land use corresponded to a statistically significant increase in bicycle intersection crashes.
4) Right turn lanes on the major roadway (at major-minor intersections) corresponded to an increase in the number of bicycle intersection crashes. An increase in the number of lanes in minor roads corresponded to less number of bicycle intersection crashes. This is likely attributed to bicyclists' diminished perception of safety with regard to crossing wide roads, resulting in bicyclists being more cautious when crossing.
5) For mid-block pedestrian crashes, the number of access points, ADT, pedestrian volume and the length of the mid-block corresponded to higher number of pedestrian crashes.
6) Higher posted speed limits at mid-blocks corresponded to a decreased number of pedestrian mid-block crashes. This is likely attributed to pedestrians' reduced perception of safety with regard to crossing or traveling along high-speed roads, resulting in lower exposure.
7) Increases in bicycle mid-block crashes corresponded (statistically significant) to increases in vehicle ADT, bicycle volume and the number of commuters who ride a bicycle to work.
8) The number of bus stops and the length of mid-blocks corresponded to an increase in bicycle mid-block crashes. The finding of a positive correlation between bus stops

and bicycle mid-block crashes is consistent with the HCM 2010, which states that the presence of such facilities can cause spillovers into the street (Transportation Research Board, 2010).

9) Higher posted speed limits were shown to correspond (statistically significant) to a decrease in bicycle mid-block crashes. This can likely be explained by bicyclists' lowered perception of safety with regard to crossing or traveling along high-speed roads, resulting in relatively lower exposure.
10) The presence of bicycle lanes was shown to decrease bicycle mid-block crashes although its impact was statistically weak. While bicycle lanes provide safer environment for bicyclists, they also increase bicycle volume which may lead to more bicycle crashes.

Cultural Factors

Cultural factors and understanding of rules of the road pertaining to pedestrians and bicyclists are instrumental to safe interactions among pedestrians, bicyclists and motorized traffic. This study examined, through field questionnaire surveys, whether there are cultural, perceptional, or educational differences in comprehension of these rules. The survey intercepted a sample of drivers, bicyclists, and pedestrians from a multitude of different backgrounds, unconstrained by location, city, gender or any other characteristic.

The analysis of survey results shows that drivers, pedestrians and bicyclists do not react with universal similarity to issues of non-motorized traffic safety, but instead, often differ greatly by city, even cities within a region where one might expect general homogeneity. Variations in understanding of traffic safety rules as an effect of city-specific resident education and culture often result in variations in responses with respect to traffic rules and regulations. Analysis of relevant traffic crash data shows that an understanding of lawful non-motorized traffic safety behaviors does not always directly relate to the frequency of non-motorized crash involvement by city.

Since the statistical analysis of survey responses revealed that one significant factor of non-motorized crashes is likely the result of a lack of traffic safety education, officials should strive to increase awareness of issues of non-motorized safety in an effort to reduce crash rates. However, these evaluations are only possible through direct measurement of reception of the public to the efforts in planning, operating, and maintaining safe non-motorized facilities, as provided by surveys, in conjunction with analysis of relevant traffic crash data (as opposed to self-reported crash involvement). Discovering and analyzing how understanding of non-motorized traffic safety differs by city, and the resultant effects on actual crash data within a city, allows transportation officials to determine specific shortcomings, to understand why these shortcomings exist, and appropriately develop safety-focused solutions.

Before-and-After Studies

In order to investigate the effectiveness of previously implemented non-motorized improvements in the study cities, before-and-after studies were conducted. In this study, a total of 37 corridors that include 74 intersections were chosen from four cities as a comparison group to determine the trend of crash occurrences. For the before-and-after comparison, the 9-year analysis period (2004-2012) was broken down into three 3-year spans. The period during 2004 - 2006 was regarded as a before period, and the period during 2010 - 2012 was an after period while all improvements were completed during 2007 - 2009. The improvement projects analyzed include shared lane markings (five sites), bicycle lanes (seven sites), sidewalk improvements (five sites) and additional improvements (seven sites). However, due to lack of non-motorized volumes in the before period and small sample size of treated sites, the before-after analysis was not able to provide generalized conclusions. More comprehensive studies for individual improvements across the state may be needed to investigate the impact of non-motorized improvements. To allow more accurate evaluation, exposure data before installation of improvements should be obtained to gauge the impact of the installations on crashes while considering the change in exposure. This report, however, presents detailed observations from individual improvement sites in Chapter 7. A summary of those observations is as follows:

Shared Lane Marking

Among the shared lane marking sites observed, South University Avenue in Ann Arbor showed an increase in bicycle crashes in the after period. Other sites had zero crashes in both the before and after periods. The increase in bicycle crashes at South University Avenue (which has on-street parallel parking with a narrow lane) might have resulted from an increase in bicycle volume in the shared lane while drivers lacked paying attention and understanding of the shared lane marking. Education campaigns should accompany installation of shared lane markings as the cultural and educational awareness of mutual bicyclist presence is not naturally inherent to these installations.

Bicycle Lanes

Installation of bicycle lanes provides safer environment for bicyclists. However, the data in this analysis showed that the number of bicycle crashes increased after installation of bicycle lanes perhaps because of increased bicyclists which may potentially lead to more crashes. Quantifying the benefit of bicycle lanes was not possible due to the lack of bicycle volume data before installation of bicycle lanes. Collecting bicycle volume before installation of bicycle lanes can help in quantifying the change in crash occurrence. Also, as stated above, sufficient sample sites would be needed to conduct a comprehensive evaluation study. On the other hand, data from sites observed indicated a decrease in pedestrian crashes at both intersections and midblock segments. The decrease in pedestrian crashes can be a result of the buffer space between vehicle traffic and pedestrians introduced by bike lanes.

Other Improvements

This study also looked at crash occurrence at other types of non-motorized improvements such as sidewalks, improving connectivity of pedestrian facilities, intersection conversions (for example, converting a roundabout to a signalized intersection), removing on-street parking, and Pedestrian Hybrid Beacons (PHB). The following is a summary of observations made:

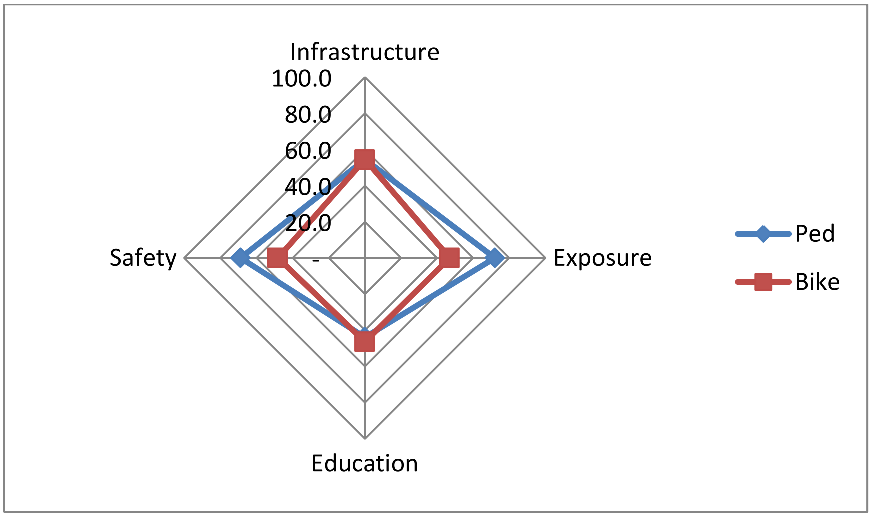
- Sidewalk improvements decreased both pedestrian and bicycle crashes.
- The improved connectivity of non-motorized facilities reduced non-motorized crashes through providing non-motorized users with a larger and more continuous separated pathway to their destination.
- The Pedestrian Hybrid Beacon (PHB) was successful in reducing non-motorized crashes in addition to reducing pedestrian delay.

Performance Measures

Performance measures for non-motorized traffic are important especially in guiding selection and implementation of countermeasures for pedestrian and bicycle safety. In this study, great efforts to obtain reliable pedestrian and bicycle volume data were made. This enabled development of both population-based and exposure-based performance measures for non-motorized safety. The methodology developed to effectively measure non-motorized safety performance in Michigan has two stages, beginning with a city-wide analysis and progressing into corridor-level analysis. The purpose of city-wide evaluation is to establish a baseline and identify any general performance issues within a city on a large-scale. The study found that performance can best be summarized into four different groups, such as infrastructure, exposure, education/enforcement, and crashes. In order to help MDOT and cities identifying areas to improve non-motorized safety, easily applicable measures were selected as shown in the table below.

Category	**Pedestrian**	**Bicycle**
Infrastructure	Sidewalks Coverage (%)	Bike Lane Coverage (%)
	Number of access points (number per mile)	Number of access points (number per mile)
Exposure	% of public transportation & walk commuters	% of bike commuters
Education	Understanding Right-of-way (Survey)	Understanding Right-of-way (Survey)
	Driver yielding rate at mid-block Crossing	Driver yielding rate at mid-block Crossing
Safety	# of ped crash / 100,000 people	# of bike crash / 100,000 people
	# of ped crash / 1,000 transit or walk commuters	# of bike crash / bike commuters

After computing individual performance indices, the perform indices in four categories can be computed and depicted by the radar graph below. The graph visualizes the category needing more improvement. For example, for the city depicted in this figure, education needs relatively more improvements.



The corridor-level analysis covered in this report presents a more targeted approach to measuring non-motorized performance and developing focused countermeasures according to the corridor scale. Selection of corridors for performance analysis begins with narrowing down regions of high-risk within the city through both crash density maps as well as crash frequency by census-tract. Once these regions have been identified, corridors can be evaluated and ranked according to various performance measures of interest, among which this report specifically studied the following:

- Signalized Intersection Performance
  - Difference between Observed and Predicted Crashes
  - Yearly Crashes per One Million Exposures
  - Equivalent Property Damage Only Crashes
- Mid-Block Performance
  - Difference between Observed and Predicted Crashes per Mile
  - Equivalent Property Damage Only Crashes per Mile

It is recommended that transportation agencies review, and if necessary expand upon, this case example to refine the process of identifying high-risk corridors with respect to non-motorized safety and responsively develop appropriate countermeasures.

Research Highlights

Volume Modeling

Introduction: Pedestrian and bicycle volumes were collected from 92 selected intersections in four Michigan cities: Ann Arbor, East Lansing, Flint and Grand Rapids. Automated sensors were used at selected locations for 12-hour count data and manual one-hour counts were performed at the remaining locations. Data collected in the field were used to develop models used to estimate non-motorized volumes at 768 other intersections.

Field Volume Collection and Extrapolation:

92 sites were selected based on criteria that included crash density, activity, land use and geographical distribution. The majority of sites selected displayed considerable historical non-motorized crash activity. The 12-hour sensor data was used to develop time-of-day travel patterns for three locations (one downtown and two outside areas of varying land use) in each study area. The one hour manual counts at 80 intersections were extrapolated to daily counts from the smoothed 12-hour time-of-day travel patterns on the basis of corresponding land-use characteristics. Figure 1 below shows an example of the modeled daily pedestrian volume at selected intersections in East Lansing.

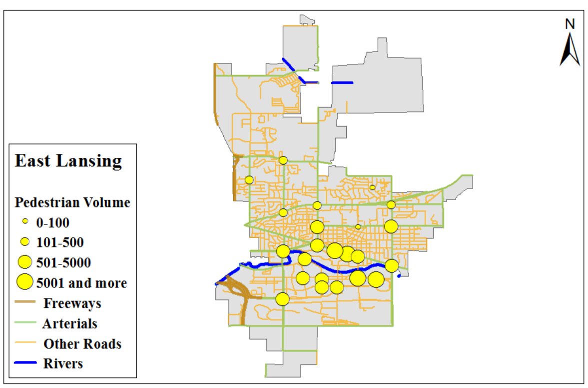


Figure 1: Daily Pedestrian Volume at Intersections in East Lansing

Volume Models: In addition to the observed and extrapolated non-motorized volumes, characteristics such as land use, demographics and physical features within a quarter- and half-mile buffer around intersections were used to develop pedestrian and bicyclist volume models, respectively. The statistical software Stata 12™ was used to estimate a log-linear pedestrian volume model and negative binomial bicyclist volume model, the significant results of which are summarized below:

- **Factors increasing pedestrian volume:**
  - Population
  - Campus land-use
  - Presence of retail stores, schools and bus stops within buffer zone
- **Factor reducing pedestrian volume:**
  - Motorized commuter population
- **Factors increasing bicyclist volume:**
  - Population
  - Campus and business land-use
- **Factors reducing bicyclist volume:**
  - Number of crimes within buffer zone

The models were used to estimate the average daily non-motorized volumes per signalized intersection in each city (for a total of 768 intersections), as shown in Table below:

Table 1: Estimated Average Daily Non-Motorized Volumes per Signalized Intersection

City	Number of Pedestrians	Number of Bicyclists
Ann Arbor	4,020	617
East Lansing	1,518	796
Flint	370	120
Grand Rapids	499	167

Census Tract Crash Analysis

Introduction: At the census tract level of analysis, the relationship between socio-economics, physical features (such as road length, access roads and side walk length), land use, non-motorized volume, and crime rates of each census tract was investigated to evaluate their effect on crash frequency and develop crash prediction models. Crash frequency models at a census tract level were developed using negative binomial regression analysis.

Crash Prediction Models: A number of combined non-motorized volume and infrastructure coverage sub-factors were investigated to determine their relationship with crash frequency. It was observed that an increase in infrastructure coverage is related to a decrease in both pedestrian and bicyclist crashes.

The pedestrian crash prediction model shows pedestrian crash frequency significantly increased with an increasing number of access points, higher pedestrian volume and higher proportion of population with a middle school education and lower. Pedestrian crashes were shown to be significantly decreased by an increasing length of bike lanes.

Similar to the pedestrian crash prediction model, a number of factors were investigated with regard to bicycle crashes. In this case, an increase in population with middle school education or lower, number of access points and bicyclist volume were factors associated with statistically significant increases in bicycle crashes.

Crash Density: ArcGIS 10.0, a mapping and spatial analysis software, was used to spatially evaluate crashes in each city by developing crash density maps. It was shown that more dense crash areas tend to be near the downtown areas, as shown in Figure 2. The red area indicates a region exhibiting high number of pedestrian crashes per square mile in Ann Arbor.

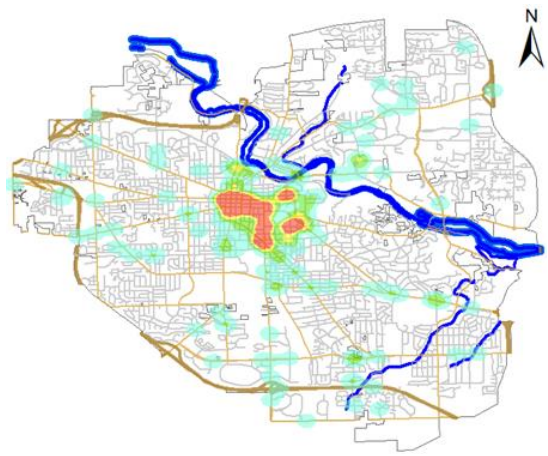


Figure 2: Ann Arbor Crash Density Map.

However, census tracts with a high proportion of night time non-motorized crashes do not necessarily concentrate in the downtown areas, as shown in Figure 3 below, depicting East Lansing's night-time pedestrian crashes by census tract. In this figure, darker color indicates high night-time crash frequency.

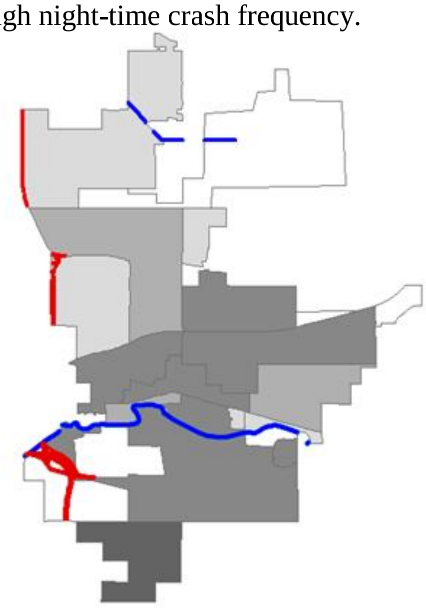


Figure 3: Concentration of Night-Time Pedestrian Crashes in East Lansing, MI.

Corridor Level Crash Analysis

Introduction: In order to investigate whether factors such as non-motorized facility features and traffic characteristics impact non-motorized crashes, a corridor-level analysis was performed. A corridor was defined as a segment with two signalized intersections at both ends. Since corridors consist of two components - intersections and mid-block, the corridor-level analyses evaluated each of these components separately. Traffic and other physical features which may impact crash frequency were investigated for each component in order to develop safety performance functions (SPFs). SPFs predict the number of crashes expected at a particular level of analysis based on a statistical analysis of the relationship between various independent factors on observed crash frequencies.

Methodology: The corridors were selected based on geographical distribution, locations of pedestrian and bicycle crashes, non-motorized improvements and recommendation by city personnel. A total of 51 corridors were selected consisting of 13 from Ann Arbor, 7 from East Lansing, 12 from Flint, and 19 from Grand Rapids. Various buffers sizes were applied to intersections and mid-blocks in order to collect crash, socioeconomic and demographic related information. Information provided by census block or census tract data was measured through a weighted average which calculated the percentage of census block or tract area included in the buffer. Additional road geometry characteristics were gathered through Google Earth Pro. Statistical models were utilized to determine which evaluated variables were significantly influencing pedestrian and bicycle crashes at intersections and mid-block segments.

Analysis Results: A summary of the analysis results can be observed in **Table 2**. The model results determine that pedestrian intersection crashes are significantly increased statistically by traffic volume, pedestrian volume and number of bars in the vicinity of the signalized intersections.

Table 2: Factors Influencing Corridor Level Crashes

Factors Influencing Non-motorized Crashes
Intersection Bicycle Crashes **Factors Increasing** • Traffic Volume • Bicycle Volume • Presence of Bus Stops • Business Land Use • Right Turn Lanes on Major Roadway **Factors Decreasing** • Number of Lanes on the Minor Roadway
Intersection Pedestrian Crashes **Factors Increasing** • Traffic Volume • Pedestrian Volume • Number of Bars **Factors Decreasing** • Individuals with a Graduate Degree • Number of Lanes on the Minor Roadway
Midblock Bicycle Crashes **Factors Increasing** • Number of Bus Stops • Number of Employees Community by Bicycle • Traffic Volume • Bicycle Volume **Factor Decreasing** • Posted Speed Limits
Midblock Pedestrian Crashes **Factors Increasing** • Number of Access Points • Traffic Volume • Length of Midblock • Pedestrian Volume **Factors Decreasing** • Posted Speed Limits

Before-and-After Analysis

Introduction: The objective of the before-and-after analysis was to investigate the effectiveness of previously implemented non-motorized improvements in four Michigan cities of Ann Arbor, East Lansing, Flint and Grand Rapids.

Methodology: A group of comparison sites were chosen from the four cities to determine the trend of crash occurrences. The sites in the comparison group were those without any improvement during the analysis period (2004-2012), but with similar roadway geometry, exposure measures, and land use as compared to the improvement sites. The non-motorized crashes that occurred on the improvement and comparison sites were separated into mid-block and intersection crashes in order to observe if the improvement projects are effective in promoting non-motorized safety at intersections, mid-blocks, or at both locations. Intersection crashes were defined as crashes that occurred at signalized road junctions, whereas mid-block crashes were defined as crashes that occurred between the signalized road junctions.

The 9-year analysis period (2004-2012) was broken down into three 3-year spans. The period during 2004 - 2006 was regarded as a before period, the 2010 – 2012 period was regarded as the after period, and all evaluated non-motorized improvement projects were the 2007 – 2009 period. Crashes that occurred during the year that the improvement project was constructed were excluded from the analysis. The mean number of pedestrian, bicycle, and total crashes at intersections and mid-blocks were analyzed before-and-after for each improvement group. The change in before-and-after crashes of the improvement site was compared with the crash trend found from the comparison sites. The comparison group's crash trend was applied to the before-and-after crashes of the improvement site in order to project the number of crashes that would have occurred at that site if no improvement was made. The difference between projected and actual crashes for the after-case was regarded as the actual change by the improvement.

Analysis Results: Among the non-motorized improvement projects compiled, analysis sites for the before-and-after studies were selected based on the projects focus and if the improvement project was construction between 2007 and 2009. The selected improvement sites were combined and classified into the four groups: shared lane markings, bicycle lanes, sidewalk improvements, and others. Others include improvement projects with one or two cases which are treated as individual improvements rather than representing a particular type.

Among the shared lane marking sites observed, South University Avenue in Ann Arbor, showed an increase in bicycle crashes in the after period. Other sites had zero crashes in both the before and after periods. The increase in bicycle crashes at South University Avenue (which has on-street parallel parking with a narrow lane) might have resulted from the increase in bicycle volume in the shared lane while drivers lacked attention and understanding of the shared lane marking. Education campaigns should accompany installation of shared lane markings as the cultural and educational awareness of mutual bicyclist presence is not naturally inherent to these installations.

Implementation of bike lanes may attract more bicyclists, resulting in increased bicycle crashes. Collecting bicycle volume before installation of bicycle lanes can help in quantifying the change in crash occurrence. Also, as stated above, sufficient sample sites would be needed to conduct a comprehensive evaluation study. On the other hand, data from sites observed indicated a decrease in pedestrian crashes at both intersections and midblock segments. The decrease in pedestrian crashes can be a result of the buffer introduced between vehicle traffic and pedestrians.

Other improvements which showed a decrease in non-motorized crashes included sidewalks, improving connectivity of pedestrian facilities, intersection conversions (for example, converting a roundabout to a signalized intersection), removing on-street parking, and Pedestrian Hybrid Beacons (PHB).

City-wide Performance Measures

Introduction: The study developed exposure-based and population-based performance measures for non-motorized safety at two levels: city-wide and corridor-level. The study categorized city-wide performance into four performance groups: infrastructure, exposure, education/enforcement, and safety performance. City-wide performance measures evaluate non-motorized performance on a broad and general scale best suited to urban planning efforts. As an example, the performance of a given city against these measures can be viewed in Figure 5. The scale in this figure is an aggregated rating of each performance measure in the four performance groups.

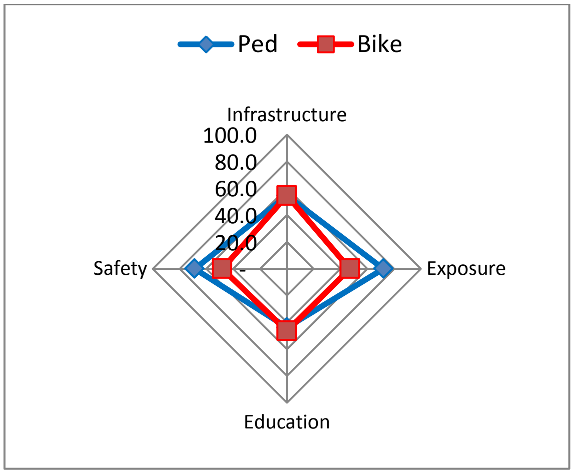


Figure 5: Example of City-wide Performance

Infrastructure Performance: With regard to infrastructure performance, the study developed performance measures that can be seen listed under "Infrastructure Performance in Figure 5. The study recommends setting a performance objective for the study cities to realize a target value (for example 50%) for marked crosswalk coverage by either delineating existing crosswalks or reducing/controlling existing access points, if possible.

Exposure Performance: In consideration of city-wide non-motorized exposure performance, the study developed measures listed under "Exposure Performance" in Figure 5. The study recommends that transportation officials promote non-motorized commuting within these cities.

Education/Enforcement Performance: The third performance group concerns non-motorized safety education/enforcement and the performance measures can be seen under "Education/Enforcement Performance" in Figure 5. Understanding of R-o-W was determined by administration of a field survey of a representative sample of each city's population. The study recommends improving aggregated city-wide non-motorized safety understanding in regard to areas of specific concern, such as R-o-W at unmarked, uncontrolled locations.

Safety Performance: The study pinpointed a number of non-motorized safety performance measures which consider crash frequency and severity for the pedestrian and bicycle modes. Crash frequency and severity is dependent on the performance of the previously covered performance groups, which include infrastructure, exposure and education/enforcement. Therefore, crash reduction efforts should focus on improving performance with regard to each of these supplementary areas.

Conclusion: The study developed city-wide non-motorized safety performance measures according to infrastructure, exposure, education/enforcement, and crash frequency/severity. The study additionally recommended appropriate performance objectives and countermeasures based on potential effectiveness towards enhancing safety, as well as feasibility in implementation.

Corridor-level Performance Measures

Introduction: As explained in the "City-wide Performance Measures" section, the study additionally developed both exposure-based and population-based performance measures at the corridor-level. Corridor-level performance measures strive to identify high-risk areas and develop safety-focused solutions from more of an engineering perspective, compared to the urban planning countermeasures proposed to improve city-wide performance. Corridor performance was evaluated against crash frequency and severity measures, at both signalized intersections and mid-blocks.

Identification of High-Risk Areas: Two different methods were utilized to pinpoint specific areas within a city that likely contain corridors with potential non-motorized safety concerns. The first of these methods utilized ArcGIS software to construct crash density maps. The second method to identify high risk areas was through development of a similarly color-intensity scaled map using crash frequency according to individual census tracts.

Identification of High-Risk Corridors After choosing high-risk areas for further analysis, individual corridors within these regions were evaluated according to crash severity and frequency at signalized intersections as well as mid-blocks. Corridors were ranked against the performance measures listed below for both pedestrians and bicyclists:

- **Signalized Intersection Performance**
  - Difference between Crashes Observed and Predicted
  - Yearly Crashes per One Million Exposures
  - Equivalent Property Damage Only Crashes
- **Mid-Block Performance**
  - Difference Between Crashes Observed and Predicted per Mile
  - Equivalent Property Damage Only per Mile

"Difference between Crashes Observed and Predicted" depicts the difference between crashes reported on the corridor during the analysis period and the predicted number of crashes for the same period according to the Safety Performance Function developed in this study. "Yearly Crashes per One Million Exposures" is the same performance measure discussed in the city-wide performance measure section, only tailored to individual corridors. Traffic safety analyses commonly utilize an "Equivalent Property Damage Only" (EPDO) measure, which calculates crash severity based on the cost of a Property Damage Only (PDO) crash.

Chapter 1 Introduction

1.1 Research Problem

Due to increases in traffic congestion and concerns on human health and environmental issues, non-motorized modes (walking and cycling) have been encouraged as alternative modes of transportation to motor vehicles. Urban transportation planning is increasingly devoting attention to accommodating these non-motorized commuters through the design of bike lanes, employment travel plans, and incentives for, and accommodation of, telecommuting (Plaut, 2005). Ensuring safety of pedestrians and bicyclists is among the crucial tasks of any jurisdiction attempting to promote non-motorized modes. Although the statistics during 2004 – 2011 have shown a declining trend, pedestrian and bicyclists fatalities are still significant contributors to deaths resulting from traffic crashes. In the U.S. in 2011, there were 5,109 (approx. 15.8%) combined pedestrian and bicyclist fatalities (NHTSA, 2013). In Michigan alone, there were 141 pedestrian and 24 bicyclist fatalities, accounting for 18.7% of total fatalities resulting from crashes in 2011 (Michigan Office of Highway Safety Planning, 2013). Except for the Detroit area, both pedestrian and bicycle crashes are randomly distributed rather than concentrated at particular locations. This random nature of crashes makes it difficult to apply crash countermeasures when scoping transportation projects. Therefore, the Michigan Department of Transportation (MDOT) needs a systematic approach to determine performance measures for non-motorized safety and to identify the need for countermeasures when designing facilities.

1.2 Research Objectives

This research has six specific objectives:

1. Building an inventory database for non-motorized safety analysis and providing a guideline for data collection, storage, and management;
2. Conducting detailed analysis of high crash and low crash communities to identify factors affecting crashes involving pedestrians and bicyclists and to develop applicable performance measures;

3. Evaluating performances of recent pedestrian and bicycle improvement projects through before and after studies and cost-benefit analyses to quantity their effectiveness;
4. Identifying cultural issues associated with pedestrian incidents, and determining what issues can and cannot be addressed by engineering solutions;
5. Developing systematic guidance for adjusting performance measurements by comparing the nationwide non-motorized performance measurements and analysis results; and
7. Developing a user guide for using performance measures and determining the need for non-motorized countermeasures.

1.3 Project Scope and Overview

In order to achieve the objective, the research team investigates non-motorized crash patterns in four Michigan cities: Ann Arbor, East Lansing, Flint, and Grand Rapids during 2004 - 2012. Tasks performed in this research include the following: (1) Literature Review; (2) Data Collection and Building Inventory Database; (3) Data Analysis; (4) Analyze Performance Measures Developed by FHWA, AASHTO and other states; (5) Develop Safety Goals and Performance Measures; and (6) Develop a Michigan Guideline for Non-Motorized Performance Measures. This report documents the findings from each task.

Chapter 2 Literature Review

2.1 Factors Causing Non-Motorized Crashes

Non-motorized crashes have been extensively researched and documented. The influential factors can be classified into following groups:

- Demographic
- Socio-Economic
- Land-use
- Facility (Speed, volumes, etc.)
- Transit and Travel mode
- Geometry and Design
- Other Factors (Environmental, Seasonal, Cultural, Educational, etc.)

In this chapter, literatures related to each of above-mentioned groups were reviewed.

2.1.1 Demographics

There have been many studies relating crash occurances with demographc charateristics. Emaasit et al. (2013) found that crash clusters have a strong correlation with African American population densities and young population, ages 15 to 19. Narayanamoorthy et al (2012) showed that census tracts with high population density and minority population groups are more likely to have higher injury counts by modeling pedestrian and bicycle injuries. Another group of researchers (Kaplan, Sigal et al, 2013) investigated risk factors associated with bicyclist injury severity on Danish roads and concluded that bicyclist injury severity increased after the age of 60. Zhou et al. (2013) compared pedestrian crash data between China and the USA and concluded that males were more likely to be involved in pedestrian crashes and young people were more likely to be involved in pedestrian crashes in United States than any other age group. Another group of researchers (Clifton K. J., Burnier C. V. and G. Akar., 2009) developed two models to examine the effects of personal and environmental characteristics on the severity level of pedestrian crash injuries. According to their results, women tended to be injured less frequently than male pedestrians. A bicycle crash study in Hong Kong (Loo & Tsui, 2010) reported that about 74% of bicyclists were male with the mean age of 32 years old and median age of 25 years. Children were more likely to sustain injuries, and the elderly were more probable to be fatally injured. Another investigation (Wier, M. et al, 2009), conducted on the census tract level, showed the number of residential populations directly controls the number of injury crashes (crashes resulting in injuries or fatalities) while a percentage of residents age 65 or older had a negative effect on this number. A study (Lee, C. and A. M. Abdel, 2005) found that middle-aged male drivers and pedestrians were involved in more pedestrian crashes than any other age group. It also suggested that intoxicated drivers and pedestrians were correlated to more crashes at night-time rather than day-time. The higher the population density (at Traffic Analysis Zone level) and the total number of dwelling units significantly caused a greater severity in the pedestrian and bicyclist crashes (Siddiqui, Chowdhury et al., 2011). An investigation (Graw & König, 2002) focused on crashes between pedestrians and bicyclists suggested that the majority of bicyclists were young while pedestrians involved with a lower tolerance of trauma were elderly people.

2.1.2 Socio-Economy

Socio-economic factors can also impact the pedestrian and bicycle crashes according to numerous studies. A higher percentage of families who are below the poverty level or have an income lower than $10,000 per year results in a higher likelihood for pedestrian crash occurrence. Also a higher unemployment rate or a higher percent of households without a car could increase pedestrian crashes at census tract level (Emaasit et al., 2013). The way in which low-income households and employee populations raise pedestrian crashes was also investigated in another study (Wier, M. et al, 2009). The total number of employment and the percent of households with non-retired workers with zero or one automobile could cause more pedestrian and bicycle crashes. The median household income and the crash frequency were inversely correlated (Siddiqui, Chowdhury et al., 2011). This can likely be explained by the affinity of low-income and unemployed people towards non-motorized modes of transportation, thus increasing exposure and likelihood of crash involvement.

2.1.3 Land Use

Land use describes the types of activities which occur in a location. As these activities influence trip generations or attractions in one place, they could also impact bicycle and pedestrian crashes depending on the exposure level they create. The percent of residential land use affected the pedestrian crash frequency as it was investigated in Austin, Texas (Wang Yiyi et al., 2013). In terms of severity, commercial neighborhoods, schools and offices were associated with more pedestrian and bicycle injury crashes. Industrial areas caused significantly high bicycle crash injury counts (Narayanamoorthy et al, 2013). Dense urban areas may decrease the severity of crashes (Kaplan, Sigal et al, 2013) because of lower speeds or increased number of pedestrians. Another investigation suggested that more pedestrian and bicycle injury rates occurred closer to the bus terminal location (Moini & Liu, 2013). Retails and community centers were also found to be correlated with pedestrian casualties. bicyclist casualties were also associated with an increase in retail land uses (Wedagama, D. P. et al., 2006). Residential-commercial mixed land use (ratio per land area) and, specifically, commercial land use are correlated with an increase in severe vehicle-pedestrian crashes (Wier, M. et al, 2009). Locations of schools, liquor stores and bus stops have also been found to be correlated with pedestrian crashes (Harwood, D. W. et al., 2008). One study, which focused on pedestrian crashes at intersections, found commercial properties and children population in the proximity of an intersection as factors associated with pedestrian crashes (Schneider, R. J. et al., 2010).

2.1.4 Facility

Transportation facilities such as intersections, a road network, bicycle lanes, parking, etc. influence pedestrian and bicycle movements: therefore, impacting pedestrian and bicycle crashes. Street density and sidewalk density were shown to be inversely correlated with pedestrian crash frequencies (Wang. et, al., 2013). The total number of intersections per traffic analysis zone (TAZ) was verified as a significant factor on pedestrian and bicycle crashes (Siddiqui, Chowdhury et al., 2011). The proportion of highways and local neighborhood roads and city streets had a negative impact on non-capacitating injuries while proportion of bicycle lanes and trails reduced incapacitating injuries (Narayanamoorthy et al, 2013). Road networks in Alameda County, California were studied and the results showed that fewer non-motorized crashes occurred in areas with greater main road density (confirming the results from previous studies). It also showed that the existence of more intersections between each pair of roads tended to have fewer pedestrian and bicycle crashes. The same study suggested that as more sub-coral networks clustered within the main road network, fewer non-motorized crashes (Zhang, Yuanyuan et al., 2013). The presence of bicycle lanes elevated the safety for bicyclists and parked vehicles, but was associated with increased vehicle-pedestrian crashes (Moini & Liu, 2013). The positive impact of bicycle facilities on lowering the risks for bicyclists was replicated in another study (Winters Meghan et al., 2013). Parked vehicles were indicated as a significant factor in elevating injury severity level (Zahabi, S.A. et al., 2011). Ellis and Van Houten (2009) found a significant crash reduction resulting from improvements of corridors with the most crashes per mile in Miami Beach.

2.1.5 Transit and Travel Mode

In this category, the influence of factors related to modes of transportation, travel characteristics and transit on non-motorized crashes are discussed. A research study showed that walking to work increased the pedestrian crashes, likely as a result of increased exposure (Emaasit et al., 2013). It could also be expected that high traffic volumes (ADT, AADT, etc.) impacted pedestrian-vehicle crashes (Shankar, Venkataraman N., et al., 2003). In addition to traffic volumes at intersections, the ratio of minor road ADT to major road ADT, pedestrian volumes and the presence of bus stops within 1,000 feet of the intersection could elevate the risk of pedestrian-vehicle crashes (Harwood, D. W. et al., 2008). The impact of ADT on the frequency of pedestrian-vehicle injury crashes was also verified in another study while the lack of public transit was implied as an elevating factor on injury crashes (Wier, M. et al, 2009). Another study confirmed the impact of traffic volume at intersections and corridors on pedestrian injury crashes (Schneider R. J. et al., 2004). The correlation between the location of transit bus stops and pedestrian injuries, and the correlation between the location of bicycle racks and bicyclist injuries were reported in another study (Moini & Liu, 2013). The fatality (or injury) risk of pedestrians in correlation with vehicle speed was evidently documented in multiple research studies (Lee and Abdel, 2005; Rosén & Sander, 2009). In summary, pedestrian and bicycle generators are related to crashes and countermeasures should seek to protect these areas.

2.1.6 Geometry and Design

Geometry and design characteristics of a road network may affect all types of crashes including pedestrians and bicycles. There are different facilities or physical features in roads such as cross walks, bicycle lanes, shared lanes, road width, intersection control type, lane configuration, signals, lightings, etc. which may increase or reduce the crash frequency or its severity. Two Way Left Turn Lanes (TWLTL) and inadequate lighting were found to be associated with elevated pedestrian crash frequency while less signal spacing was associated with fewer pedestrian crashes (Shankar, Venkataraman N., et al., 2003).This might be explained by the fact that transportation agencies do not place signals where they are unwarranted, thus these places inherently experience adequate pedestrian safety. Drivers' behavior also strongly affected non-motorized crashes. One study suggested that appropriate geometry and on-street parking designs, which had less conflict with bicycles, could improve safety even though it included the conversion of separate bicycle lanes to shared lanes (Barnes, Emma et al., 2013). Another study suggested that inadequate walking facilities and lighting could increase pedestrian crash risks at night-time (Moini & Liu, 2013). The correlation between slope of the surface and bicycle crash was revealed in another study (Winters Meghan et al., 2013). Crossings were also considered as important locations to facilitate the movement of pedestrians inside a traffic network. Findings showed that more crossings resulted in less pedestrian crashes (Clifton K. J., Burnier C. V. and G. Akar., 2009). However, the number of crossings are influenced by the same factors that influence pedestrian crash frequency, thus it could be concluded that the correlation between number of crossings and pedestrian crash frequency is weak. On the other hand, if pedestrians were supposed to cross more number of lanes (at intersections), a higher crash frequency was expected (Harwood, D. W. et al., 2008). Incomplete sidewalks at road segments resulted in more pedestrian crash frequencies (Schneider R. J. et al., 2004). Exclusive right turns at intersections increased pedestrian crashes, while raising the medians mitigated the frequency (Schneider, R. J. et al., 2010). Undivided roads could also increase the pedestrian crash frequency, while intersections equipped with traffic control devices resulted in fewer severe pedestrian crashes (Lee, C. and A. M. Abdel, 2005). This is an intuitive result as medians and refuge islands serve to protect pedestrians and provide peace of mind. Poor lighting was recognized as another factor which resulted in more severe and a higher number of pedestrian crashes (Lee and Abdel, 2005;

Spainhour et al., 2006; Zahabi et al., 2011). The configuration of crosswalk marking as a kind of a pavement marking also could significantly impact safety (Fitzpatrick et al, 2011). Poor pavement conditions create dangerous conditions for bicyclists (Allen-Munley, 2004). Roadway grades (straight grades, curved grades) was found to be significant in affecting the severity of bicycle crashes (Klop and Khattak, 1999). Another study shows street lighting, paved surfaces and low-angled grades may improve bicyclist safety (Reynolds, 2009).

2.1.7 Miscellaneous Factors

In addition to factors that were previously mentioned, there are numerous other factors (behavior, temperature, weather, road condition, vehicles, cultural issues, etc.) that could contribute to non-motorized crashes. Some of those factors are introduced here, though an intensive literature review should be carried out to extend the list. In terms of behavioral influence of involved parties in a crash, studies showed that more crashes were likely to occur when pedestrians, drivers or bicyclists were intoxicated (Lee and Abdel, 2005; Oxley et al., 2006; Spainhour et al., 2006). Intoxication is also associated with more severe non-motorized crashes. Vehicle straight movement (also categorized as behavioral factor) resulted in more severe crashes for pedestrians and bicycles (Zahabi et al., 2011; Kaplan et al, 2013). The type of car (van, truck, bus, etc.), road condition (slippery), environment and so on could also impact the non-motorized crash frequency or crash severity as well (Lee and Abdel, 2005; Spainhour et al., 2006; Zahabi et al., 2011; Kaplan et al, 2013). Higher speed limits may lead to more severe bike crashes (Klop and Khattak, 1999). Vehicles traveling at greater than 50 MPH notably increase fatal injuries, by more than 16-fold (Kim et al, 2007).

2.2 Performance Measures by Others

Many agencies and organizations have developed their own performance measures according to their priorities and to evaluate performance in terms of improving safety of non-motorized transportation. In this study, efforts made by others to develop performance measures are reviewed to evaluate their benefits, improve them and/or propose new performance measures appropriate for use in Michigan. According to the existing literature, safety performance measures could be categorized in the below mentioned groups:

1. Crash frequency of special types of crashes
2. Different rates of pedestrian/bike crashes
3. Facilities
4. Investment & achieved benefits
5. Enforcement efforts
6. Cultural issues and their effects
7. Cost of crashes
8. Other

2.2.1 Crash Quantity Performance Measures

Many agencies and organizations utilize performance measures pertaining to crash quantity. In a report for the US DOT, Herbel (2009) considered bike and pedestrian crashes and injuries as a core safety performance measure. Many state DOTs measure and make accommodations for pedestrian safety in their transportation safety plans (Alabama Department of Economic and Community Affairs, 2012), (Alaska Highway Safety Office, 2013), (Connecticut Department of Transportation, 2012) and (Colorado Department of Transportation, 2013). The number of pedestrians or bicyclists who sustained serious injuries was considered as a performance measure in the State of Indiana (Indiana Criminal Justice Institute, 2012). The Idaho DOT considered the five year average number of pedestrian killed by motor vehicle as a safety performance measure (Idaho Office of Highway Safety, 2013).

The Rhode Island DOT defined the number of pedestrian fatalities with a known BAC of 0.8 or greater as a safety performance measure (Rhode Island Department of Transportation, 2012). The Arizona Department of Transportation (ADOT) considered the below mentioned items as their bicyclist safety performance measures (Arizona Department of Transportation, 2012):

1. Number of total statewide bicyclist fatalities
2. Proportion of trunk-line bicyclist fatalities

The number of statewide bicyclist fatalities was also considered by the national Highway Safety Office and FDOT (Florida Department of Transportation, 2013) (District of Columbia, Highway Safety Office, 2013).

2.2.2 Crash Rate Performance Measure

Consideration of crash rate is also very common to many state DOTs and other agencies in evaluating non-motorized safety performance. Seattle's Department of Transportation (SDOT) considered the number of crashes per pedestrian trips as, "the exposure variable", and is based on annual police-reported crashes and the 2006 Puget Sound Regional Council Household Travel Survey (Seattle Department of Transportation, 2013). The number of reported bicycle crashes per total number of bicyclists counted and annual traffic volumes was also introduced by SDOT as a performance measure. The Southeast Michigan Council of Governments (SEMCOG) used frequency and rate of traffic crashes between various modes including autos, trucks, rail, transit, pedestrians, and bicyclists, as well as frequency and rate of injury or fatal crashes as safety performance measures (Herbel, 2009). The State of Utah divided pedestrian and bike crashes into two groups, of urban and rural crashes, and for each group developed a performance measure as the number of pedestrian and bike crash per 10,000 population (Utah, Department of Public Safety, 2012). The Department of Transportation in Connecticut also considered bicyclists killed or injured per 100,000 population (Connecticut Department of Transportation, 2012). The National Highway Traffic Safety Administration (NHTSA) also defined the number of pedestrian and bike crashes per population, child (age 13 and under) pedestrian and bike fatalities per population, adult (age 14-65) pedestrian and bike fatalities per population, older person (age 65+) pedestrian bicyclist fatalities per population. They also defined the percentage of traffic fatalities, which are pedestrian or bike related, as other types of safety performance measures (Hedlund, 2008). Sanders (2011) proposed "Annual pedestrian and bicycle injury and fatality rates per trips" as a rate-type safety performance measure.

2.2.3 Crash Place Performance Measures

Crash place performance measures focus on the location of crashes to evaluate safety by observing the effects of place on the number of crashes. In addition to this general performance measure, the NHTSA specified the number of pedestrian injuries in crosswalks as a subset crash place performance measure (Hedlund, 2008). Sanders proposed the number of pedestrian and bicycle hotspots (high collision concentrations) on urban arterials as a safety performance measure regarding the facility type (Sanders, 2011).

2.2.4 Investment/Expenditure Performance Measures

Investment/expenditure performance measures compare dedicated budgets for improving safety and/or making new facilities in areas under consideration. Sanders (2011) focused on the Caltrans urban arterial, and as a type of performance measure, considered all the projects (new expenditures) which are designed to increase safety for non-motorized users, as summarized below:

- Percent of signalized intersections along urban arterials with marked crosswalks and one or more of the following: countdown signals, leading pedestrian intervals, bulb-outs, or pedestrian refuge islands.
- Percent of unsignalized 4-way (multilane intersections along urban arterials with marked crosswalks and one or more of the following: Pedestrian Hybrid Beacon, yield to pedestrian signage, user-activated overhead warning lights.
- Percent of urban arterial intersections with one or more of the following improvements geared toward bicyclists: bike box, painted bicycle lane through the intersection, bicycle signal, bicycle detectors, bicycle left turn lane.
- Percent of urban arterials on which the 85th percentile driving speed is no greater than 25 mph.

The Pennsylvania Department of Transportation considered the amount of capital or resources devoted to planning, design, construction and maintenance of bicycle/pedestrian facilities, and they considered the number of lane miles of construction as a safety performance measure (Pennsylvania Department of Transportation, 2013). SEMCOG developed the percent of total regional transportation plan investment spent on safety as another type of safety performance measure from the perspective of investment (Herbel, 2009). “RideRichmond” which is a non-profit community organization in Richmond, Virginia considered annual funding for “Safe Routes to Schools” as a safety performance measure (RideRichmond, 2011).

2.2.5 Enforcement-type Performance Measures

The Delaware Office of Highway Safety defined an enforcement type of safety performance measure as the number of pedestrian arrests (Delaware Office of Highway, 2012). In addition, the number of warnings or citations targeting road user behaviors that compromise bicycle safety was considered by the City of Wichita as a proposed safety performance measure in their Bicycle Master Plan (Wichita Department of Sedgwick County Planning, 2013).

2.2.6 Cultural-type Performance Measure

Consideration of cultural issues could be effective in improving non-motorized safety, especially when the behaviors and habits of people might affect their understanding of, or compliance with, traffic laws. The percentage of bike fatalities while wearing a helmet was considered as a safety performance measure by Hedlund (2008) and is also commonly evaluated in other states. Concerning the matter of cultural issues, driver and pedestrian awareness of pedestrian laws is defined as a performance measure by SDOT, who sets an objective to increase awareness of pedestrian laws among both pedestrians and drivers. Their target would be that all public schools participate in a pedestrian program within the next 10 years (Seattle Department of Transportation, 2013). Regarding development of a cultural safety performance measure, the Colorado DOT evaluates the number of communities with adopted "Share the Road" programs or policies (Colorado Department of Transportation, 2013).

2.2.7 Cost-type Performance Measures

Kittelson (2011) paid attention to economic aspects of crashes and defined the cost of traffic crashes per person of population as a safety performance measure. Although calculating the cost of non-motorized traffic crashes could be challenging, it provides an easy to understand measure of safety performance.

2.2.8 Other Performance Measures

There are many other performance measures used by other agencies. The Vermont Agency of Transportation (2006) proposed the pedestrian and bicycle performance measures as listed below:

- Number of minutes per day the average resident spends doing pedestrian and bicycle activity.
- Change in percent of all workers who commute to work by walking or bicycling.
- Number of pedestrians and bicyclists observed in different parts of Vermont.
- Police-reported pedestrian and bicycle crashes per number of minutes spent walking and bicycling.

- Miles of sidewalk on State-owned roadways.
- Miles of shared-use paths.
- Total number of VTrans funded bicycle and pedestrian projects and new facilities.
- Total number of VTrans staff and consultants (including regional planning commissions) and local officials who participate in scheduled training sessions on pedestrian and bicycle accommodation and design.
- Increase in walking and bicycling to and from school for schools participating in Safe Routes to Schools programs.
- Number of schools and students participating in pedestrian or bicycle safety education programs or events. (e.g., Safe Routes to School, Bike Smart, etc.)

2.3 Summary and Findings

As discussed, many different factors contribute to non-motorized crash frequency and severity. A summary of previous literature shows that many researchers reach some common conclusions within each of the influential factor groups introduced in Section 2.1. With regard to demographics, much of the research agreed that young people are more at risk to be involved with non-motorized crashes, while the elderly experience more severe crashes. Also, males are more likely to be involved in a crash as opposed to females. Concerning socio-economics, as the affluence level increases in an area/household, the less likely non-motorized crashes are to occur. This is possibly explained by the tendency towards increased private automobile usage as allowed by higher affluence. Land usage also affects non-motorized crash frequency/severity. Due to the nature of commercial/industrial areas in raising the density of trip generators/terminators, crash rates tend to be higher in these locations compared to residential areas. With regard to transportation facilities, as the density of facilities increases, both motorized and non-motorized alike, the number of crashes tends to decrease. The impact of travel volumes on these facilities has also been investigated, with most research displaying a positive relationship between volume (exposure) and crash frequency. The geometry and design of transportation facilities also shows a significant impact on non-motorized safety, with non-motorized crashes most commonly resulting from inadequate lighting conditions.

Many transportation agencies nation-wide have attempted to evaluate the performance of their transportation networks in mitigating non-motorized safety. Most of the existing performance measures can be categorized into one of the groups listed in Section 2.2. As shown, the various performance measures concerning crash quantity or crash rate appear to currently enjoy the most utilization by state DOTs. This is likely due to the ability of such a performance measure to aggregate the performance of all other supplementary groups into one statistic. However, crash frequency performance does not tell the whole story. Agencies wishing to determine the root cause behind higher than expected crash frequency should strive to dig a little deeper and investigate some of the other performance groups within their jurisdiction, such as infrastructure, exposure, enforcement/education, and other similar features. Table 2-1 summarizes non-motorized safety performance measures used by other agencies.

Table 2-1 Summary of Non-Motorized Safety Performance Measures by Others

	Measure	Bike	Pedestrian	Source
Quantity	Number of pedestrian fatalities		●	NHTSA
	Pedestrian serious bodily injured		●	Indiana safety plan
	Five year average number of pedestrian killed by motor vehicle		●	Idaho Safety Plan
	Pedestrian injuries		●	annual State highway safety plans & SHSPs
	Number of pedestrian fatalities with a known BAC or 0.8 or greater		●	Rhode Island Safety Plan
	Number of statewide bicyclist fatalities	●		ADOT
	Number of state highway system bicyclist fatalities	●		ADOT
	Number of injuries	●		annual State highway safety plans & SHSPs
	Number of pedal cyclists serious bodily injured	●		Indiana safety plan
Rates	Rate of crashes involving pedestrians		●	Seattle DOT Report
	Rate of pedestrian Injuries & Fatalities		●	in urban arterials
	Pedestrian injuries/pop		●	annual State highway safety plans & SHSPs
	% of traffic fatalities that are pedestrians		●	U.S. DOT / NHTSA Office of Behavioral Safety Research
	Child (age 13 and under) pedestrian fatalities/population		●	U.S. DOT / NHTSA Office of Behavioral Safety Research
	Adult (age 14-65) pedestrian fatalities/population		●	U.S. DOT / NHTSA Office of Behavioral Safety Research
	Older person (age 65+) bicyclist fatalities/population		●	U.S. DOT / NHTSA Office of Behavioral Safety Research

	Measure	Bike	Pedestrian	Source
Rates	% of traffic fatalities that are bicyclists	●		U.S. DOT / NHTSA Office of Behavioral Safety Research
	Child (age 13 and under) bicyclist fatalities/population	●		U.S. DOT / NHTSA Office of Behavioral Safety Research
	Adult (age 14-65) bicyclist fatalities/population	●		U.S. DOT / NHTSA Office of Behavioral Safety Research
	Older person (age 65+) bicyclist fatalities/population	●		U.S. DOT / NHTSA Office of Behavioral Safety Research
	Bicyclist killed or injured per 100000 population	●		Connecticut Safety Plan 2012
	Frequency and rate of traffic crashes between modes: autos, trucks, rail, transit, pedestrians, and bicyclists	●	●	SEMCOG
	Frequency and rate of traffic/injury/fatal crashes	●	●	SEMCOG
	Urban ped/bike crash per 10000 population	●	●	Utah safety Plan
	Rural ped/bike crash per 10000 population	●	●	Utah safety Plan
Facility	Number of ped injuries in crosswalks		●	annual State highway safety plans & SHSPs
	Number of Pedestrian Hotspots in urban arterials		●	Sanders (2011)
Invest-ment	Annual Funding for Safe Routes to Schools	●	●	RideRichmond
	Percent of total Regional Transportation Plan investment spent on safety	●	●	Southeast Michigan Council of Governments
	Amount of capital or resources devoted to planning, design, construction and maintenance of bicycle/pedestrian facilities.	●	●	Pennsylvania DOT
Enforce-ment	Number of pedestrian arrests		●	Delaware safety plan
	Number of warnings or citations targeting road user behaviors that compromise bicycle safety	●		Wichita Bicycle Master Plan
Cultural	Driver and pedestrian awareness of pedestrian laws		●	Seattle DOT Report
	Number of communities with adopted Share the Road programs or policies	●	●	Colorado DOT
	% bike fatalities wearing helmet	●		annual State highway safety plans & SHSPs
Cost	Cost of traffic crashes per person of population	●	●	Kittelson (2011)
Other	School participation in pedestrian safety, education, and encouragement programs		●	Seattle DOT Report
	Police-reported pedestrian and bicycle crashes per number of minutes spent walking and bicycling.	●	●	Vermont Pedestrian and bicycle policy Plan
	Percentage of schools participating in Safe Routes to Schools	●	●	RideRichmond

Chapter 3 Data Collection

3.1 Introduction

This chapter summarizes the research's data collection efforts. Data were collected in four Michigan cities: Ann Arbor, East Lansing, Flint and Grand Rapids. The data collected in this study are categorized into following several groups:

- Non-motorized crash data
- Pedestrian and bicycle volume as exposure measures
- Non-motorized Facility Inventory
- Non-motorized Improvement Projects
- Activity locations
- Socioeconomic and demographic data
- Crime rates
- Land use data
- Traffic volume data (for corridor level analysis)

As this study dealt with a large amount of data, it was important to develop a good data management system. The research team employed ESRI® ArcGIS 10.0 and compiled all data in the GIS database. The GIS database enabled the research team to process the data in an analyzable format.

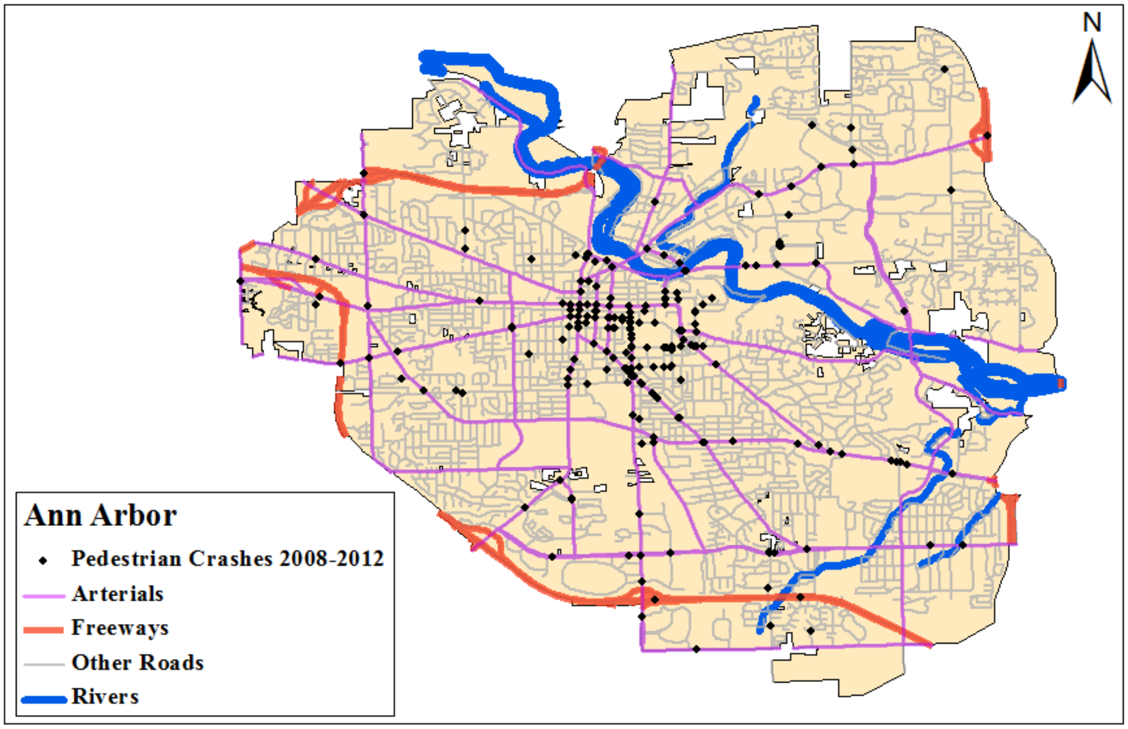
In this study, performance measures were evaluated in three levels – city level, Census tract level, and corridor level. Accordingly, the data collected had to be processed in these three levels. As this study used a modeling approach in estimating pedestrian and bicycle volumes, all necessary data, including socio-economic data, had to be processed for individual intersections. The census-tract level analysis also required the processing of all necessary data for each census tract. The corridor level analysis required more detailed data processing efforts. A detailed data collection effort for non-motorized volume is presented in Chapter 4, and data for corridors is presented in Chapter 5. This chapter focuses on presenting overall data collection efforts.

3.2 Crash Data Collection

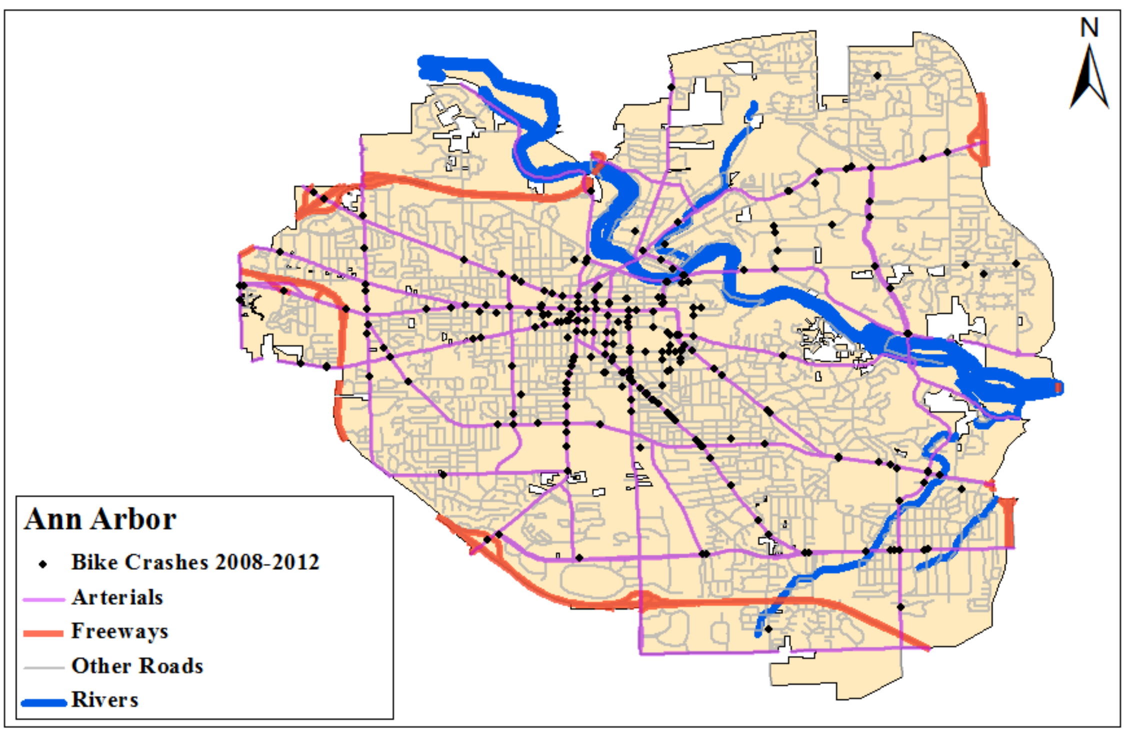
Crash data were supplied by the Michigan Office of Highway Safety Planning (OHSP). The data are identical to those available in the Michigan Traffic Crash Facts (MTCF) website (www.michigantrafficcrashfacts.org). Non-motorized crash data from 2004 to 2012 were processed for each city and included into the ArcGIS database based on the geocode. A non-motorized crash is defined as any crash that involves at least a pedestrian or bicycle. Each crash includes detailed information as follows:

- Time
- Date
- Number of injuries in different levels of severity
- Traffic control device present at the site of the crash
- Road Specification
- Weather Condition
- Light Condition
- The involved party’s conditions
- Geo-coordinates of Crashes
- Road Type

Figure 3-1 - Figure 3-4 depict pedestrian and bicycle crashes that occurred during a five-year period (2008-2012). Individual pedestrian and bicycle crashes were included in ArcGIS database based on longitude and latitude coordinates. As shown in these figures, crashes were mostly along major arterials, but locational patterns between pedestrian crashes and bicycle crashes were quite different. While some patterns can be observed from the figures, it was difficult to observe patterns from fatal and severe (K and A) crashes. There crashes were geographically quite random, which increased the level of difficulty to observe locational characteristics.

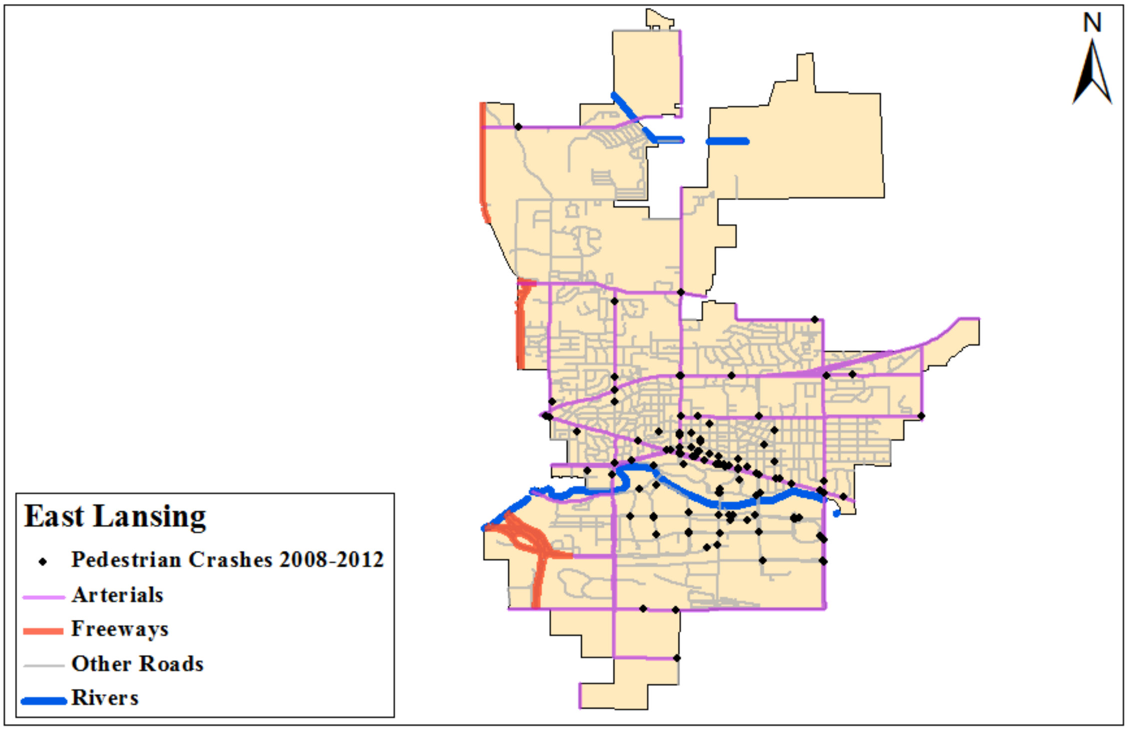


(a) Pedestrian

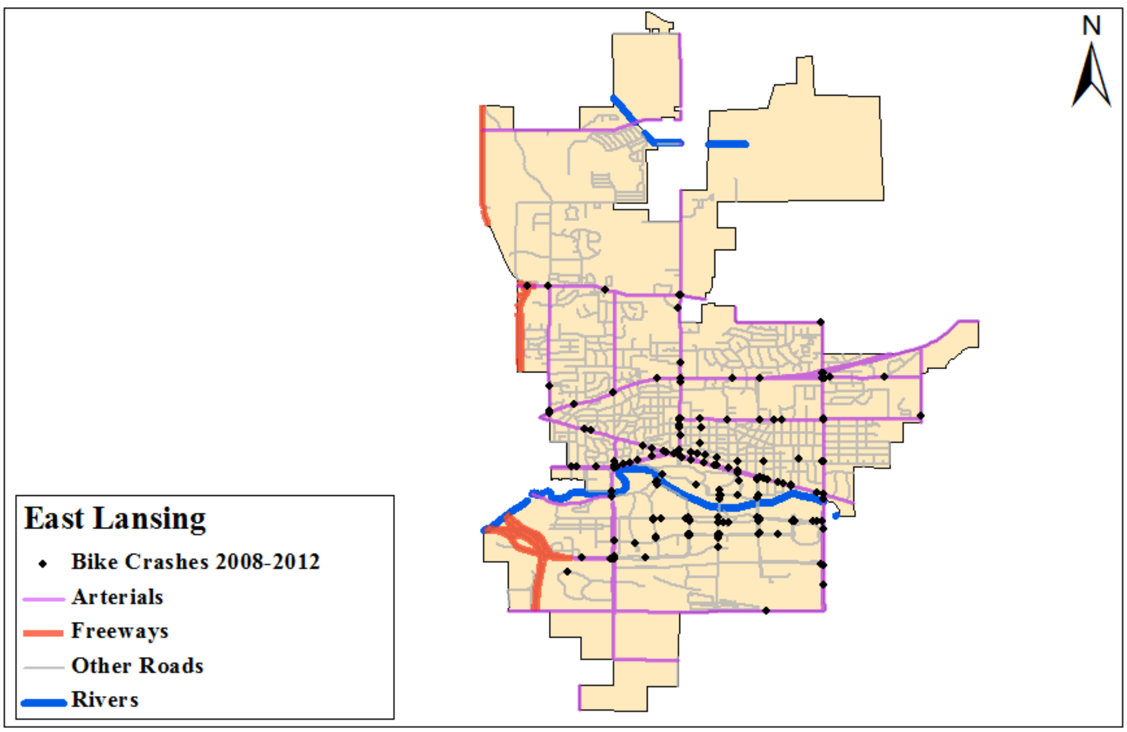


(b) Bicycle

Figure 3-1 Non-motorized Crashes in Ann Arbor (2008-2012)

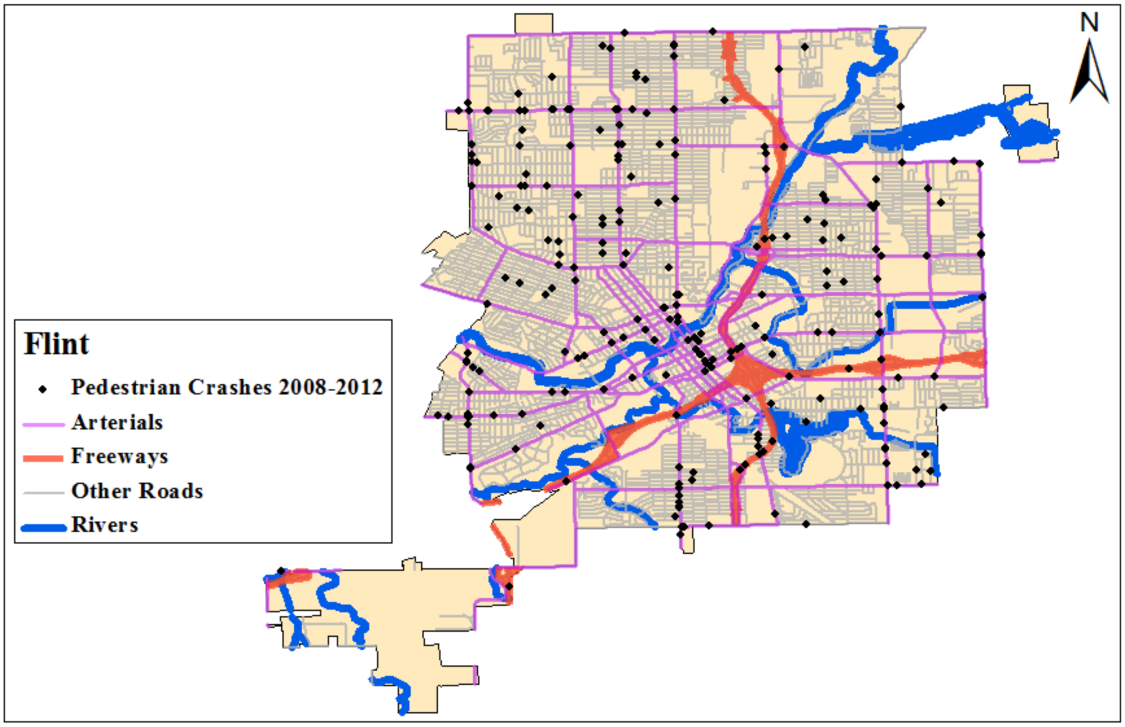


(a) Pedestrian

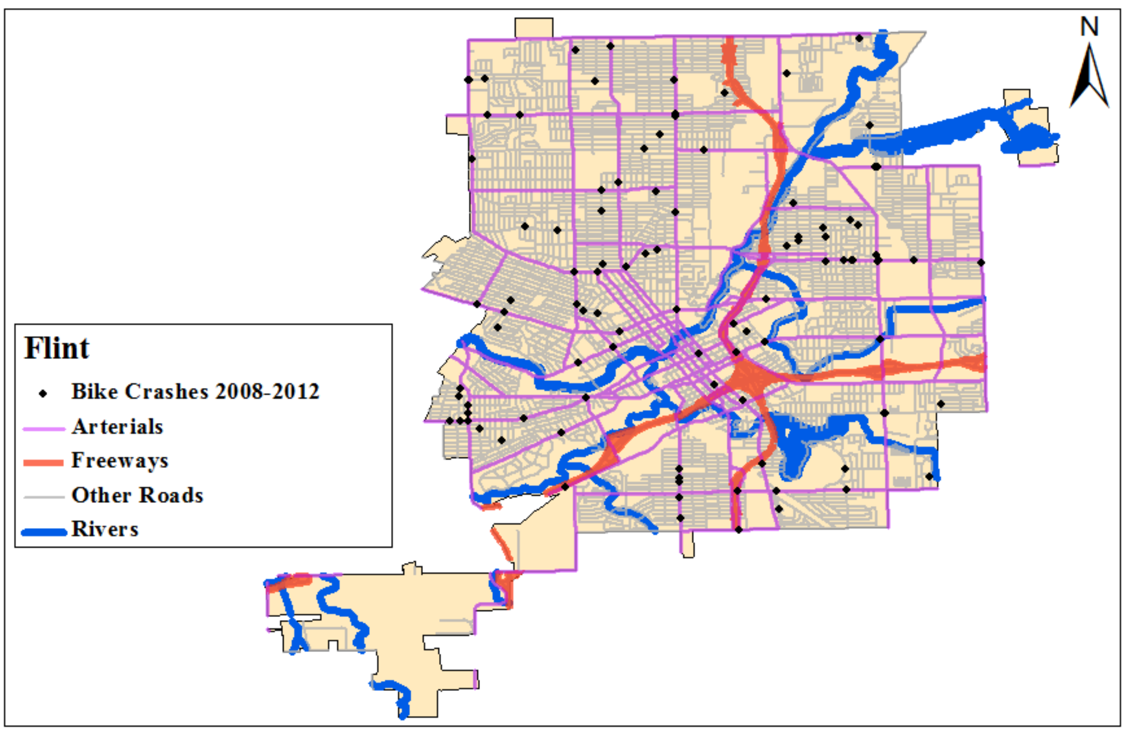


(b) Bicycle

Figure 3-2 Non-morized Crashes in East Lansing (2008-2012)

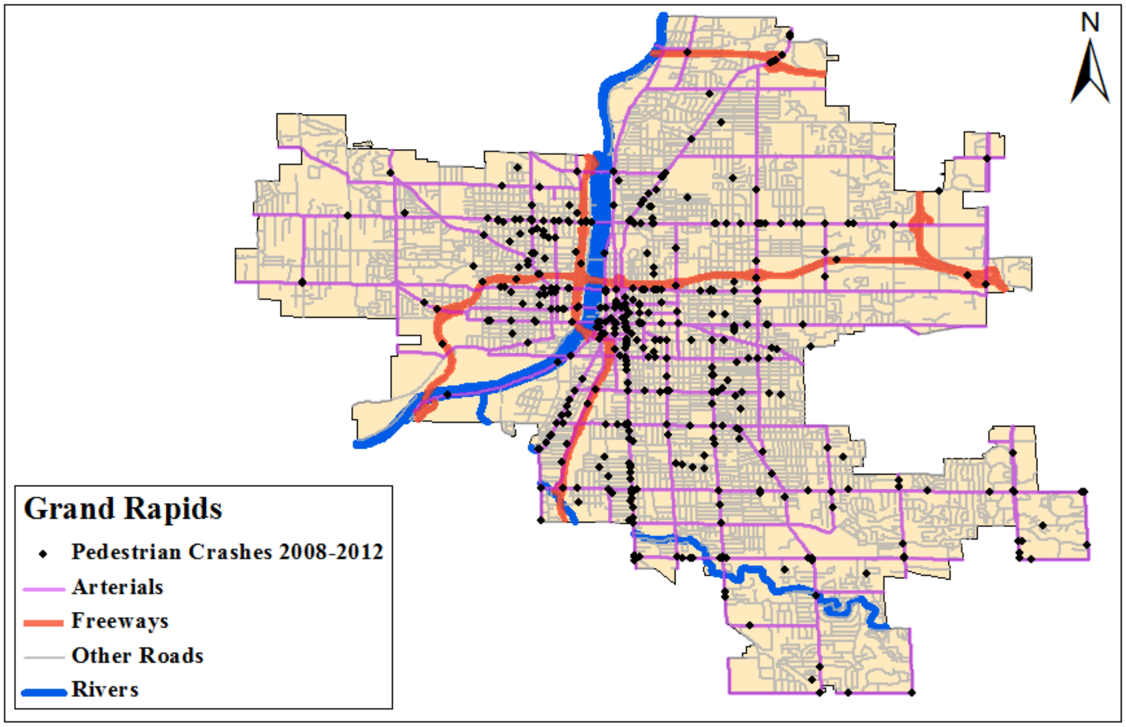


(a) Pedestrian

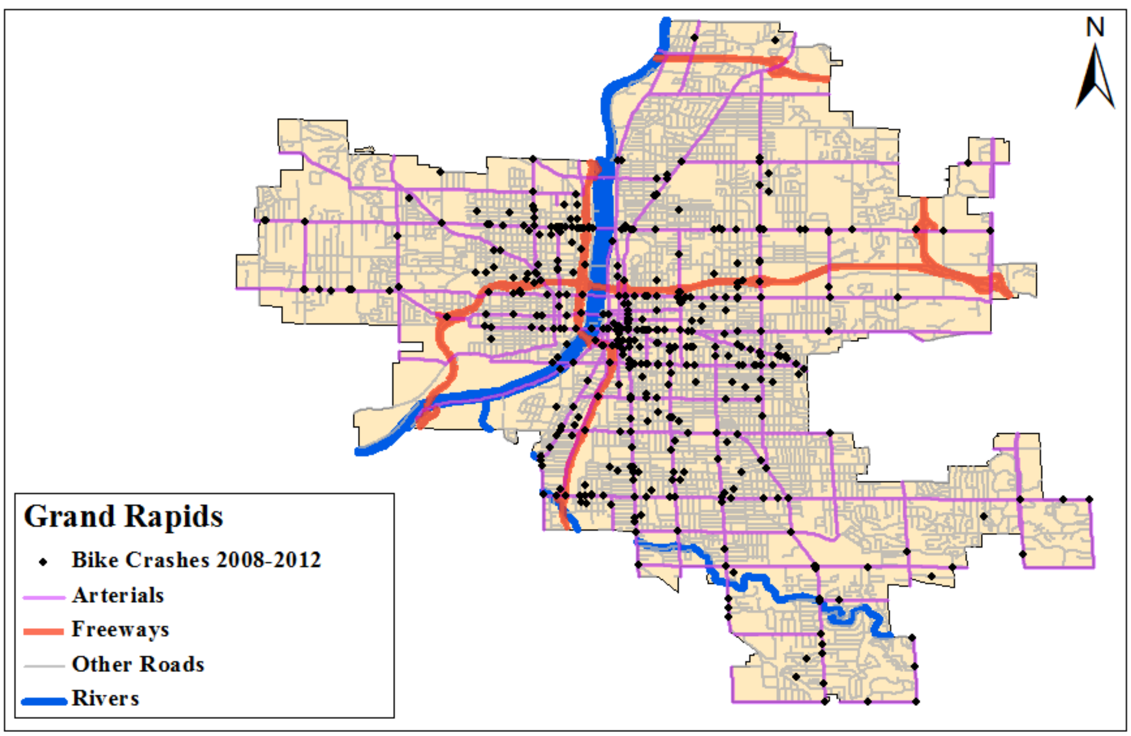


(b) Bicycle

Figure 3-3 Non-motorized Crashes in Flint (2008-2012)



(a) Pedestrian



(b) Bicycle

Figure 3-4 Non-motorized Crashes in Grand Rapids (2008-2012)

During the analysis period (2004 – 2012), there were 2,810,412 crashes in Michigan. Among those, 18,303 crashes involved at least one bicycle, and 21,053 involved pedestrians (MTCF, 2013). Table 3-1 summarizes crash data during the past nine years that were broken into three periods. While the total number of crashes decreased during the period, the percentage of non-motorized crashes was increasing. Although the number of non-motorized crashes was only 1.4% of the total crashes, the fatal rate of non-motorized crashes was far higher (5.6% for pedestrian crashes; 1.2% for bicycle crashes) than the overall average (0.3%). Non-motorized crashes accounted for 17% of the total Michigan fatal crashes in the period, and the percentage showed an increasing trend.

Table 3-1 Non-Motorized Crashes in Michigan

Period		**2004-2006**	**2007-2009**	**2010-2012**	**Total (04-12)**
Total Number of Crashes		1,039,188	931,209	840,015	2,810,412
	Total Non-Motorized Crashes (%)	14,086 (1.4%)	12,732 (1.4%)	12,538 (1.5%)	39,356 (1.4%)
	Total Pedestrian Crashes	7,779	6,535	6,739	21,053
	Total Bicycle Crashes	6,307	6,197	5,799	18,303
Total Number of Fatal Crashes		3,087	2,708	2,572	8,367
	Non-Motorized Fatal Crashes (%)	489 (16%)	430 (16%)	480 (19%)	1,399 (17%)
	Pedestrian Fatal Crashes	415	367	405	1,187
	Bicycle Fatal Crashes	74	63	75	212
Fatal Rate (%)	All Crashes	0.3%	0.3%	0.3%	0.3%
	Non-Motorized Crashes	3.5%	3.4%	3.8%	3.6%
	Pedestrian Crashes	5.3%	5.6%	6.0%	5.6%
	Bicycle Crashes	1.2%	1.0%	1.3%	1.2%

As summarized in Table 3-2, the total number of crashes in four study cities showed a decreasing trend, but that of fatal crashes was increasing during the past nine years. While the number of non-motorized crashes was fluctuating, that of fatal non-motorized crashes increased from 20 (2004-2006) to 26 (2010-2012). More importantly, the percentage of the non-motorized fatal crashes over the total fatal crashes increased from 29% to 35% during the same period. That is, 35% of the total fatal crashes were non-motorized crashes during recent three years.

Table 3-2 Crash Data in Four Michigan Cities

Period	2004-2006	2007-2009	2010-2012	Total (04-12)
Total Number of Crashes	49,402	41,627	41,576	132,605
Ann Arbor	9,453	8,345	9,153	26,951
East Lansing	4,230	3,373	3,416	11,019
Flint	2,257	9,532	8,779	30,568
Grand Rapids	23,462	20,377	20,228	64,067
Total Number of Fatal Crashes (A)	69	71	75	215
Ann Arbor	4	3	8	15
East Lansing	5	6	2	13
Flint	29	36	35	100
Grand Rapids	31	26	30	87
Total Number of Non-Motorized Crashes	1,476	1,293	1,364	4,133
Ann Arbor	247	299	350	896
East Lansing	232	199	215	646
Flint	311	248	212	771
Grand Rapids	686	547	587	1,820
Total Number of Fatal Non-Motorized Crashes (B)	20	19	26	65
Ann Arbor	2	1	2	5
East Lansing	3	2	-	5
Flint	6	12	14	32
Grand Rapids	9	4	10	23
Percentage of Non-motorized Fatal Crash (B/A, %)	29%	27%	35%	30%
Ann Arbor	50%	33%	25%	33%
East Lansing	60%	33%	0%	38%
Flint	21%	33%	40%	32%
Grand Rapids	29%	15%	33%	26%

3.3 Pedestrian and Bicyclist Volume Data Collection

In this study, pedestrian and bicycle volume data were collected from selected intersections in four Michigan cities: Ann Arbor, East Lansing, Flint and Grand Rapids. As this study aimed to measure non-motorized safety performance, these volume data as exposure measures were important when determining the performance. As it was impractical to collect these data from all locations, pedestrian and bicycle volume data were collected from selected locations as shown in Figure 3-5 - Figure 3-8 after carefully reviewing crash data, land use and locational characteristics. These data were used for developing models for estimating pedestrian and bicycle volumes. More details are presented in Chapter 4.

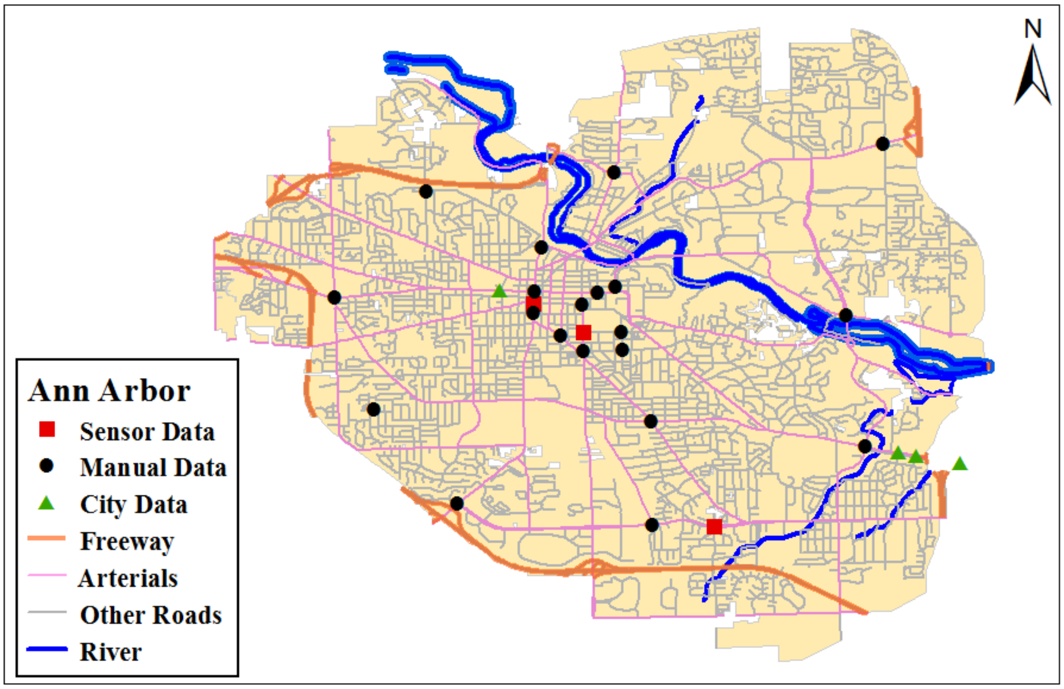


Figure 3-5 Locations for Non-motorized Volume Data in Ann Arbor

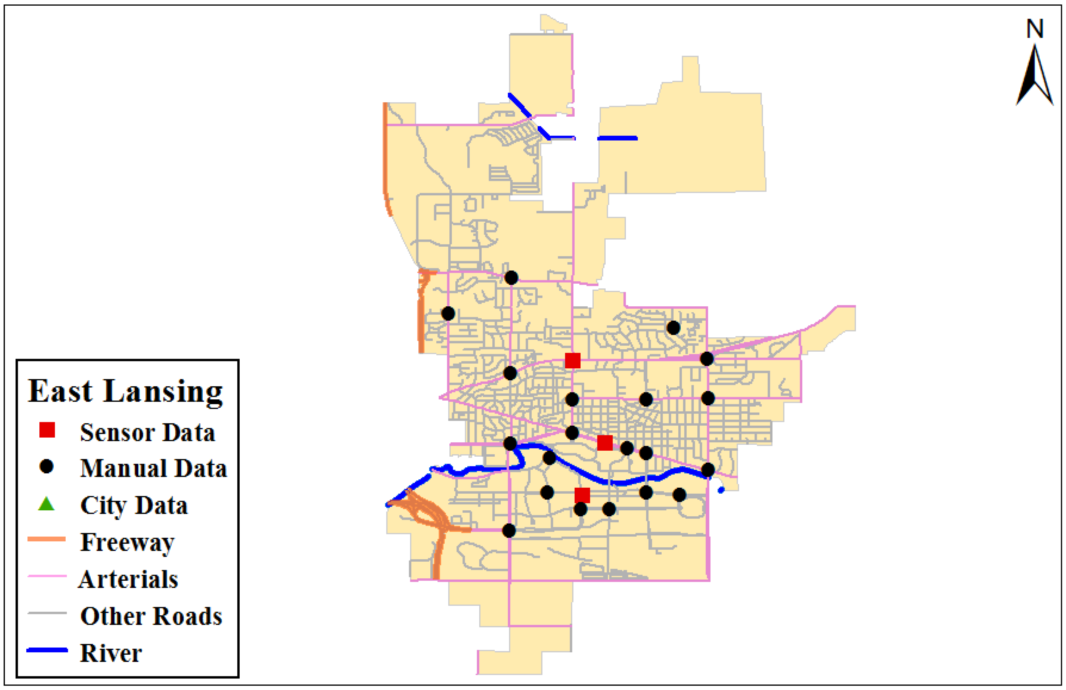


Figure 3-6 Locations for Non-motorized Volume Data in East Lansing

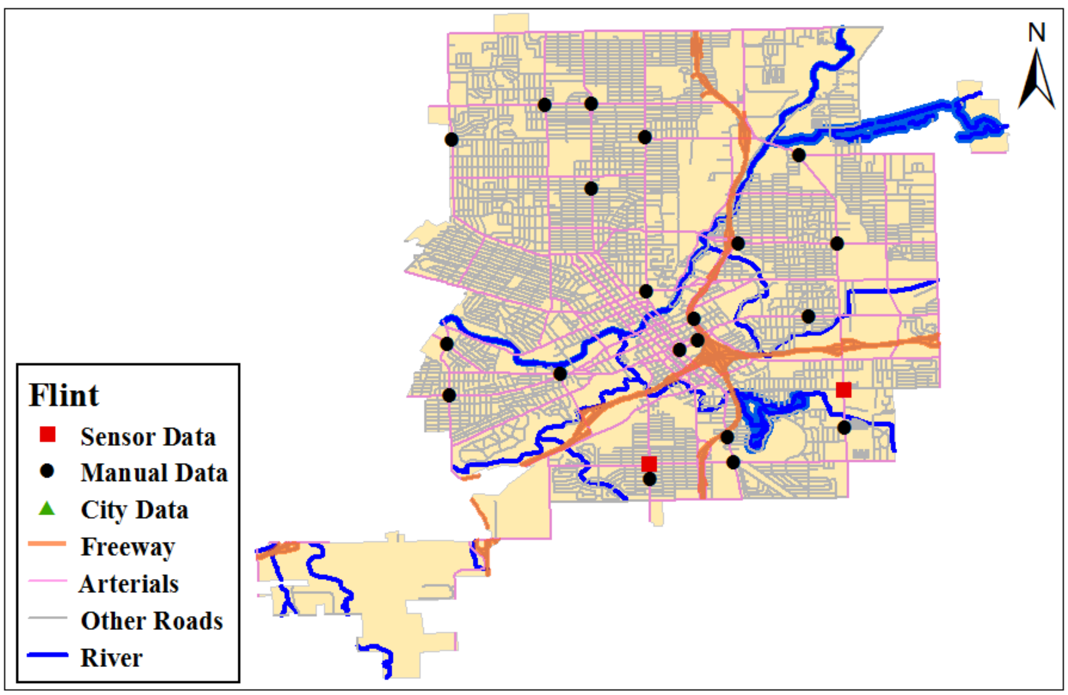


Figure 3-7 Locations for Non-motorized Volume Data in Flint

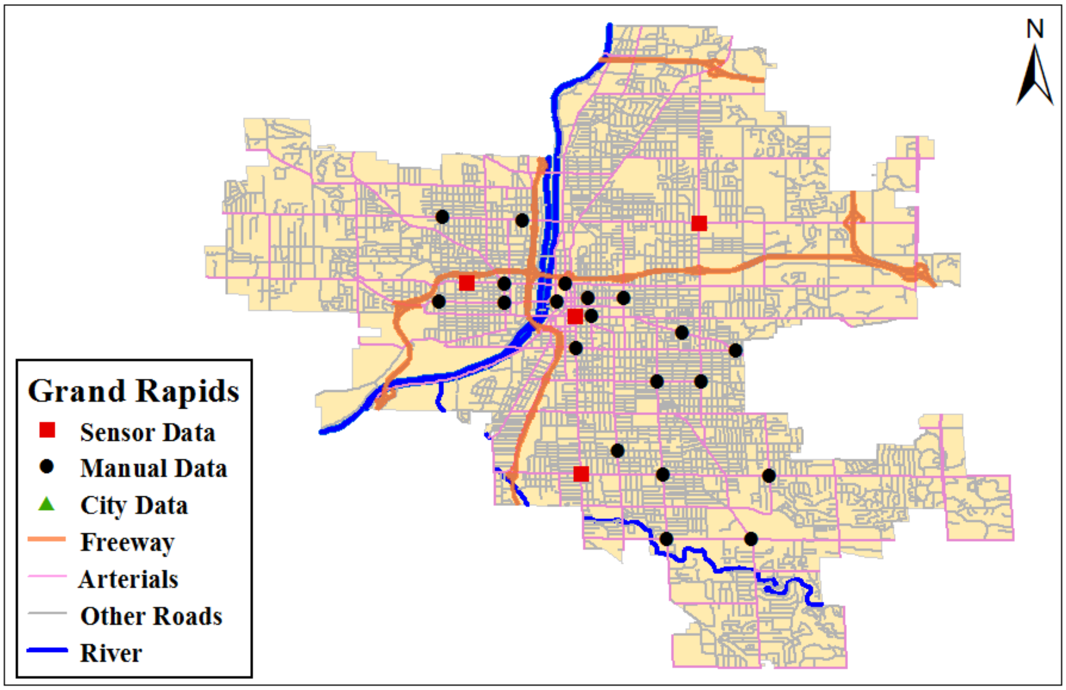


Figure 3-8 Locations for Non-motorized Volume Data in Grand Rapids

3.4 Facilities Related with Non-Motorized Dynamics

3.4.1 City Boundary and Road Network

Shapefiles of city limits and road networks were retrieved from the Michigan DTMB website (CGI - Center for Geography Information). The boundary of each city was used not only to define the each city area but also to trim the extent of the road networks. Road classifications were based on the National Functional Classification (NFC).

3.4.2 Non-Motorized Facilities Inventory

Spatial data of non-motorized facilities were obtained from each city and metropolitan planning organizations (MPOs) – Washtenaw Area Transportation Study (Ann Arbor), Tri-County Regional Planning Commission (East Lansing), Genesee County Metropolitan Planning Commission (Flint), and Grand Valley Metro Council (Grand Rapids). A substantial amount of non-motorized facility data was available for most cities; however, the data collected from cities and MPOs were not sufficient to cover all necessary data for this research. While bicycle lane and sidewalk data was mostly available from cities and MPOs, not all cities had data inventory for signalized intersections, signalized crosswalks, and midblock crosswalks. Therefore, the research team members generated shape files for additional information through visual inspection from Google Earth. Additionally generated GIS shape files were merged into the existing data from cities and MPOs. Figure 3-9 - Figure 3-12 depicts non-motorized facility inventories for each city.

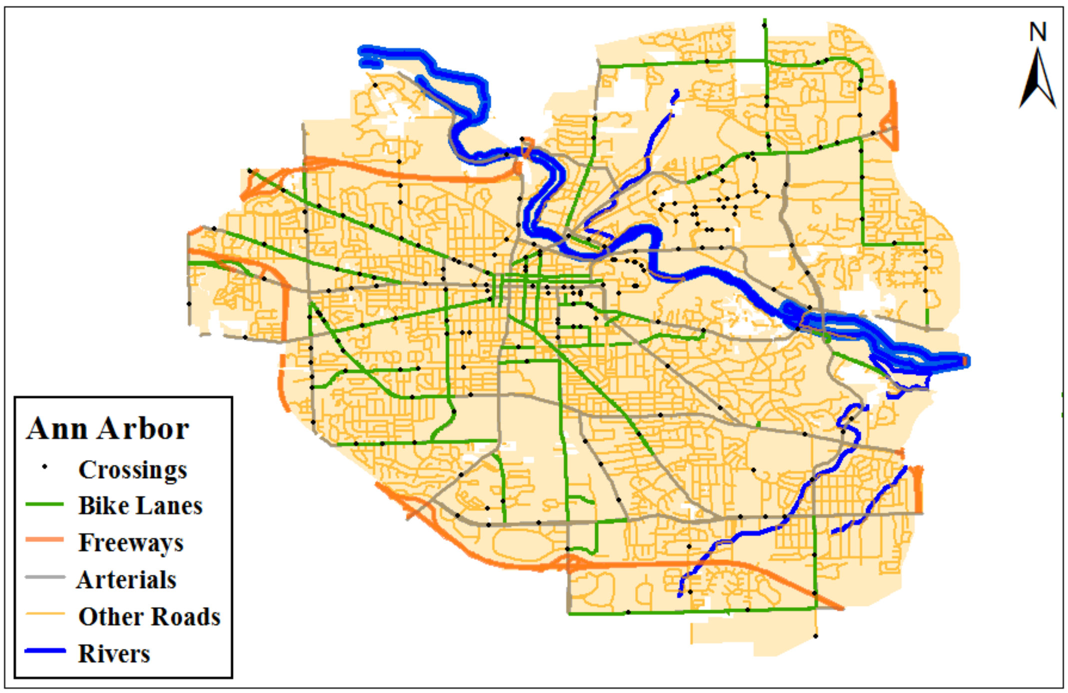


Figure 3-9 Non-Motorized Facilities Inventory in Ann Arbor

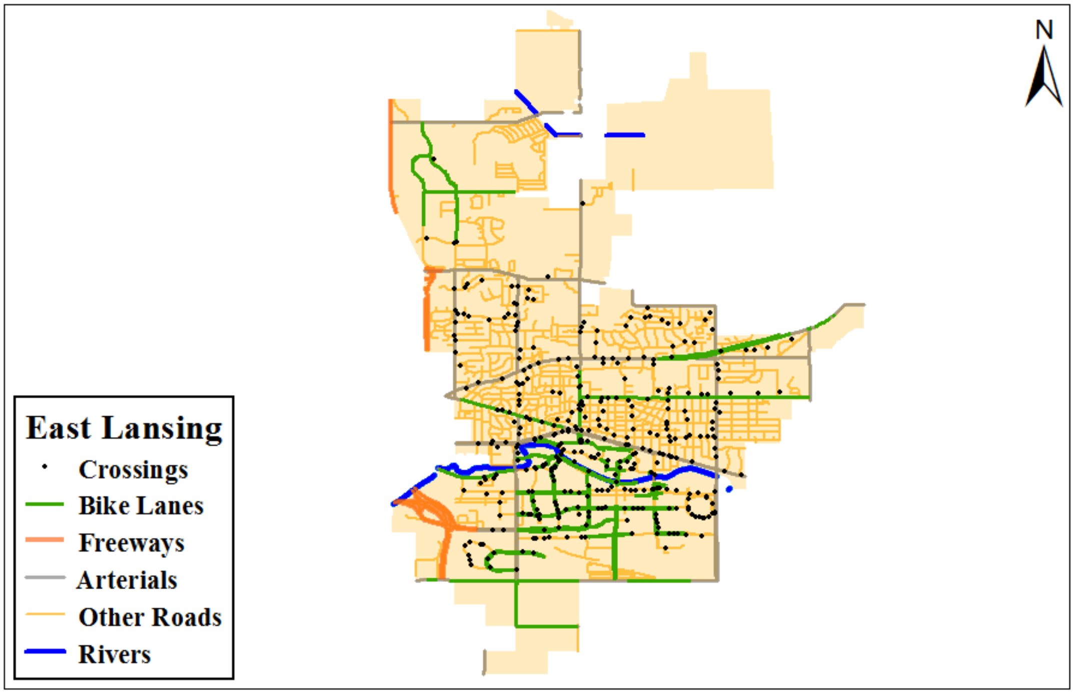


Figure 3-10 Non-Motorized Facilities Inventory in East Lansing

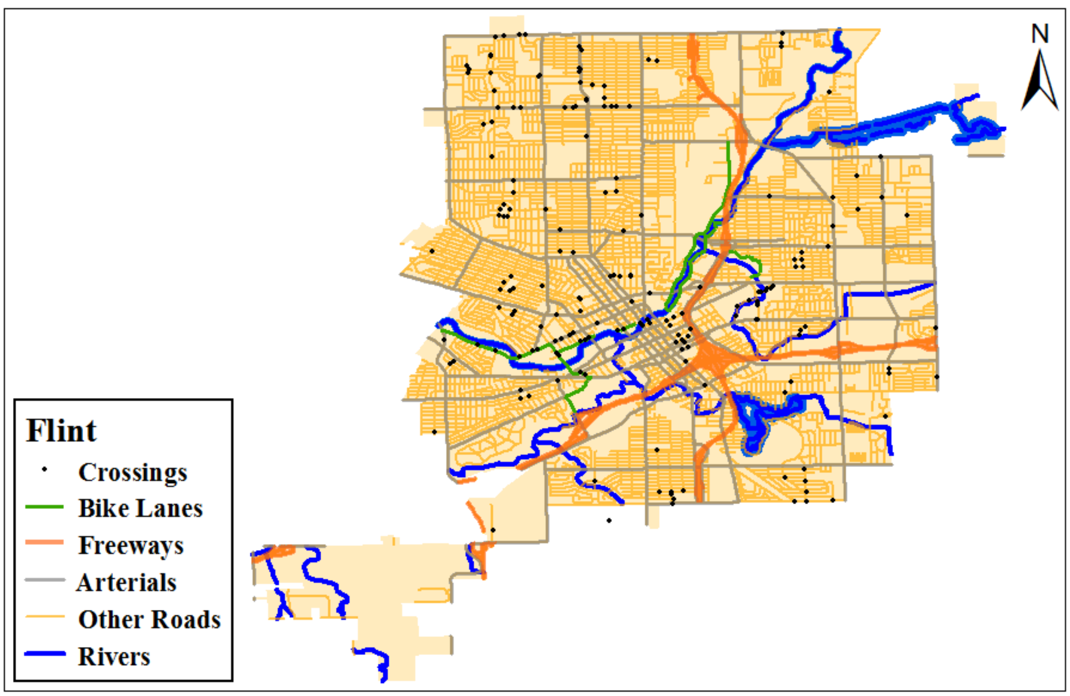


Figure 3-11 Non-Motorized Facilities Inventory, Flint

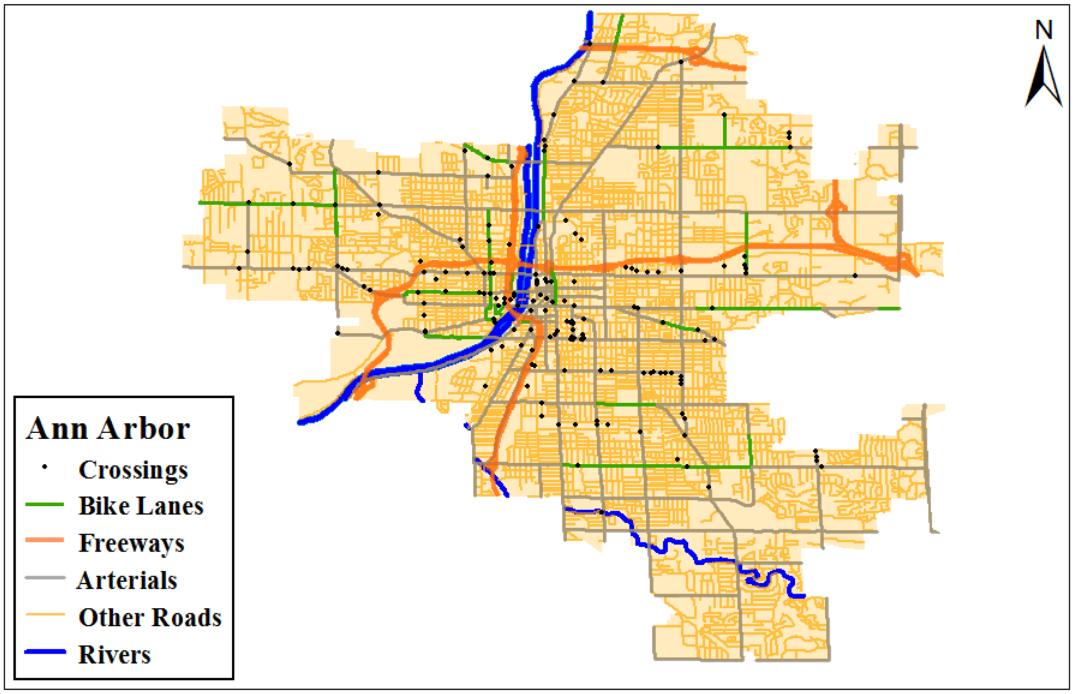
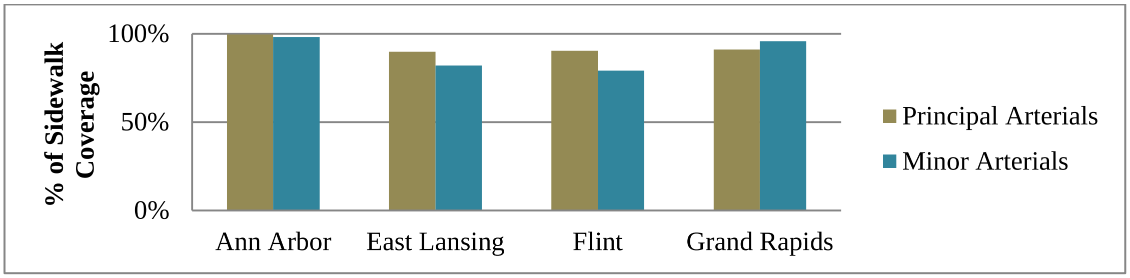


Figure 3-12 Non-Motorized Facilities Inventory in Grand Rapids

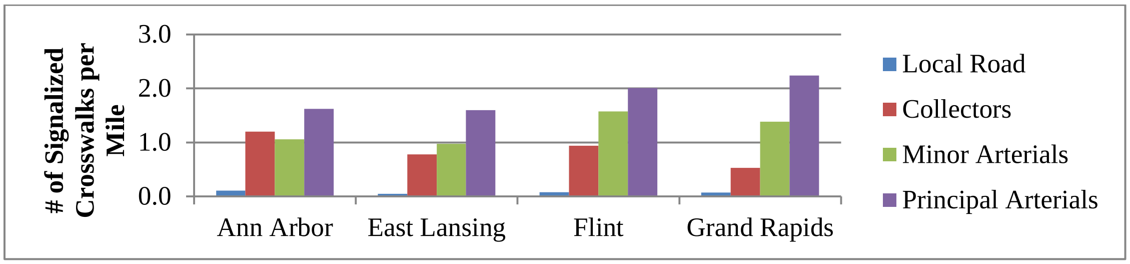
Table 3-3 summarizes non-motorized facilities by city, and Figure 3-13 graphically compares them. Sidewalks were available mostly in all cities, but the sidewalk coverage on minor arterials in Flint was relatively lower than other cities. While there were no significant differences in density of signalized crosswalks, more midblock crosswalks were available in campus towns, such as East Lansing and Ann Arbor. The number of access points varied by roadway types. While Ann Arbor had more access points in principal arterials, the other cities have more access points along minor arterials. Ann Arbor and East Lansing had more roadways with bicycle lanes than Flint and Grand Rapids. Especially, Flint's roadways have the least bicycle lane coverage.

Table 3-3 Summary of Non-motorized facilities by City

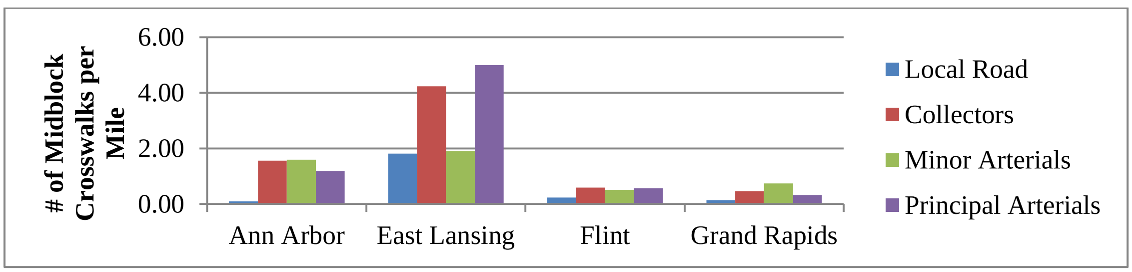
	Road Type	Ann Arbor	East Lansing	Flint	Grand Rapids
Sidewalk Coverage	Principal Arterials	99.6%	89.8%	90.3%	91.1%
	Minor Arterials	98.1%	82.0%	79.2%	95.7%
Number of Signalized Crosswalks per Mile	Local Road	0.11	0.04	0.08	0.07
	Collectors	1.20	0.78	0.94	0.53
	Minor Arterials	1.06	0.97	1.57	1.38
	Principal Arterials	1.62	1.60	2.01	2.24
Number of Midblock Crossings per Mile	Local Road	0.10	1.82	0.24	0.15
	Collectors	1.56	4.24	0.60	0.47
	Minor Arterials	1.60	1.90	0.51	0.74
	Principal Arterials	1.19	4.99	0.57	0.33
Number of Access Points per Mile	Principal Arterials	6.5	2.8	5.4	6.8
	Minor Arterials	9.1	15.0	14.2	14.0
	Collectors	10.2	9.1	10.6	10.0
Road Coverage by Bicycle Lanes	Local Road	1.5%	1. 8%	0.5%	0.1%
	Collectors	38.4%	52.3%	3.2%	2.0%
	Minor Arterials	36.9%	22.6%	5.5%	13.8%
	Principal Arterials	31.1%	30.5%	1.1%	10.4%



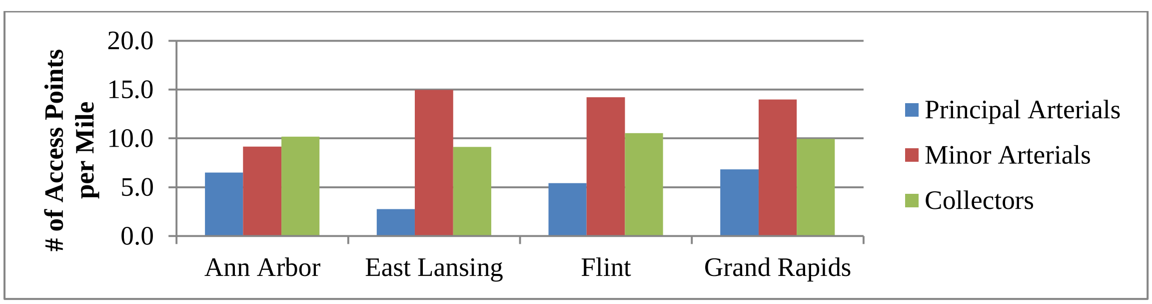
(a) Percentage of Sidewalk Coverage



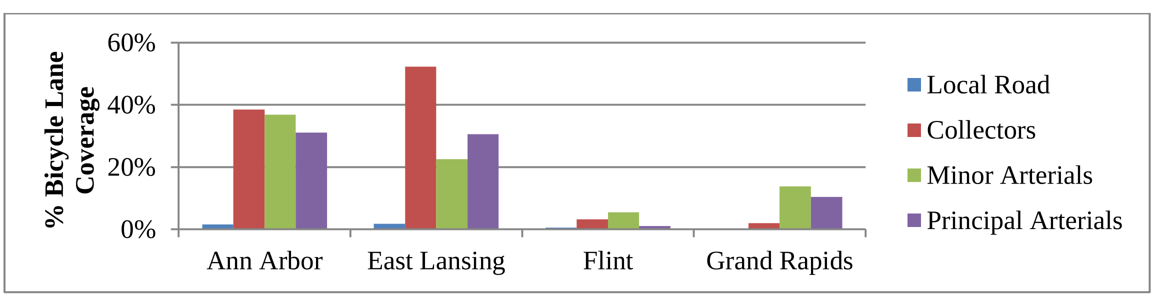
(b) Number of Signalized Crosswalks per Mile



(c) Number of Midblock Crosswalks per Mile



(d) Number of Access Points per Mile



(e) Road Coverage by Bicycle Lanes

Figure 3-13 Comparison of Non-Motorized Facilities by City

3.4.3 Non-motorized Improvement Projects

In addition to existing non-motorized facilities, information on recent non-motorized improvement projects was requested from cities, MPOs and MDOT. Non-motorized improvement information was provided through the personnel of the city's transportation engineers, MPOs and MDOT personnel. The information received provided details related to the improvement projects, such as what it entailed, the configuration of the roadway before the improvement, street location, time period of the project and the overall cost. One of main difficulties was extracting non-motorized projects from inclusive projects because of the wide scope of possible related non-motorized improvement projects. It was also difficult to separate non-motorized improvement costs out of the total project costs. Transportation agencies may consider altering their improvement project inventory preparation process to allow non-motorized improvements to be more readably extracted from inclusive projects. Figure 3-14 - Figure 3-17 show locations of improvement sites, and Table 3-5 provides brief description of non-motorized improvement projects.

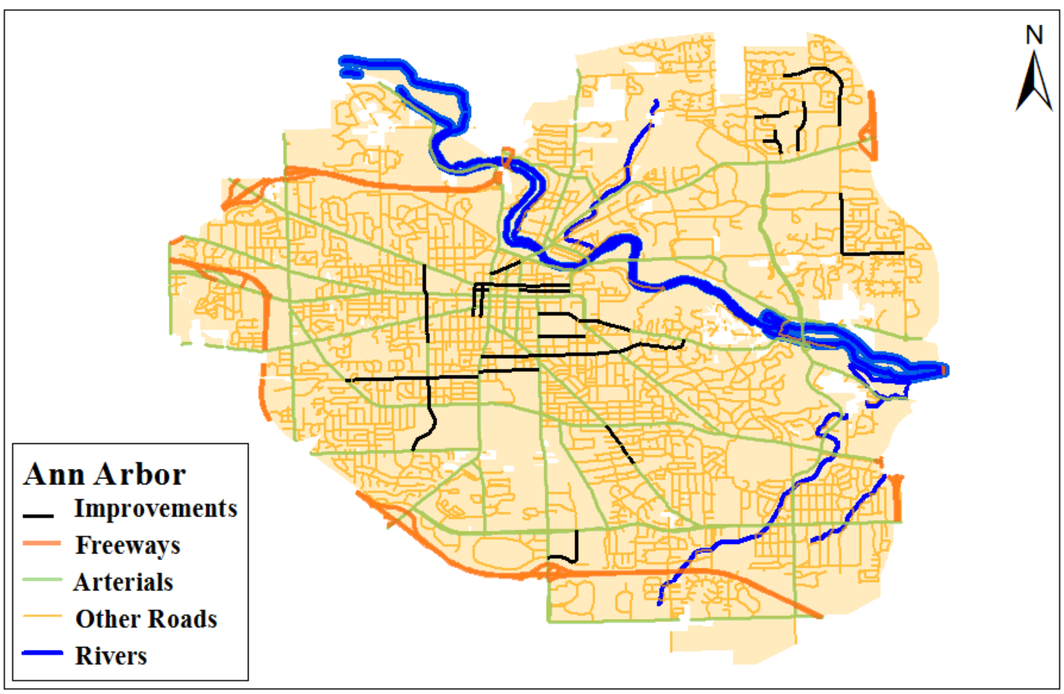


Figure 3-14 Locations of Improvement Projects in Ann Arbor

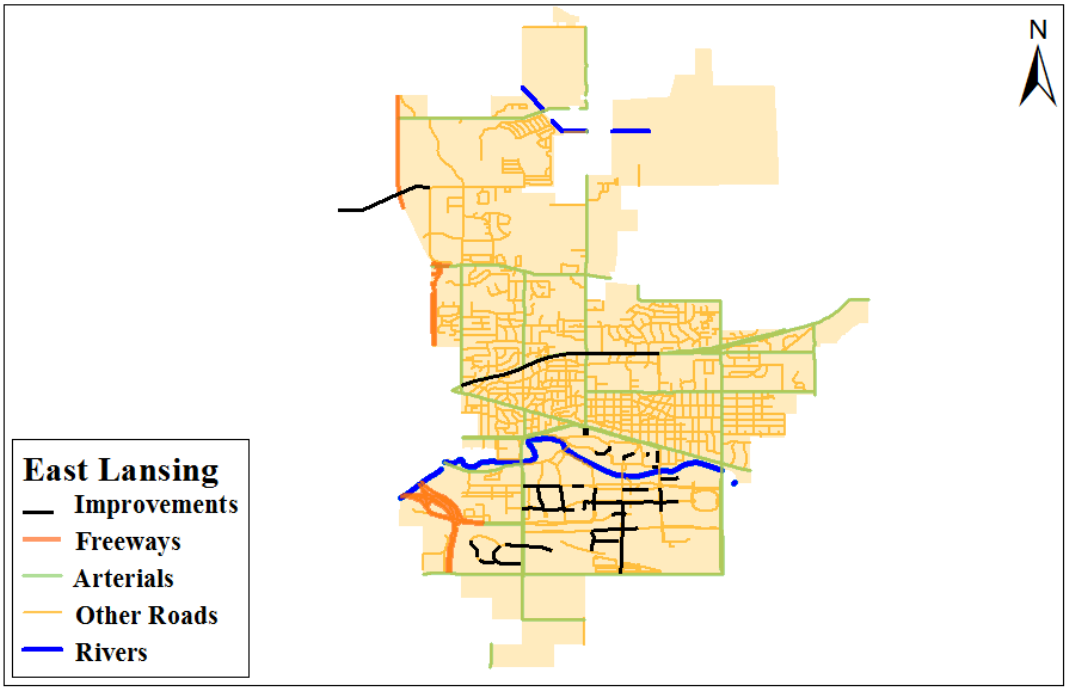


Figure 3-15 Locations of Improvement Projects in East Lansing

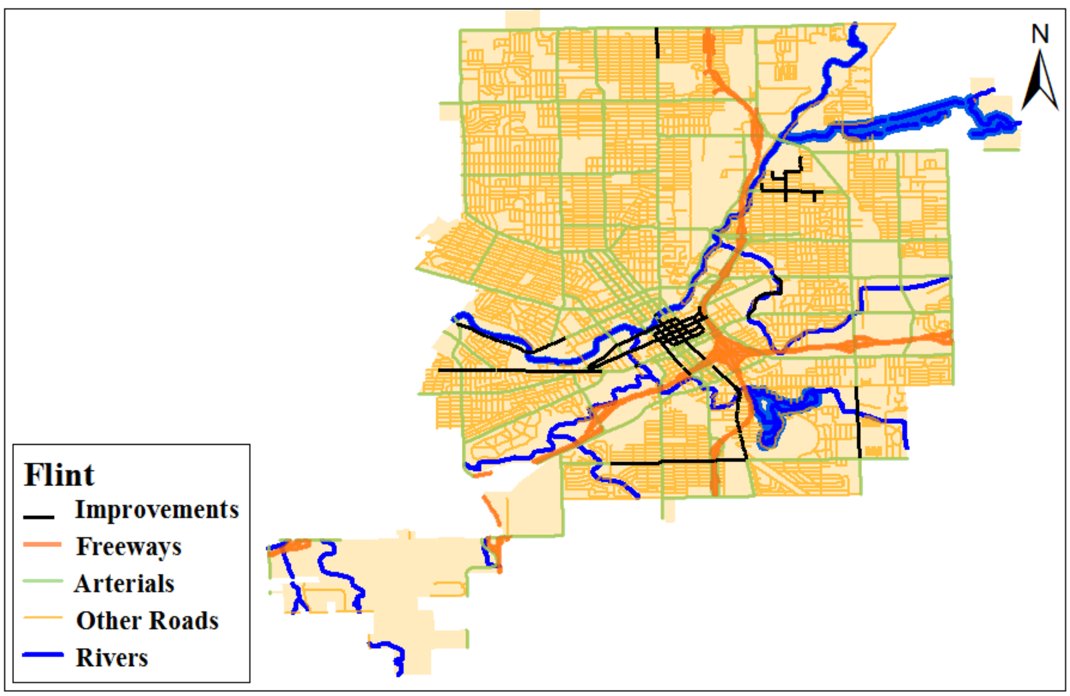


Figure 3-16 Locations of Improvement Projects in Flint

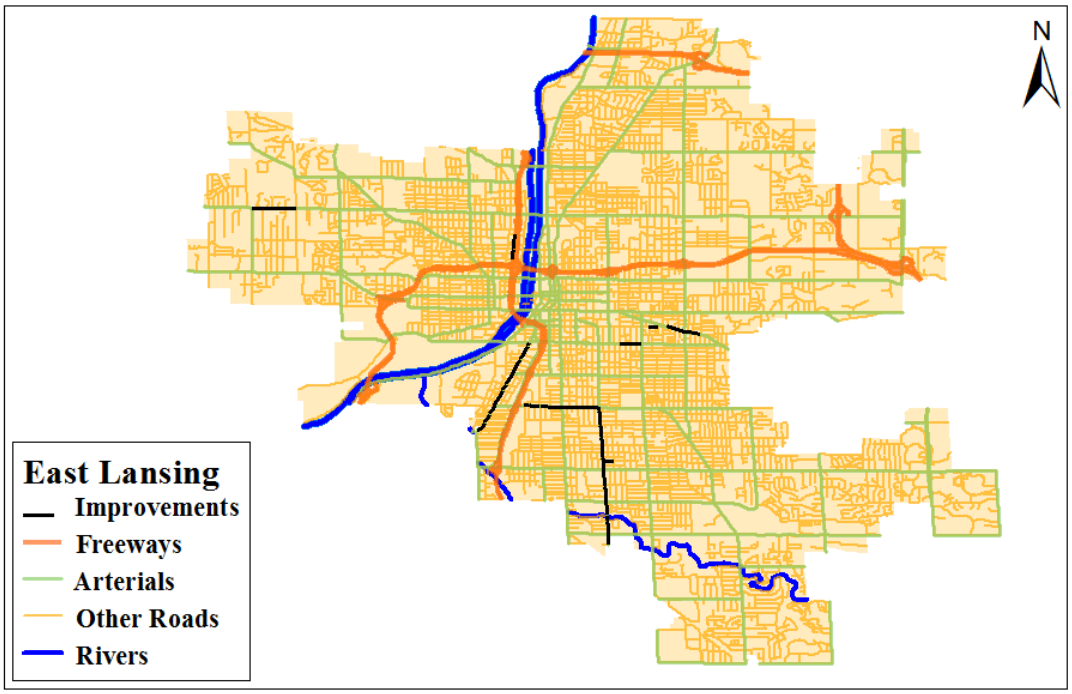


Figure 3-17 Locations of Improvement Projects in Grand Rapids

Table 3-4 List of Non-motorized Improvement Projects

City	Project Area	Year	Description of Improvements
Ann Arbor	Catherine & Packard St.	2007	Road Diet & Bicycle Lanes Added
	1st St., 7th St., Ashley St., Miller St., Ann St, N. University Ave., Hill St., & Stadium Blvd.	2008	Bicycle Lanes Added
	S. University Ave, Ann St., Pauline Blvd., & E. University Ave.	2008	Shared Lane Markings Added
	Huron St.	2010	Installed Pedestrian Hybrid Beacon
	Glazier Way, Victors Way & Beakes St.	2010	Bicycle Lanes Added
	Thurston Elementary	2010	Pavement Marking at Intersections, Advanced School Warning Signs & Sidewalk & Intersection Improvements
East Lansing	Chestnut	2007	Remove Parking and Added Bicycle Lanes
	East Shaw Lane	2007	Repaved, updated sidewalk path ramps and truncated domes
	Farm Lane	2008	Bicycle Lanes Added and 2 Lane Expansion
	Saginaw St.	2009	Non-Motorized Pathway Construction
	Wilson Road	2009	Addition of Bicycle Lanes and Corridor Reconstruction
Flint	Saginaw St.	2007	Sidewalk Improvements
	Atherton Rd.	2008	Sidewalk Improvements
	Flint River Trails: Apple Wood	2008	Addition of Non-Motorized Pathway
	Flint River Trails: Kettering University	2009	Addition of Non-Motorized Pathway
	Williams Elementary School	2009	Repair & Replacement of Sidewalks, Ramps, Curbs & Gutters. Improve Crosswalk Pavement Markings.
	Downtown Road Conversion	2010	Road Diets, Added Biking Lanes, & Parking Designated
	Court & Dort St.	2011	Sidewalk Resurface, Reconstruction, & Ramp Upgrade
Grand Rapids	Cherry St.	2007	Bicycle Sharing Added. Rehabilitation of Brick Street. Improved Street Lighting.
	Leonard Street	2008	Road Diet
	Lake Drive	2009	Remove Parking and Added Bicycle Lanes

3.4.4 Facilities Impacting Non-Motorized Exposures and Safety

Many facilities are strongly related with non-motorized exposures and safety. Most of these locations were introduced in the literature review. In this study, facilities listed in in Table 3-5 were included in the GIS database to make these facilities available as variables in safety analysis. While ESRI database provided locations of many facilities, some of them were processed through Google earth. Locations were searched, and then ".KML" format files, which included name, address and coordinates (longitude and latitude), were downloaded and transferred to the GIS database.

Table 3-5 Locations of Interest

Data Source	Facilities
Google Earth	Bus Stops, Schools, Liquor Stores, Bars, Retails
ESRI	University Buildings, Churches, Libraries, Terminals, Museums, Hospitals / Clinics, Government Offices

3.5 Socioeconomic and Demographic Data

3.5.1 Census Data

Socioeconomic and demographic data have been found to be contributing factors to non-motorized exposures as well as crashes. 2010 census data at a census block level (just demographics available for public) and at a census tract level (demographics and socio-economic level) were obtained from the Census Bureau website. In this study, both census block and census tract data were included in the GIS database. The lists of data available at the census block level and the census tract level are listed in Table 3-6 and Table 3-7, respectively. For further GIS data processing, shapefiles related to census blocks and census tracts were acquired from the Michigan DTMB website (CGI, 2012) and the Census Bureau website. Table 3-8 and Figure 3-18 provide population and the number of employees by commuting transportation modes by city. In addition, Figure 3-19 - Figure 3-22 depict population in each census tract for each city.

Table 3-6 Data Collected at Census Block Level (2010)

Area	
Total Population	
African American Population	
Hispanic Population	
Total White Population	
Children 14 and Below	
Age 15 to 19	
Age 20 to 59	
Age 60 and Older	
Median Age	Both sexes
	Male
	Female
Households with one or more people 60 years and over	
Households with no people 60 years and over	
Total Male Population	
Total Female Population	
Proportion of Housing Units that are Vacant	
Households Owner Occupied	
Household Renter Occupied	
Family Households	
Family Households 2-Person	
Family Households 3-Person	
Family Households 4-Person	
Family Households 5-Person	
Family Households 6-Person	
Family Households 7-Person	
Nonfamily Households	
Nonfamily Households 1-Person	
Nonfamily Households 2-Person	
Nonfamily Households 3-Person	
Nonfamily Households 4-Person	
Nonfamily Households 5-Person	
Nonfamily Households 6-Person	
Nonfamily Households 7-Person	

Table 3-7 Data Collected at Census Tract Level (2010)

Means of Transportation to Work	Car, Truck, or Van
	Drove Alone
	Carpooled
	Public Transportation Excluding Taxicab
	Bus or Trolley Bus
	Bicycle
	Walked
	Other Means
	Work At Home
Means of Transportation to Work by Vehicle Available	No Vehicle Available
	1 Vehicle Available
	2 Vehicles Available
	3 or More Vehicles Available
Income in the Past 12 Months Below Poverty Level	
Income in the Past 12 Months Above the Poverty Level	
Average Percentage Income in Past 12 Months Below Poverty Level	
Household Low Income in the Past 12 Months	Less than $10,000
	$10,000 to $14,999
	$15,000 to $19,9999
Employment Status for the Population 16 Years and Over	Employed
	Unemployed
	Not in Labor Force
Educational Attainment for 18 years and Older	No High School Diploma or GED
	High School Diploma or GED
	Some College or Associate's Degree
	Bachelor's Degree
	Graduate Degree or Higher
Median Household Income in the Past 12 Months	
Student Enrollment Status	8th Grade and Lower
	9th to 12th Grade
	College or Professional School
	Not Enrolled
1- Unit Structure	
2-Unit Structure	
Mobile Homes	

Table 3-8 Population and Employee's Transportation Mode

City	Population (2010)	Employee's Means of Transportation to Work					
		Car, etc.	Bus	Bike	Walk	Work Home	Others
Ann Arbor	113,939	34,585	5,292	1,728	8,378	3,303	406
East Lansing	48,557	11,136	1,227	1,468	5,360	884	125
Flint	102,434	25,353	1,362	20	813	715	228
Grand Rapids	188,040	71,153	2,967	764	2,823	3,984	530

Source) Census Bureau, 2012

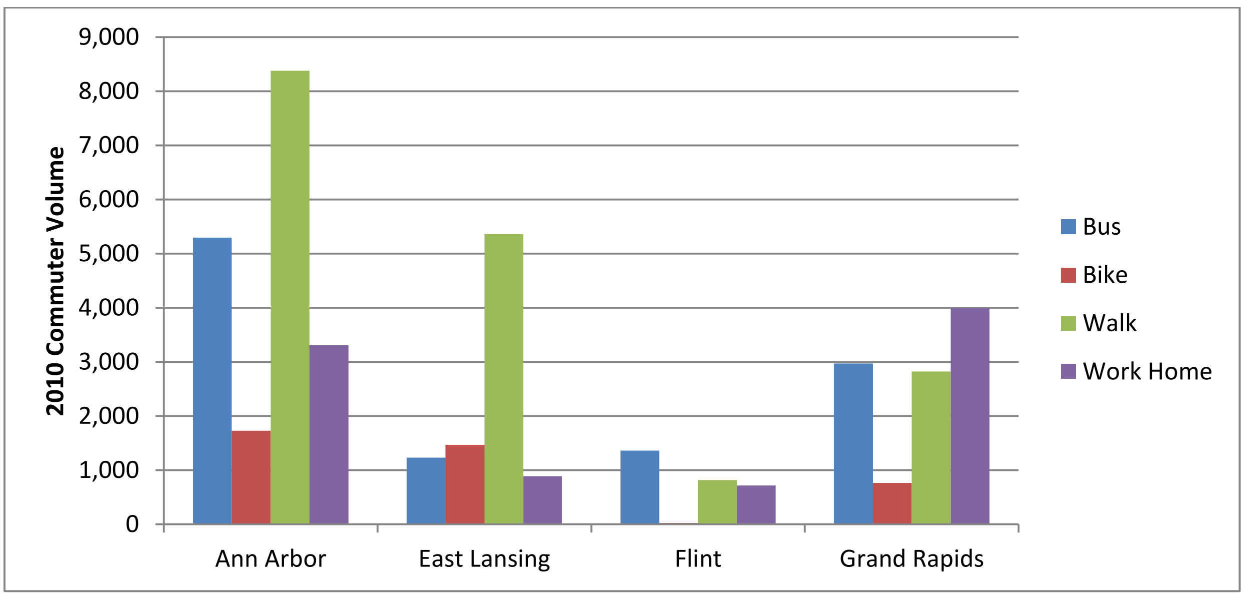


Figure 3-18 Transportation Modes to Work (Avg. 2008-2010)

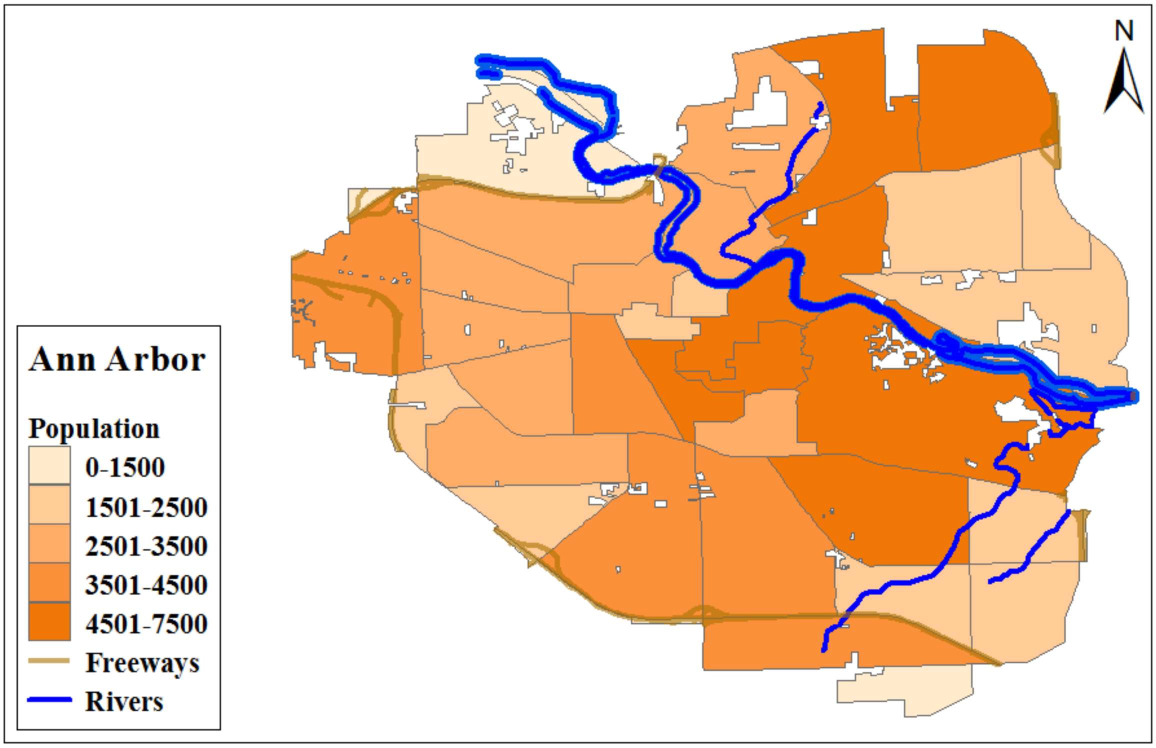


Figure 3-19 Population in Census Tract Level: Ann Arbor

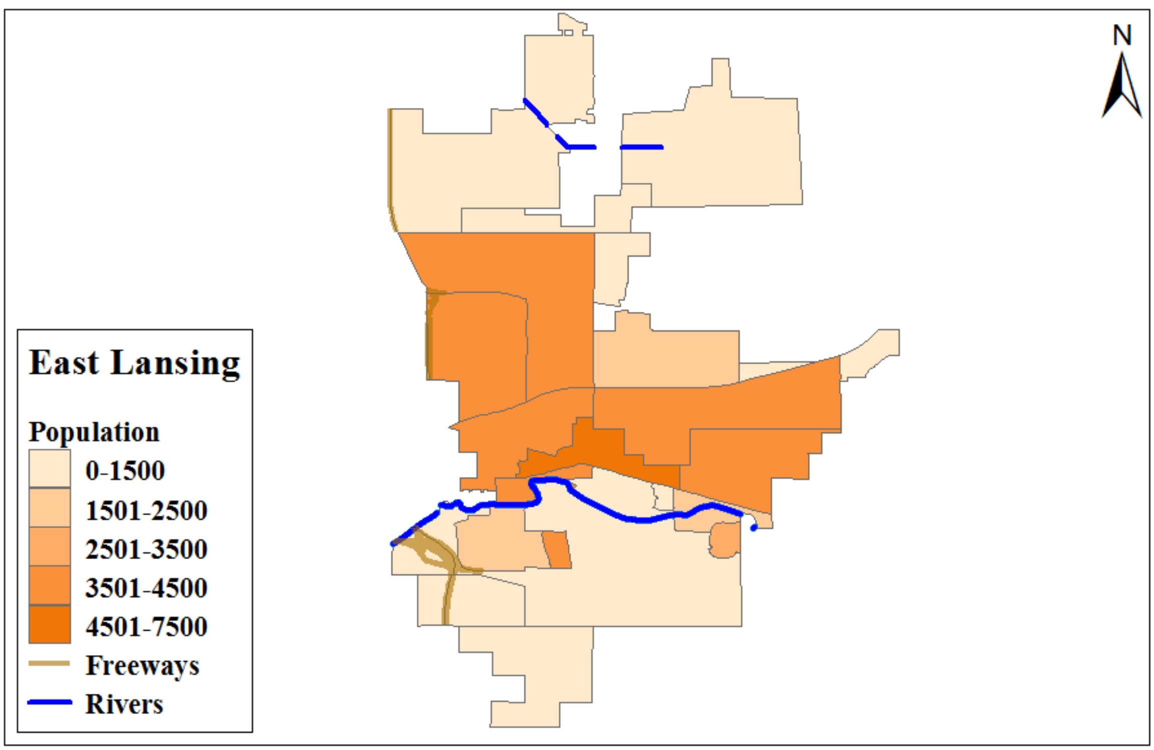


Figure 3-20 Population in Census Tract Level: Ann Arbor

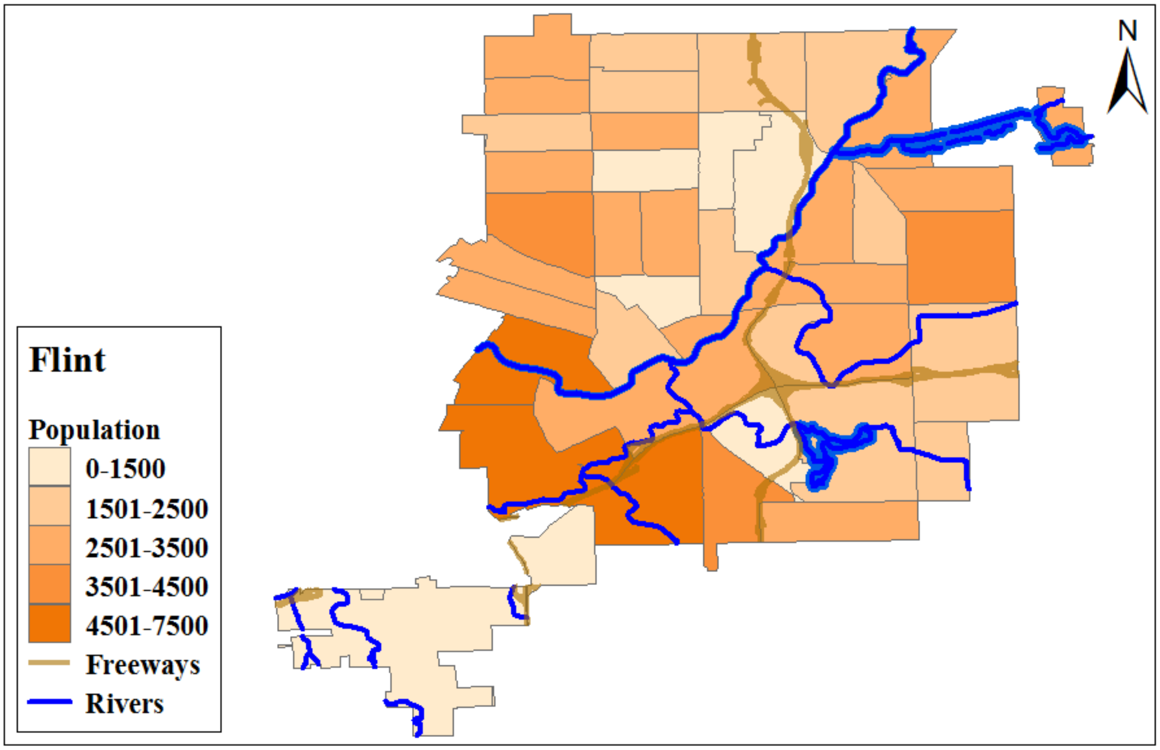


Figure 3-21 Population in Census Tract Level: Flint

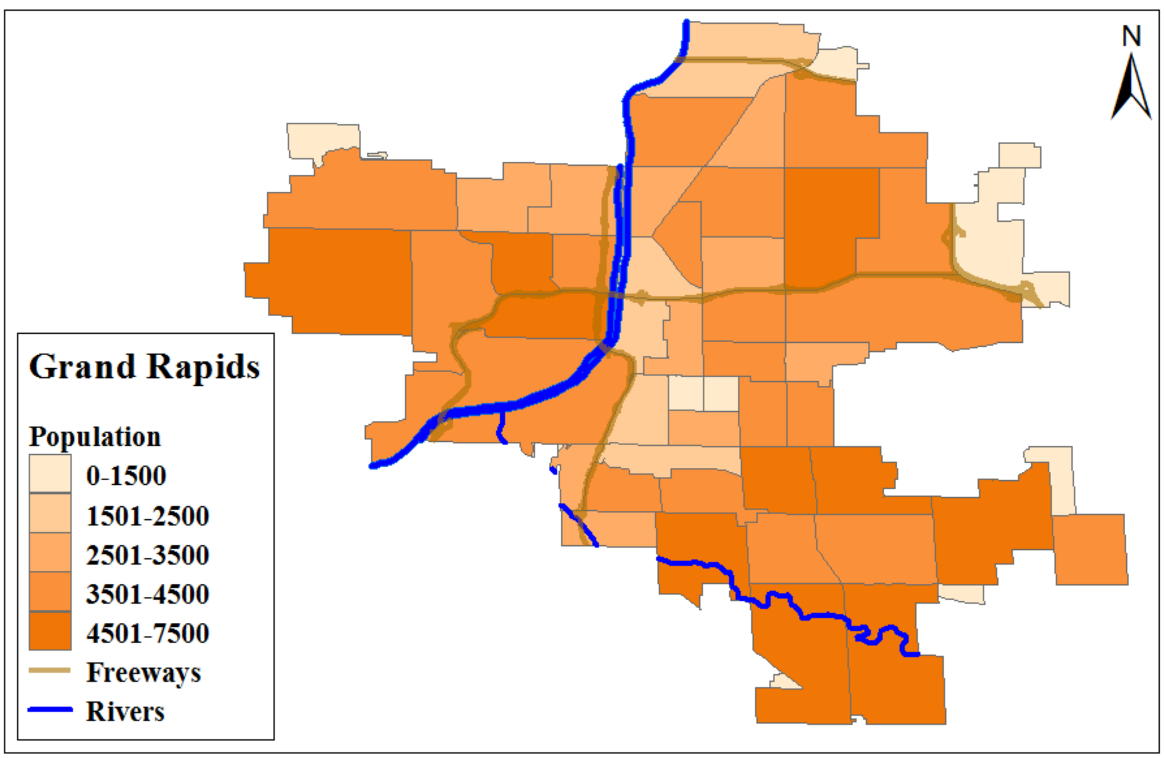


Figure 3-22 Population in Census Tract Level: Grand Rapids

3.5.2 Crime Data

Crime rate in an area may also impact non-motorized travel and safety. In order to investigate the possible impact of crime rates on non-motorized dynamics, crime data were collected from the Michigan State Police (MSP). While most crimes may influence non-motorized travel and safety, forgery does not have significant effects on non-motorized transportation. Therefore, forgery was excluded from the crime dataset in this study. Recently, MSP started collecting geocode information for each crime, so the percentages of crime data with geocode were highly varied by city. While only 6% of Flint data had geocode information, 97% of Grand Rapids data had geocode. Accordingly, crime data were expanded and reprocessed to each census tract based on the rate of geocode samples. Figure 3-23 - Figure 3-26 depict crime rates in individual census tract.

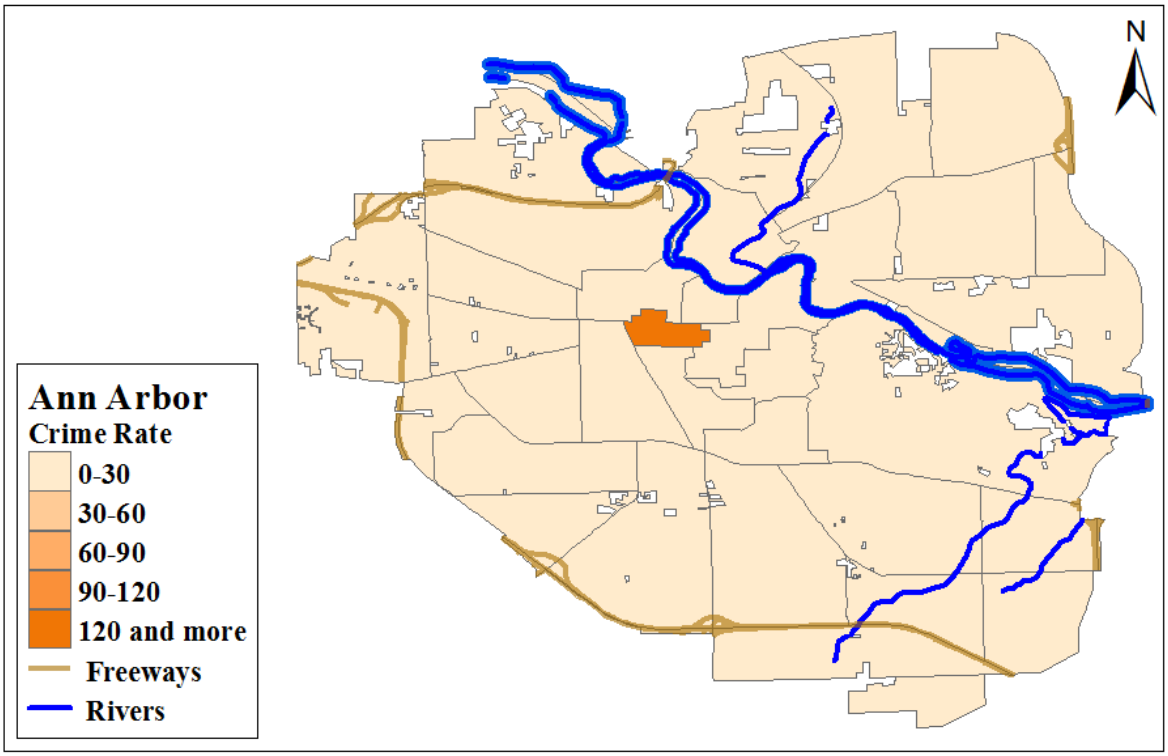


Figure 3-23 Crime Rate in Census Tract Level: Ann Arbor

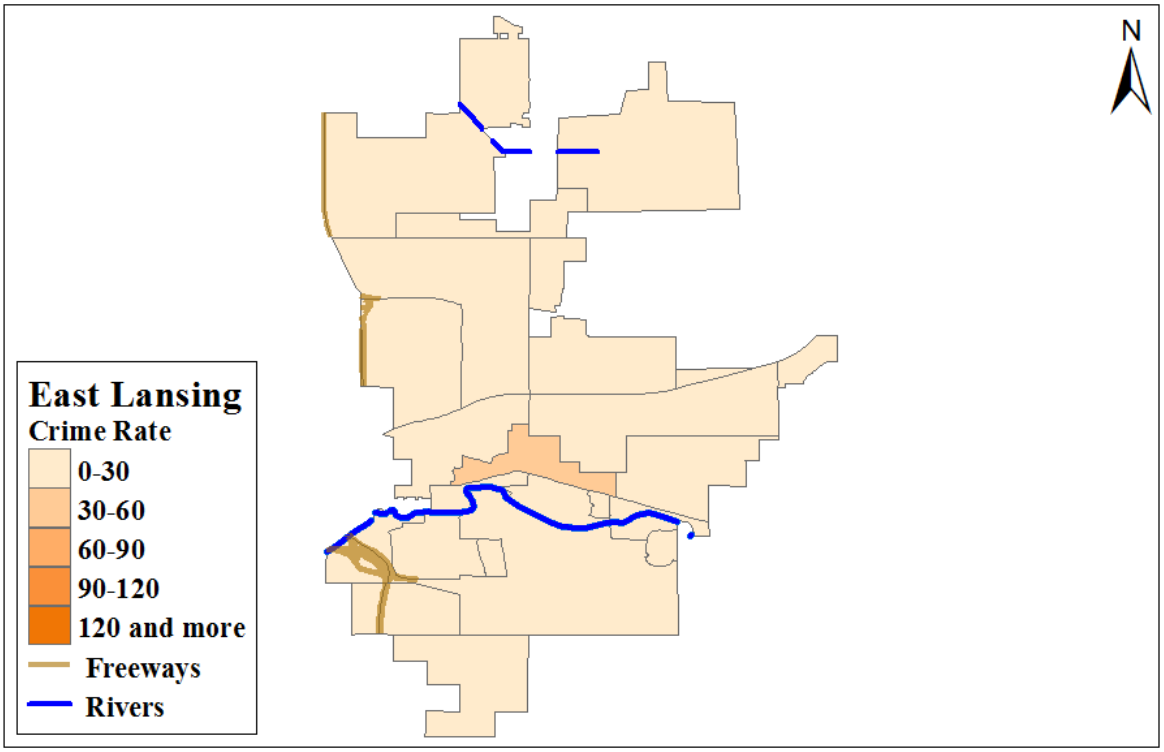


Figure 3-24 Crime Rate in Census Tract Level: East Lansing

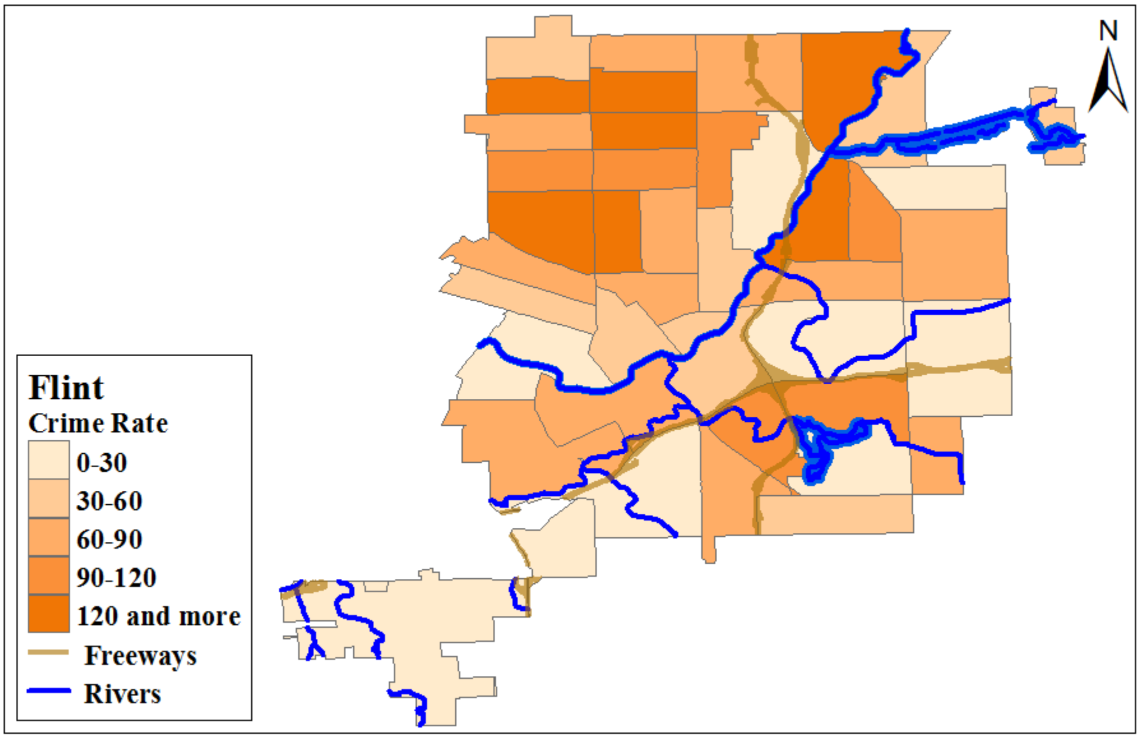


Figure 3-25 Crime Rate in Census Tract Level: Flint

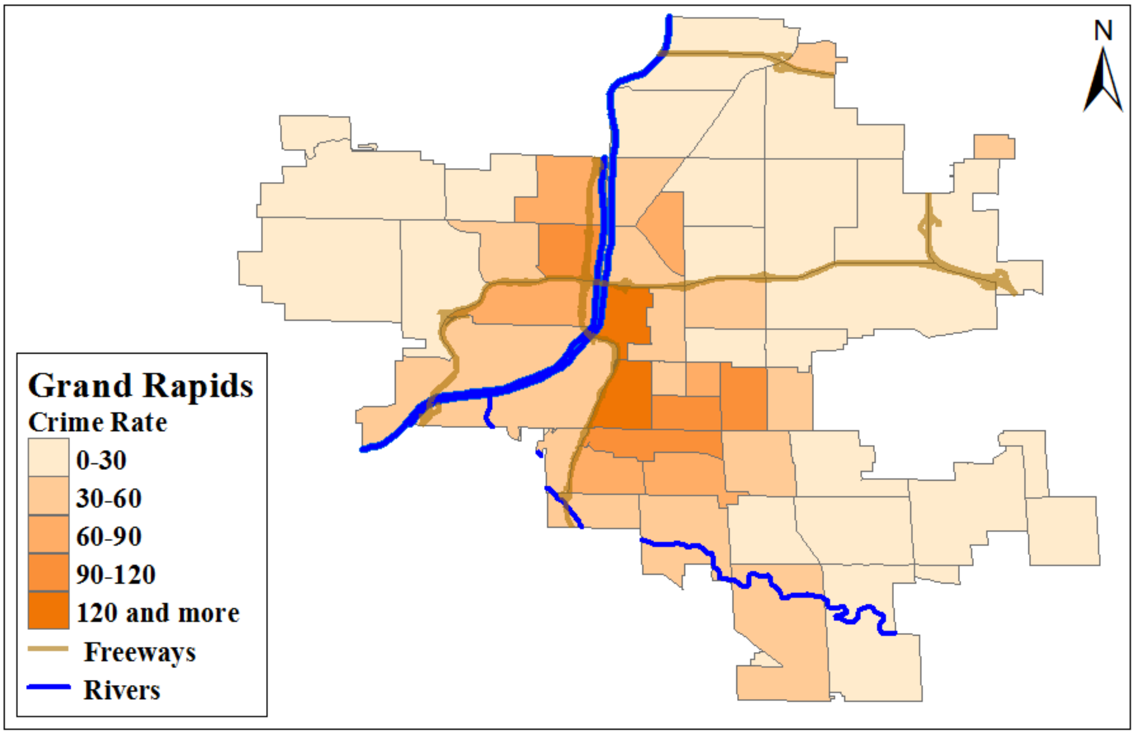


Figure 3-26 Crime Rate in Census Tract Level: Grand Rapids

3.5.3 Land Use Data

Land use describes the dominate usage of the land in the scope of study. This data was provided by the cities. However, since each city had different descriptions and categories for defining the land use, the land use was re-categorized into six types by observing actual land use through Google Earth: residential, campus, business, industrial, vegetation, and others. Figure 3-27 - Figure 3-30 depicts land use for each city in ArcGIS.

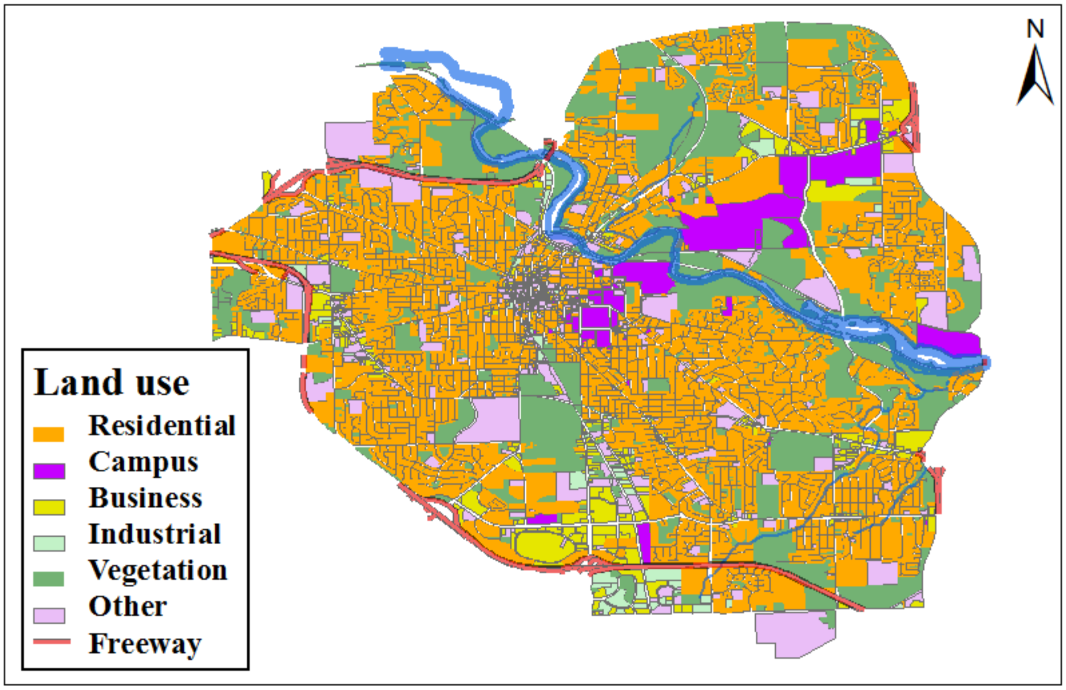


Figure 3-27 Land Use in Ann Arbor

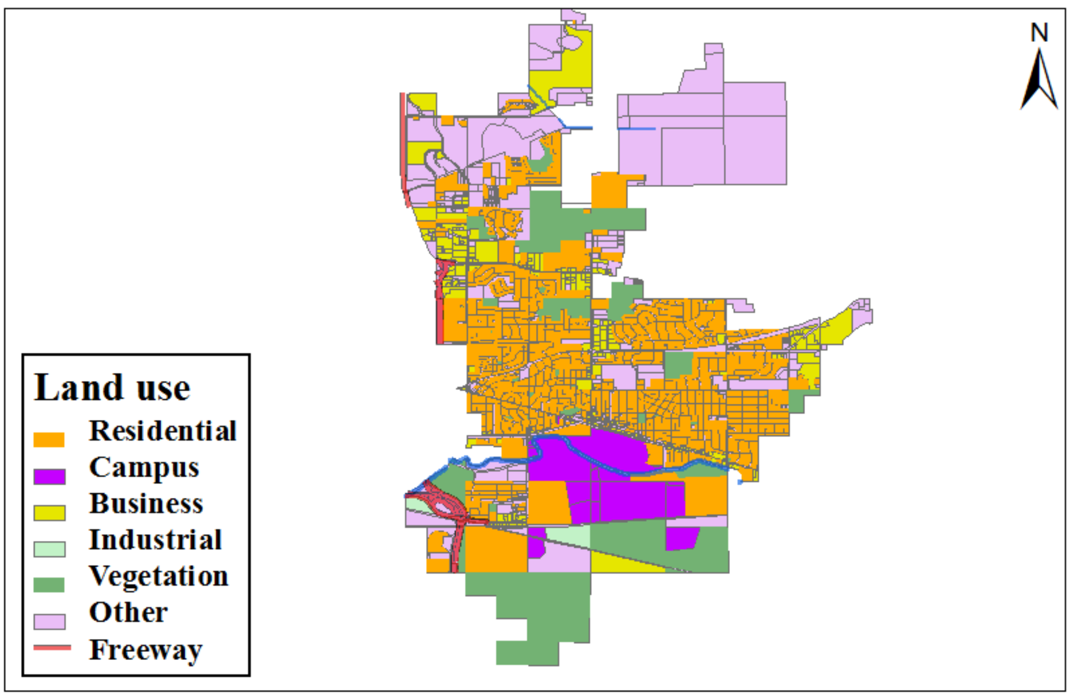


Figure 3-28 Land Use in East Lansing

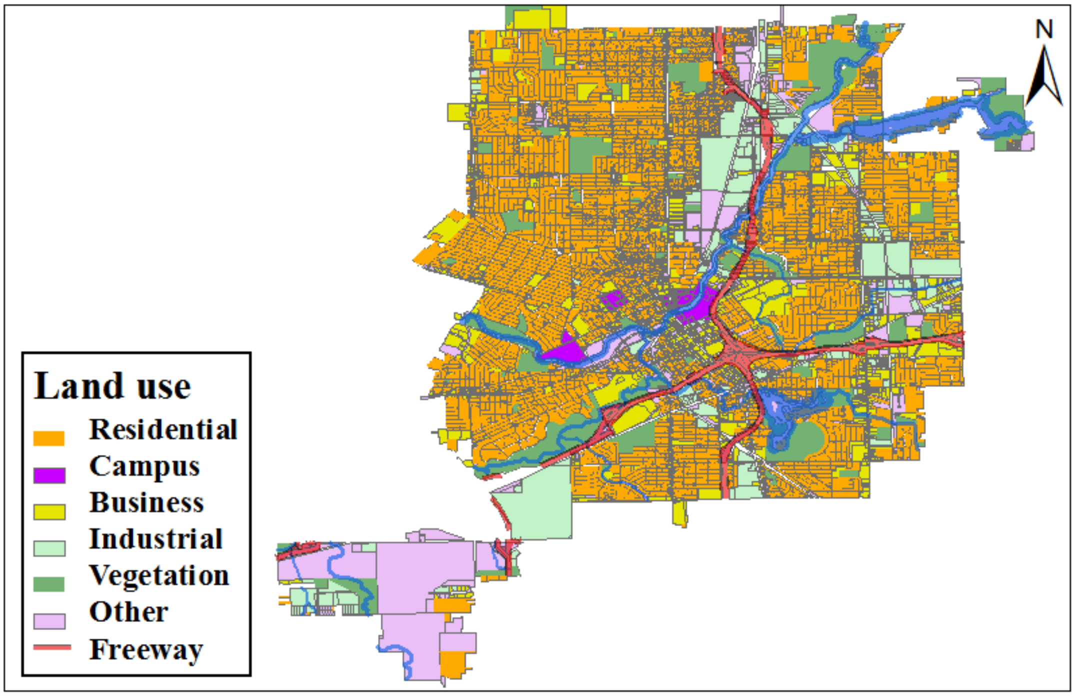


Figure 3-29 Land Use in Flint

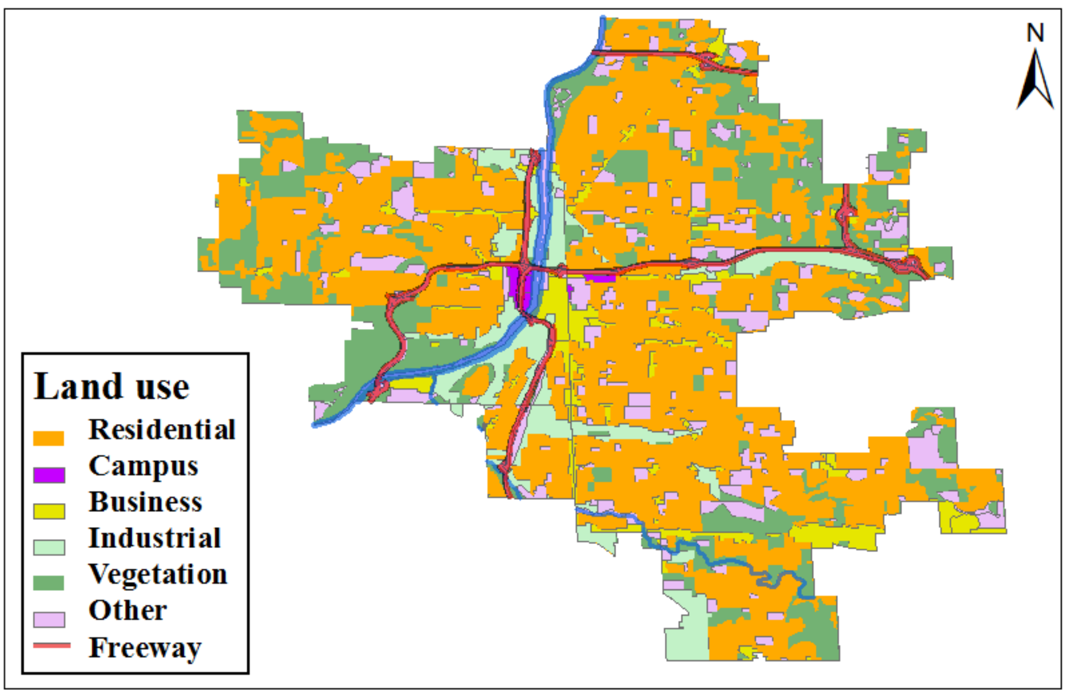


Figure 3-30 Land Use in Grand Rapids

Chapter 4 Volume Modeling

4.1 Introduction

According to Raford and Ragland (2005), the term “exposure” refers to the “rate of contact with a potentially harmful agent or event.” Pedestrian and bicyclist exposures are defined in similar fashion as the rate of pedestrian or bicyclist’s contact with motorized traffic. Clearly, higher exposure potentially results in more crashes. Even though pedestrian and bicycle volumes are essential for safety performance analysis and planning non-motorized facilities, there have been very limited efforts to collect and archive data, mainly due to the lack of reliable and economic data collection means. In order to efficiently measure non-motorized volumes, there have been efforts to develop sensors for detecting, counting, and classifying pedestrians and bicycles. Among many automated detection technologies, active infrared and video image processing have been regarded as the technologies suitable for pedestrian and bicycle detection (Dharmaraju et al., 2002). Researchers (Noyce et al, 2006; Malinovskiy et al., 2009l Belbachir et al., 2010) have developed detection algorithms applying such technologies. Currently, commercial devices applying such technologies are available for use in field and have been used for collecting pedestrian and bicycle counts (Schneider et al., 2009; Hudson et al., 2010). Even though pedestrian and bicycle sensors are available, it is not feasible to collect data from all locations. Accordingly, researchers have been developing models for estimating pedestrian and bicycle volumes (Sandrock, 1988; Raford and Ragland, 2005; Liu et al., 2009; Schneider et al., 2009; Molino et al., 2009; Jones et al., 2010; Griswold et al., 2011; Hankey et al., 2012; Gallop et al., 2012; Strauss et al., 2012). Most approaches applied discrete count models, such as multinomial regression models, to estimate pedestrian or bicycle volume with land use, demographic, transit facility, and/or other characteristics. In this study, count models were examined in addition to linear models.

4.2 Volume Data Collection

4.2.1 Pedestrian and Bicycle Counts

In this study, pedestrian and bicycle volume data were collected from selected intersections in four Michigan cities: Ann Arbor, East Lansing, Flint and Grand Rapids. Two types of data collection methods were used due to the limited budget. The first type was to collect 12-hour data at selected locations using automated pedestrian and bicycle sensors, and the second type was to collect data manually for one hour at coverage locations. The counts from locations for the first type were used to identify time-of-day, non-motorized traffic patterns representing the area. For each city, three locations were determined for this type, and commercially available video image sensors from Miovision were installed for data collection. In order to select data collection sites, first, pedestrian and bicycle crashes from 2004 to 2012 were mapped using ArcGIS. Then, sites were selected using multiple criteria such as crash density, activity at locations (schools, non-motorized facilities, etc.), land use characteristics (using Google Map), and geographical distribution, and locations proposed by local transportation planning agencies. As a result, one sensor was installed in a busy downtown intersection in each city while the other two sensors were located in less crowded areas with different types of land-use. Manual data collection was conducted at 20 locations for each city by five trained students. The majority of sites chosen had a considerable number of pedestrian crashes in their records, or at least one crash had occurred during the study timeframe.

Figure 4-1 Miovision Sensor Installation

Field data collection was scheduled and began in October, 2012. Weather forecasts were carefully considered to ensure smooth and more accurate data collection. Thus, field data collection was conducted on only non-rainy days with mild temperatures only. Data was collected on October 17th, 22nd, 24th and 25th, 2012 in the cities of Grand Rapids, Ann Arbor, East Lansing and Flint, respectively. In each city, data collection began at 7:00 AM and continued until 7:00 PM. Sensors were installed before 7:00 AM and taken down after 12 hours. Meanwhile, members of the data collection crew were collecting one-hour data at coverage locations.

4.2.2 Data Validation

Video data collected on the field were submitted to Miovision for automated data processing, and Miovision provided pedestrian and bicycle counts as well as 144 hours of video files for all 12 intersections. Since the accuracy and reliability of the results were the main concern, randomly sampled Miovision outputs were compared with the counts processed manually from the videos. For comparison, the mean absolute percentage errors were computed as follows:

$$\text{Mean Absolute Percentage Error} = \frac{\Sigma\left(\frac{[|\text{Observed Value}-\text{Sensor Value}|]}{\text{Obsereved Value}}\times 100\right)}{the\ total\ number} \quad (4\text{-}1)$$

As shown in Table 4-1, the error for pedestrian counts was 11.4% while error for the bicycle counts was more than 55.4% for the sample data. As the sample error for bicycle count was too large, all bicycle counts were manually reprocessed from the video image files. Therefore, the bicycle counts used in this study for analyses were manually obtained from the videos.

Table 4-1 Sensor Count Validation

	Pedestrian Counts	Bicycle Counts I	Bicycle Counts II
Number of Samples	82	53	576
Sample Rate	14.2%	9.2%	100%
Mean Absolute Percentage Error	11.4%	55.4%	51.4%
12 Hour Total Count Error	8.4%	38.5%	30.8%

Note) Each sample represents 15-minute interval data.

4.2.3 Data Extrapolation

With the processed 12-hour pedestrian and bicycle counts, the time-of-day patterns for pedestrian and bicycle counts were developed for the reference locations. In order to remove sharp spikes in the 15-minute interval data, the time-of-day patterns were smoothed using the simple moving average technique. The count for each 15-minute period was smoothed with the data before and after the period. Figure 4-2 (a) shows an example of data smoothing.

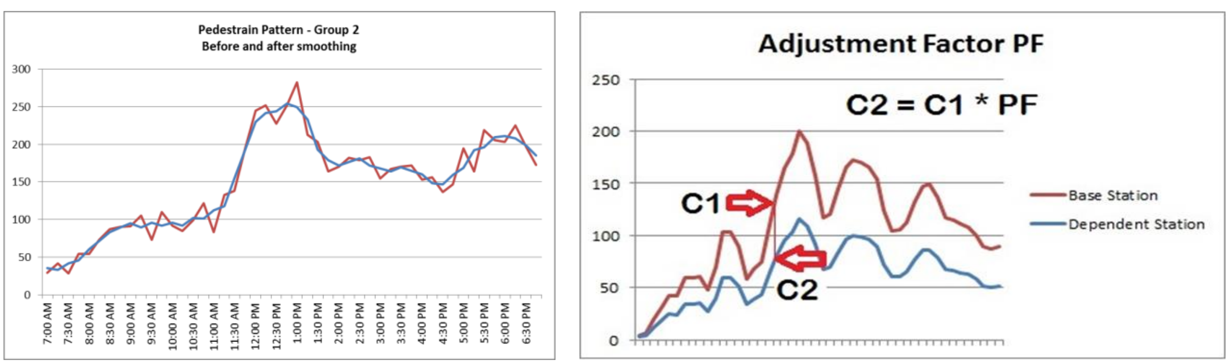
$$\bar{C}_t = \frac{C_{t-1}+C_t+C_{t+1}}{3} \qquad (4\text{-}2)$$

where,

$\bar{C}_t$ = smoothed counts for the period t

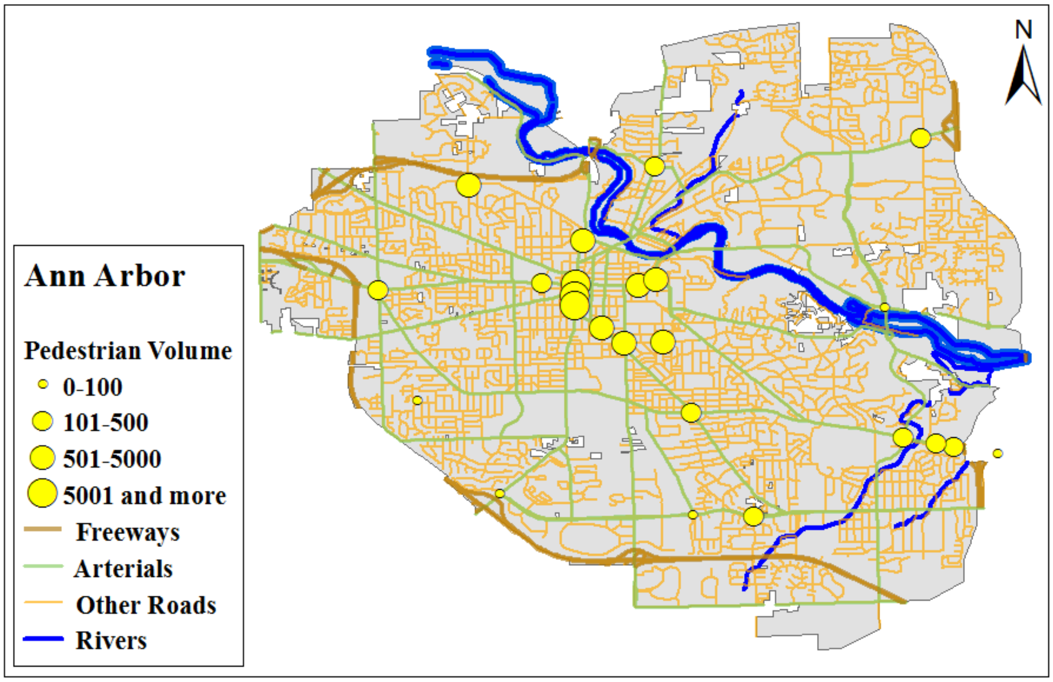
C_t = counts for the period t

These patterns were used for extrapolating one-hour manual counts to 12-hour data for all coverage locations. Based on each location's land-use characteristics, a corresponding time-of-day pattern was selected from the twelve reference dataset. After calculating the adjustment factor, (the ratio of the hourly manual count to the count during the same period in the corresponding period), 12-hour pedestrian and bicycle counts were extrapolated as shown in Figure 4-2 (b). All 80 intersections manually collected data for an hour were extrapolated, and Figure 4-3 - Figure 4-6 show pedestrian and bicycle counts for all sites including 12-hour reference sites and 80 extrapolated sites.

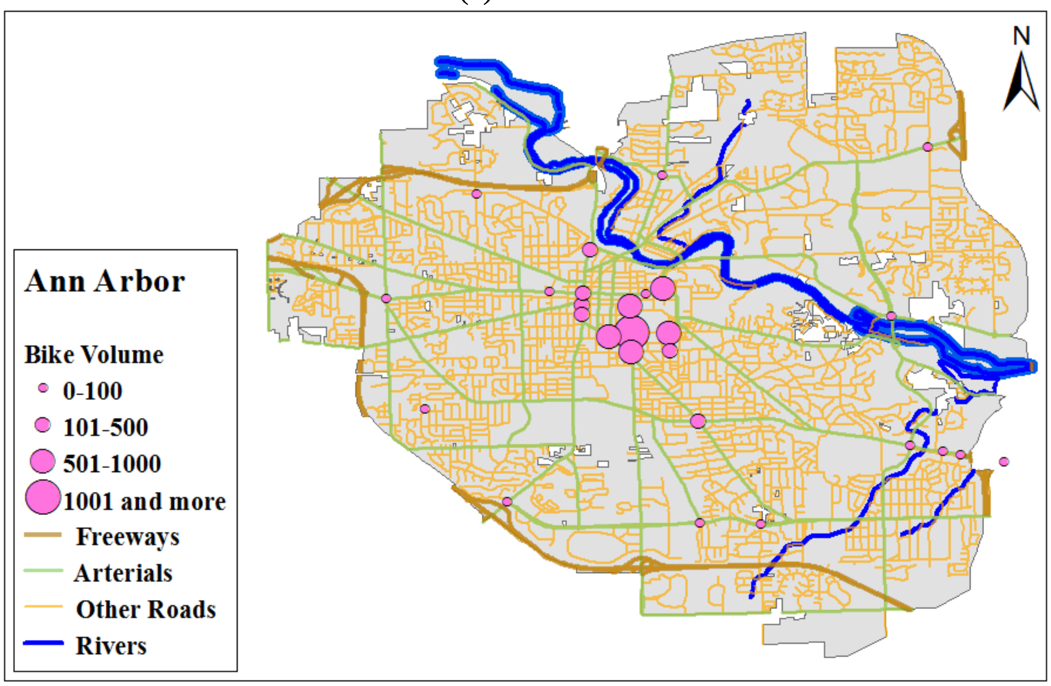


(a) Before and after smoothing data pattern (b) Adjustment factor and data extrapolation

Figure 4-2 Data Smoothing and Extrapolation

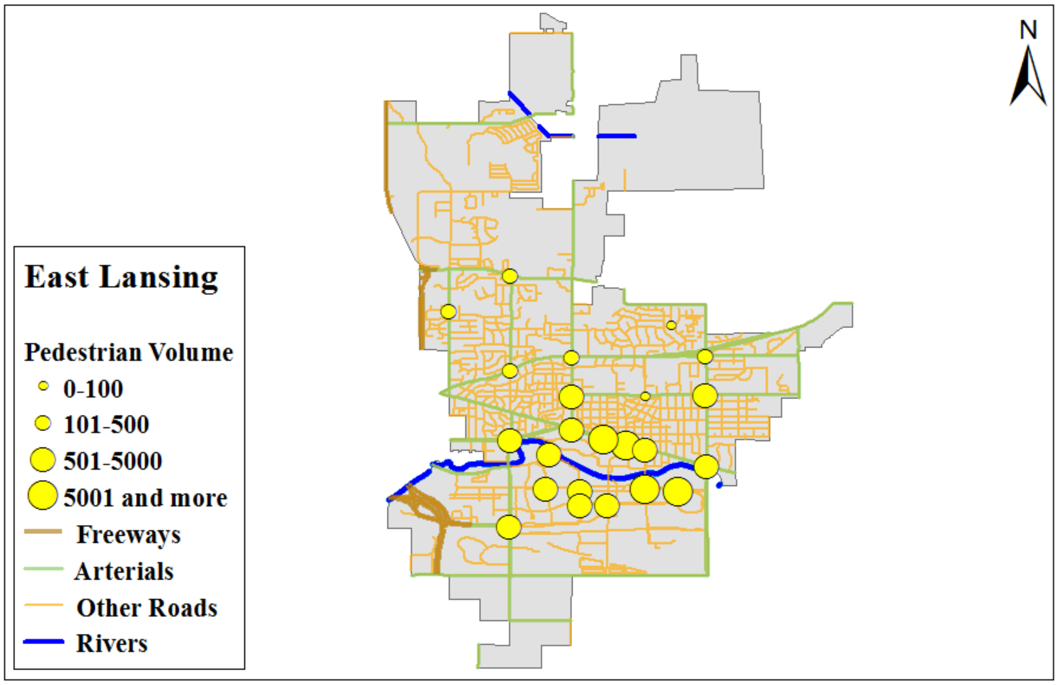


(a) Pedestrian

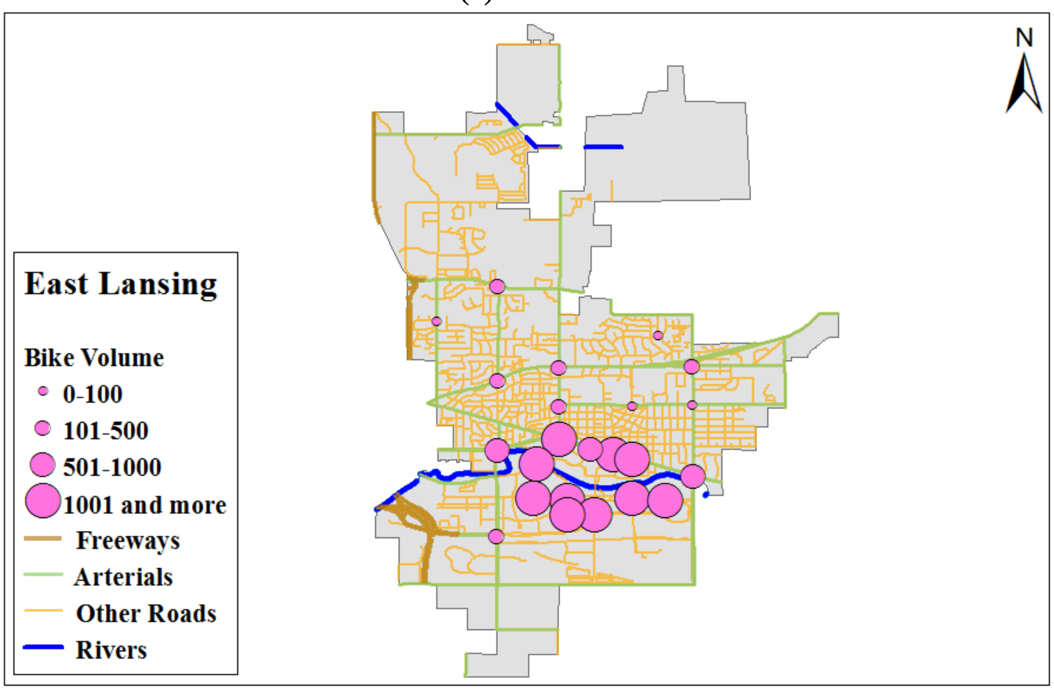


(b) Bicycle

Figure 4-3 Non-motorized Volume, Ann Arbor

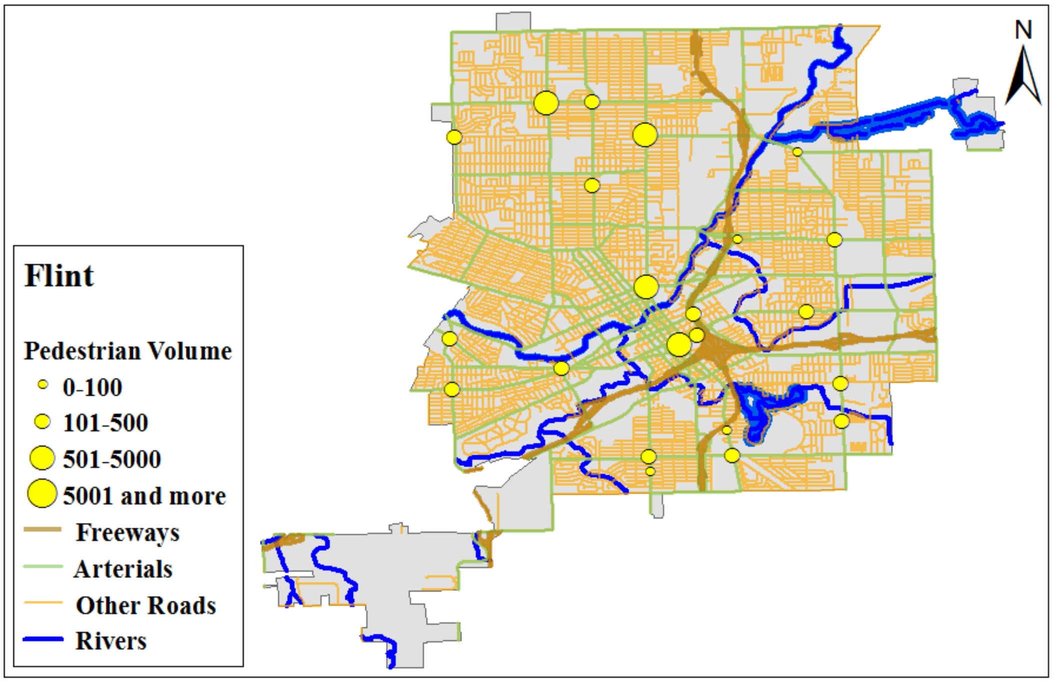


(a) Pedestrian

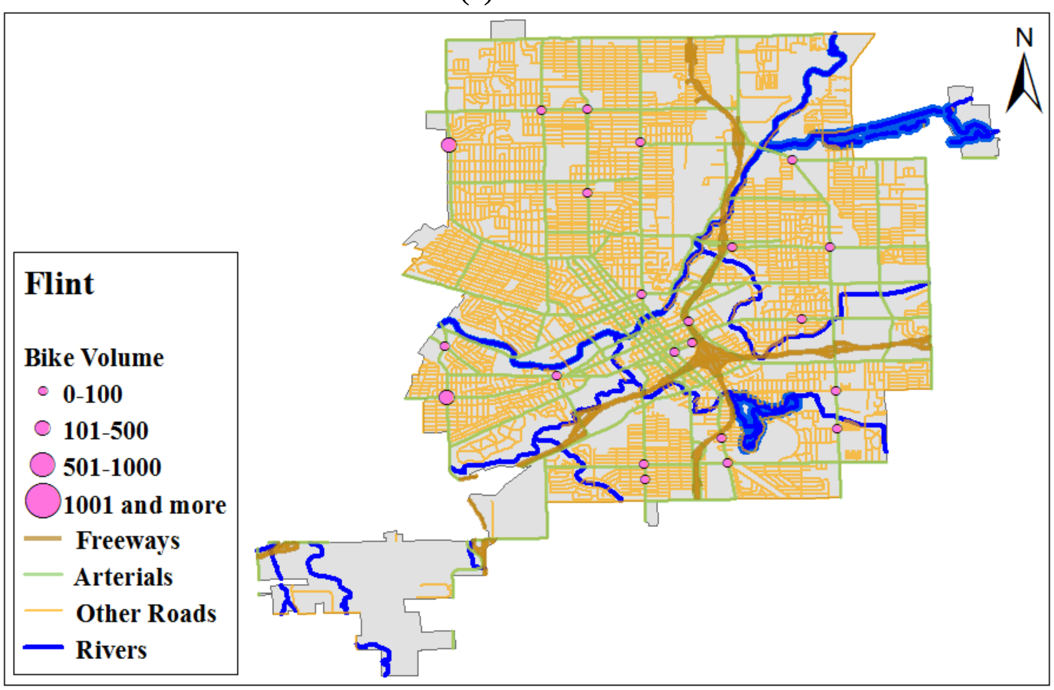


(b) Bicycle

Figure 4-4 Non-motorized Volume, East Lansing

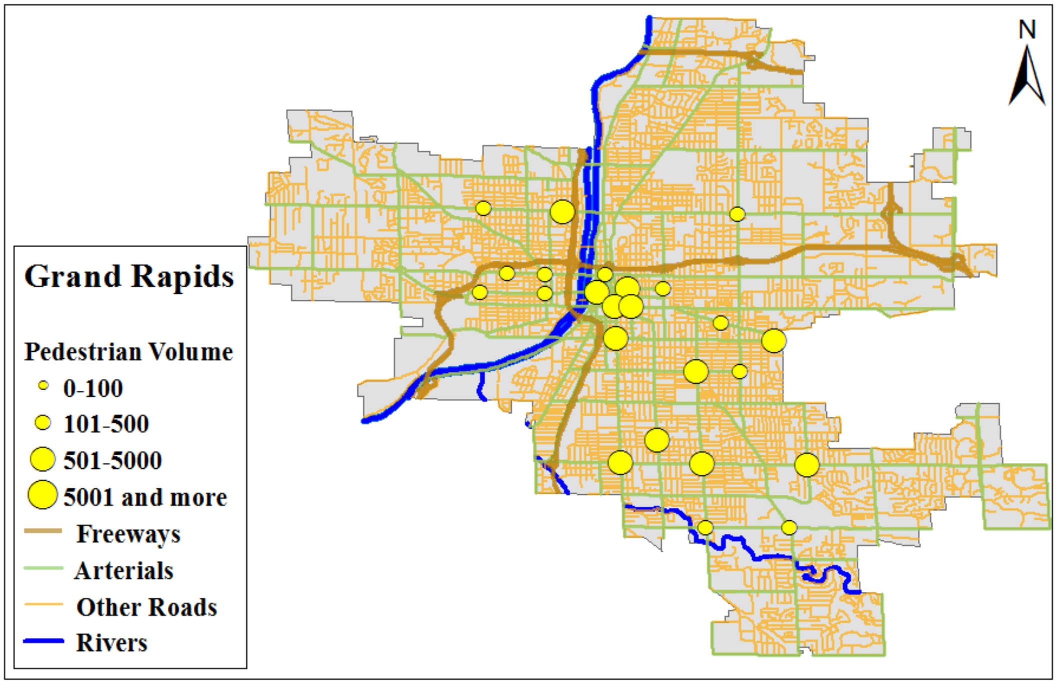


(a) Pedestrian

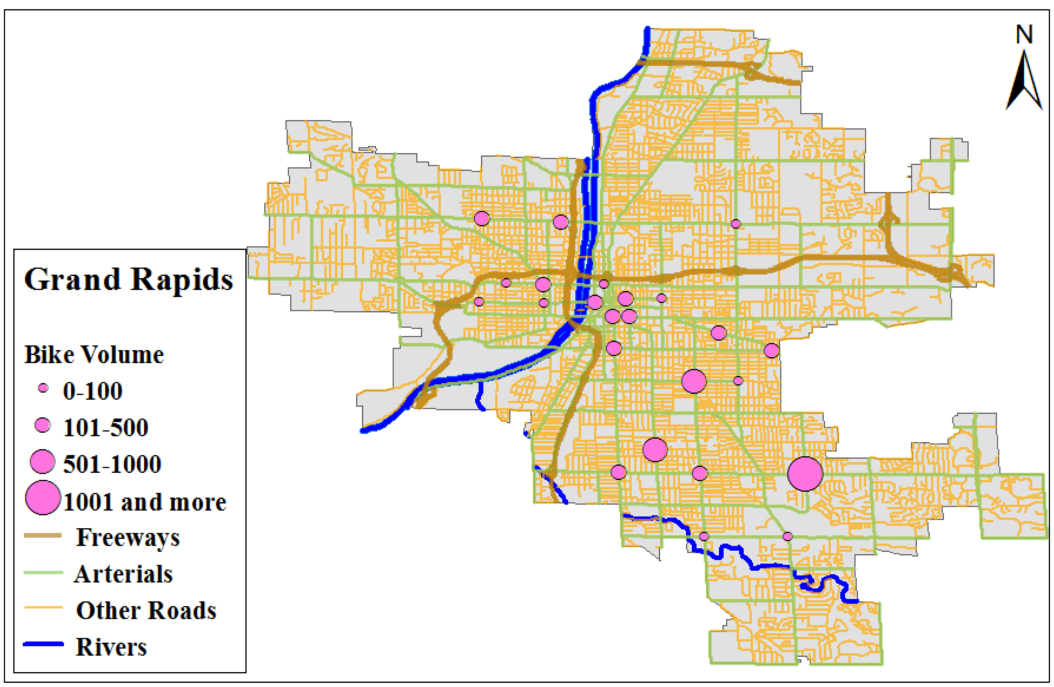


(b) Bicycle

Figure 4-5 Non-motorized Volume, Flint



(a) Pedestrian



(b) Bicycle

Figure 4-6 Non-motorized Volume, Grand Rapids

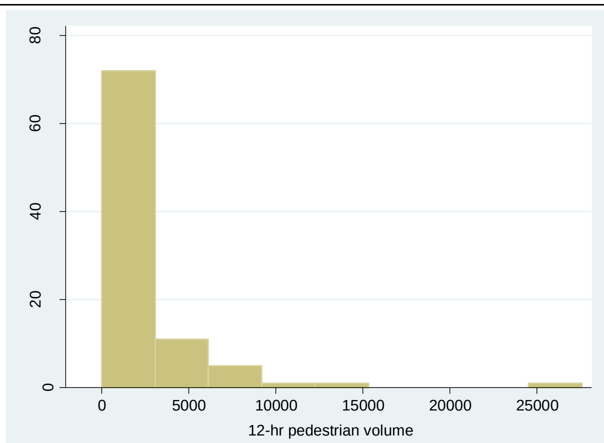
4.2.4 Demographic and Spatial Data

As described in Chapter 3, this study developed a GIS database that includes not only demographic and socio-economic data, but also spatial data related with non-motorized transportation and activities, transportation facility data, and non-motorized crash data.

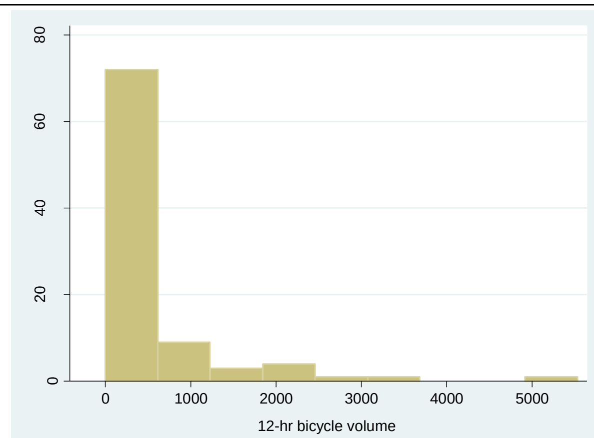
- *Demographic and socio-economic data:* 2010 data at the census block and the census tract levels (demographics and socio-economic level) were obtained from the Census Bureau website. Since the publicly available data at the census block level were limited, demographic data were extracted from census blocks and socio-economic data were acquired from census tracts.
- *Spatial data related with non-motorized transportation and activities*: Some land uses generate activities impacting pedestrian exposure or crash rates. Pedestrian interactions with other modes in road networks are scattered geographically. In this study, spatial analysis was the key to analyzing the impact of characteristics of different locations on non-motorized dynamics. Spatial data included land-use, bus stops, schools, liquor stores, bars, retails, and many non-motorized traffic attractors (e.g., university buildings, churches, libraries, terminals, museums, hospitals and government offices). These data were collected from city GIS databases, Google Earth, or ESRI GIS databases. All data were transferred to the GIS database to allow geo-spatial analysis.
- *Other spatial and transportation data*: GIS data for city limits and, road networks were retrieved from the Michigan Department of Technology's, Management and Budget (DTMB) website (www.michigan.gov/cgi). The boundary of each city was used to trim the extent of the road networks.
- *Non-motorized crash data*: Crash data from 2004 to 2012 were obtained from the Michigan State Police. The geocoded crash data were added into the GIS database with all attributes.

4.3 Modeling Pedestrian and Bicycle Volumes

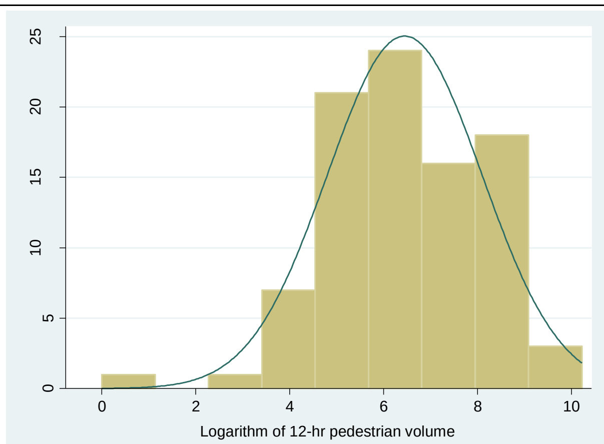
For modeling pedestrian and bicycle volume, data from 91 signalized intersections in four Michigan cities (i.e., Ann Arbor, East Lansing, Flint and Grand Rapids) were processed. In addition to the processed pedestrian and bicycle volume data, land use, demographic and other intersection characteristics within both 1/4-mile and 1/2-mile buffers were also processed from the GIS database. With collected and extrapolated pedestrian and bicycle volumes, individual models that can be used to estimate pedestrian and bicycle volumes at signalized intersections were developed. In order to determine the appropriate modeling approach for each volume dataset, their distributions were first examined. Figure 4-7 (a) and (b) show that none of the volumes followed normal distribution; hence, rendering ordinary least square (OLS) estimation is inappropriate for the datasets. However, transformation of the volumes by applying a natural logarithm resulted in approximate normal distributions as shown in Figure 4-7 (c) and (d).



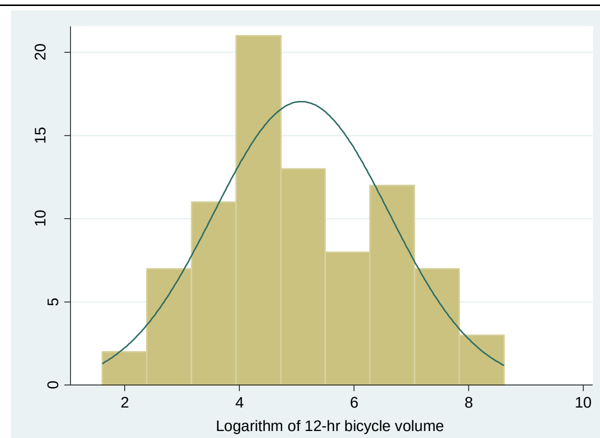
(a). Distribution of 12-hour pedestrian volume



(b). Distribution of 12-hour bicycle volume



(c). Distribution of logarithm of 12-hour pedestrian volume



(b). Distribution of logarithm of 12-hour bicycle volume

Figure 4-7 Distribution of Transformed and Non-transformed Volumes

Detailed examination of the data indicated that the pedestrian dataset was characterized with high volumes, which suggested that a log-linear model was appropriate. Greene (2012) provides derivation of the log-linear model, which takes the form of:

$$E[ln(y)|\boldsymbol{X}] = \alpha + \boldsymbol{X}'\boldsymbol{\beta} \quad (4\text{-}3)$$

For bicycle volume, however, it was observed that about 8 percent of intersections had zero bicycle counts, and a 25 percentile of the observations were less than 45 bicycles compared to 233 pedestrians. Therefore, the commonly used count data model distribution (Poisson and Negative Binomial), was tested for suitability. Standard textbooks (Hilbe 2011, Greene 2012, Washington et al, 2011) present clear derivation of the Poisson and Negative Binomial (NB) models. Under Poisson distribution assumption, the mean and variance of bicycle volume at a signalized intersection are equal (i.e. $E[y_i] = Var[y_i]$). However, the bicycle volume data collected in this study indicated significantly different mean and standard deviation as shown in Table 4-2. To handle the cases where the mean and variance are not equal, the Poisson model is generalized by introducing an individual, unobserved effect, ε_i, in the function relating bicycle volume and explanatory variables as follows:

$$\lambda_i = EXP(\boldsymbol{\beta}\boldsymbol{X}_i + \varepsilon_i) \quad (4\text{-}4)$$

in which $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean one and variance α^2. With such a modification, the mean λ_i becomes a variable that follows binomial distribution. The mean-variance relationship becomes:

$$Var[y_i] = E(y_i) \cdot [1 + \alpha E(y_i)] = E[y_i] + \alpha E(y_i)^2 \quad (4\text{-}5)$$

If α is equal to zero, the negative binomial distribution reduces to Poisson distribution. If α is significantly different from zero, the bicycle volume data are said to be over-dispersed (positive value) or under-dispersed (negative value). When α is significantly different from zero, the resulting negative binomial probability distribution is:

$$P(y_i) = \frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y_i\right)}{\Gamma\left(\frac{1}{\alpha}\right) y_i!} \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right) + \lambda_i}\right)^{y_i} \tag{4-6}$$

where $\Gamma(x)$ is a value of the gamma function, y_i is the number of bicycles at a signalized intersection; *i* and α is an over-dispersion parameter.

Table 4-2 presents descriptive statistics of the variables used to estimate both the pedestrian and bicycle models. As it can be seen, the mean of bicycle volume is significantly different from the variance (458.97 vs. $(857.17)^2$).

Table 4-2 Descriptive Statistics of the Variables Used to Estimate Models

Variable	Mean	Std. Dev.	Min	Max
Pedestrian Model				
Logarithm of 12-hr pedestrian volume	6.45	1.65	0.00	10.22
Indicator of campus landuse within 1/4-mile buffer	0.19	0.39	0.00	1.00
Number of retail stores within 1/4-mile buffer	7.16	11.81	0.00	70.00
Indicator of presence of bus stop within 1/4-mile buffer	0.96	0.21	0.00	1.00
Total population within 1/4-mile buffer	1371.82	1165.57	0.00	5574.92
Bicycle Model				
12-hr bicycle volume	458.97	857.17	0.00	5533.00
Indicator of campus landuse within 1/2-mile buffer	0.14	0.35	0.00	1.00
Indicator of residential landuse within 1/2-mile buffer	0.68	0.47	0.00	1.00
Indicator of presence of bike lane with 1/2-mile buffer	0.37	0.49	0.00	1.00
Total population within 1/2-mile buffer	5145.08	3370.382 9	32.90	15973.78

The statistical software Stata 12™ was used to estimate both the log-linear model for pedestrian volume and the negative binomial model for bicycle volume. Table 4-3 presents the log-linear model results for pedestrian volume.

Table 4-3 Estimated Parameters for Pedestrian Volume Model

Natural Log of Observed Pedestrian Volume	Coefficient	Std. Err.	t-statistic
Population with 1/4 mile (Pop_25)	0.0009	0.0001	6.23
Retail stores within 1/4 mile (No_retail_25)	0.0541	0.0107	5.07
Schools within 1/4 mile (No_sch_25)	0.4018	0.2049	1.96
Motorized commuters within 1/4 mile (Motor_com_25)	-0.0014	0.0007	-2.18
Presence of bus stop within 1/4 mile (Dum_bus _25)	1.3787	0.5609	2.46
Presence of campus within 1/4 mile (Dum_cam_25)	1.6867	0.3243	5.20
Model Constant	3.6779	0.5525	6.66

Auxiliary Statistics
Number of obs = 91
F(6, 84) = 20.83
Prob > F = 0.0000
R-squared = 0.5981
Adj R-squared = 0.5694
Root MSE = 1.0813

The results in Table 4-3 indicate that a signalized intersection located on campus land-use is likely to have more pedestrian volume compared to an intersection located elsewhere. Similarly, the number of retail stores within a 1/4-mile radius; presence of a bus stop within a 1/4-mile buffer; total population within a 1/4-mile; and number of schools within a 1/4-mile radius, increase the pedestrian volume observed at signalized intersections. Conversely, the large number of motorized commuters within a 1/4-mile radius of a signalized intersection reduces the pedestrian volume.

Table 4-4 presents the results of the bicycle volume model. Similar to the pedestrian volume, the results indicate that a signalized intersection in the vicinity or located on a campus have more bicyclist volume compared to intersections located elsewhere. In addition, a signalized intersection located in a business area is more likely to have higher bicycle volume. The data also showed that the population within a 1/2-mile buffer of a signalized intersection is significantly important in estimating bicycle volume – with a positive impact on the number of bicycles. It was however found that the number of crimes within a 1/4-mile radius of an intersection reduce the number of bicyclists at the intersection.

Table 4-4 Estimated Parameters for Bicycle Volume Model

Observed Bicycle Volume	Coefficient	Std. Err.	z-statistic
Presence of campus within 1/2 mile (Dum_cam_50)	1.32671	0.40195	3.30
Business land-use within 1/2 mile (Dum_business_50)	1.43488	0.32251	4.45
Population within 1/2 mile (Pop_50)	0.00020	0.00005	4.00
Number of crimes within 1/4 mile (No_crime _25)	-0.00337	0.00159	-2.12
Model Constant	3.44674	0.28674	12.02
/lnalpha	0.29428	0.13913	
alpha	1.34216	0.18673	

Auxiliary Statistics
Number of obs = 91
LR chi2(4) = 69.70
Prob > chi2 = 0.0000
Log likelihood = -581.40038
Pseudo R2 = 0.0566
Likelihood-ratio test of alpha=0: chibar2(01) = 4.1e+04, Prob>=chibar2 = 0.000

Validity of the models for pedestrian and bicycle volumes presented above was checked by bootstrapping – a statistical approach in which properties of an estimator (e.g., the variance) are estimated through resampling techniques. The bootstrapping results indicated a prediction error of 0.223 for pedestrian model and a prediction error of 59.8 for bicycle model. It should be noted that the pedestrian error is based on logarithm of the volume. Pedestrian and bicycle volume at any intersection can be estimated with the formula below.

- Pedestrian Volume = exp (3.6779 + 0.0009 Pop_25 + 0.0541 No_retail_25 + 0.4018 No_sch_25 - 0.0014 Motor_com_25 + 1.3787 Dum_bus_25 + 1.6867 Dum_cam_25)
- Bicycle Volume = exp (3.44674 + 1.32671 Dum_cam_50 + 1.43488 Dum_business_50 + 0.00020 Pop_50 – 0.00337 No_crime_25)

where

Pop_25 = population within a 1/4 mile radius

No_retail_25 = the number of retail stores within a 1/4 mile radius

No_sch_25 = the number of schools within a 1/4 mile radius

Motor_com_25 = the number of motor commuters within a 1/4 mile radius

Dum_bus_25 = 1 if a bus stop is located within a 1/4 mile radius; 0 otherwise

Dum_cam_25 = 1 if the dominant lane use within a 1/4 mile is campus; 0 otherwise

Dum_cam_50 = 1 if the dominant lane use within a 1/2 mile is campus; 0 otherwise

Dum_business_50 = 1 if the land use within a 1/2 mile radius is business; 0 otherwise

Pop_50 = population within a 1/2 mile radius

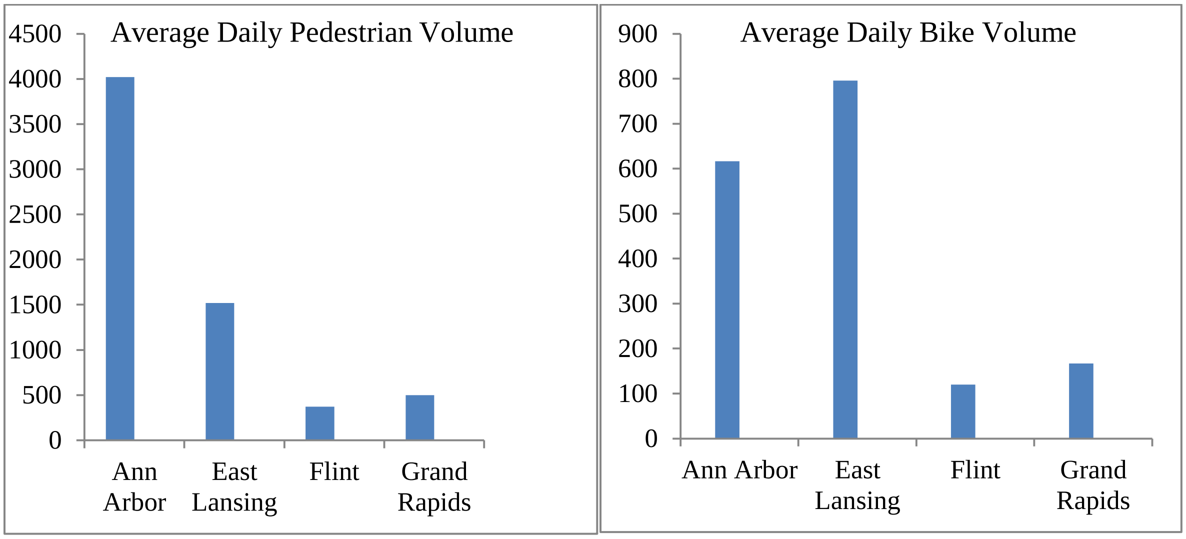
No_crime_25 = the number of crimes within a 1/4 mile radius

4.4 Estimation of Non-motorized Volume

In this study, exposures at intersections were estimated using the volume models developed in the previous section. Understandably, the observed exposure measures are desirable, but the non-motorized volume models developed in this study can provide rough estimates for the intersections where non-motorized volume data are unavailable. For more accurate models, extensive data collection efforts are needed. The models were applied to all signalized intersections in the four cities. Although the exposures were limited only to signalized intersections, the average value for a given area can represent overall pedestrian or bicyclist exposure. Table 4-5 and Figure 4-8 compare the averages of estimated pedestrian and bicycle volumes for each city. Ann Arbor and East Lansing were estimated to have more non-motorized traffic than the other two cities mainly due to the universities. While the pedestrian volume was the most in Ann Arbor, the bicycle volume was the most in East Lansing. The estimated exposure measures represent the characteristics of each city's non-motorized transportation environment.

Table 4-5 Estimated Average Daily Non-Motorized Volumes Per Signalized Intersection

City	Number of Pedestrians	Number of Bicyclists
Ann Arbor	4,020	617
East Lansing	1,518	796
Flint	370	120
Grand Rapids	499	167



(a) Pedestrian (b) Bicycle

Figure 4-8 Estimated Average Non-motorized Volume Per Signalized Intersection

4.5 Summary

This study developed models for estimating pedestrian and bicycle volumes at signalized intersections, and estimated exposure measures for each city. Through data collection, sensor data validation, and data extrapolation, a set of pedestrian and bicycle data was prepared for modeling exposure measures and evaluating non-motorized safety performance. In this study, after carefully reviewing data distribution, a log-linear regression model and a negative binomial model were adopted for developing the pedestrian and bicycle volume models, respectively. Using the models, pedestrian and bicycle volumes for a total of 768 intersections in four cities were estimated. The average value for all signalized intersections was used as a representative pedestrian/bicycle volume for each city.

Chapter 5 Crash Data Analysis

5.1 Introduction

In Chapter 3, data was prepared in ArcGIS as point data (crash, crime locations, facility locations, etc.), line data (roadways, sidewalks, bicycle lanes, etc.), area data (land use) or data aggregated by census block or tract (socioeconomic and demographic data). To use these data for modeling and analysis, the data were reprocessed in different aggregation levels. For intersection pedestrian and bicycle volumes, all socioeconomic data was reprocessed for each intersection.

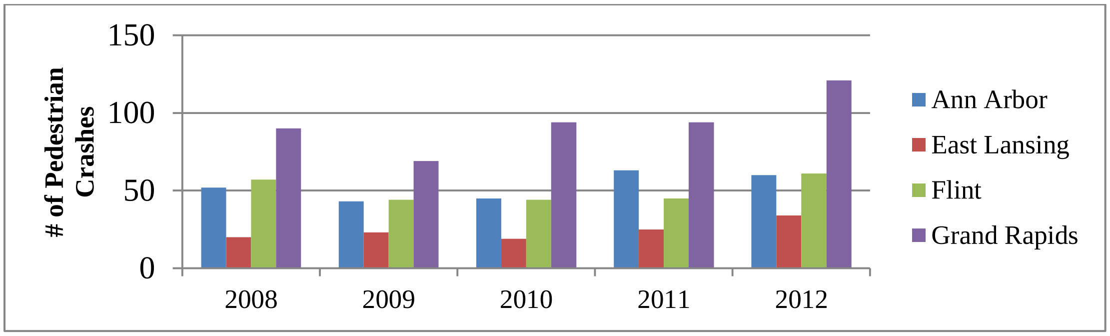
As analyzed in Chapter 3, non-motorized crash frequency and severity vary by city. In this study, this variation was investigated by determining and evaluating the significant variables that affect crash frequency and severity. At the census tract level, the study evaluated the effects of socio-economic, demographic, exposure and physical feature variables on crashes in an effort to develop crash prediction models.

Although analysis of crash data at the census tract level may explain the effects of significant census tract characteristics on crashes, the census tract spans a large geographic area, which may lead to unreliable inferences. In order to investigate whether factors such as non-motorized facility features and traffic characteristics impact non-motorized crashes, corridor-level analyses were performed. Since corridors consist of two components (intersection and midblock), the corridor-level analyses evaluated each of these components separately. For each component, traffic and other physical features, which may impact crash frequency and severity, were investigated to develop safety performance functions (SPFs). SPFs predict the number of crashes expected at a particular level of analysis based on a statistical analysis of the relationship between various factors on observed crash frequencies.

5.2 Observed Non-Motorized Crash Frequency

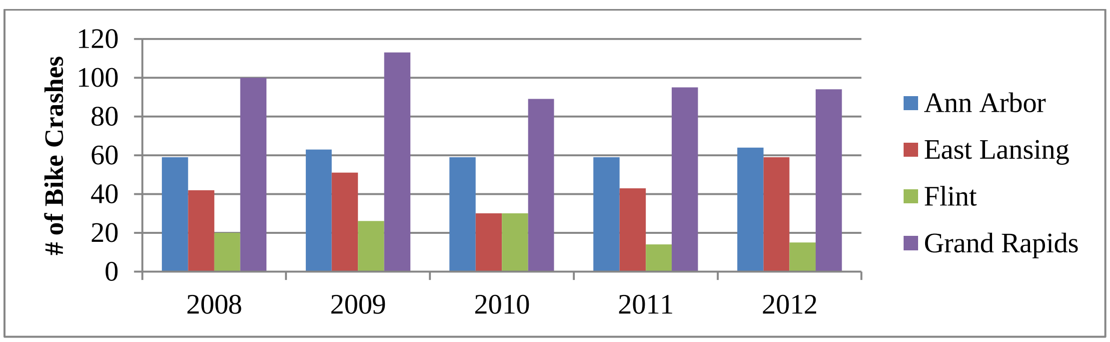
5.2.1 City-wide Analysis

As illustrated in Figure 5-1 and Figure 5-2, the number of pedestrian and bicycle crashes is different among the cities. As seen in Figure 5-1, pedestrian crash frequency during the five-year analysis period was highest in Grand Rapids and lowest in East Lansing. As shown in Figure 5-2, the number of bike crashes was highest in Grand Rapids and lowest in Flint. Flint likely has low bike crash frequency due to the low number of bike commuters or bike volumes (exposure), as shown by census data and count numbers.



City	Number of Pedestrian Crashes					
	2008	2009	2010	2011	2012	Total
Ann Arbor	52	43	45	63	60	263
East Lansing	20	23	19	25	34	121
Flint	57	44	44	45	61	251
Grand Rapids	90	69	94	94	121	468

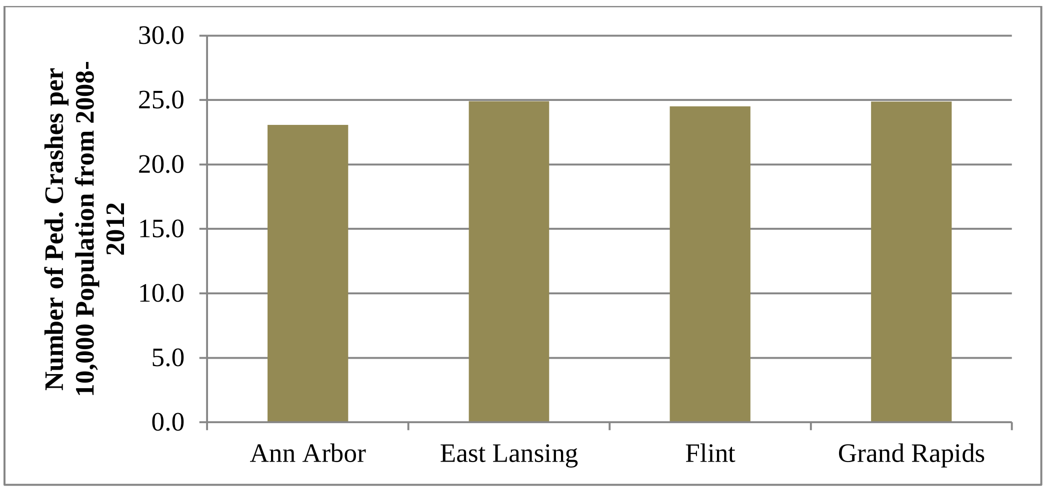
Figure 5-1 Pedestrian Crash Frequency by City



City	Number of Bike Crashes					
	2008	2009	2010	2011	2012	Total
Ann Arbor	59	63	59	59	64	304
East Lansing	42	51	30	43	59	225
Flint	20	26	30	14	15	105
Grand Rapids	100	113	89	95	94	491

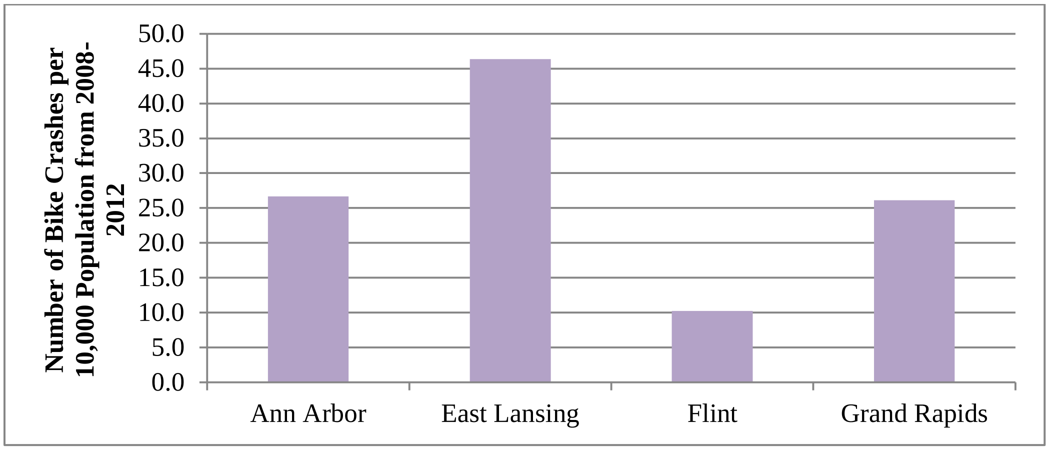
Figure 5-2 Bike Crash Frequency by City

Although the number of crashes could be a good measure to evaluate cities in terms of non-motorized safety, as mentioned before, populations vary by city. To more accurately reflect crash frequency performance, the number of crashes per 10,000 people was determined for each city, as shown in Figure 5-3 and Figure 5-4. As illustrated in Figure 5-3, all cities perform similarly with regard to population-based pedestrian crash frequency. However, Figure 5-4 reveals that population-based bike crash frequency varies widely by city, with crash rates being highest in East Lansing and lowest in Flint.



City	Total Number of Pedestrian Crash per 10,000 Population					
	2008	2009	2010	2011	2012	Total
Ann Arbor	4.6	3.8	3.9	5.5	5.3	23.1
East Lansing	4.1	4.7	3.9	5.1	7.0	24.9
Flint	5.6	4.3	4.3	4.4	6.0	24.5
Grand Rapids	4.8	3.7	5.0	5.0	6.4	24.9

Figure 5-3 Total Number of Pedestrian Crashes per 10,000 Population



City	Total Number of Bike Crash per 10,000 Population					
	2008	2009	2010	2011	2012	Total
Ann Arbor	5.2	5.5	5.2	5.2	5.6	26.7
East Lansing	8.6	10.5	6.2	8.9	12.2	46.3
Flint	2	2.5	2.9	1.4	1.5	10.3
Grand Rapids	5.3	6	4.7	5.1	5	26.1

Figure 5-4 Total Number of Bike Crashes per 10,000 Population

As discussed in Chapter 4, exposures at intersections were measured based on the volume models developed in this study. Based on the exposure measures estimated from all signalized intersections, the exposure-based safety performances for pedestrian, $PM(p)$, and for bicyclists, $PM(b)$, are measured as shown below:

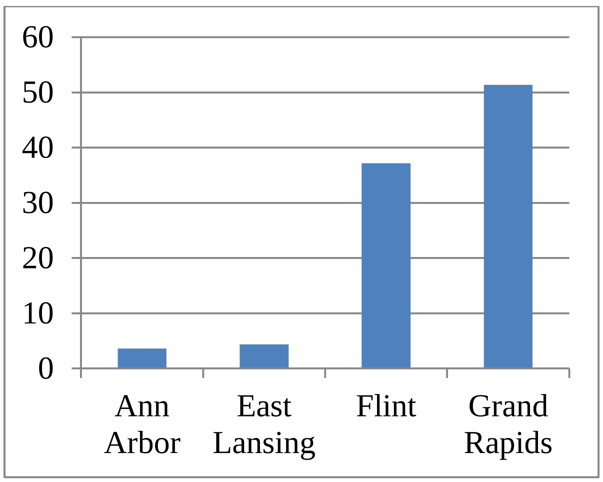
$$PM(p) = \frac{Number\ of\ Pedestrian\ Crashes}{Total\ Pedestrian\ Exposures}$$

$$= \frac{Number\ of\ Pedestrian\ Crashes \times 100{,}000}{\text{Average Daily Pedestrian Volume} \times 365 \times \text{Number of Analysis Year}}$$

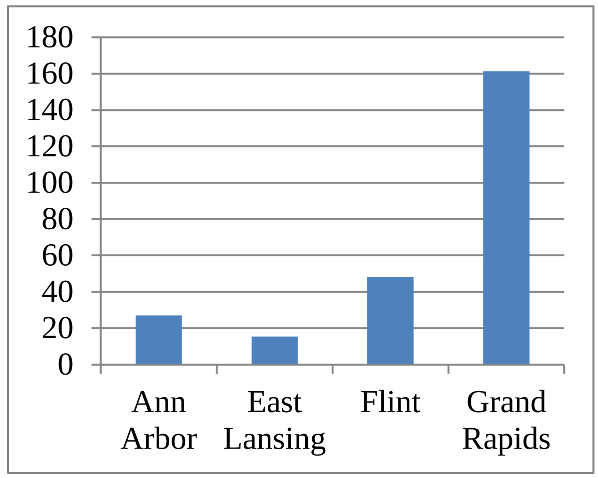
$$PM(b) = \frac{Number\ of\ Bicycle\ Crashes}{Total\ Bicycle\ Exposures}$$

$$= \frac{Number\ of\ Bicycle\ Crashes \times 100{,}000}{\text{Average Daily Bicycle Volume} \times 365 \times \text{Number of Analysis Year}}$$

The exposure-based performance measures indicate the number of crashes involving a pedestrian (or a bicyclist) when crossing intersections 100,000 times. As shown in Figure 5-5, the exposure-based performance measures were high in Grand Rapids and Flint. These measures were different from population-based measures in Figure 5-3 and Figure 5-4. While population-based measures may be regarded as general performance measures, the exposure-based measures provide direct risks for pedestrian or bicyclists.



(a) Pedestrian Crashes per 100,000 Pedestrian Exposures at Signalized Intersection



(b) Bicycle Crashes per 100,000 Bicyclist Exposures at Signalized Intersection

Figure 5-5 Exposure-based Non-Motorized Safety Performance Measures

Given that census tracts span a wide area, it might be more appropriate to focus on the smaller portions, or roads, as the most important physical feature. Each road type has different characteristics; there are different road lengths among the cities, and these variances among roads could affect crash frequency. Figure 5-6 shows the percentage of pedestrian crashes on different types of roads. As shown, most pedestrian crashes usually happen on arterials, thus increased attention should be paid to increasing safety of arterials. Figure 5-7 shows that except in East Lansing, bike crashes occurred more frequently on local roads compared to other types of roads. However, as with the pedestrian case, a large portion of bike crashes occurred on arterial roads. Therefore, transportation authorities should target bicycle safety improvement projects at local roads as well as arterial roads.

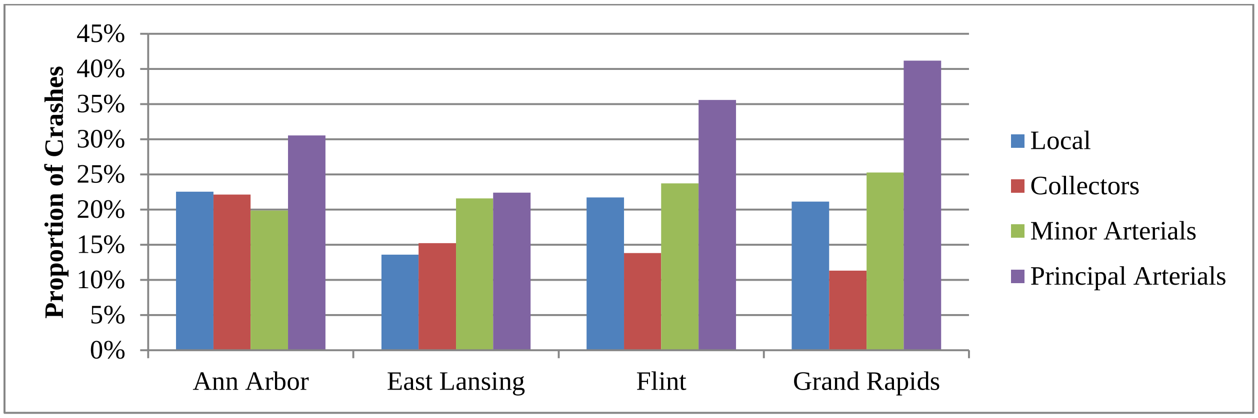


Figure 5-6 Pedestrian Crashes by Roadway Type

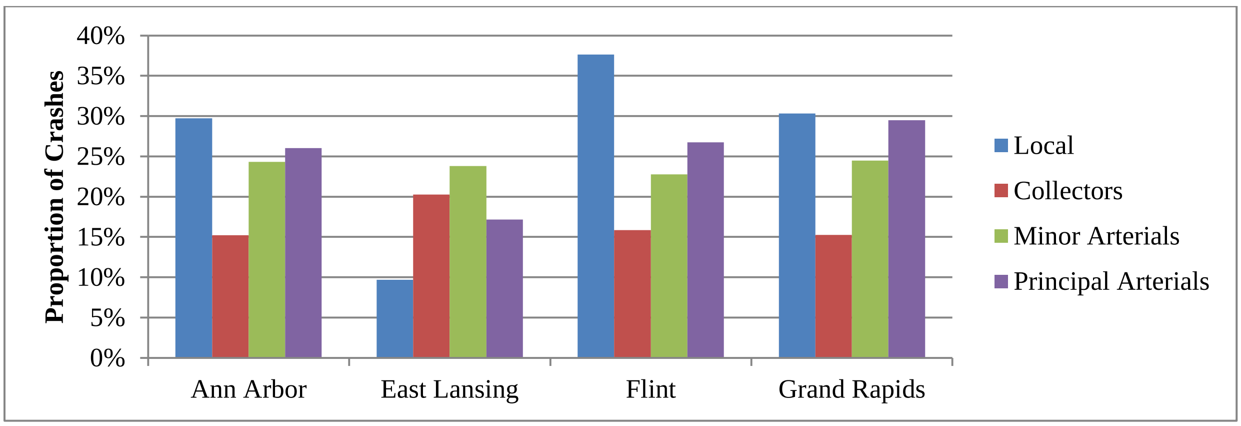
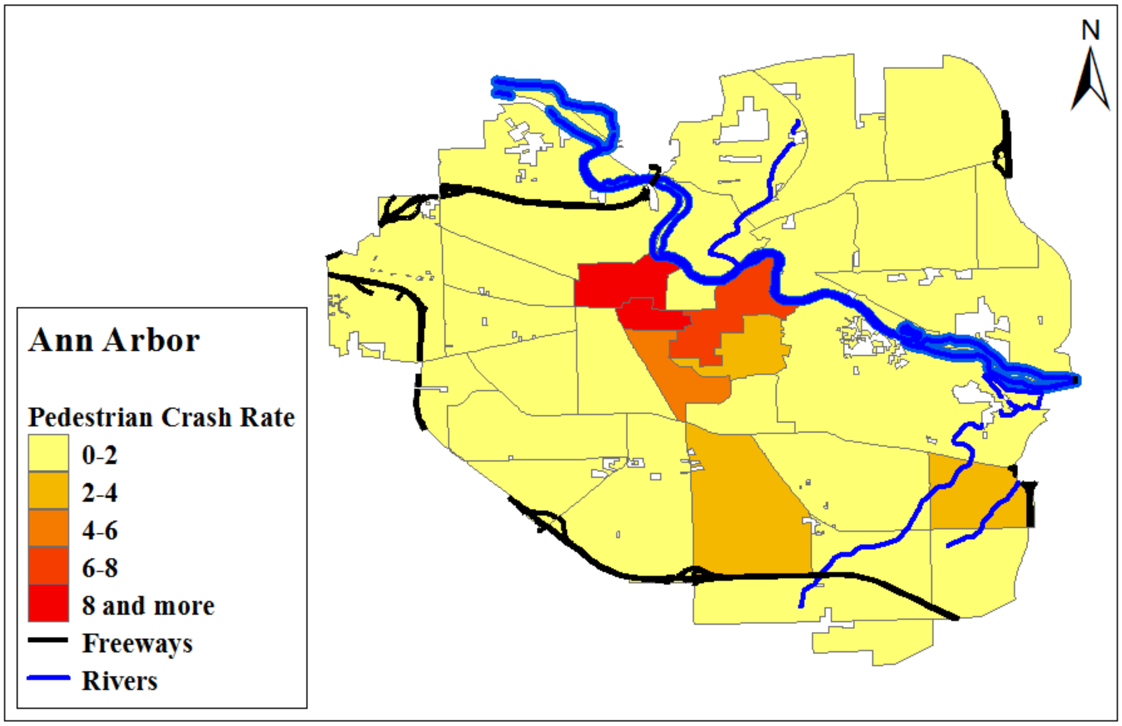


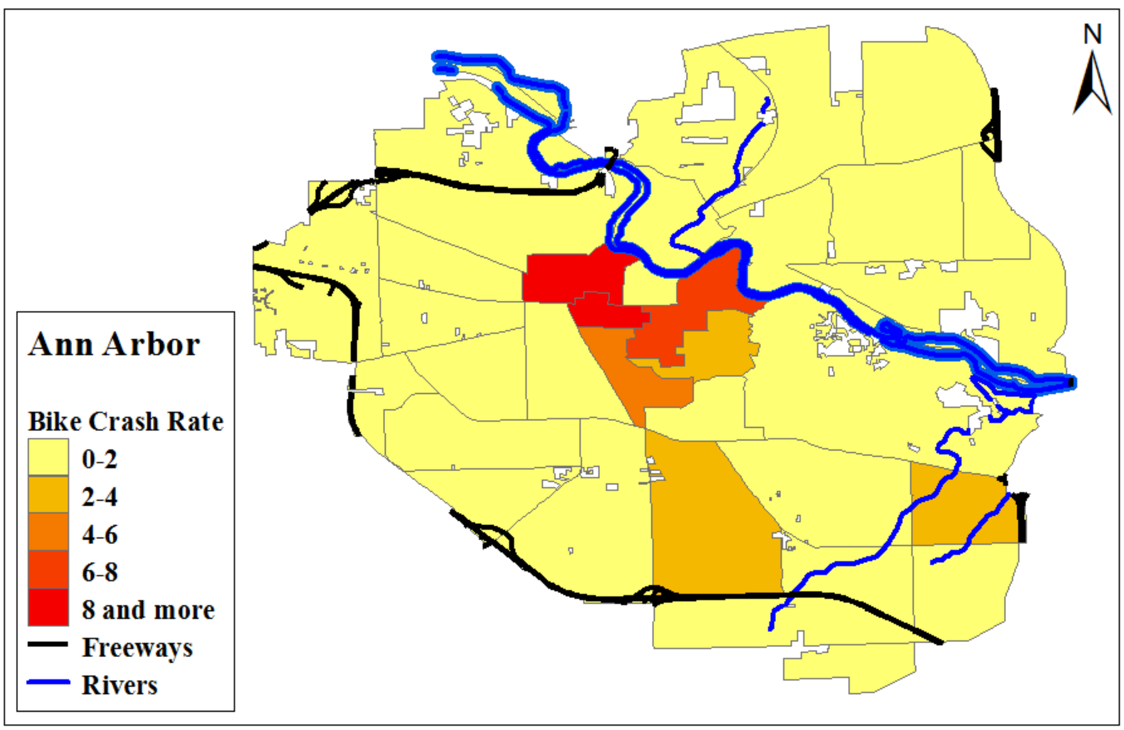
Figure 5-7 Bike Crashes by Roadway Type

5.2.2 Census Tract Level Analysis

Since city-wide crash statistics are simply aggregated census tract crash statistics, pedestrian crash rate by census tract for each city can be a good indicator of spatial distribution of non-motorized crashes, as displayed in Figure 5-8 - Figure 5-11. Crash rate varies by region within the cities, but it could be inferred that the crash rate in downtown areas is higher relative to other parts of the cities due to higher concentration of trip absorbing/creating features, such as retail, bars, governmental offices, etc. Also, since crashes are normalized by population, the rates in downtown areas are higher due to low population (based on residents). Figure 5-8 - Figure 5-11 also display bicycle crash frequency by census tract. Similar to pedestrian crashes, the concentration of bicycle crashes is highest in downtown areas, except for Flint, which had only 21 bicycle crashes on average between 2008-2012 (MTCF, 2013).

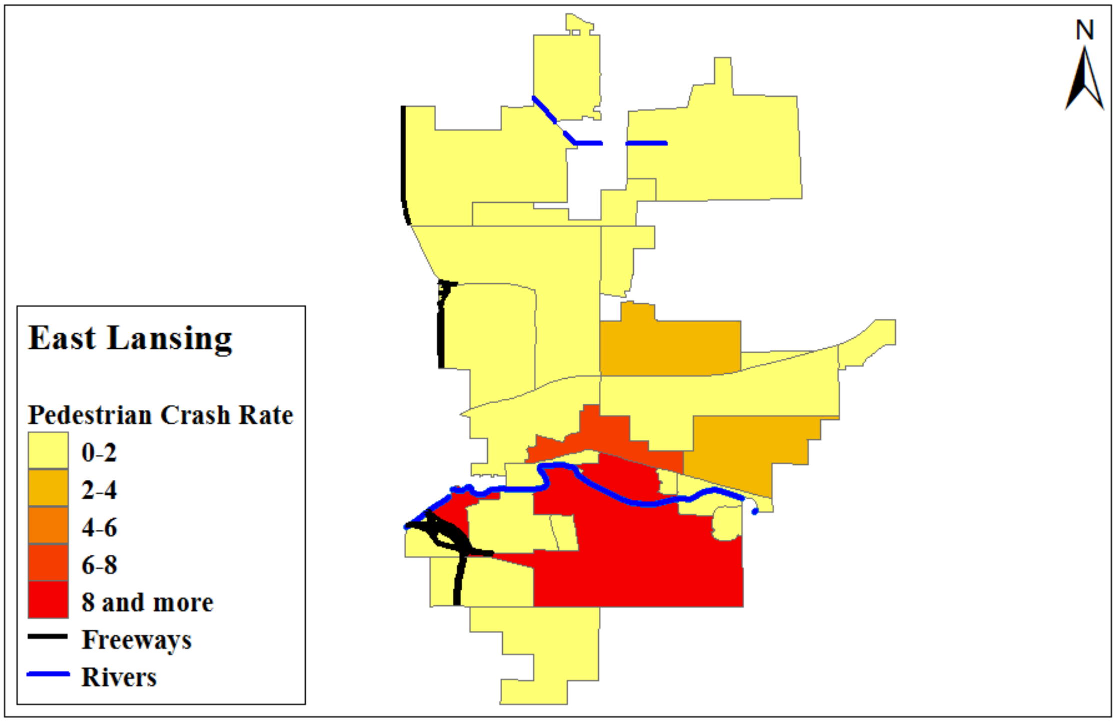


(a) Pedestrian

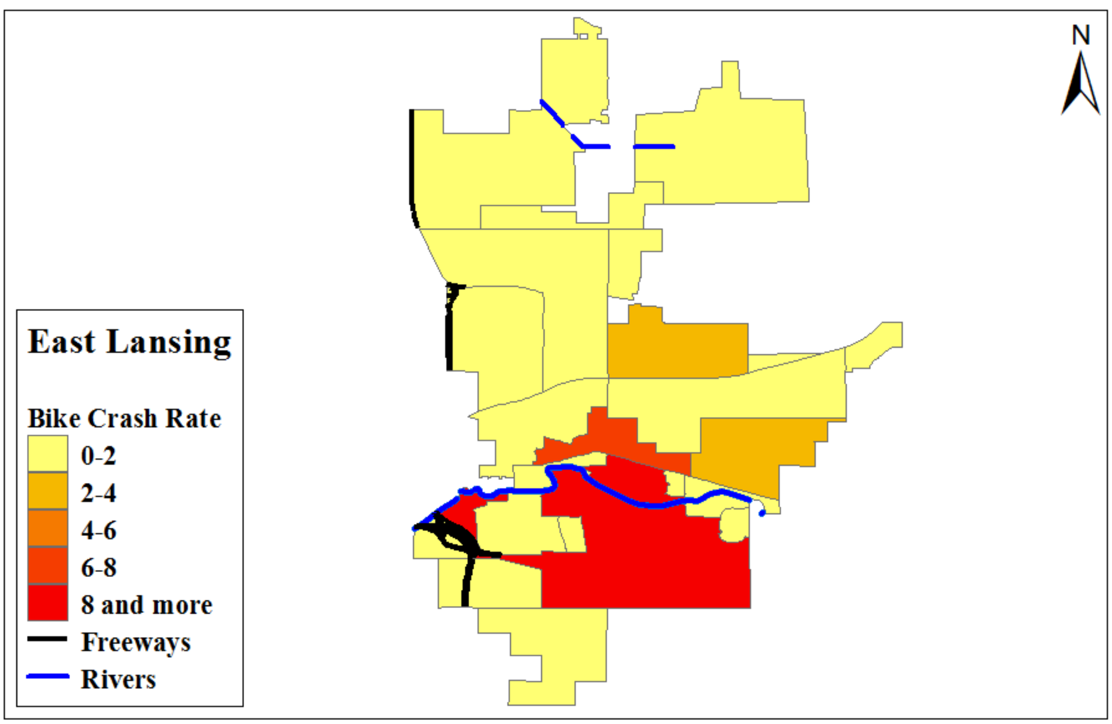


(b) Bicycle

Figure 5-8 Crash Rate Based on Population: Ann Arbor

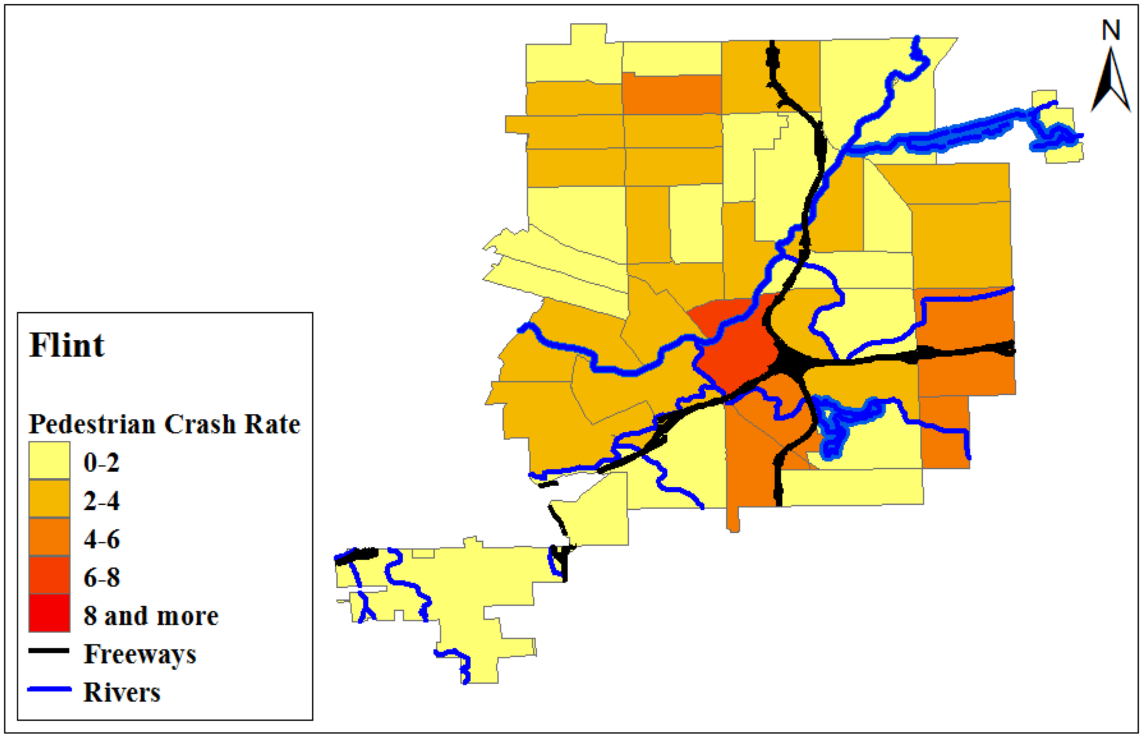


(a) Pedestrian

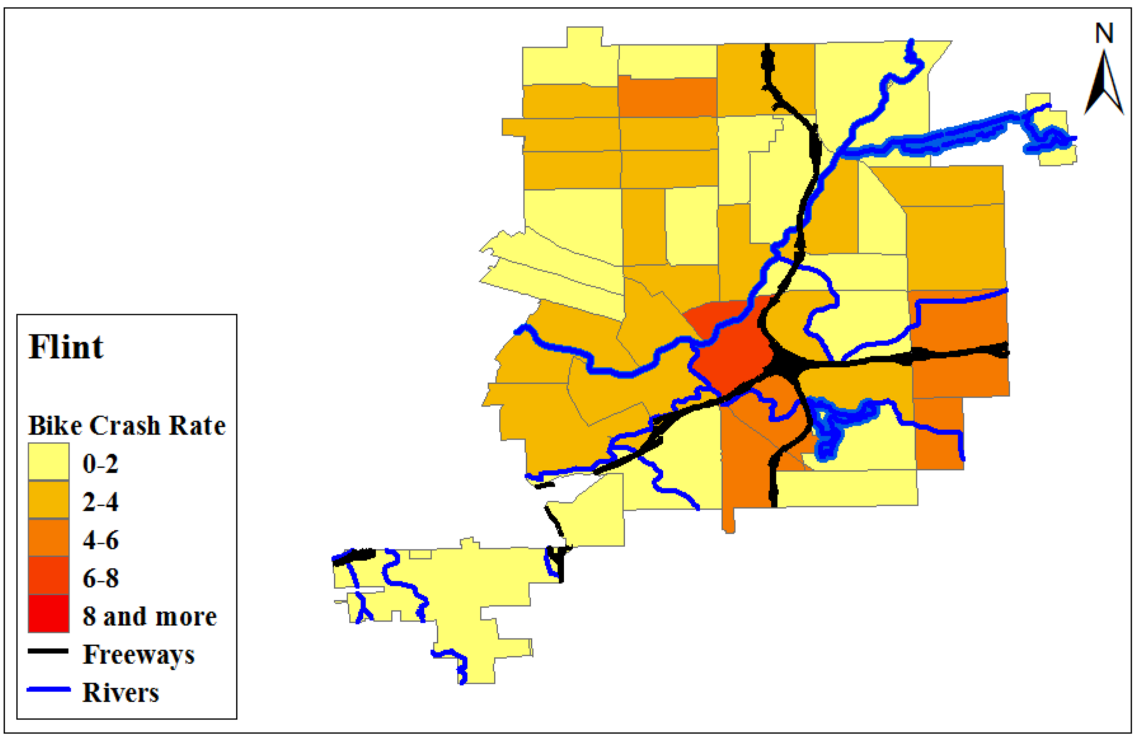


(b) Bicycle

Figure 5-9 Crash Rate Based on Population: East Lansing

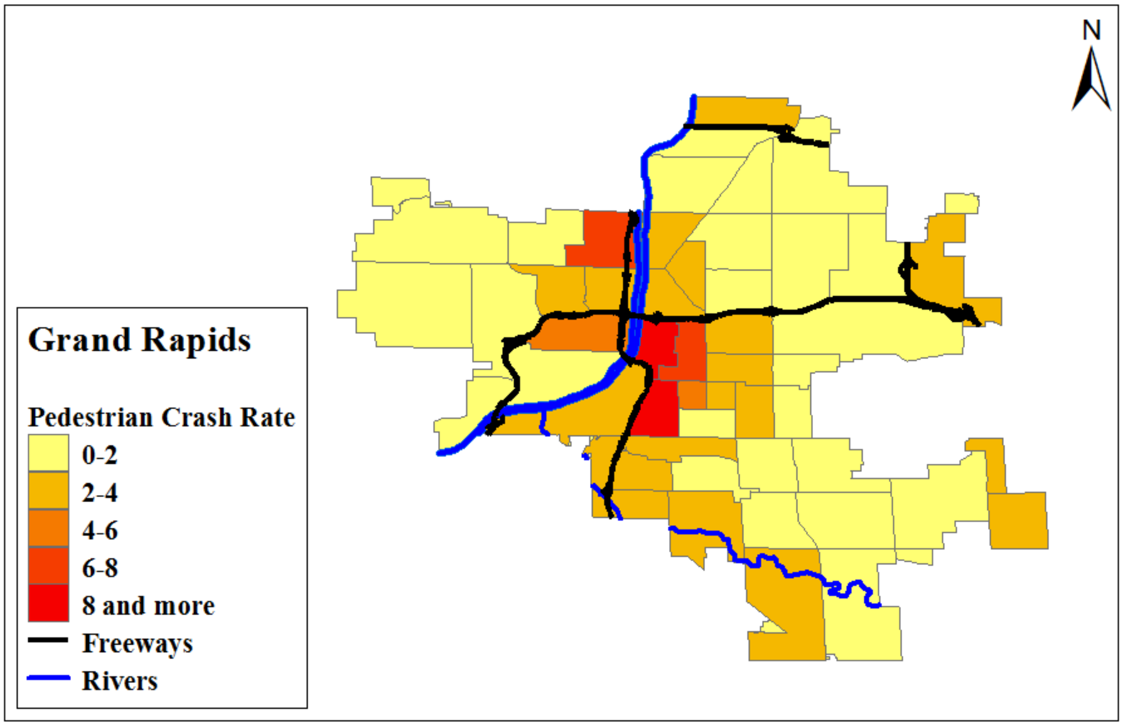


(a) Pedestrian

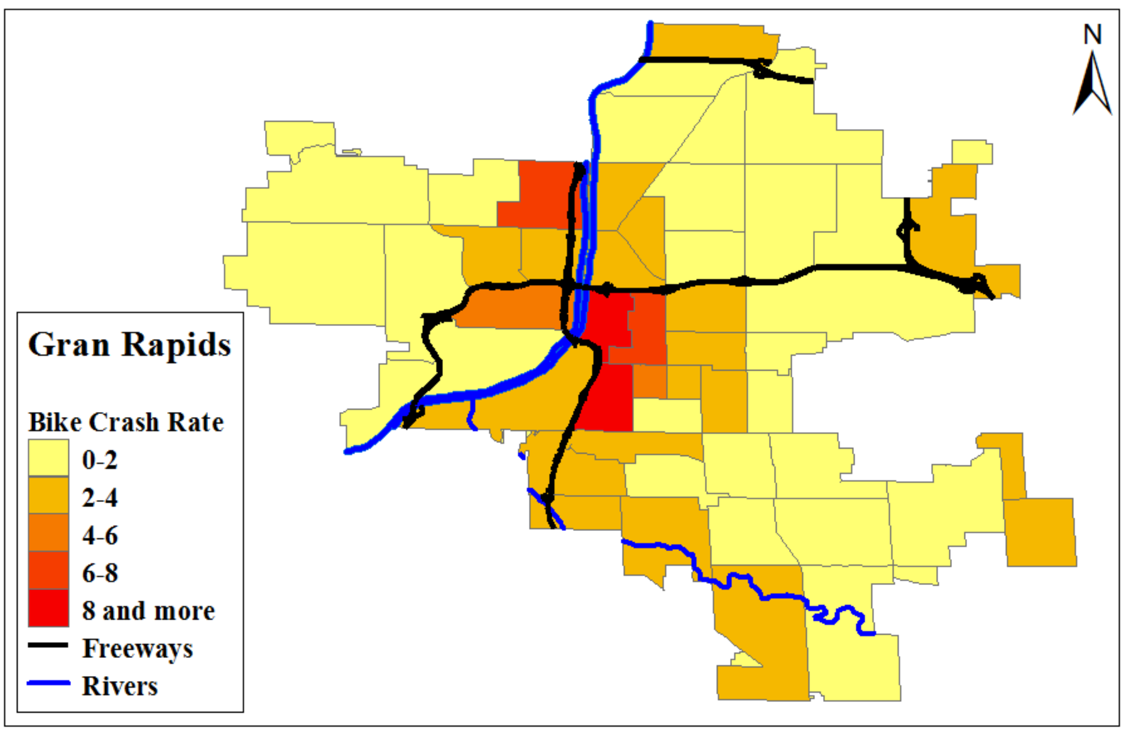


(b) Bicycle

Figure 5-10 Crash Rate Based on Population: Flint



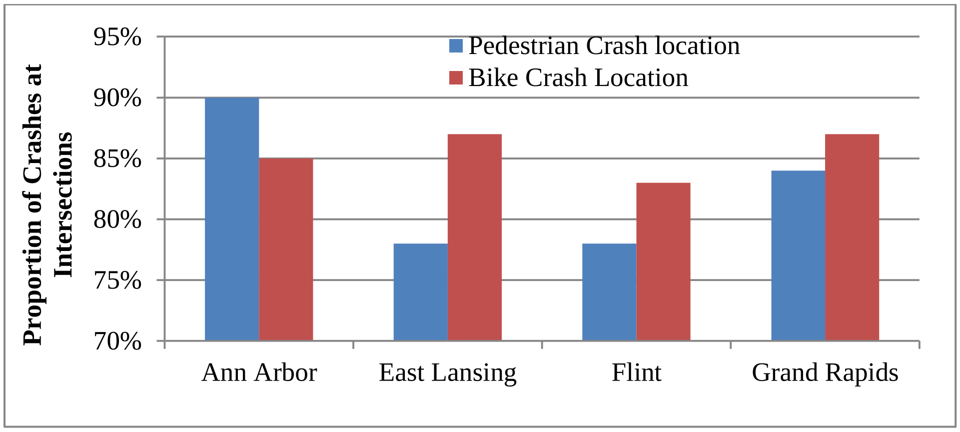
(a) Pedestrian



(b) Bicycle

Figure 5-11 Crash Rate Based on Population: Grand Rapids

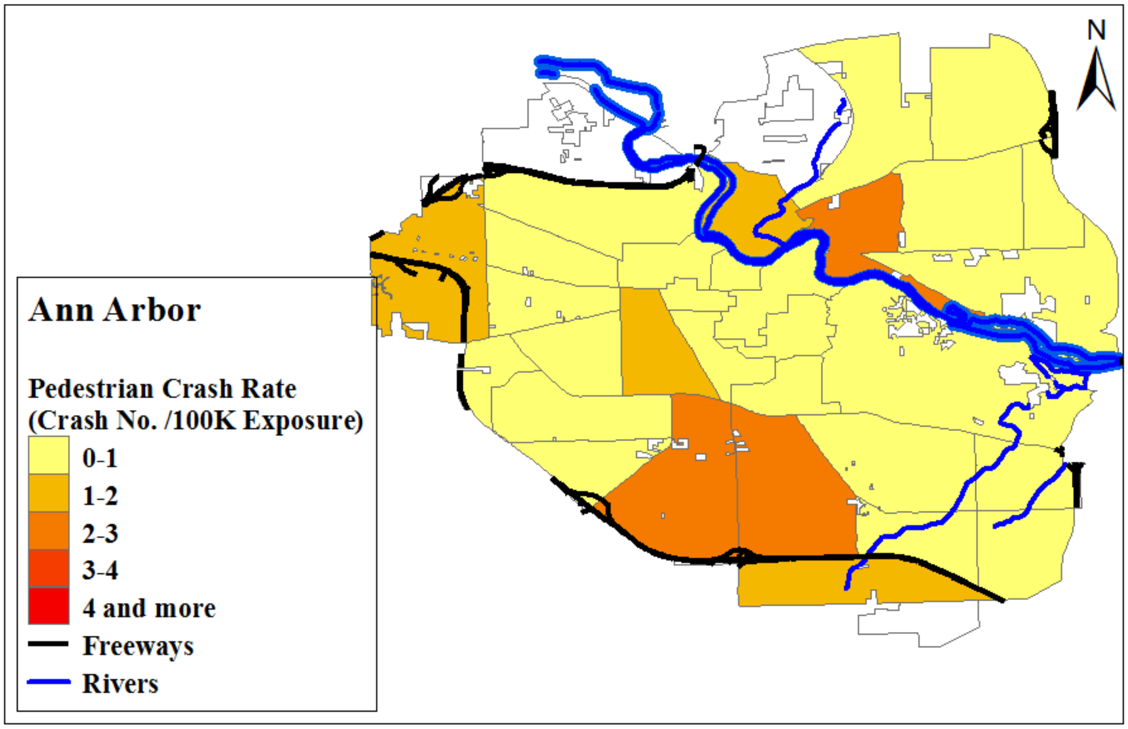
The next level of analysis investigated the two separate components of a street facility: intersections and mid-blocks. The frequency of non-motorized crashes on intersections versus mid-blocks was investigated as it was stipulated that non-motorized crashes tend to happen more often on intersections compared to mid-blocks. These results are displayed in Figure 5-12.



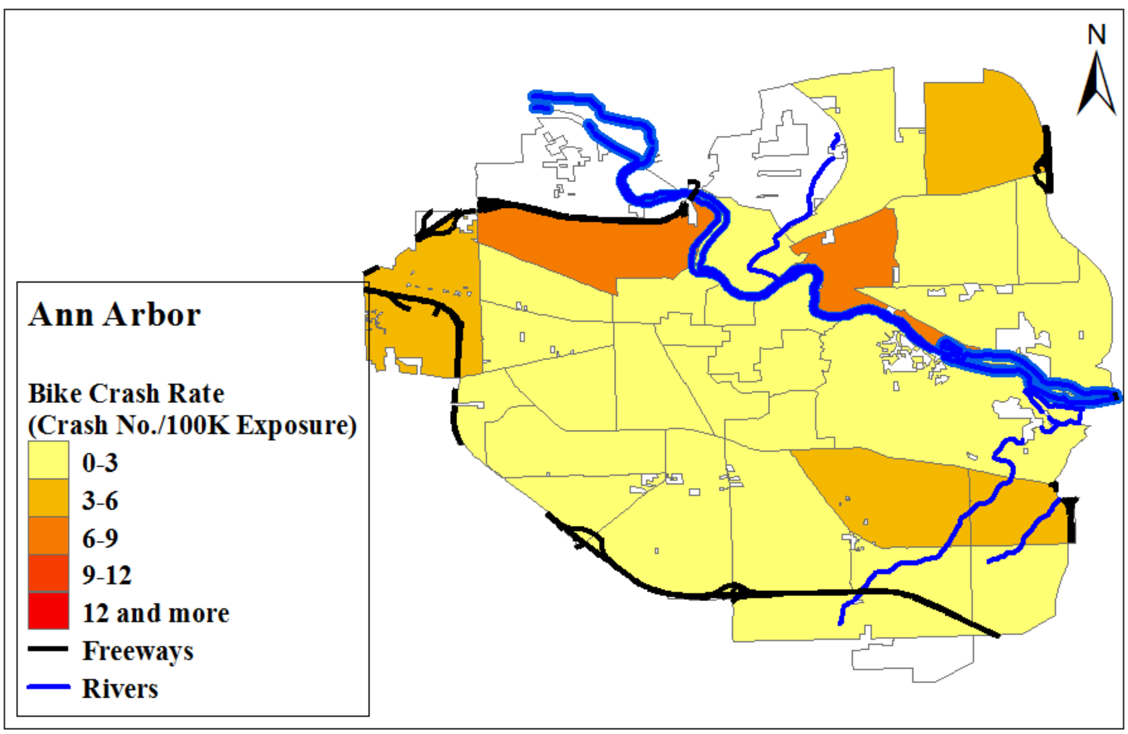
City	Pedestrian Crash location		Bike Crash Location	
	Intersection	Mid-Block	Intersection	Mid-Block
Ann Arbor	90%	10%	85%	15%
East Lansing	78%	22%	87%	13%
Flint	78%	22%	83%	17%
Grand Rapids	84%	16%	87%	13%

Figure 5-12 Percentage of Non-Motorized Crashes on Intersections

An important variable related to crashes at intersections is non-motorized exposure (i.e., volumes). Therefore, non-motorized exposure-based crash safety by census tract was investigated by calculating the number of non-motorized crashes per 100,000 estimated exposures (pedestrian or bicycle volume) at all signalized intersections within the census tract. Comparing exposure-based crash rates (Figure 5-13 - Figure 5-16) with population-based crash rates (Figure 5-8 - Figure 5-11), it could be inferred that the pedestrian crash rates based on population are high in the downtown areas. However, exposure-based crash rates are lower in downtown areas. This indicates that the exposure-based performance measures are important measures complementary to the population-based measures.

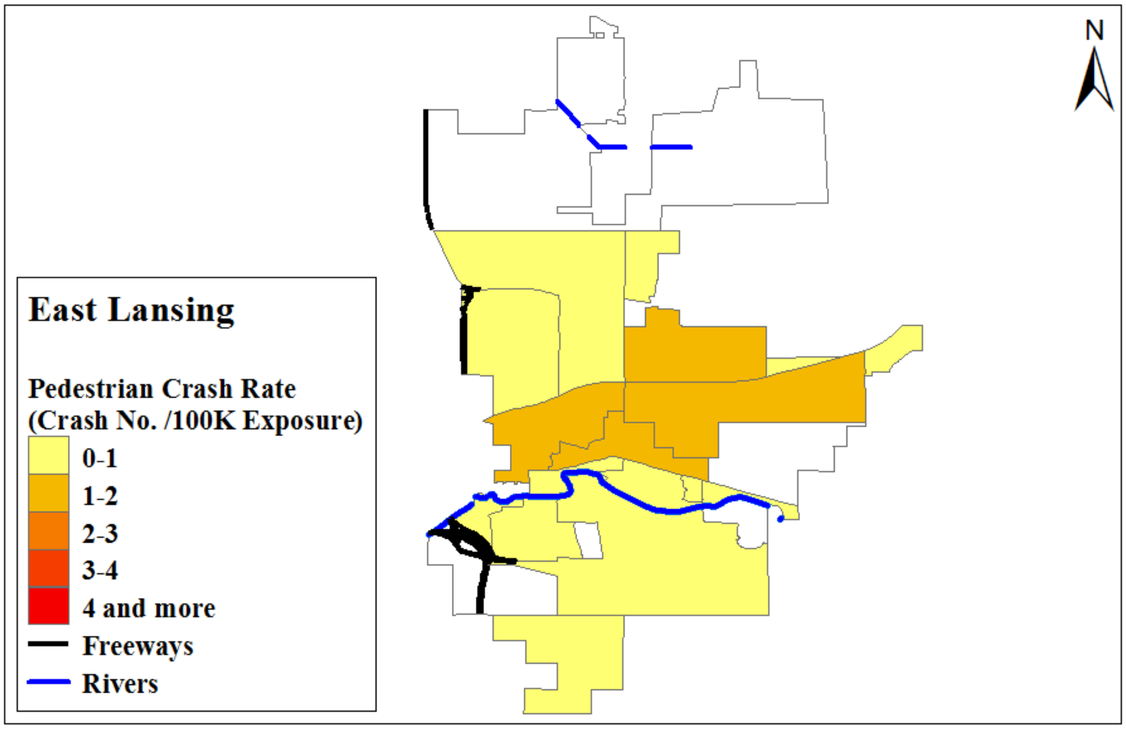


(a) Pedestrian

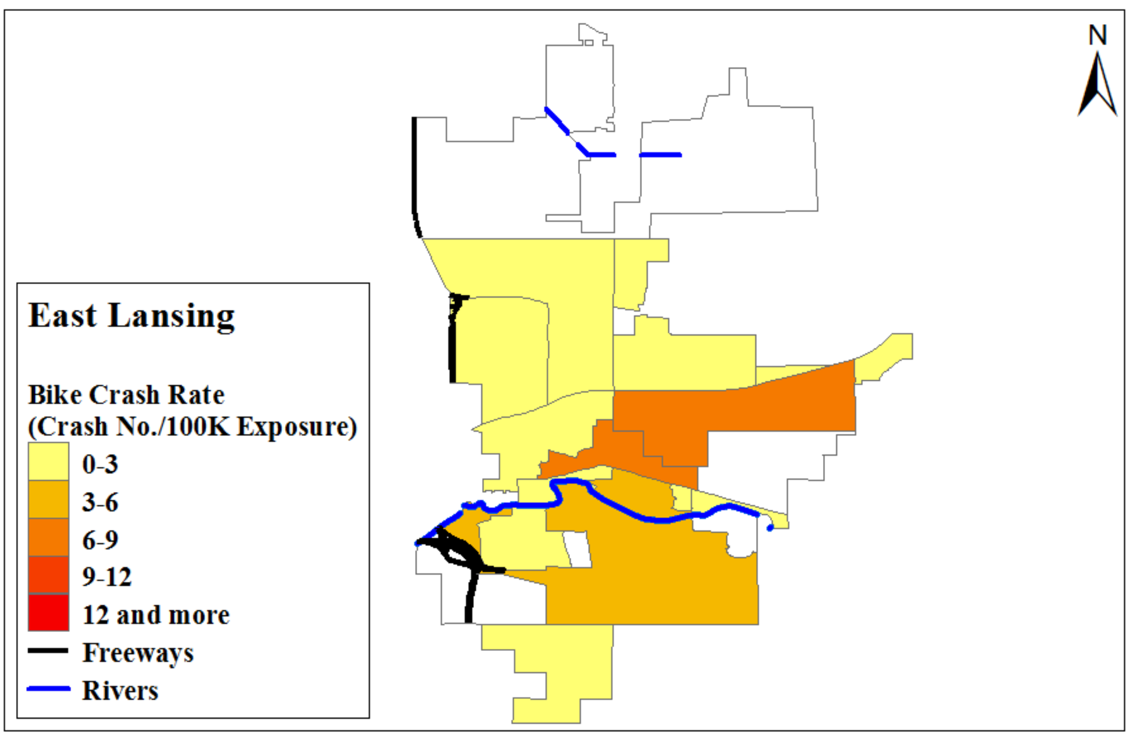


(b) Bicycle

Figure 5-13 Crashes Rate Based on Exposures: Ann Arbor

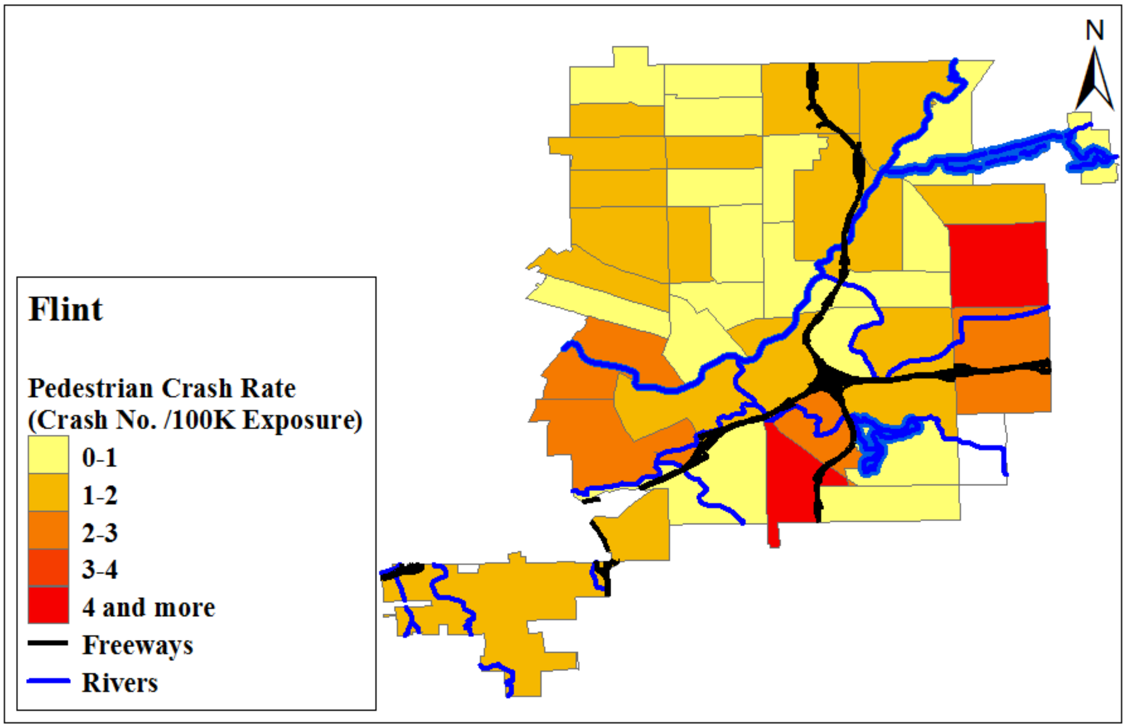


(a) Pedestrian

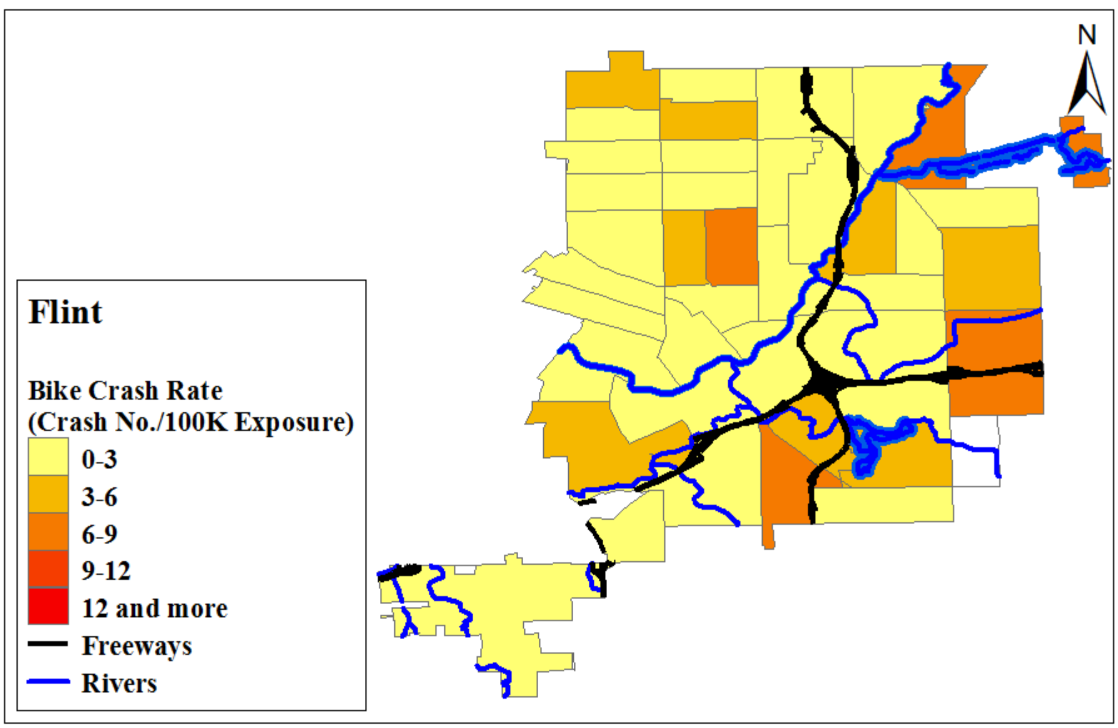


(b) Bicycle

Figure 5-14 Crashes Rate Based on Exposures: East Lansing

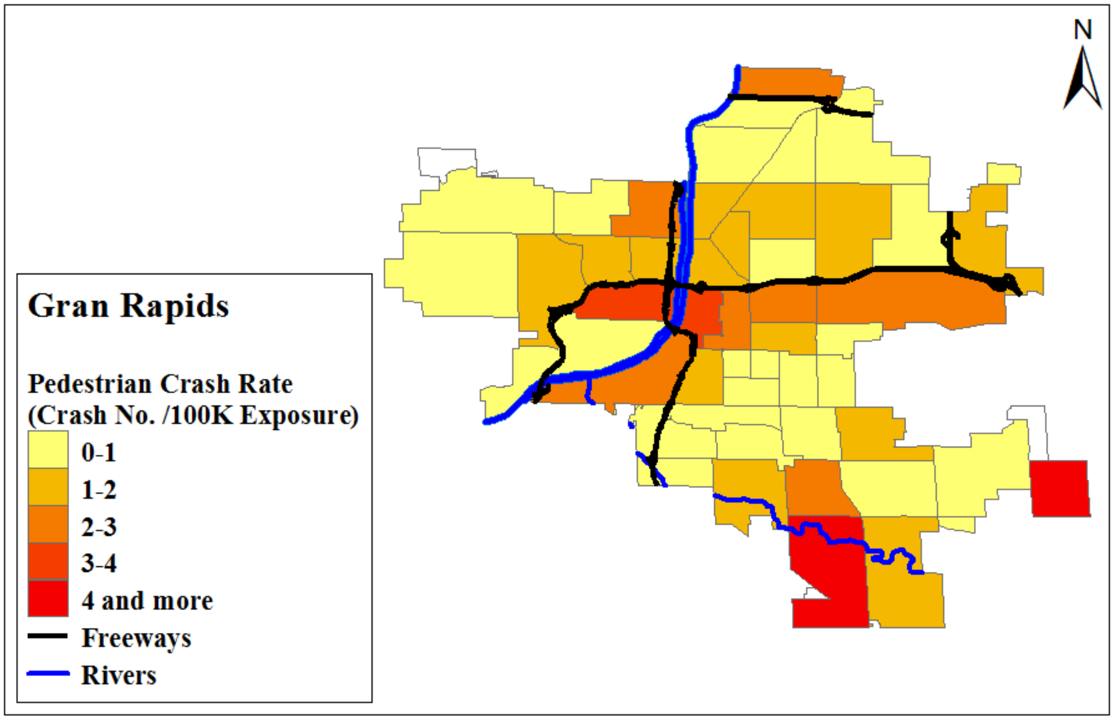


(a) Pedestrian

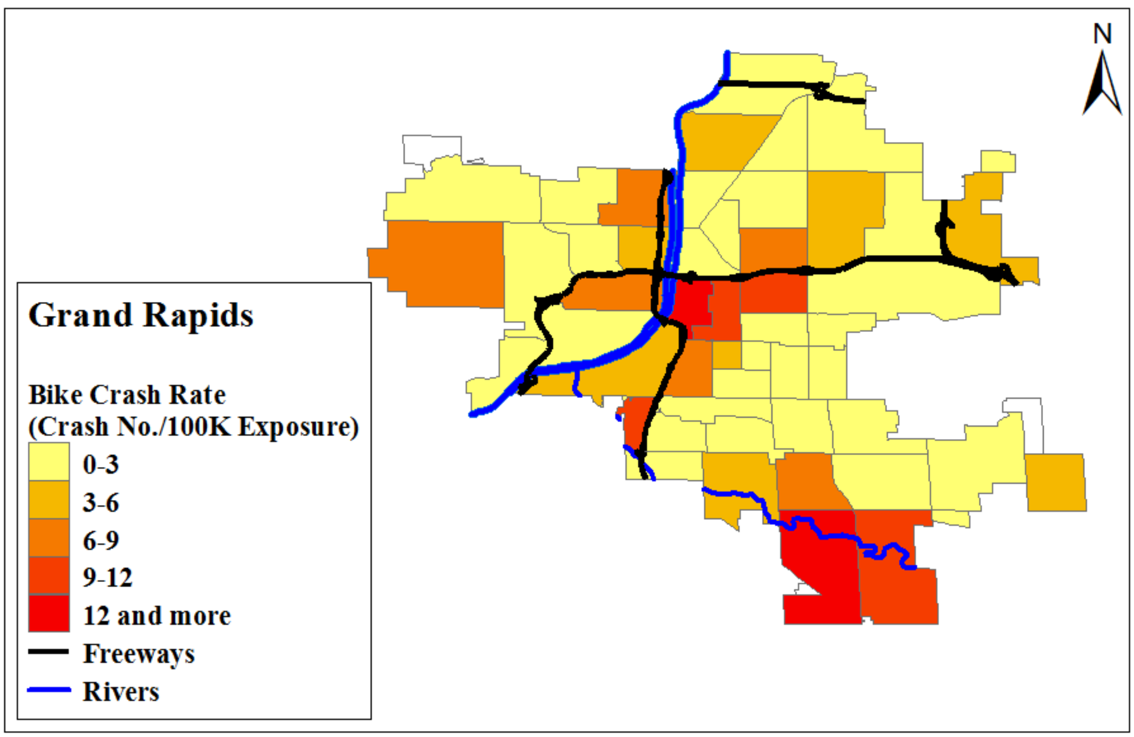


(b) Bicycle

Figure 5-15 Crashes Rate Based on Exposures: Flint



(a) Pedestrian



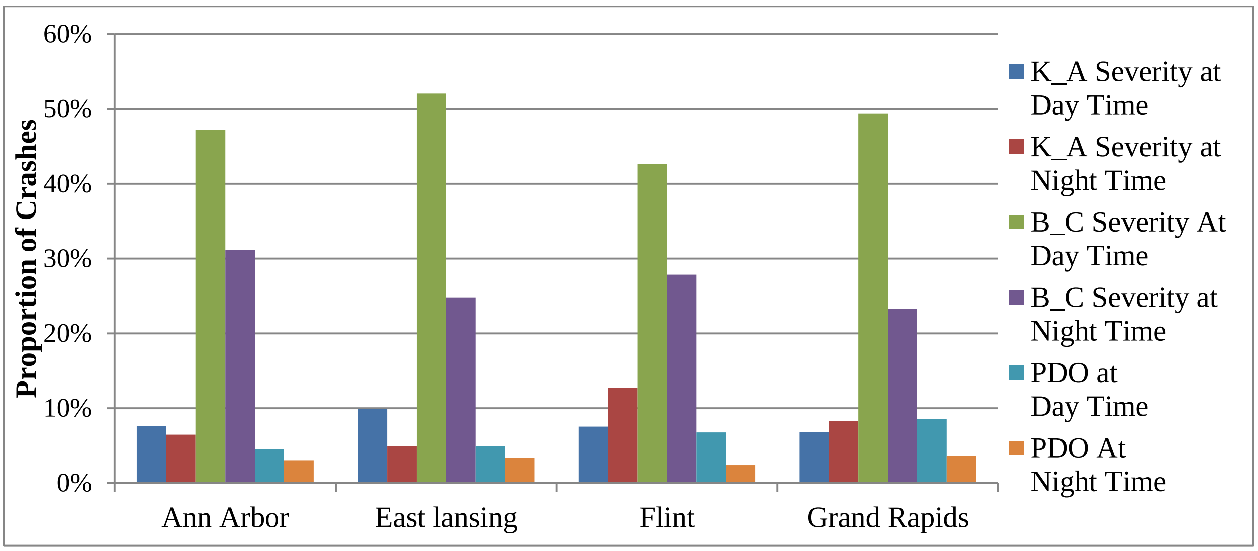
(b) Bicycle

Figure 5-16 Crashes Rate Based on Exposures: Grand Rapids

5.3 Observed Non-Motorized Crash Severity

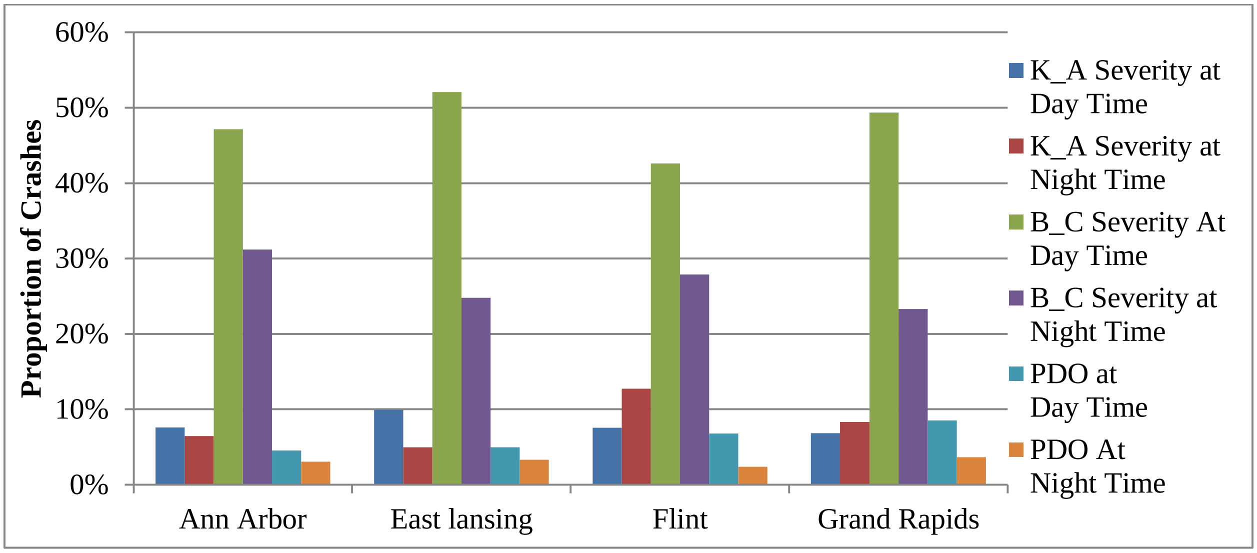
5.3.1 City-wide Analysis

The previous section explored non-motorized crash frequency on both a city-wide scale, as well as on the census tract level. This section begins with investigation of non-motorized severity by city. Particularly, this study pays more attention to severe crashes, fatal crashes (type K) and incapacitated injury (type A). Other crash severity types include evident injury (type B), possible injury (type C) and property-damage only (PDO). As shown in Figure 5-17, pedestrian crashes of K-A severity occur more frequently at night in Flint and Grand Rapids while they occur more often during the day in East Lansing and Ann Arbor. With regard to the bicycle mode, Figure 5-18 displays the same trend, besides one exception: Grand Rapids experiences a higher portion of K and A crashes during the day rather than at night.



City	K_A Severity at Day Time	K_A Severity at Night Time	B_C Severity At Day Time	B_C Severity at Night Time	PDO at Day Time	PDO At Night Time
Ann Arbor	7.6%	6.5%	47.1%	31.2%	4.6%	3.0%
East Lansing	9.9%	5.0%	52.1%	24.8%	5.0%	3.3%
Flint	7.6%	12.7%	42.6%	27.9%	6.8%	2.4%
Grand Rapids	6.8%	8.3%	49.4%	23.3%	8.5%	3.6%

Figure 5-17 Pedestrian Crash Severity by Day/Night

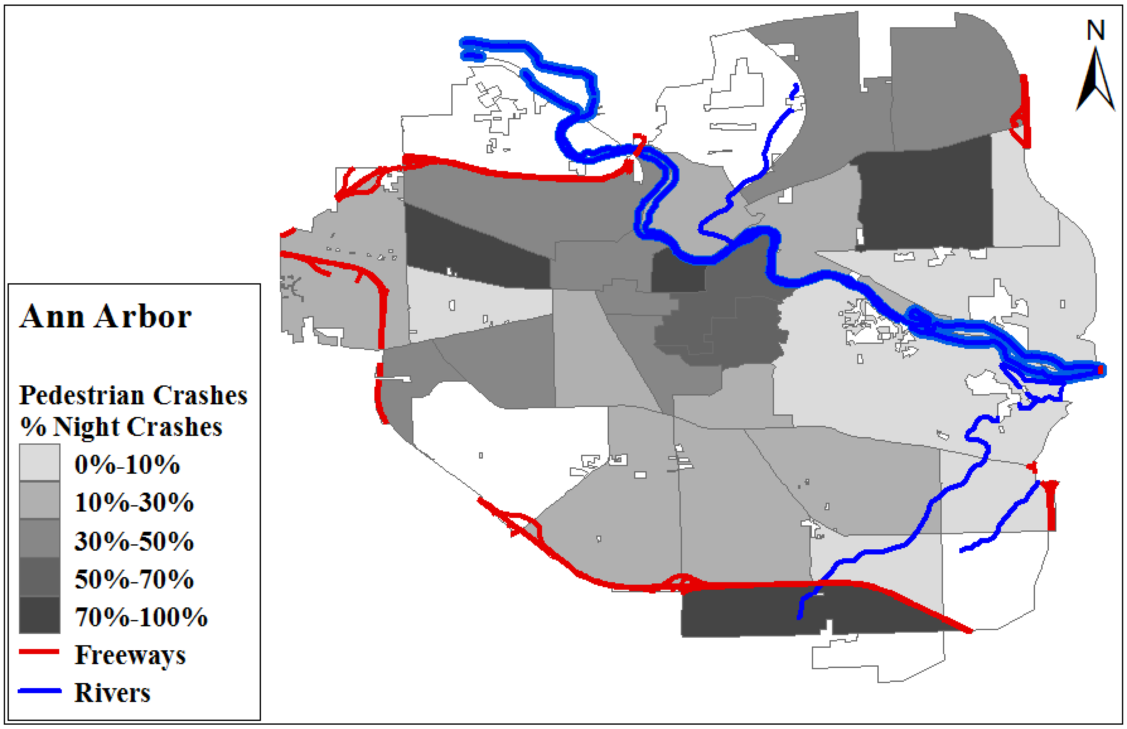


City	K_A Severity at Day Time	K_A Severity at Night Time	B_C Severity At Day Time	B_C Severity at Night Time	PDO at Day Time	PDO At Night Time
Ann Arbor	5.30%	0.30%	64.80%	15.80%	10.50%	3.30%
East Lansing	6.20%	1.30%	60.00%	13.30%	16.00%	3.10%
Flint	1.90%	4.80%	48.60%	30.50%	11.40%	2.90%
Grand Rapids	3.90%	1.60%	54.40%	23.00%	12.20%	4.90%

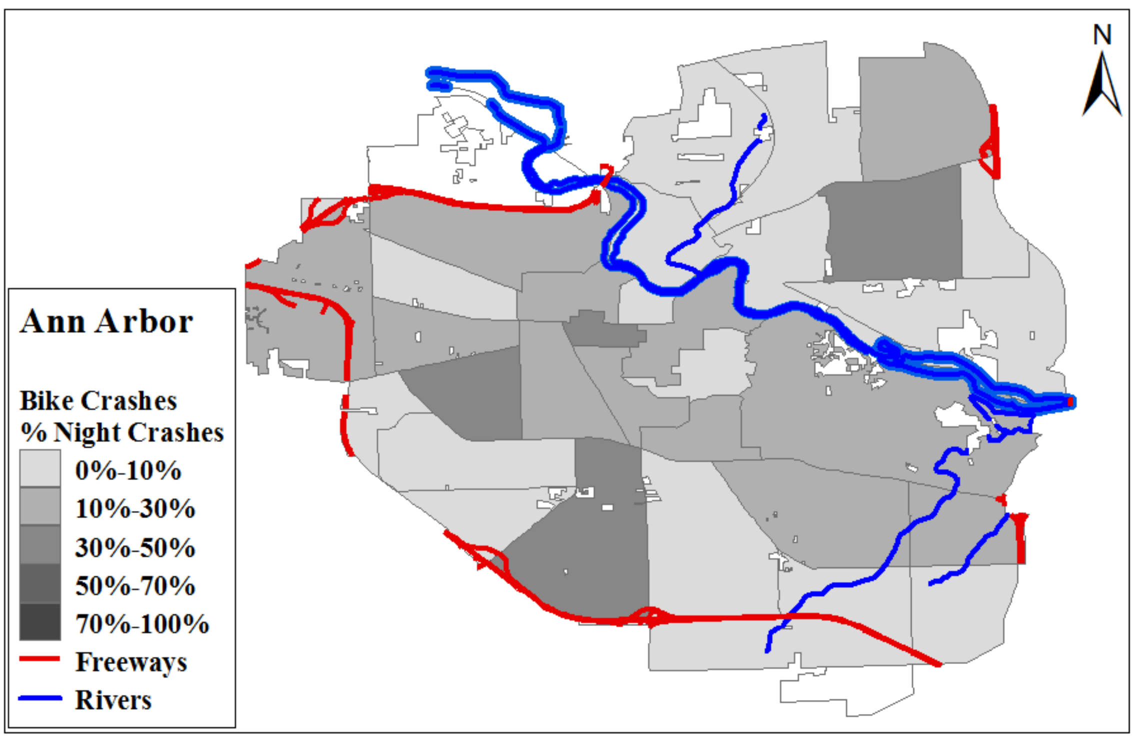
Figure 5-18 Bike Crash Severity by Day/Night

5.3.2 Census Tract Level Analysis

As in the crash frequency analysis section, non-motorized crash severity was also investigated on the census tract level. As shown in Figure 5-19 - Figure 5-22, census tracts with a high proportion of night time pedestrian crashes do not necessarily concentrate in the downtown areas of all four cities, but instead they distribute unevenly throughout the city boundaries. Likewise, these figures reveal that census tracts with a high proportion of night time bicycle crashes also tend to propagate throughout the cities with no bias towards downtown locations, except possibly in Flint. However, care must be taken with Flint’s results, as Flint has a very low bicycle-riding population. Additionally, census tracts with a high percentage of night time pedestrian crashes often do not similarly have a high percentage of night-time bicycle crashes.

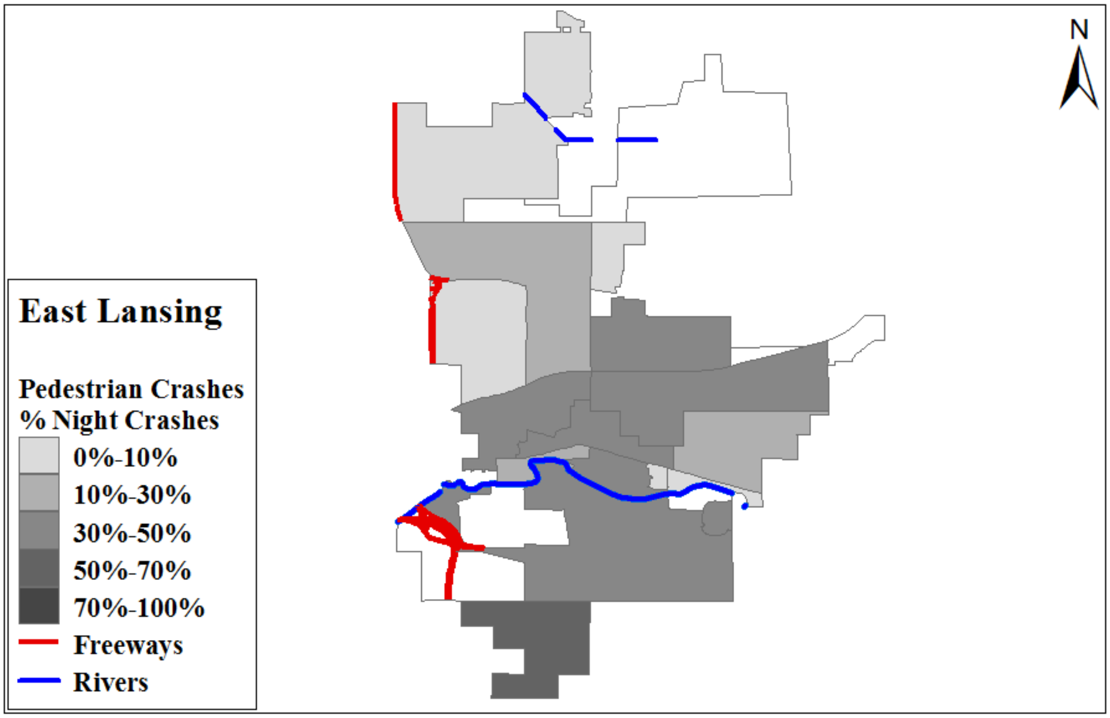


(a) Pedestrian

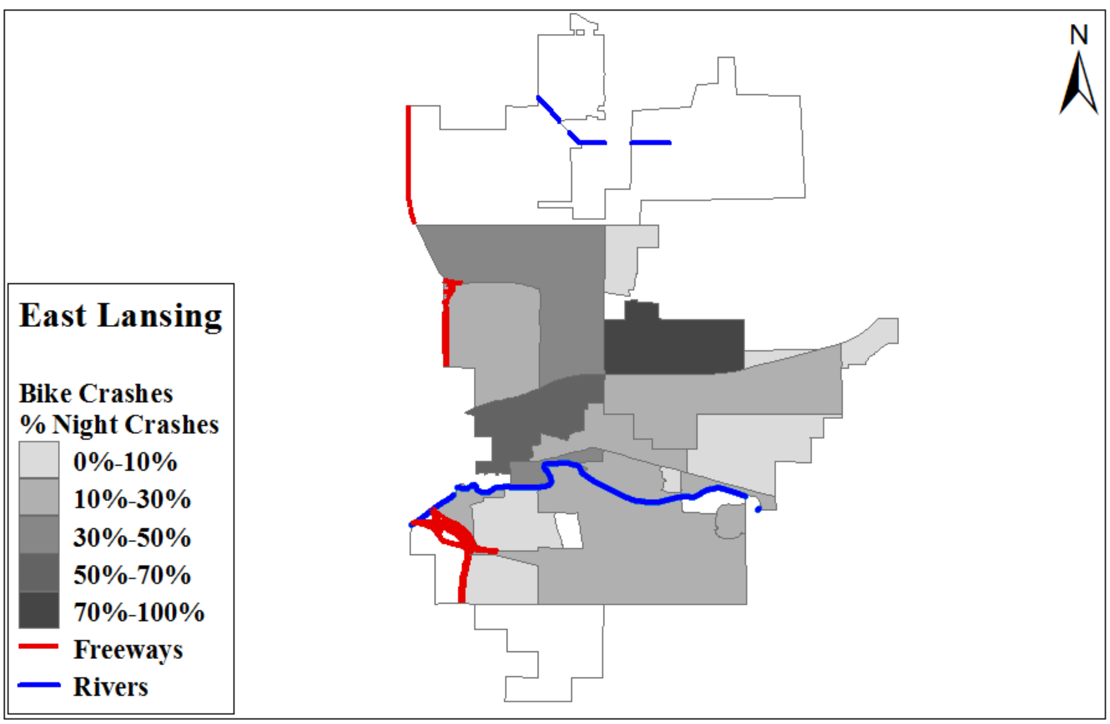


(b) Bicycle

Figure 5-19 Night Time Crashes at Census Tract Level: Ann Arbor

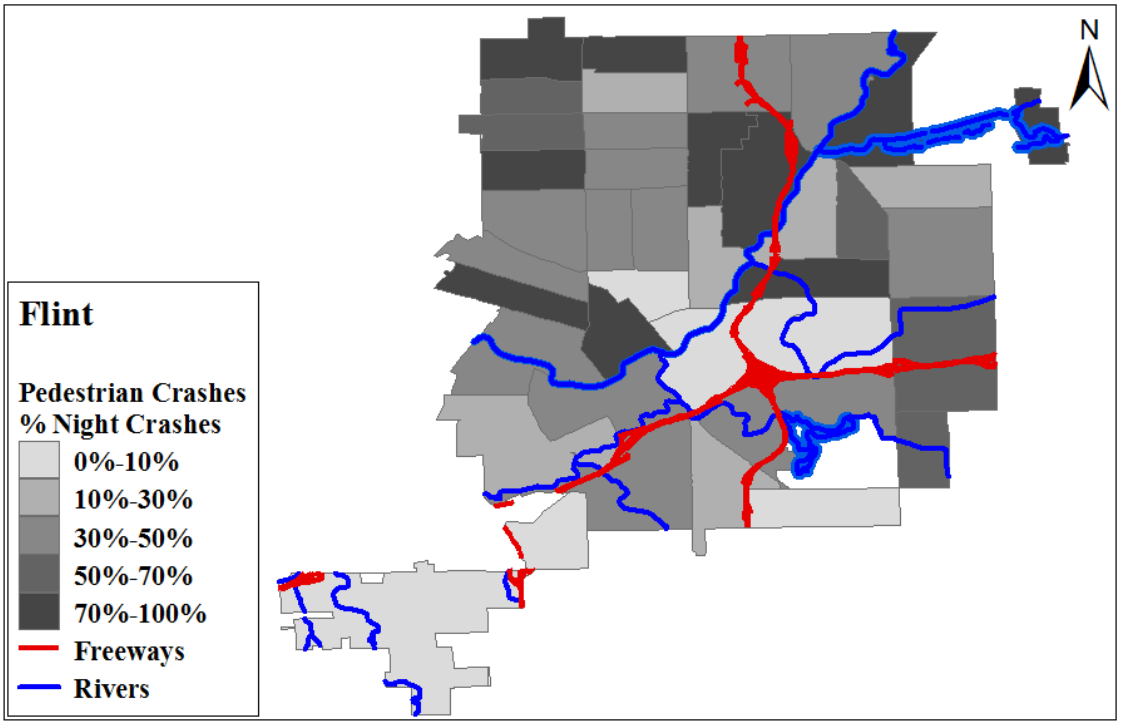


(a) Pedestrian

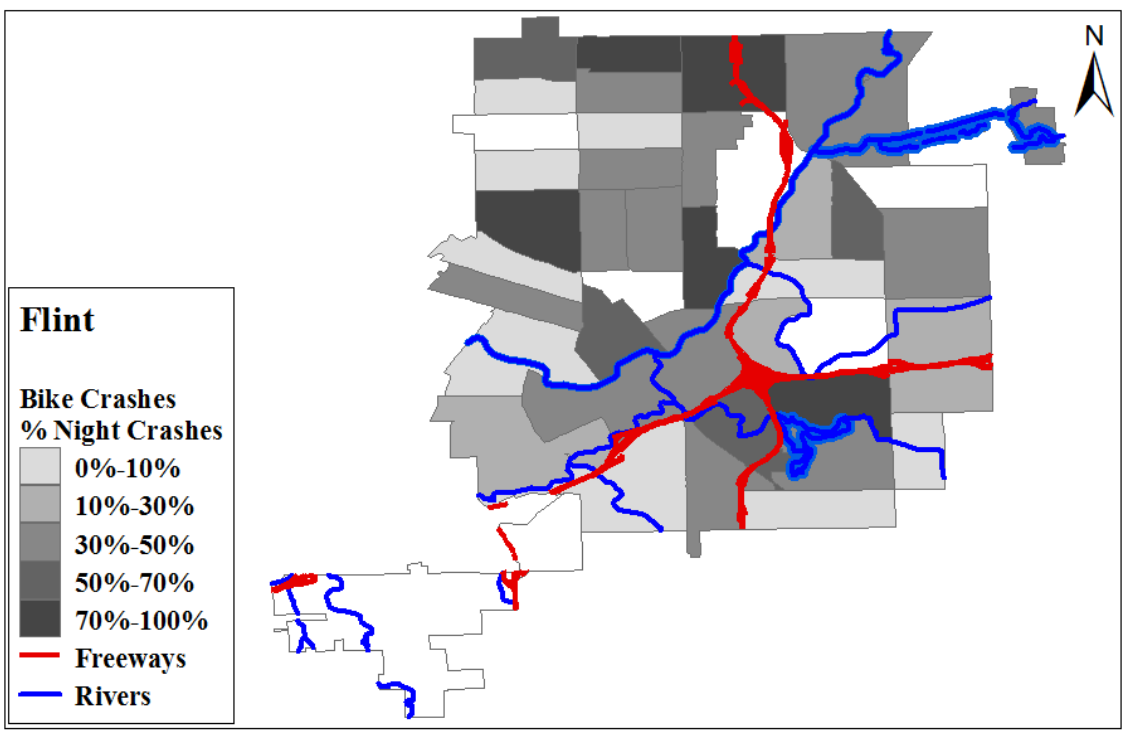


(b) Bicycle

Figure 5-20 Night Time Crashes at Census Tract Level: East Lansing

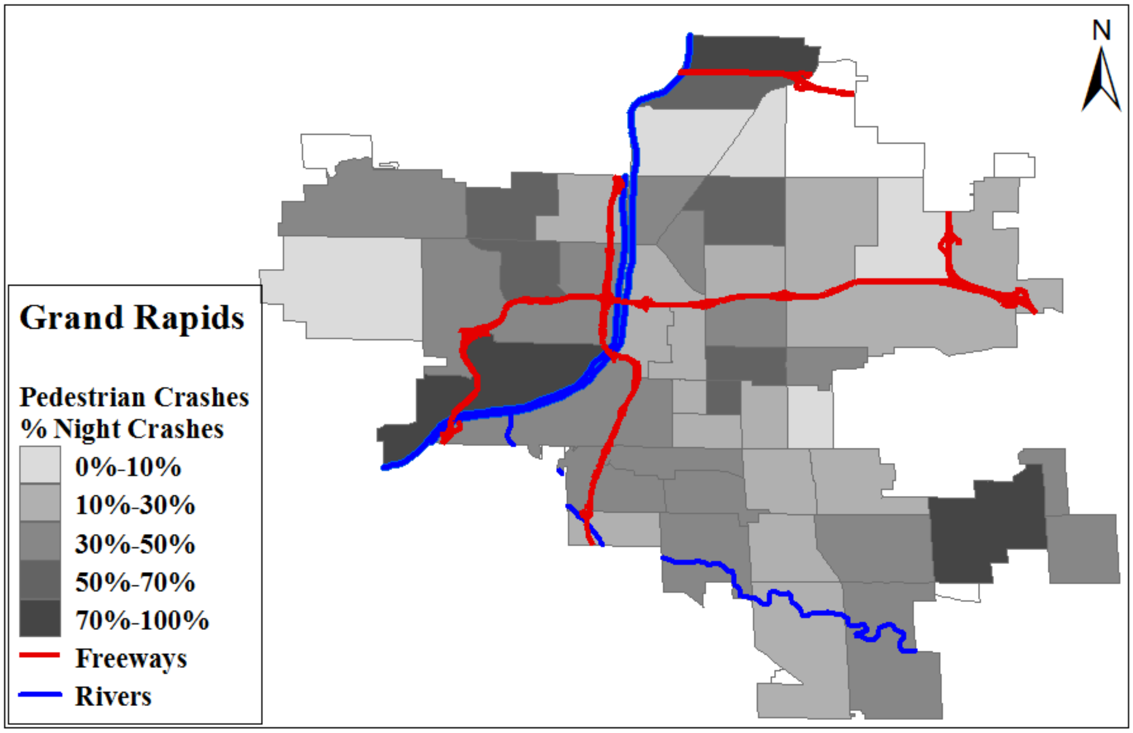


(a) Pedestrian

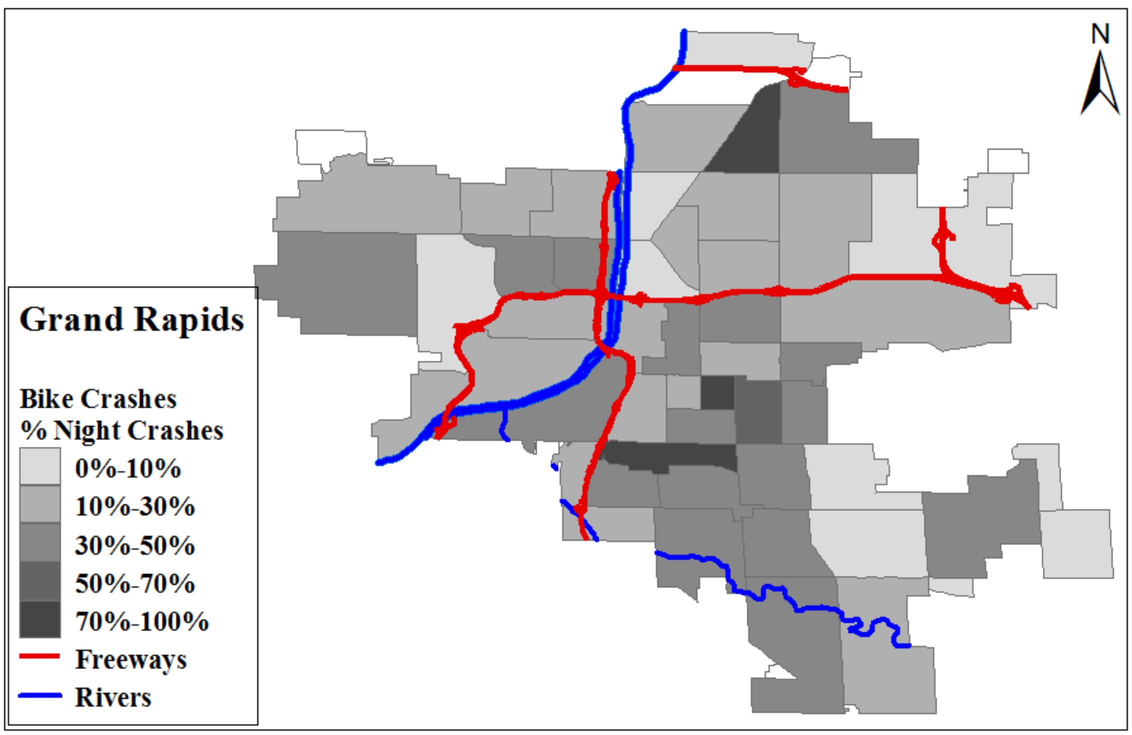


(b) Bicycle

Figure 5-21 Night Time Crashes at Census Tract Level: Flint



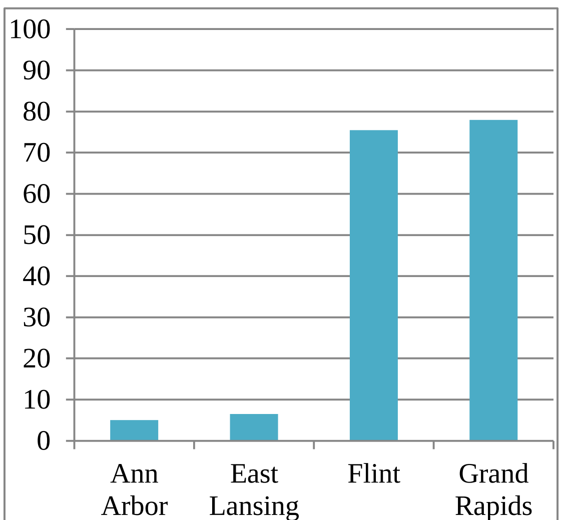
(a) Pedestrian



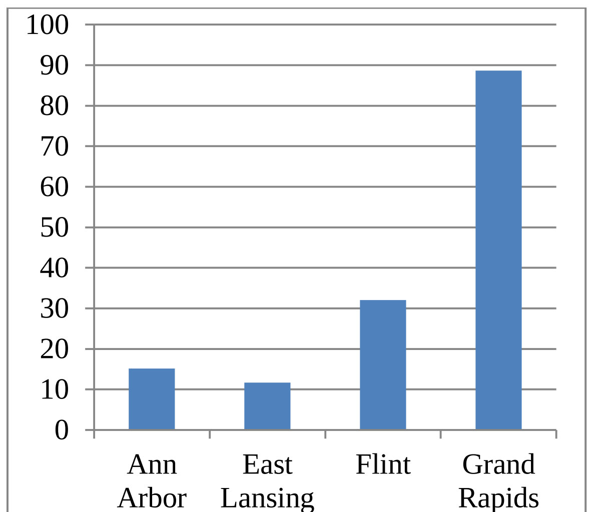
(b) Bicycle

Figure 5-22 Night Time Crashes at Census Tract Level: Grand Rapids

Similar to the crash frequency analysis, exposure-based non-motorized safety was evaluated regarding crash severity at the census tract level. Figure 5-23 shows that crash rates based on exposures were higher in Grand Rapids and Flint than in Ann Arbor and East Lansing. With regard to pedestrian exposure-based crash severity, Figure 5-24 - Figure 5-27 illustrate that only Flint shows high crash severity in downtown census tracts, while census tracts of high crash severity are randomly dispersed throughout each of the other three cities. As shown in the figures for bicycle, East Lansing and Grand Rapids show high exposure-based bicycle crash severity in downtown locations, while Ann Arbor and Flint display lower crash severity in general, and likewise in downtown locations.



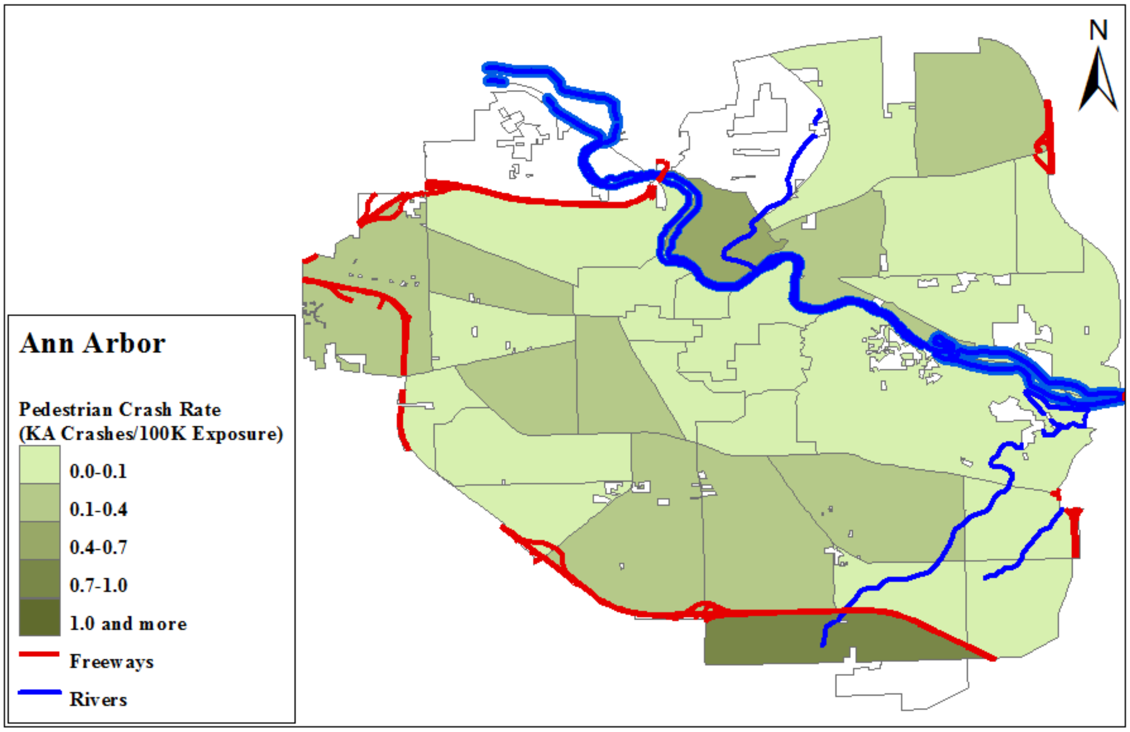
(a) K-A Ped Crashes Per 1M Ped



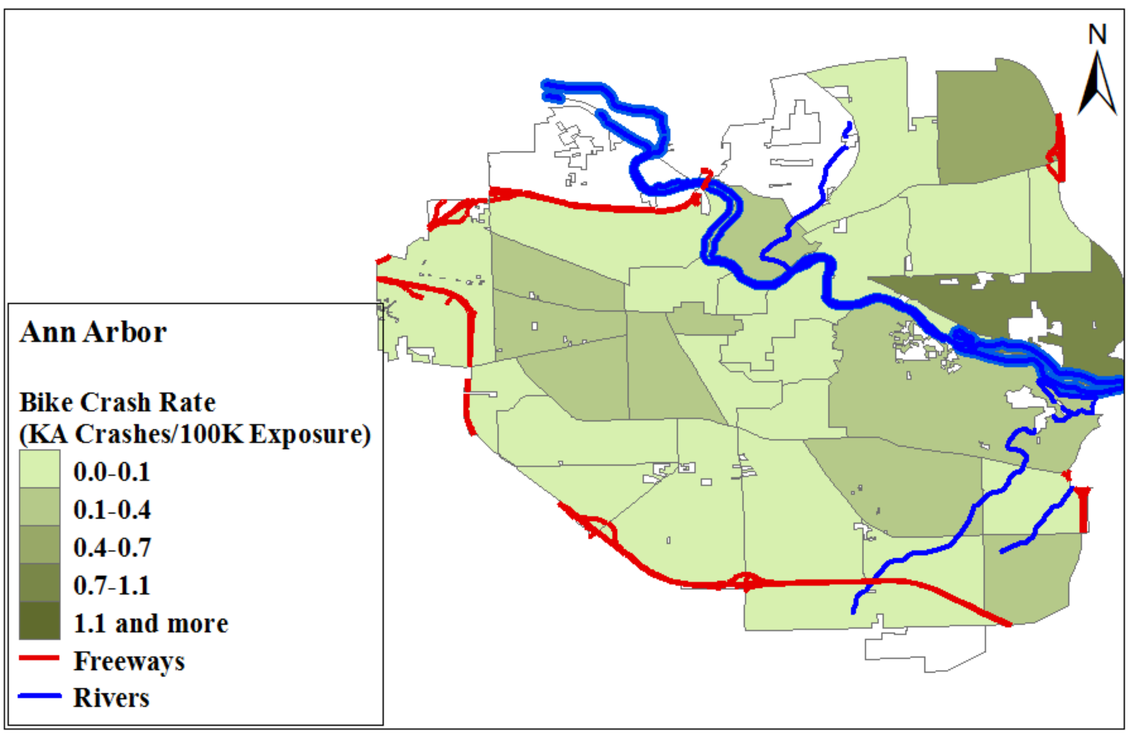
(b) K-A Bike Crashes Per 1M bicyclists at Signalized Intersection

Figure 5-23 Exposure-based Severe (K & A) Crash Rates

The proportion of K-A non-motorized crashes of total non-motorized crashes by census tract was also investigated. As shown in Figure 5-28 - Figure 5-31, census tracts with a high proportion of pedestrian K-A crashes tend to locate towards the downtown region only in Grand Rapids (which has a larger downtown area). However, the figures for bicycle show that the majority of census tracts with a high proportion of bicycle K-A severity crashes are located near or within the downtown areas of each city, besides in Ann Arbor.

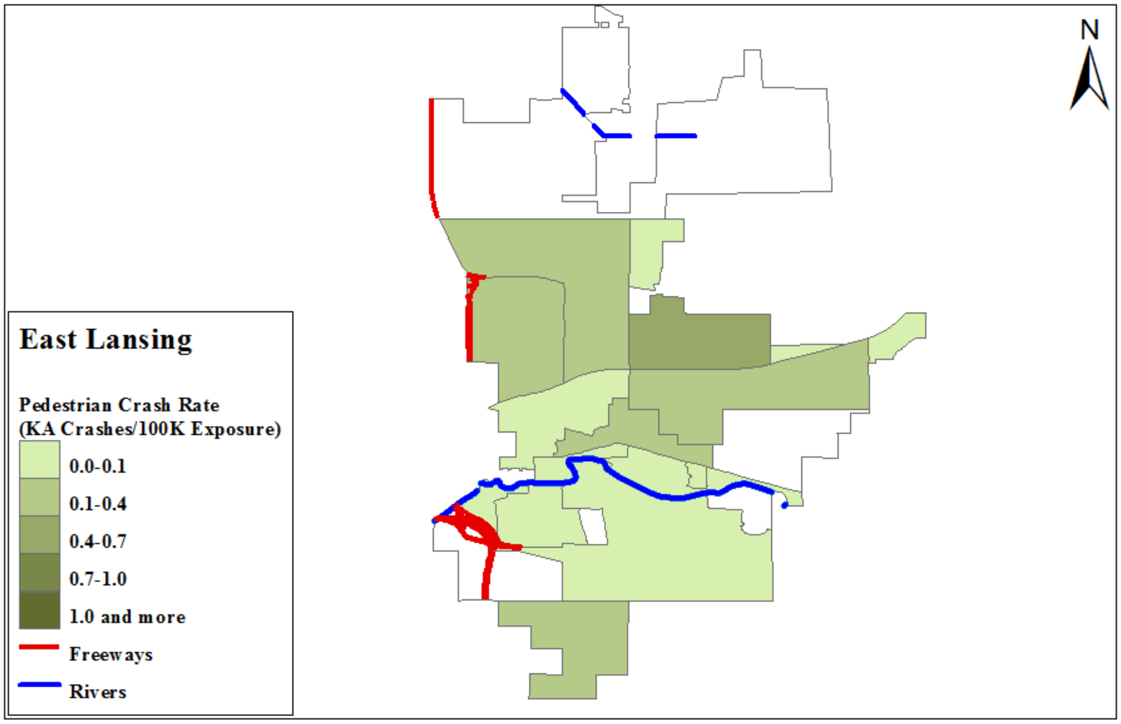


(a) Pedestrian

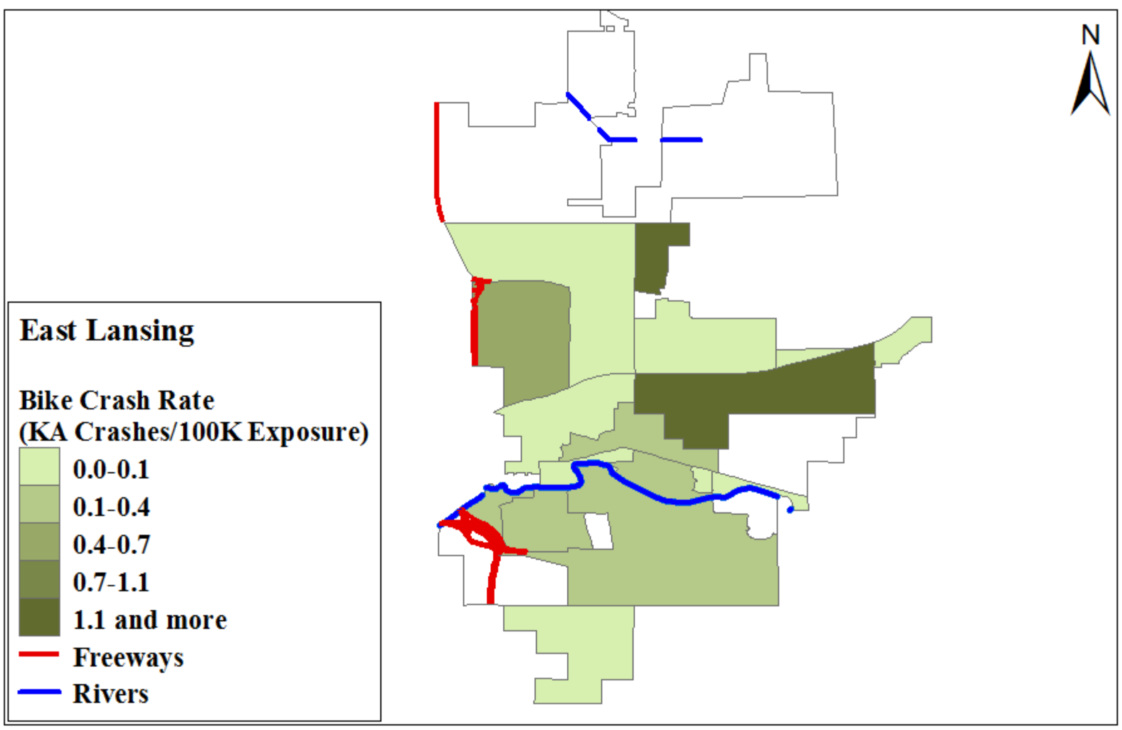


(b) Bicycle

Figure 5-24 KA Crash Per 100K Exposures: Ann Arbor

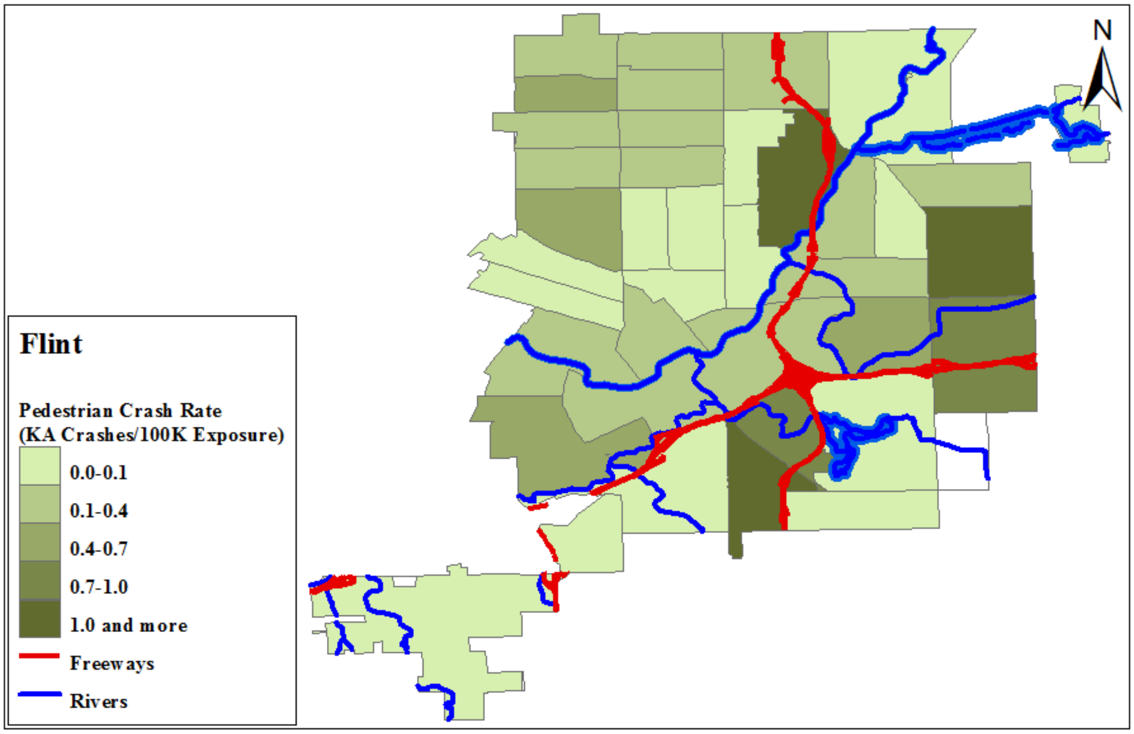


(a) Pedestrian

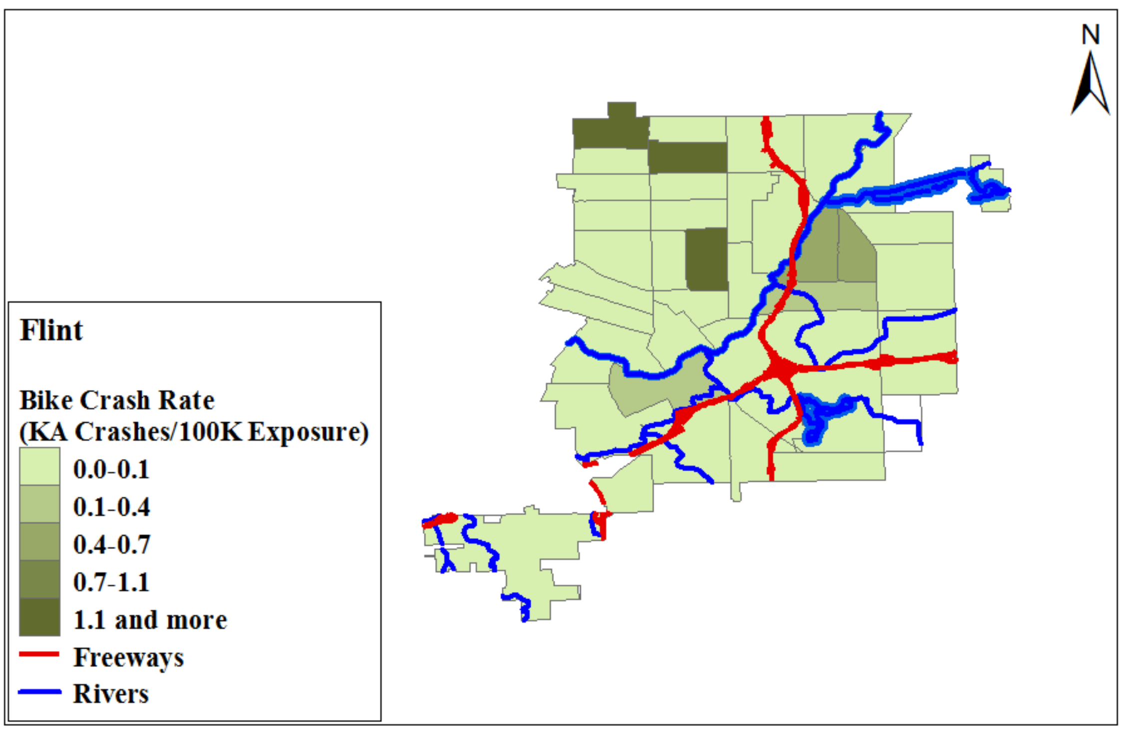


(b) Bicycle

Figure 5-25 KA Crash Per 100K Exposures: East Lansing

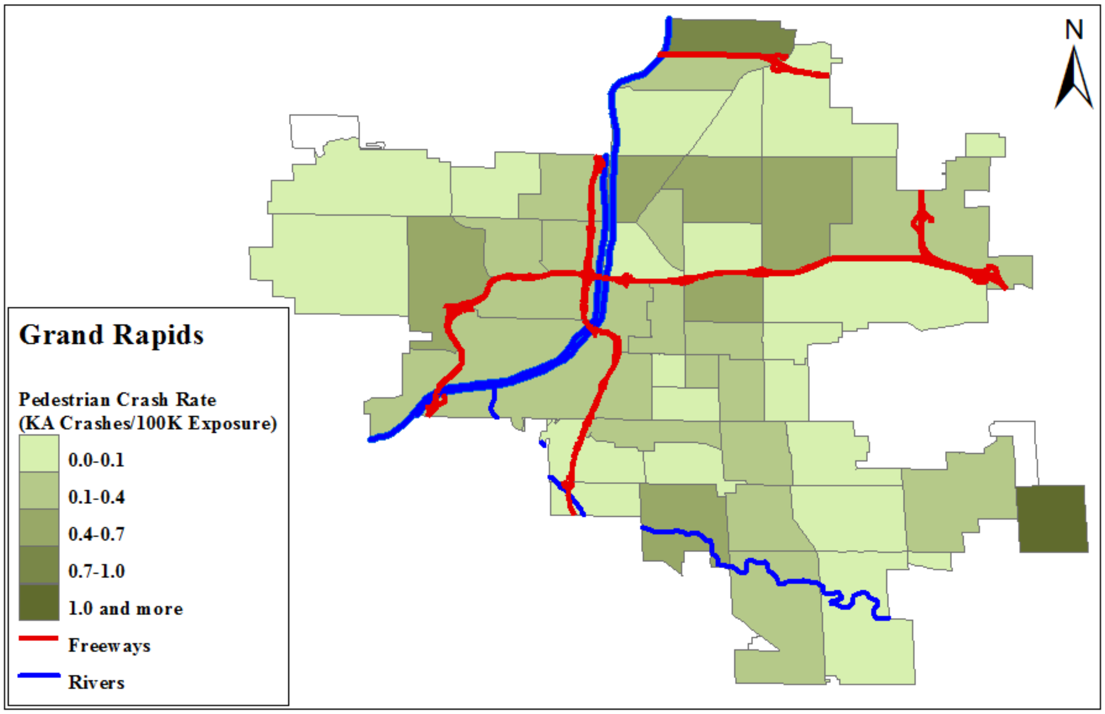


(a) Pedestrian

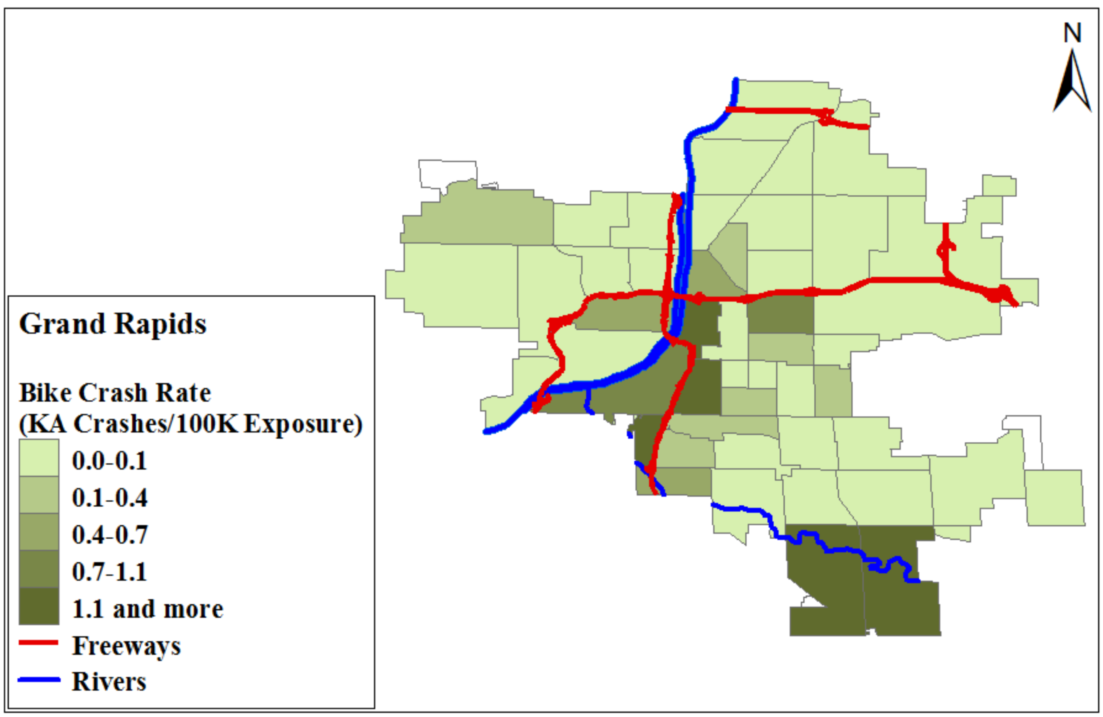


(b) Bicycle

Figure 5-26 KA Crash Per 100K Exposures: Flint

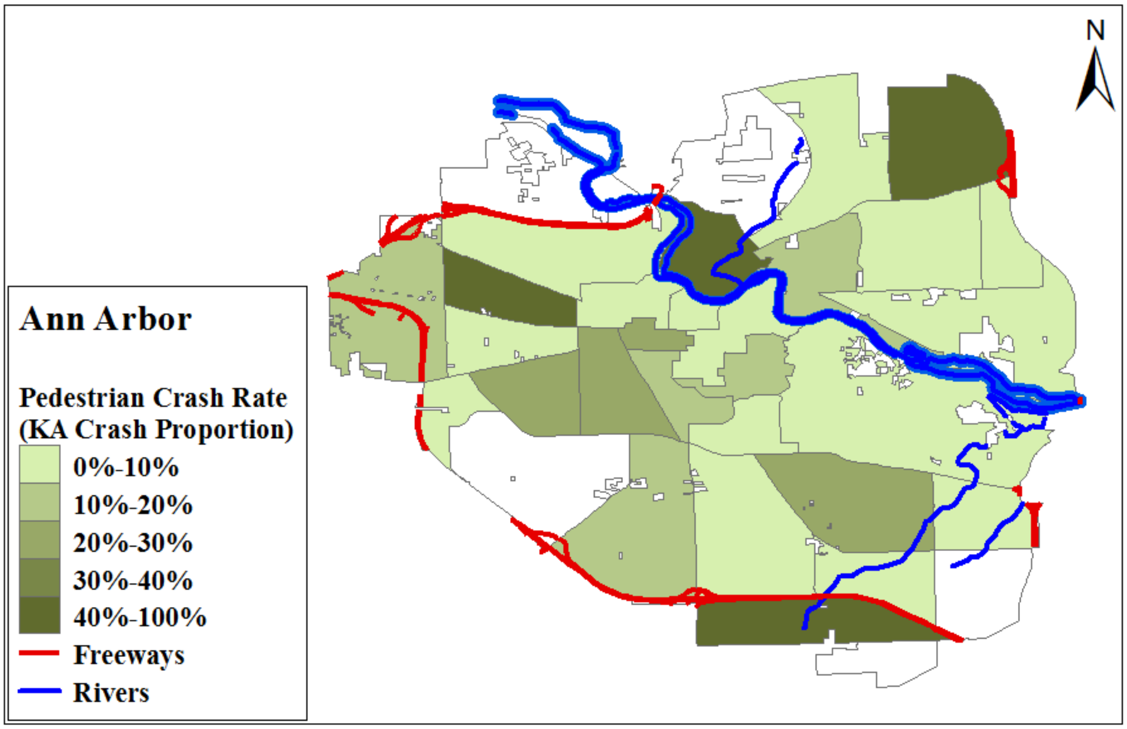


(a) Pedestrian

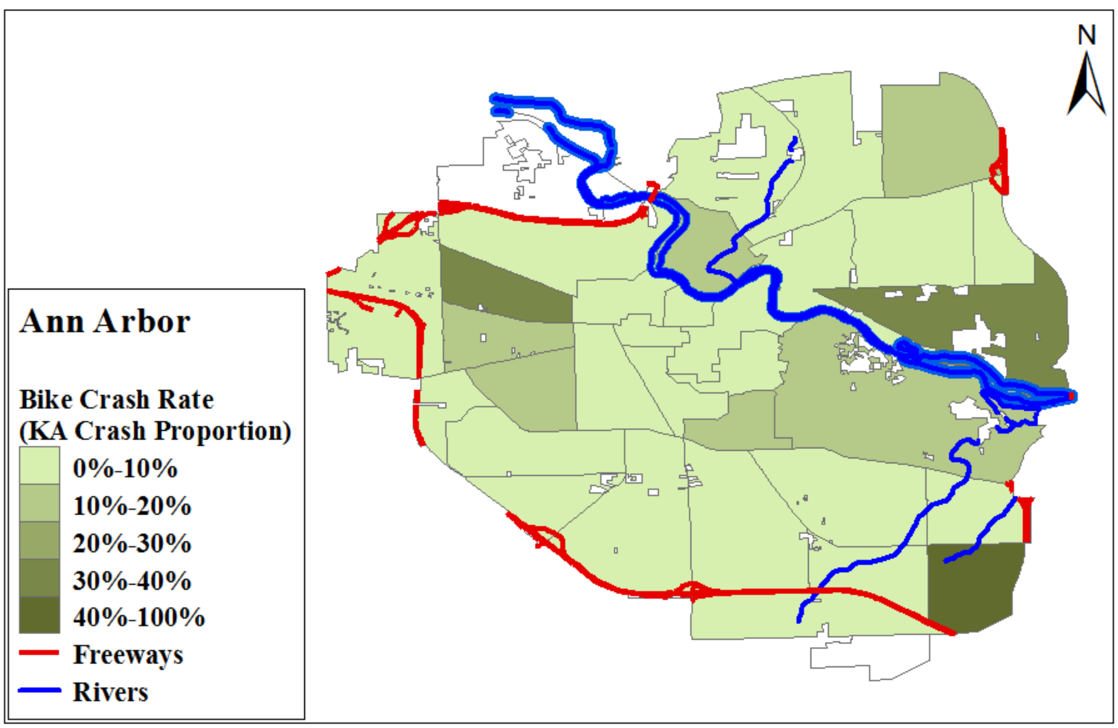


(b) Bicycle

Figure 5-27 KA Crash Per 100K Exposures: Grand Rapids

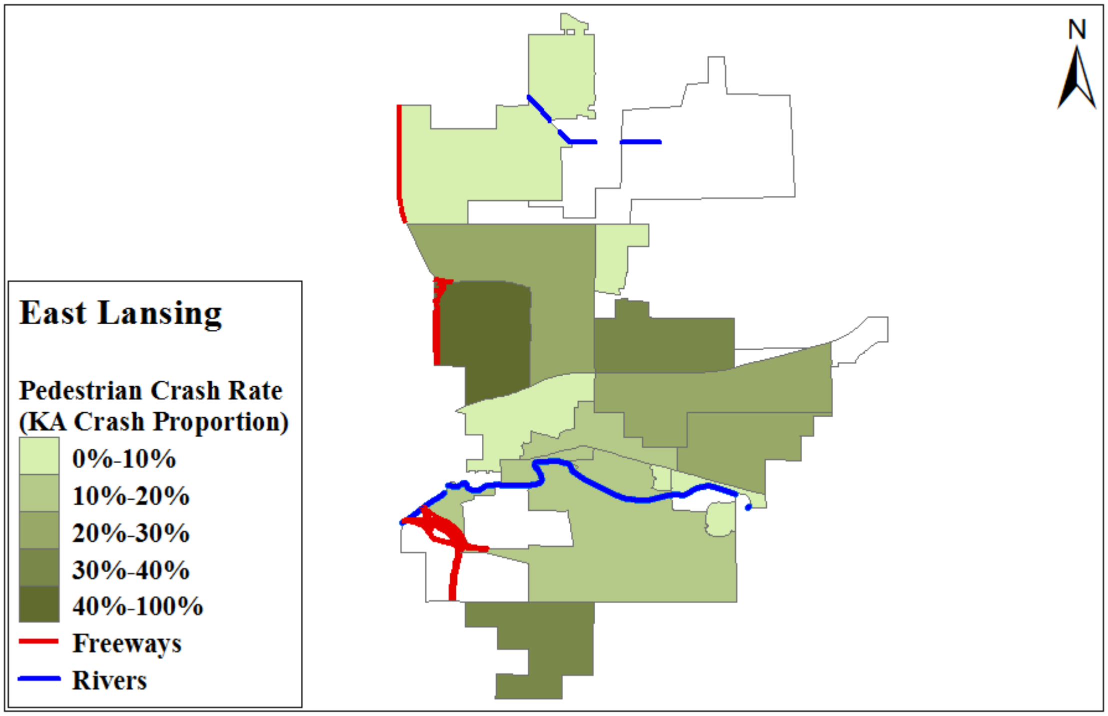


(a) Pedestrian

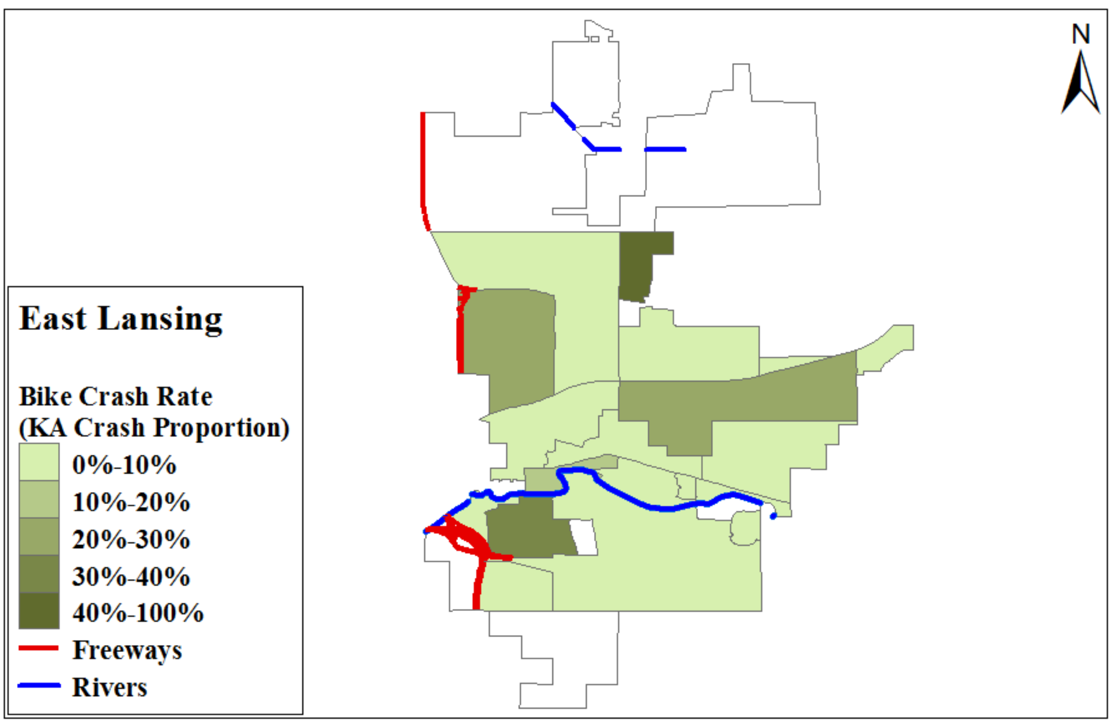


(b) Bicycle

Figure 5-28 Proportion of K-A Crashes: Ann Arbor

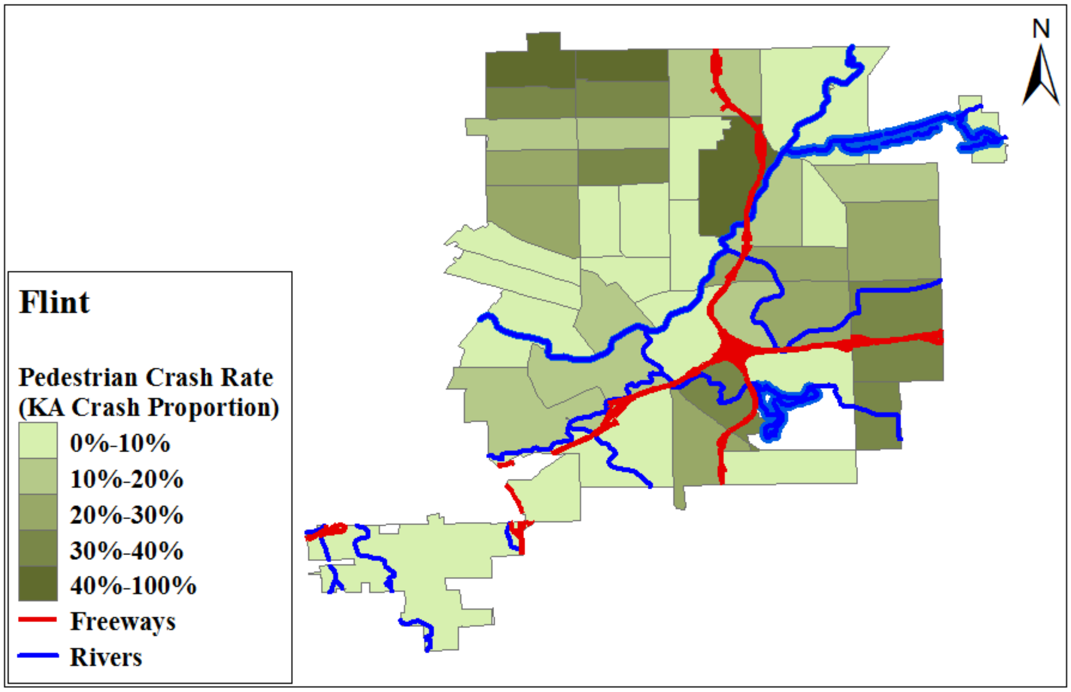


(a) Pedestrian

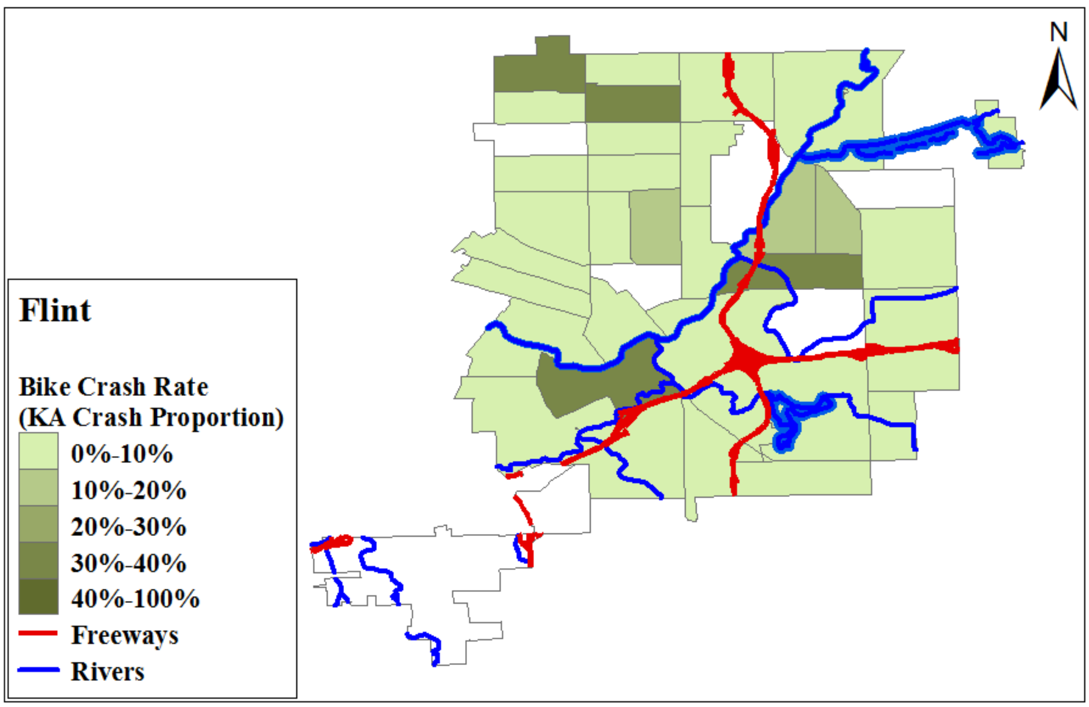


(b) Bicycle

Figure 5-29 Proportion of K-A Crashes: East Lansing

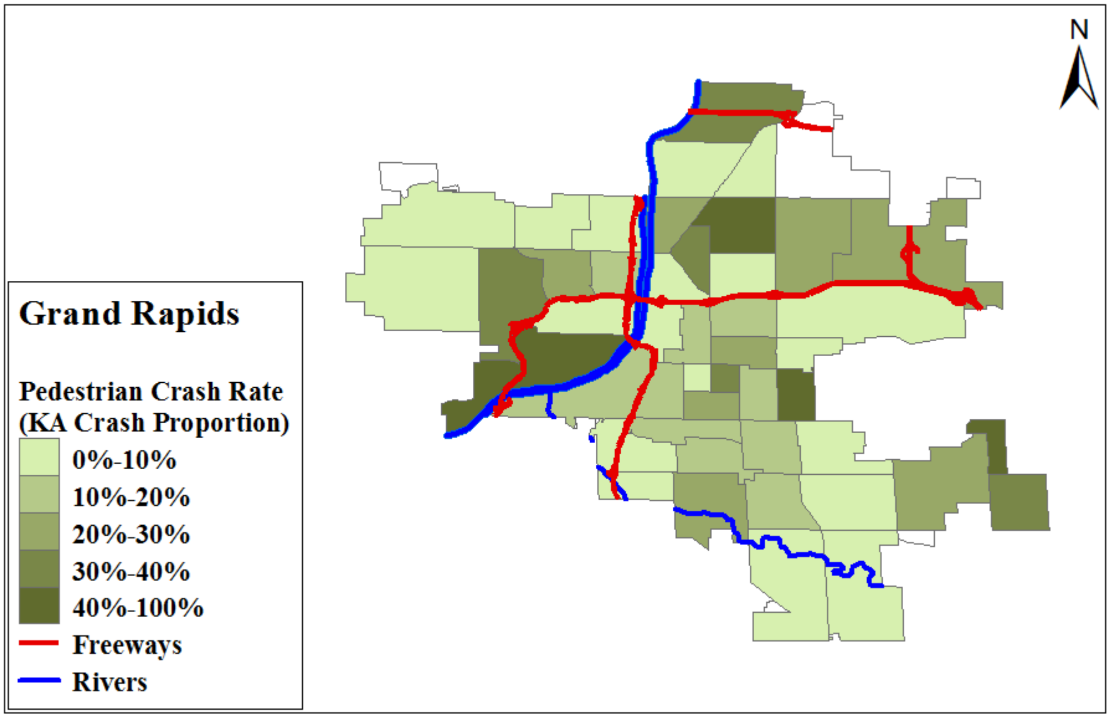


(a) Pedestrian

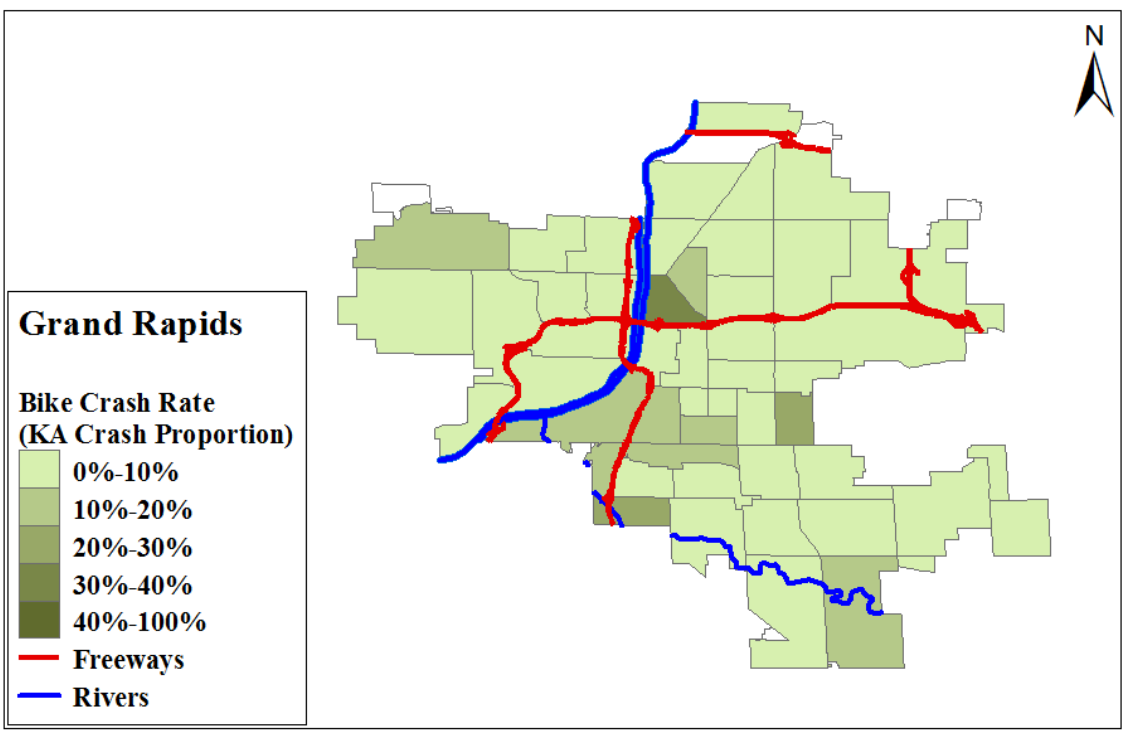


(b) Bicycle

Figure 5-30 Proportion of K-A Crashes: Flint



(a) Pedestrian



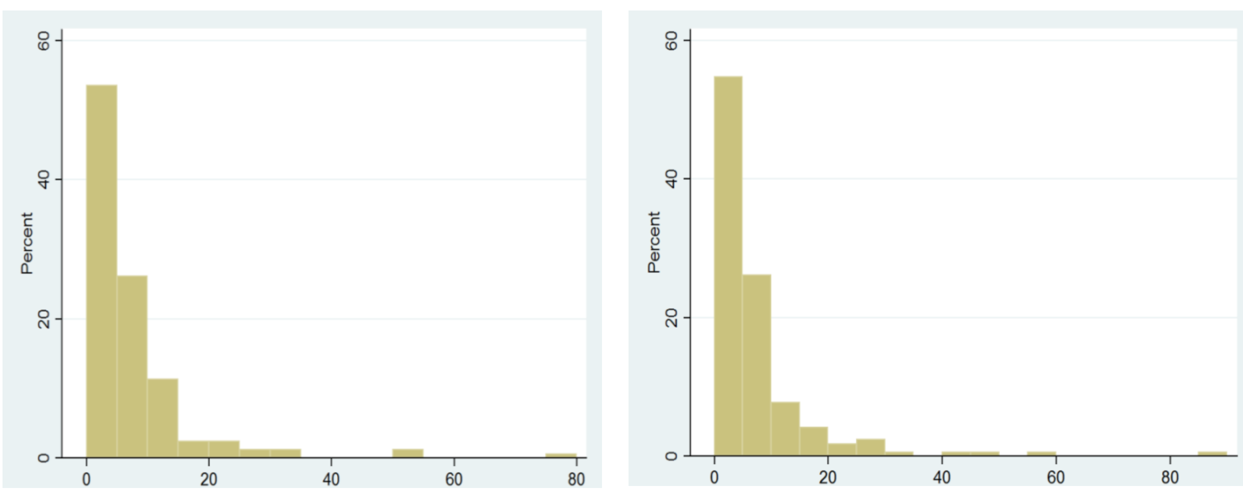
(b) Bicycle

Figure 5-31 Proportion of K-A Crashes: Grand Rapids

5.4 Crash Models at Census Tract Level

At the census tract level, socio-economic data, demographic data, aggregation of exposures (pedestrian and bike volumes) at signalized intersections, crime data (number of crimes and crime rate) and the total number of certain physical features within a census tract were analyzed to investigate their effects on non-motorized crash frequency and severity. This data is summarized in the Appendix.

Census tract level crash prediction began with determining the relationship between variables relevant to non-motorized crash frequency and ender with developing a crash prediction model. According to the previous literature and nature of the crash data (Figure 5-32), negative binomial regression was employed to develop the crash prediction models. Similar models have been commonly used by other researchers to model crashes between pedestrian and motorized traffic (for example Shankar *et al.*, 2003). The negative binomial model relaxes the Poisson model assumption of the mean being equal to the variance.



(a) Pedestrian Crash Frequency (b) Bicycle Crash Frequency

Figure 5-32 Non-Motorized Crash Frequency

5.4.1 Pedestrian Crash Model at Census Tract Level

Among the many variables processed for the non-motorized crash analysis, the variables shown in Table 5-1 were found as the significant variables in terms of statistical measures for the pedestrian crash frequency model.

Table 5-1 Significant Variables for Pedestrian Crashes at Census Tract Level

Definition	Min	Max	Median	Mean	Standard Deviation
Population with 8th grade education and lower	0	1,208	314	327	285
Total bike lane length in miles	0	23,296	0	1,563	3,353
Number of access points	0	94	23	26	22
Total number of pedestrian volumes in signalized intersections	0	384,114	934	5,862	31,684

Considering the postive correlation between pedestrian volume and pedestrian crashes, a number of combined pedestrian volume sub-factors were investigated to determine their relationship with the number of pedestrian crashes. These combined factors represent the ratio of certain infrastacture features to pedestrian volume and include the following:

1. Number of Signalized Intersections / Pedestrian Volume
2. Sidewalk Length / Pedestrian Volume
3. Number of Midblock Crossings / Pedestrian Volume
4. Number of Signalized Crosswalks / Pedestrian Volume

A negative correlation was observed between each combined factor and the number of pedestrian crashes. This indicates that as infrastructure coverage increases based on pedestrian volume, the number of pedestrian crashes will decrease. The factors “number of signalized intersections / pedestrian volume” and “sidewalk length / pedestrian volume” appear to show the strongest fit with the number of pedestrian crashes.

The same four combined factors that were used in the pedestrian crash analysis were used in the bicycle model. In the bike case, negative correlation was observed between each of the combined factors and the number of bicycle crashes. This indicates that as infrastructure coverage increases relative to bicycle volume, bicycle crash rate tends to decrease, similar to the pedestrian analysis.

When developing a crash prediction model, a number of factors were investigated to determine their relative impact on non-motorized crashes. Table 5-2 below shows the relationship between a number of these factors and the number of observed pedestrian crashes. The factors of "pedestrian volume," "number of access points," and "population with middle school education or lower" show a positive association with the number of pedestrian crashes. However, "length of bike lanes" displays a negative association with the number of pedestrian crashes. Among each of these factors, the number of pedestrian crashes appears to be most sensitive to the number of access points.

Table 5-2 Pedestrian Crash Model at Census Tract Level

No. of Ped. Crash	**Coefficient**	**Std. Err.**	**z**	**P>|z|**
No. of Access_points	0.02685	0.00375	7.16	0.000
Pedestrian Volume	0.00004	0.00001	6.02	0.000
Length of Bike Lane	-0.00004	0.00002	-2.05	0.041
Population with education less than middle school	0.00115	0.00025	4.56	0.000
Model Constant	0.29158	0.13782	2.12	0.034
alpha	0.41408	0.07879		

Auxiliary Statistics
Number of obs = 166
LR chi2(4) = 121.86
Prob > chi2 = 0.0000
Log likelihood = -410.65893
Pseudo R2 = 0.1292
Likelihood-ratio test of alpha=0: chi-bar2(01) = 158.75; Prob>=chibar2 = 0.000

This model predicts the number of pedestrian crashes within a census tract based on the factors affecting pedestrian crashes. A summary of the statistical analysis of each pedestrian crash frequency factor is shown in Table 5-2 . Given that each Z-statistic is above 1.96, it is reasonable to say that each of the factors has a significant relationship with pedestrian crash frequency. The models are based on estimation, and hence, have statistical error. While they show significant trends (factors) some caution is necessary in using them for actual prediction. The pedestrian crash prediction model takes the following form:

$$Ped\ Crash\ Frequency = EXP(0.0269(A) + 0.00004(B) - 0.0004(C) + 0.0011(D) + 0.2916)$$

where
A=Number of pedestrian crashes,
B=Pedestrian volume,
C=Length of bike lanes, and
D=Population with education less than Middle School.

5.4.2 Bicycle Crash Model at Census Tract Level

Similar to the pedestrian crash prediction model, a number of factors were investigated with regard to significant factors causing bicycle crashes. The variables in Table 5-3 were found to be significant for the bicycle crash frequency model.

Table 5-3 Significant Variables for Bicycle Crashes at Census Tract Level

Definition	Min	Max	Median	Mean	Standard Deviation
Population with 8th grade education and lower	0	1208	314	327	285
Number of access points	0	94	23	26	22
Total number of bike volumes in signalized intersections	0	33002	361	1368	3826

Table 5-4 Bike Crash Model at Census Tract Level

No. of Bicycle. Crashes	**Coefficient**	**Std. Err.**	**z**	**P>|z|**
No. of Access_points	0.02639	0.00438	6.02	0.000
Bicycle Volume	0.00017	0.00003	5.03	0.000
Population with education less than middle school	0.00093	0.00031	3.01	0.003
Model Constant	0.28646	0.16443	1.74	0.081
alpha	0.7318249	0.1112169		0.543

Auxiliary Statistics
Number of obs = 167
LR chi2(3) = 93.45
Prob > chi2 = 0.0000
Log likelihood = -433.0518
Pseudo R2 = 0.0974
Likelihood-ratio test of alpha=0: chibar2(01) = 465.61 Prob>=chibar2 = 0.000

As shown in Table 5-4, each of these factors displays a positive association with the number of bicycle crashes. As in the pedestrian case, bicylce volume and the number of access points appear to have the largest impact on the quantity of bike crashes.

As in the pedestrian case, the bicycle crash prediction model at the census tract level seeks to predict the expected number of bicycle crashes within each census tract based on the contributing factors. Since each Z-statistic is greater than 1.96 as shown in Table 5-4, it is reasonable to say that each factor displays a significant relationship with bicycle crash frequency. As in the pedestrian case, some caution is necessary in using the models based on estimation for actual prediction. The bicycle crash prediction model is given below:

$$Bike\ Crash\ Frequency = EXP(0.0264(A) + 0.0002(B) + 0.0009(C) + 0.2865)$$

where

A = Number of access points,

B = Bike Volume, and

C = Population with education less than Middle School.

5.4.3 Crash Severity Model at Census Tract Level

Even though attempts were made to develop crash severity models for pedestrian and bicycle crashes, no statistical significance was observed. It was primarily because the number of severe crashes was not sufficient to provide valid statistics, and occurrence of these severe crashes was highly random. Therefore, no severity models were provided in this study.

5.5 Corridor Level Crash Data Analysis

5.5.1 Selection of Analysis Corridors

In addition to data analysis in a census tract level, this study analyzed more details at a corridor level. In this study, these corridors were selected with the following selection criteria:

- geographical distribution,
- locations with pedestrian and bicycle crashes,
- locations with non-motorized improvements, and
- locations recommended by city personnel.

In all, a total of 51 corridors were selected for further analysis as shown in Figure 5-33 - Figure 5-36. Corridors selected are as follows

- 13 corridors from Ann Arbor,
- 7 corridors from East Lansing,
- 12 corridors from Flint, and
- 19 corridors from Grand Rapids.

A corridor is defined as a segment with a signalized intersection at each end. An intersection was considered as the area within a radius of 250 feet of the intersection of two streets, FHWA (2012) defined intersection crashes to be within this range. For the corridor analysis, influencing areas in a corridor were defined in different size of buffers. While crashes within the radius of 250 feet of an intersection were defined as intersection crashes, crashes on a roadway segment were defined as midblock crashes.

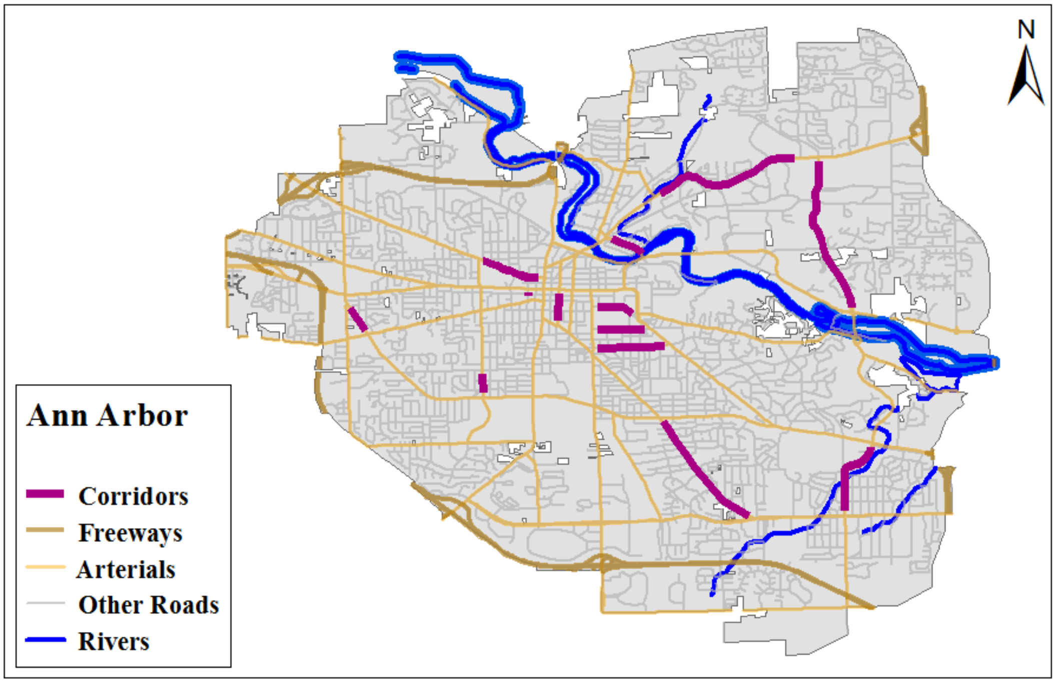


Figure 5-33 Selected Corridors: Ann Arbor

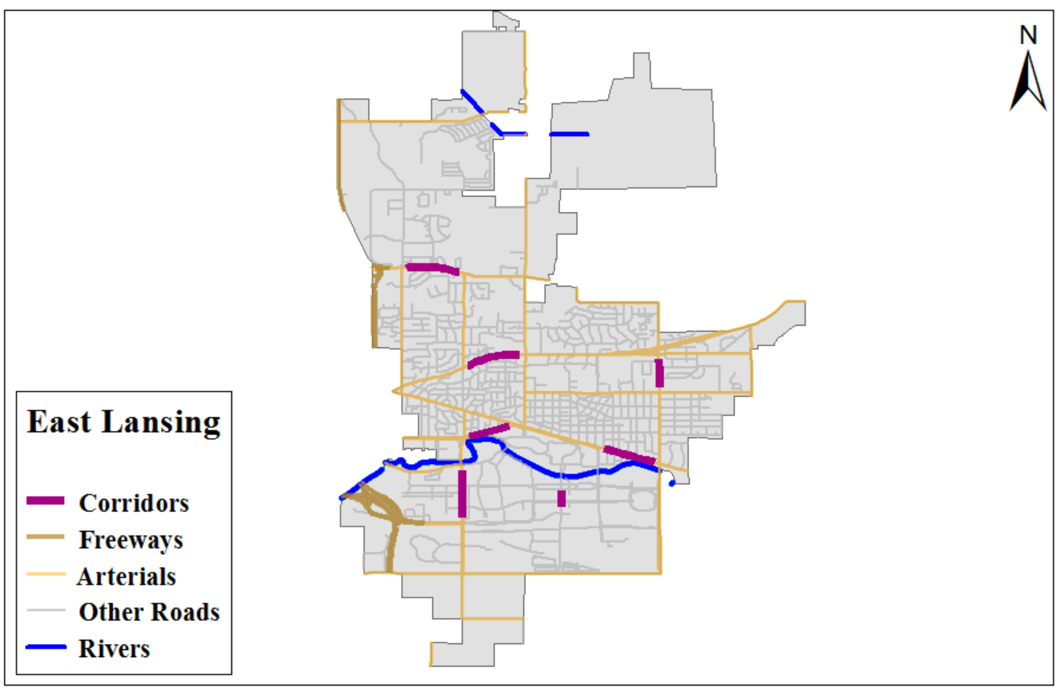


Figure 5-34 Selected Corridors: East Lansing

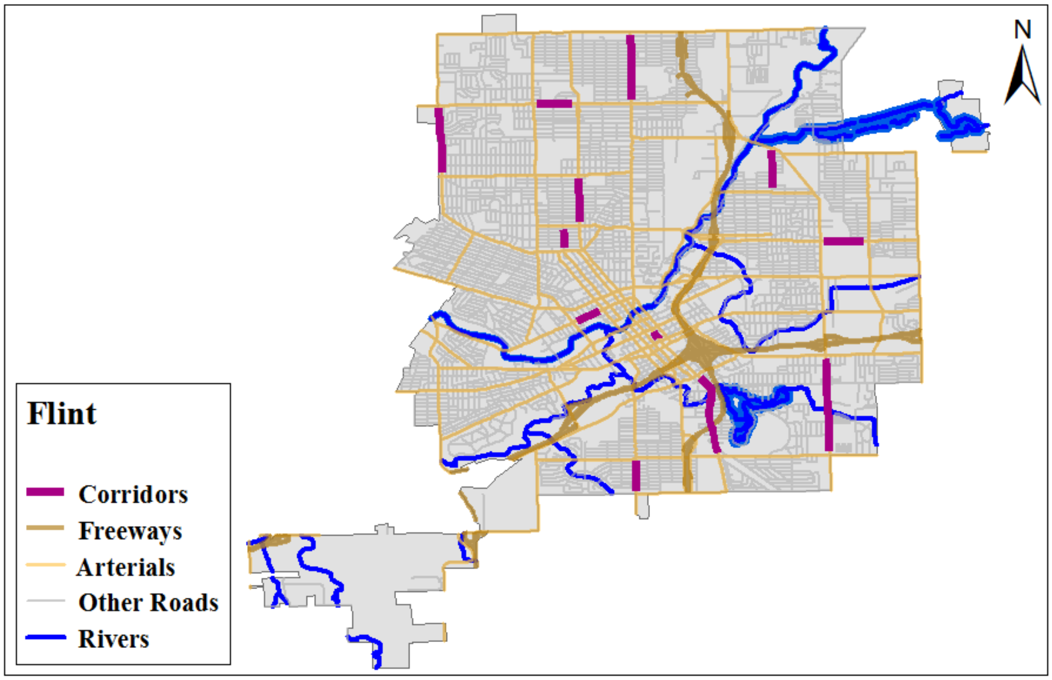


Figure 5-35 Selected Corridors: Flint

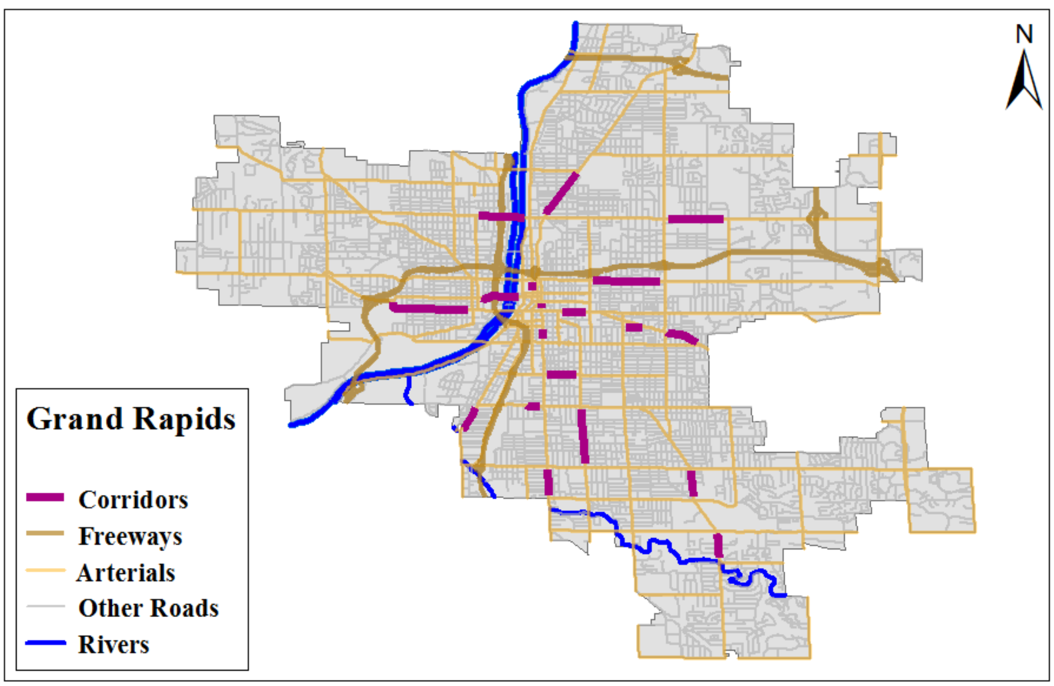


Figure 5-36 Selected Corridors: Grand Rapids

5.5.2 Data Processing for Corridor Analysis

For socioeconomic and demographic data, the area was defined as either a circle for an intersection or a rectangle for a segment of midblock. A 250 foot circle buffer was applied around the center of the intersection in order to determine the number of pedestrian and bicyclist crashes that occur in the vicinity of the signalized intersection. Similarly, a circular buffer was applied around the center of the intersection to determine socio-demographic data within the vicinity of the signalized intersections. A 0.25 and 0.5 circular mile buffer was utilized for extraction of socio-demographic data for pedestrians and bicyclists, respectively. A larger buffer size was used for bicyclists because they are more likely to commute a longer distance as compared to pedestrians. A 0.1 mile rectangular buffer was applied around the mid-block area outside the 250 foot intersection range in order to gather the socio-demographic data at mid-blocks. The mid-block non-motorized crashes that occurred were also collected.

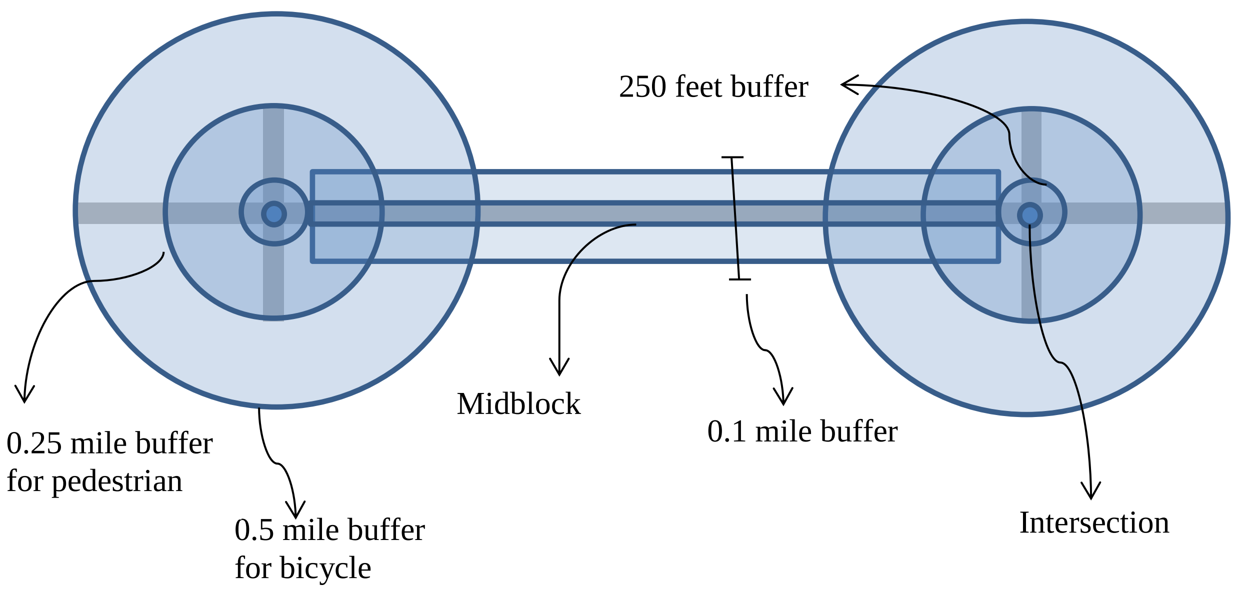


Figure 5-37 Definition of Buffer Areas for Corridor Analysis

Data were reprocessed for each buffer area. For measures in a point data format, the representative values for the buffer area were computed by summing these points in the area. However, the measures from census block or track data needed a different approach. In this study, a weighted average was calculated by the percentage of the census block or tract area included in the buffer.

As noticed from literature, traffic volume directly impacts non-motorized safety, and the number of lanes on each approach might impact non-motorized crashes. Therefore, in addition to data prepared in Chapter 3, these data were collected for detailed corridor analysis. These data were collected using Google-Earth Pro for both midblock segments and intersections. Traffic volume data (ADT) at intersections and midblock segments are presented in Figure 5-38 - Figure 5-45.

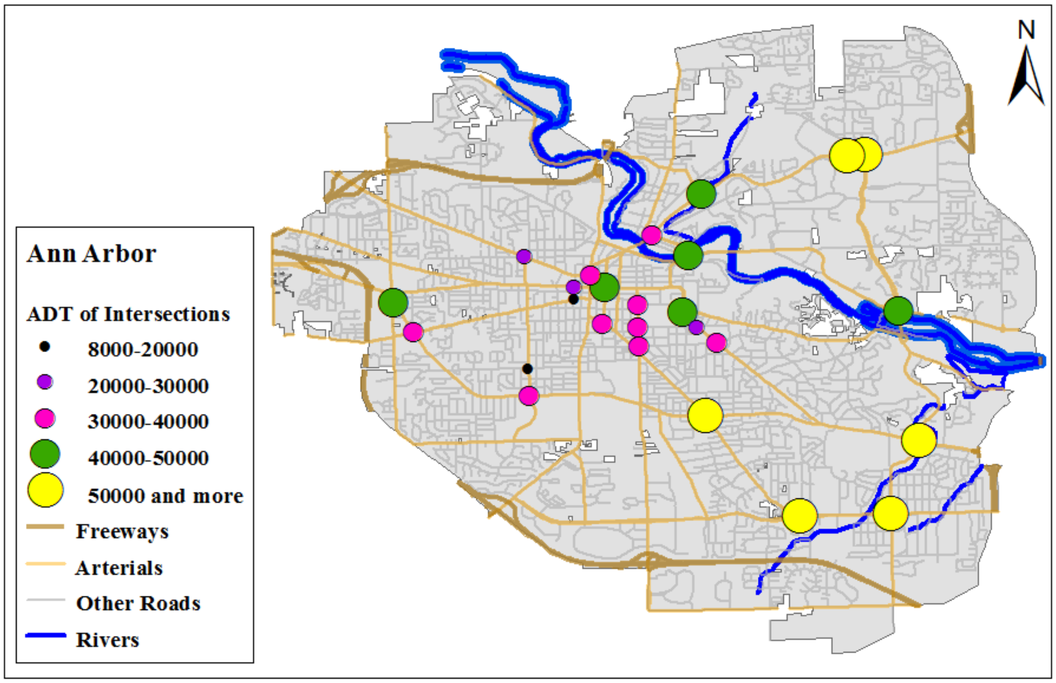


Figure 5-38 Vehicle Traffic ADT at Intersections, Ann Arbor

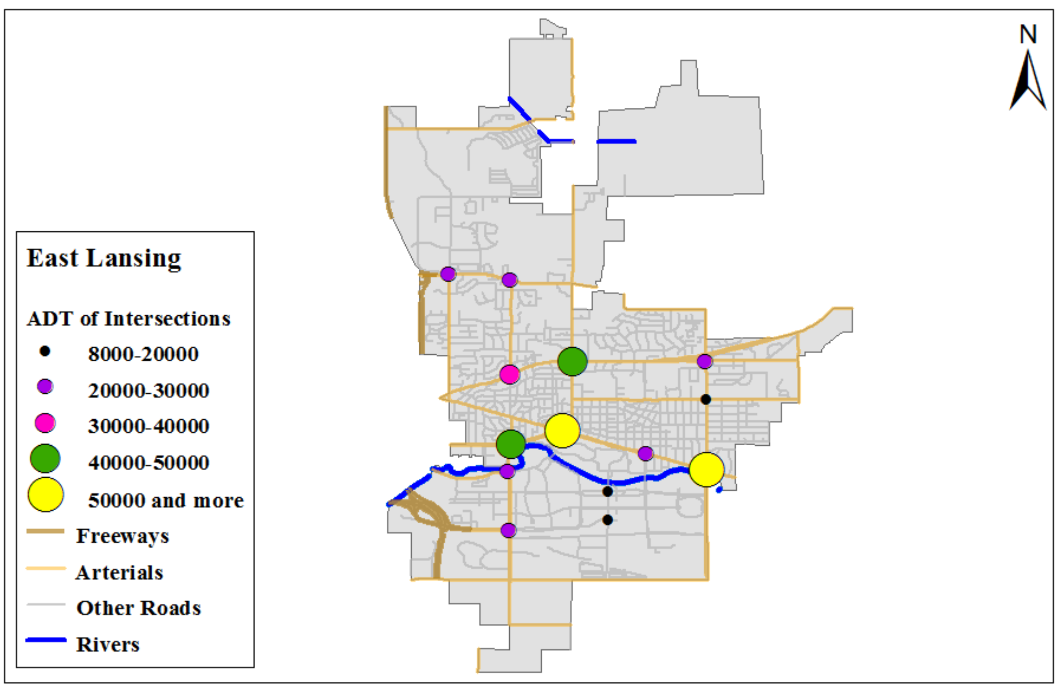


Figure 5-39 Vehicle Traffic ADT at Intersections, East Lansing

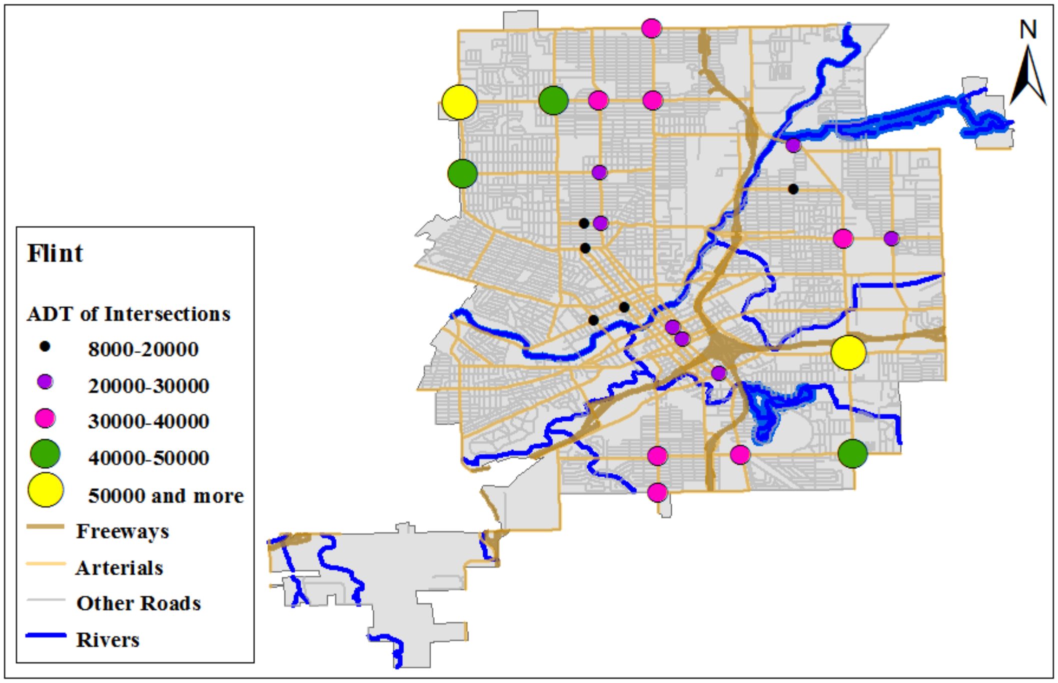


Figure 5-40 Vehicle Traffic ADT at Intersections, Flint

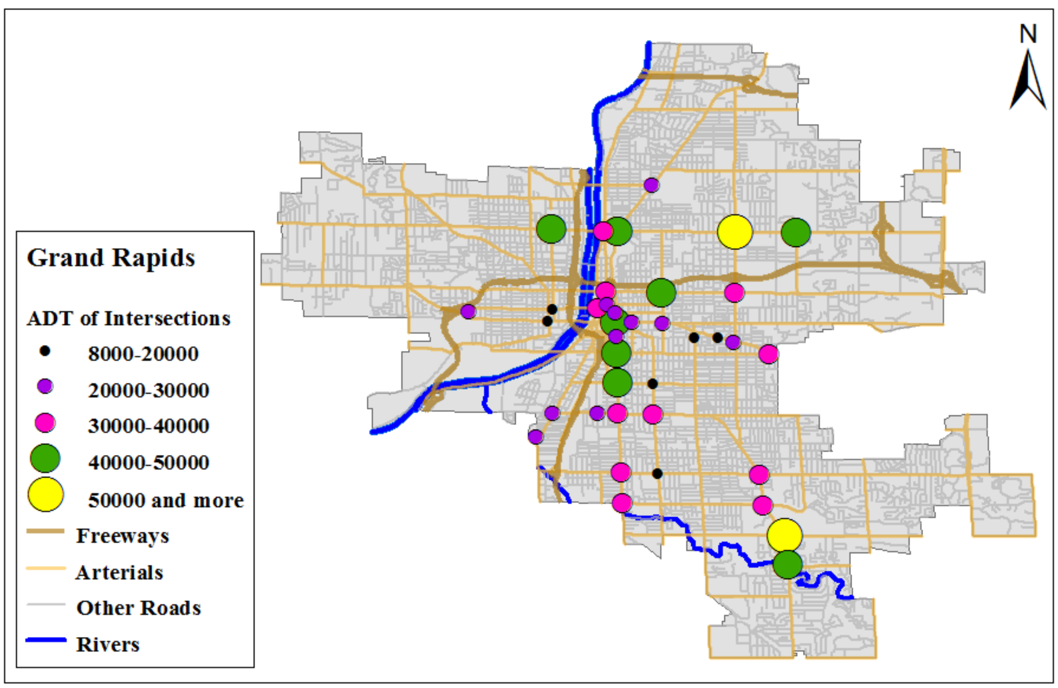


Figure 5-41 Vehicle Traffic ADT at Intersections, Grand Rapids

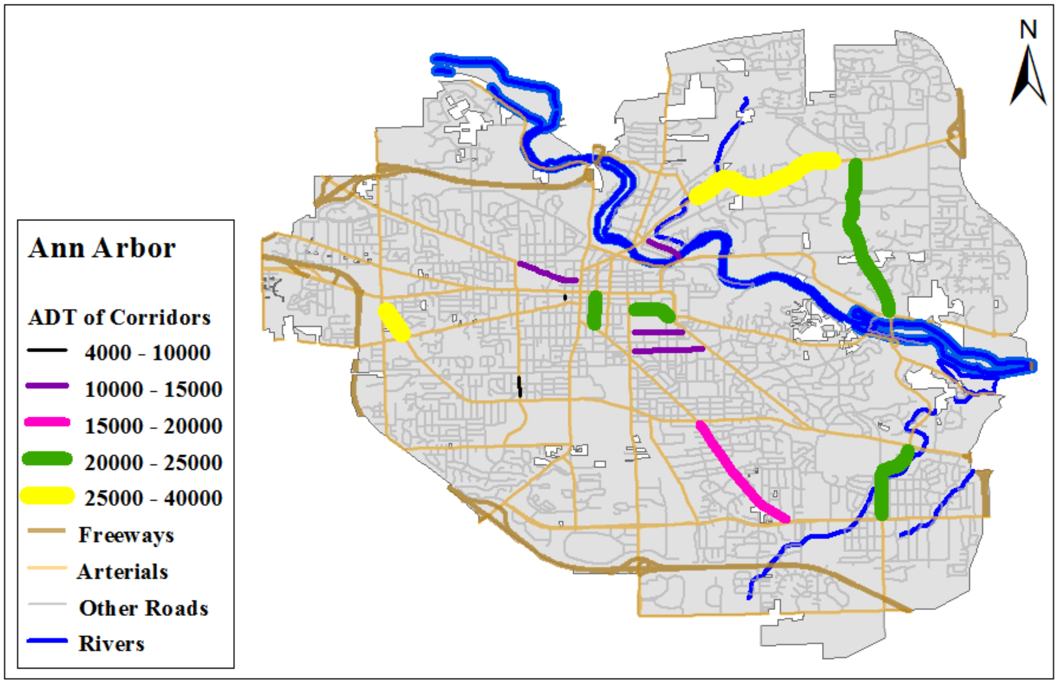


Figure 5-42 Vehicle Traffic ADT along Corridors, Ann Arbor

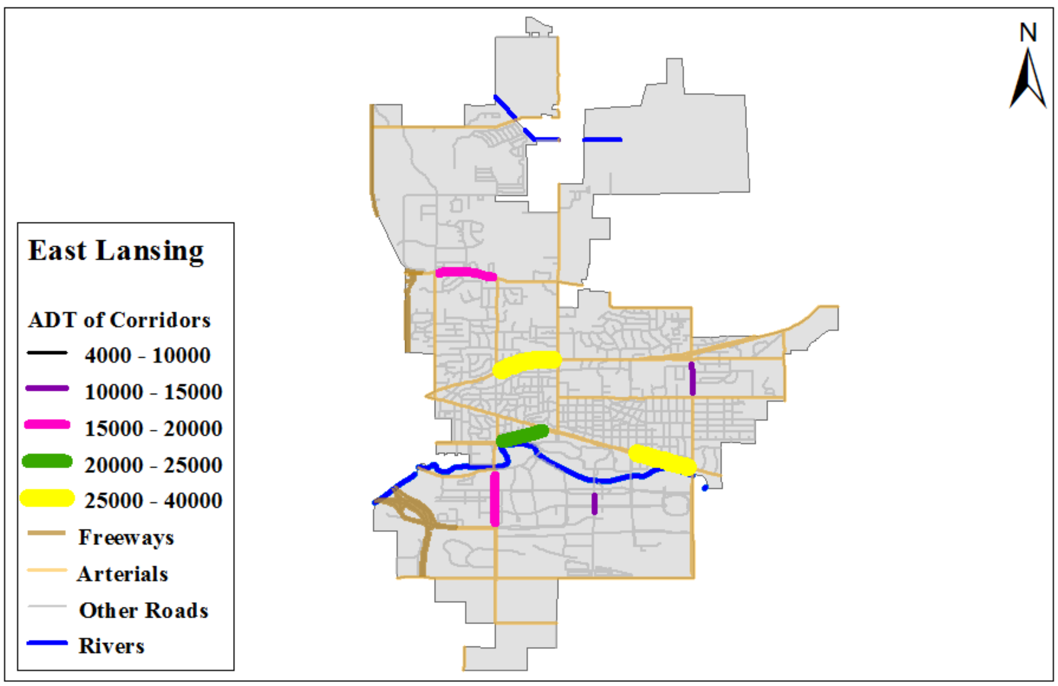


Figure 5-43 Vehicle Traffic ADT along Corridors, East Lansing

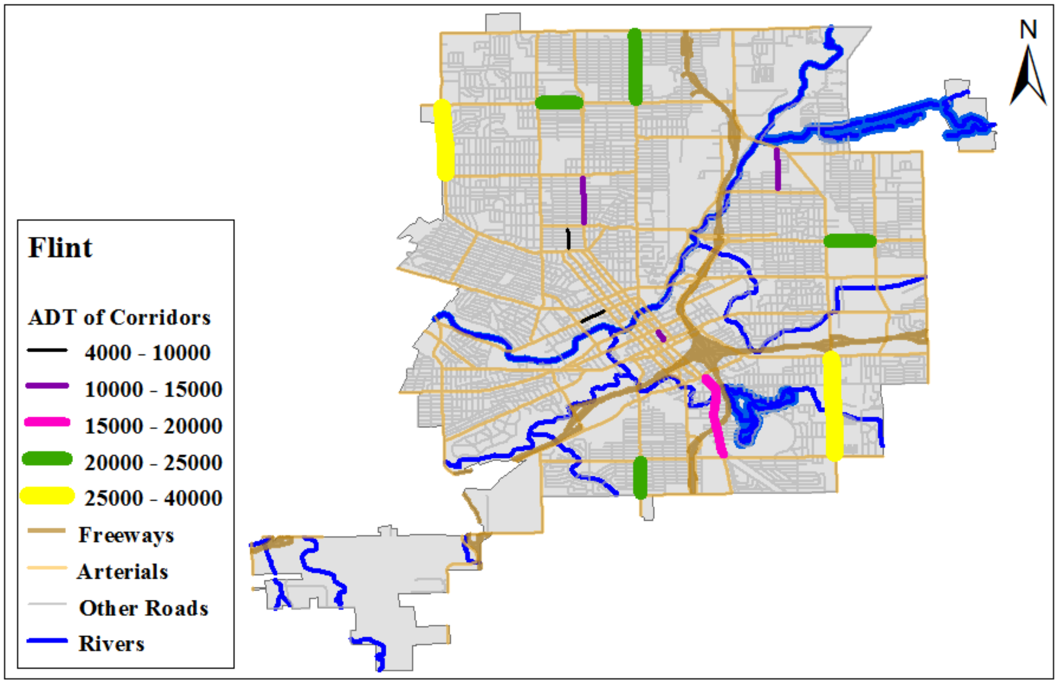


Figure 5-44 Vehicle Traffic ADT along Corridors, Flint

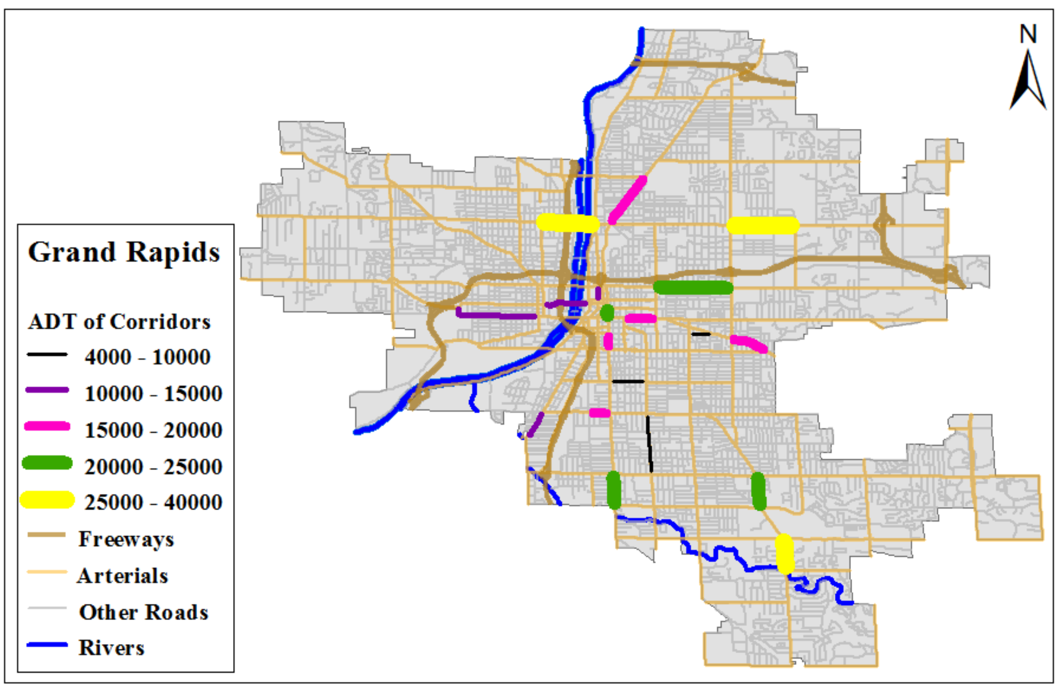


Figure 5-45 Vehicle Traffic ADT along Corridors, Grand Rapids

5.5.3 Model Selection

Since the mean and variance of intersection crashes were closely related in magnitude, it was determined that Poisson Regression was appropriate when analyzing both pedestrian and bicycle crash data at intersections. A Poisson Regression statistical analysis assumes that the mean and variance are equal. The approximately equal means and variances of pedestrian and bicycle crashes for signalized intersections can be viewed in Table 5-5. (The number of observations in Table 5-5 represents the number of corridors under analysis (51), each with two signalized intersections (102).) However, for mid-block data, the mean was significantly different from the variance as shown in the table. This suggests that applying a Negative Binomial regression model is appropriate.

Table 5-5 Summary of Crashes in Selected Corridors

Variable	Observations	Mean	Variance	Min	Max
<u>Intersection</u>					
Number of Pedestrian Crashes	102	1.43	2.4964	0	7
Number of Bicycle Crashes	102	1.64	3.9601	0	12
<u>Midblock</u>					
Number of Pedestrian Crashes	51	2.39	7.3441	0	12
Number of Bicycle Crashes	51	2.53	8.8209	0	15

5.5.4 Non-motorized SPFs for Intersections

Safety Performance Functions (SPFs) represent crash frequency as a function of influential facility attributes, user attributes, and other characteristics. SPFs have become the most utilized method to estimate the crash rate at specific roadway locations (e.g. segments, intersections, ramps). In this section, the influential variables affecting pedestrian and bicycle crashes were identified at signalized intersections and mid-blocks in order to develop an SPF. All evaluated variables can be found in the Appendix.

Certain variables were eliminated from the pedestrian crash signalized intersection model because of their strong correlation with each other. Among the two correlated variables, the variable that was determined to be more influential in the number of pedestrian crashes remained in the model. Similar to the pedestrian crash model, variables that had strong correlation with each other in the signalized intersection bicycle crash model were removed. The variable that was determined to be more influential in the number of bicycle crashes remained in the model. Table 5-6 presents the descriptive statistics for significant variables used when developing non-motorized SPFs for signalized intersections.

Table 5-6 Significant Variable for Intersection Crashes

Definition	Min	Max	Median	Mean	Std. Dev.
Pedestrian volume	59	40,718	355	1,725	5,505
Bicycle volume	27	5,066	196	339	606.7
Total traffic volume (ADT)	2,861	96,261	32,028	33,704	15,269
Dummy variable for existence of bus stops in 250 feet around the intersection	0	1	1	0.71	0.46
Dummy variable for campus land use as the dominant land use	0	1	0	0.08	0.27
Dummy variable for business land use as the dominant land use	0	1	0	0.2	0.37
Dummy variable for presence of right turn lane on major road	0	1	0	0.2	0.42
Employees commuting by walk within ¼ mile	0	680	22	95.6	158.1
Employees commuting by bicycle with ½ mile	0	1,443	62	170.3	269.4
Graduate degree or higher within ¼ mile	0	372	61	84.4	82.3
Number of liquor stores within ¼ mile	0	4	0	0.7	1.0
Number of bars within ¼ mile	0	31	0	7.7	6.7
Number of retail stores within ¼ mile	0	81	4	3.0	12.5
Total number of lanes on minor roads	0	12	8	7.6	2.7

Note) Data from 102 intersections in 51 selected corridors

Numerous variables were evaluated in determining the SPF for the number of pedestrian crashes at signalized intersections. The variables that were determined to be influential at signalized intersections were number of bars, graduate degree attainment, pedestrian volume and ADT of major and minor roads. Number of lanes of the minor roadway was not determined to be a significant factor, but it still demonstrated a correlation with the number of pedestrian crashes at signalized intersections. The number of bars and graduate degree attainment information was obtained through implementing a .25 mile circular buffer around the signalized intersection. These variables and their coefficients with the number of pedestrian crashes at signalized intersections can be observed in Table 5-7.

Table 5-7 Pedestrian Crash Model for Intersections

Pedestrian Crash No.	**Coef.**	**Std. Err.**	**z**	**P>|z|**
No. of Lanes on Minor Road	-0.04345	0.02972	-1.46	0.1440
Total ADT	0.00002	0.00001	2.79	0.0050
Pedestrian Volume	0.00006	0.00001	4.70	0.0000
No. of Bars within 0.25 Mile	0.04557	0.01199	3.80	0.0000
Population with Graduate Degree within 0.25 Mile	-0.00354	0.00132	-2.68	0.0070
Constant	0.04399	0.30828	0.14	0.8870
Number of observation = 101 LR chi2(5) = 43.22 Prob > chi2 = 0.0000 Log likelihood = -150.1658 Pseudo R2 = 0.1258				

Similar to the pedestrian case, bicycle crashes at signalized intersections were analyzed. The results of the evaluation determined that business land use, presence of bus stops, bicycle volume, total of lanes on the minor roadway and the ADT of the minor and major roadways were significant factors that influenced bicycle crashes at signalized intersections. The number of right turn lanes on the major roadway was not a significant factor, but still demonstrates a high correlation with the number of bicycle crashes at signalized intersections. Business land use and presence of bus stop information was respectively acquired through applying a .5 mile and a 250 foot circular buffer around the signalized intersections. The coefficients for the number of bicycle crashes and statistics can be observed in Table 5-8.

Table 5-8 Bicycle Crash Model for Intersections

Bike Crash No.	**Coef.**	**Std. Err.**	**z**	**P>|z|**
Right Turn Lanes on Major Road	0.26783	0.18400	1.46	0.146
Number of Lanes on Minor Road	-0.09138	0.02831	-3.23	0.001
Total ADT	0.00002	0.00001	3.57	0.000
Bike Volume	0.00064	0.00020	3.16	0.002
Bus Dum (250 ft)	0.66610	0.20461	3.26	0.001
Business Dum (.5 mil)	0.50150	0.23235	2.16	0.031
Constant	-0.42365	0.33593	-1.26	0.207
Number of obs = 101 LR chi2(6) = 44.17 Prob > chi2 = 0.0000 Log likelihood = -171.11195				

The model results were used for developing SPFs. These SPFs can be used when predicting the number of pedestrian crashes and bicycle crashes at signalized intersections. However, caution should be used when predicting crash frequency with the models as they are based on estimation and possess statistical error. SPFs developed are as follows:

$$N_{Pedestrian\ Crash\ No.@\ Intersection} = \exp(-.043449\ NLN_{minor\ road} + .000018\ ADT + .000056\ Pedestrian\ Volume + .0455736\ Number\ of\ Bars - .0035416\ Grad\ Degree + .043991)$$

$$N_{Bike\ Crash\ No.@\ Intersection} = exp(.26783\ D_{Major\ Right\ Lane\ No} - .0913841\ NLN_{minor\ road} + .0000211\ ADT + .0006378\ Bike\ Vol\ ume + .6660973\ Dum_{Bus\ Stop} + .5015012\ Dum_{Business\ Landuse} - 0.4236471)$$

where

$N_{Pedestrian\ Crash\ No.@\ Intersection}$ = the number of pedestrian crashes at intersections

$N_{Bike\ Crash\ No.@\ Intersection}$ = the number of bicycle crashes at intersections

$NLN_{minor\ road}$ = the total number of lanes on minor roads

ADT = average daily traffic approaching to the intersection

$Pedestrian\ Volume$= the number of pedestrian crossing the intersection

$Bike\ Vol\ ume$ = the number of pedestrian crossing the intersection

$Number\ of\ Bars$ = the number of bars

$Number\ of\ Grad\ Degree$ = the number of people with a graduate degree with ¼ mile

$Dum_{Bus\ Stop}$ = 1 if a bus stop exists; 0 otherwise

$Dum_{Business\ Landuse}$ = 1 if business area; 0 otherwise

5.5.5 Non-motorized SPFs for Midblock Segments

Out of 163 variables developed for the midblock-level crash analysis, variables listed in Table 5-9 were found to have a significant impact on pedestrian or bicycle crashes.

Table 5-9 Significant Variables for Midblock Crashes

Definition	Min	Max	Median	Mean	Standard Deviation
Average of pedestrian volume of both ends	85	20,953	472	1725	4059.1
Average of bicycle volume of both ends	26	3211	171	320.1	498.0
Posted speed in the corridor	25	45	30	30.1	5.0
Length of midblock segment	0	2	0	0.5	0.3
ADT	4,209	39,476	18,453	18,582.1	7,837.2
Number of crimes	0	180	18	31.6	40.3
Employees commuting by bicycle	0	44	2	5.9	9.2
Total number of access points	0	114	27	33.8	26.1
Number of bus stops	0	15	3	3.7	3.5
Number of liquor stores	0	21	2	0.5	4.3
Dummy variable for existence of bicycle lanes	0	1	0	0.3	0.5
Dummy variable for existence of medians	0	1	0	0.2	0.4
Number of lanes	2	4	4	3.5	0.9

Note) Data were within 0.1 mile buffer

In developing SPFs for mid-block crashes, a negative binomial regression was utilized. First, two models were developed to investigate impacts on pedestrian crashes. Model 1 in Table 5-10 was intended to investigate the significance of physical variables, such as the number of access points, existence of medians or bicycle lanes, the number of lanes, etc. The result shows that many of these variables were not statistically significant, although signs (positive or negative impact) were all intuitively correct. Therefore, model 2 was developed after eliminating insignificant variables. As shown Table 5-11, the results of the negative binomial regression analysis shows that higher speed limits tend to reduce pedestrian crashes. It may have been because less pedestrians attempt to cross high speed arterials. The number of access points was again found to be a significant variable that increases pedestrian crashes, which was the same in the census tract analysis. Traffic volume and pedestrian volume were also positive factors increasing pedestrian crashes.

Table 5-10 Pedestrian Crash Model for Midblock Segments (Model 1)

Ped Crash No.	**Coef.**	**Std. Err.**	**z**	**P>|z|**
AccessPoints	0.01078	0.00648	1.66	0.096
Presence of Median	-0.54984	0.38313	-1.44	0.151
Presence of Bike_lane	-0.30974	0.37036	-0.84	0.403
No_Lanes	-0.09801	0.17217	-0.57	0.569
ADT	0.00004	0.00002	1.59	0.111
Ped_vol	0.00007	0.00003	2.21	0.027
Speed_limit	-0.09028	0.03827	-2.36	0.018
Length	1.14512	0.50862	2.25	0.024
Constant	2.15157	0.99120	2.17	0.030
alpha	0.3019647	0.1674882		

Auxiliary Statistics
Number of obs = 51
LR chi2(8) = 26.04
Prob > chi2 = 0.0010
Log likelihood = -91.875153
Pseudo R2 = 0.1241
Likelihood-ratio test of alpha=0: chibar2(01) = 7.88 Prob>=chibar2 = 0.002

Table 5-11 Pedestrian Crash Model for Midblock Segments (Model 2)

Ped Crash No.	**Coef.**	**Std. Err.**	**z**	**P>|z|**
AccessPoints	0.01703	0.00622	2.74	0.006
ADT	0.00004	0.00002	1.63	0.103
Ped_vol	0.00005	0.00003	1.81	0.071
Speed_limit	-0.10484	0.03901	-2.69	0.007
Length	0.76422	0.48970	1.56	0.119
Constant	2.04384	0.96362	2.12	0.034
alpha	0.394995	0.1840582		

Auxiliary Statistics
Number of obs = 51
LR chi2(5) = 22.46
Prob > chi2 = 0.0004
Log likelihood = -93.664602
Pseudo R2 = 0.1071
Likelihood-ratio test of alpha=0: chibar2(01) = 13.35 Prob>=chibar2 = 0.000

In the bicycle crash model as shown in Table 5-12, many variables were significant. While the speed limit and existence of bicycle lanes were factors reducing bicycle crashes, the number of bus stops and the number of employees commuting by bicycle were determined to be positive factors increasing bicycle crashes, in addition to exposure measures, such as traffic and bicycle volume.

Table 5-12 Bicycle Crash Model for Midblock Segments

Bike Crash No.	**Coef.**	**Std. Err.**	**z**	**P>|z|**
ADT	0.00006	0.00002	3.37	0.001
Bike_vol	0.00111	0.00040	2.79	0.005
Speed_limit	-0.11734	0.02755	-4.26	0.000
No_BusStop	0.07349	0.04282	1.72	0.086
BikeCommuter	0.02559	0.01209	2.12	0.034
D_BikeLane	-0.31038	0.28112	-1.10	0.270
Length	0.71856	0.40385	1.78	0.075
Constant	2.03331	0.72543	2.80	0.005
alpha	0.11934	0.10677		

Auxiliary Statistics
Number of obs = 50
LR chi2(7) = 36.67
Prob > chi2 = 0.0000
Log likelihood = -86.671599
Pseudo R2 = 0.1746
Likelihood-ratio test of alpha=0: chibar2(01) = 2.31 Prob>=chibar2 = 0.064

Finally, the model results were used to develop SPFs. These SPFs can be used when predicting the number of pedestrian crashes and bicycle crashes at midblock segments. However, caution should be used when predicting crash frequency with the models as they are based on estimation and possess statistical error.

Developed SPFs are as follows:

$$N_{Pedesrian\ Crash\ @\ midblock} = exp(.017 * Access\_points + 0.00004 * ADT + 0.00005 * Ped\_Vol - 0.105 * Speed\_Limit + 0.76 * Length\_Corridor + 2.04)$$

$$N_{bike\ crashes\ @\ midblock} = \exp(.00006 * ADT + 0.011 * Bike\_vol - 0.117 * Speed\_limit$$
$$+0.073 * No\_BusStop + 0.026 * Bike\_Commuter$$
$$-0.31 * D\_Bike\_Ln + 0.72 * Length\_Corridor + 2.03)$$

where,

$N_{Pedesrian\ Crash\ @\ midblock}$ = the number of pedestrian crashes at midblock

$N_{bike\ crashes\ @\ midblock}$ = the number of bicycle crashes at midblock

$Access\_points$ = the number of access points

ADT= average daily traffic of two ends

Ped_Vol = average of pedestrian volumes

$Bike\_vol$= average of bicycle volumes

$Speed\_Limit$ = speed limit of the arterial

$No\_BusStop$ = the number of bus stops along the corridor

$Bike\_Commuter$ = the number of employees commuting by bicycle

D_Bike_Ln = 1 if bicycle lanes exist; 0 otherwise

$Length\_Corridor$= the length of corridor

5.6 Intersection Level of Safety

This section attempts to address intersection level of safety (LOS) based on the number of crashes and the non-motorized volume. While the intersection level of safety can be described only by the number of crashes, the non-motorized volume as an exposure measure is integrated in this analysis.

Data used in this analysis include the numbers of pedestrian and bicycle crashes during past five years, and 12-hour pedestrian volume and bicycle volume. Pedestrian and bicycle volume data were estimates from the models developed unless actual observations were available. First, all signalized intersections in four cities were categorized into groups based on the percentile of pedestrian and bicycle crashes. The result shows that the number of crashes can be broken down into seven groups, such as 0, 1, 2, 3, 4, 5 and 6 or more, for both pedestrian and bicycle crashes. Table 5-13 shows both percentages of intersections and crashes in each group.

Table 5-13 Categories by the Number of Crashes

		Number of crashes						
		0	1	2	3	4	5	6+
Pedestrian	% of Intersection	60.4%	22.0%	7.7%	5.1%	1.8%	1.2%	1.8%
	% of Crashes	0.0%	28.4%	19.8%	19.7%	9.4%	7.6%	15.1%
Bicycle	% of Intersection	60.4%	19.9%	9.4%	5.1%	2.1%	1.6%	1.6%
	% of Crashes	0.0%	24.3%	22.9%	18.6%	10.2%	9.5%	14.6%

Second, intersection pedestrian and bicycle volumes were grouped into six categories: very high (VH), high (H), medium high (MH), medium low (ML), low (L), and very low (VL). As shown in Table 5-14, very high pedestrian volume intersections are only 3.1%, but those intersections carry nearly 50 percent of the total pedestrian volume. Similarly, about 6% of intersections in the very high volume category carry more than 40 percent of the total bicycle volume.

Table 5-14 Categories by Volume Level

Volume Level	Pedestrian		Bicycle	
	% of Intersections	% of Volume	% of Intersections	% of Volume
VH (7000 - More)	3.1%	49.2%	5.6%	41.2%
H (3000 - 7000)	4.9%	17.1%	5.9%	13.6%
MH (1600 - 3000)	5.7%	9.5%	10.3%	13.4%
ML (600 - 1600)	12.2%	9.2%	15.9%	12.7%
L (300 - 600)	24.5%	7.9%	23.3%	12.6%
VL (0 - 300)	49.5%	7.1%	39.1%	6.5%

For each intersection, an index for the level of safety is determined by the formula below. In the formula, a natural log of the volume was applied as a denominator to properly scale the pedestrian and bicycle volumes.

$$\text{Level of safety Index} = \frac{\text{the number of crashes}}{\ln(\text{volume})} \times 100$$

Table 5-15 Determinant Index Value for Pedestrian Intersection Level of Safety

Pedestrian LOS	Index Range		% of Intersections	% of Volume	% of Crash
A	0	10.0	60.4%	31.1%	0.00%
B	10.0	22.5	21.6%	22.4%	29.75%
C	22.5	35.0	6.5%	12.0%	15.29%
D	35.0	47.5	5.6%	18.5%	21.18%
E	47.5	60.0	2.5%	5.5%	9.41%
F	60.0	More	3.4%	10.4%	24.37%

Table 5-16 Determinant Index Value for Bicycle Intersection Level of Safety

Bike LOS	Index Range		% of Intersections	% of Volume	% of Crash
A	0	15	61.6%	48.0%	1.11%
B	15	30	20.2%	20.5%	26.03%
C	30	45	6.5%	10.0%	15.24%
D	45	60	5.5%	7.9%	19.21%
E	60	75	2.6%	5.8%	14.44%
F	75	More	3.6%	7.8%	23.97%

Based on the percentile of intersections, volumes and crashes, index ranges for pedestrian and bicycle level of safety (LOS) were determined. In this case, those intersections with zero crash are categorized into LOS A while those with more than five crashes are LOS F regardless of the non-motorized volume. However, LOS for those intersections with crashes between two and five are dependent on the volume.

Table 5-17 Intersection Level of Safety for Pedestrian

	Pedestrian Crash						
Pedestrian Volume	0	1	2	3	4	5	6+
VH (7000 - More)	A	B	B	C	D	E	F
H (3000 - 7000)	A	B	C	D	D	E	F
MH (1600 - 3000)	A	B	C	D	E	F	F
ML (600 - 1600)	A	B	C	D	F	F	F
L (300 - 600)	A	B	C	E	F	F	F
VL (0 - 300)	A	B	D	E	F	F	F

Table 5-18 Intersection Level of Safety for Bicycle

	Bike Crash						
Bike Volume	0	1	2	3	4	5	6+
VH (7000 - More)	A	A	B	C	D	E	F
H (3000 - 7000)	A	B	C	D	E	F	F
MH (1600 - 3000)	A	B	C	D	E	F	F
ML (600 - 1600)	A	B	C	D	E	F	F
L (300 - 600)	A	B	C	E	F	F	F
VL (0 - 300)	A	B	D	E	F	F	F

5.7 Findings

In this chapter, crash data were analyzed in city-wide level, census tract level, and also corridor level. In the city-wide and census tract level analyses, the following were identified:

1) While population-based crash rates deliver good information on non-motorized crashes, exposure-based crash rates provide direct performance measures complementary to the population-based rates.
2) In study areas, approximately 80 percent of non-motorized crashes occurred within 500 feet of intersections.
3) Night-time crashes tend to occur more outside of the downtown, possibly due to lighting problems or lack of activity after 5:00 PM.

4) GIS maps successfully identify locations with higher concerns on non-motorized safety, which can be useful in determining potential locations for countermeasure treatments.

Crash frequency models in a census tract level were developed using negative binomial regression analysis, and these models revealed the following:

1) The number of access point is one of the most significant factors increasing non-motorized crashes.
2) It was not possible to observe whether bicycle lanes reduced bicycle crashes although bicycle lanes may have enhanced safety for bicyclists. It may have been because bicycle lanes also increase bicycle volumes. However, interestingly, it was observed that bicycle lanes tend to reduce pedestrian crashes by providing separation between vehicle traffic and pedestrians.
3) More non-motorized crashes were observed from areas with higher population of low education (middle school or lower) residents.
4) Higher non-motorized exposure increases the likelihood of crash occurrence. However, when non-motorized facility coverage increases proportionally to the increase in non-motorized volumes, the crash prediction models showed a reduction in crash frequency.

Fifty-one corridors were selected for detailed analysis. The corridors were again classified into two parts, intersections and midblock segments because of their different characteristics. Through a Possion regression model or a negative binomial regression model, the following four safety performance functions (SPFs) were developed.

$$N_{Pedestrian\ Crash\ No.@\ Intersection} = \exp(-.043449\ NLN_{minor\ road} + .000018\ ADT + .000056\ Pedestrian\ Volume + .0455736\ Number\ of\ Bars - .0035416\ Grad\ Degree + .043991)$$

$$N_{Bike\ Crash\ No.@\ Intersection} = exp(.26783\ D_{Major\ Right\ Lane\ No} - .0913841\ NLN_{minor\ road} + .0000211\ ADT\ +\ .0006378\ Bike\ Vol\ ume +\ .6660973\ Dum_{Bus\ Stop} + .5015012\ Dum_{Business\ Landuse} - 0.4236471\ )$$

$$N_{Pedesrian\ Crash\ @\ midblock} = exp(.017 * Access\_points + 0.00004 * ADT + 0.00005 * Ped\_Vol - 0.105 * Speed\_Limit\ + 0.76 * Length\_Corridor + 2.04\ )$$

$$N_{bike\ crashes\ @\ midblock} = \exp(.00006 * ADT + 0.011 * Bike\_vol - 0.117 * Speed\_limit + 0.073 * No\_BusStop + 0.026 * Bike\_Commuter - 0.31 * D\_Bike\_Ln + 0.72 * Length\_Corridor + 2.03)$$

From these models, the following were found:

1) The model results show that an increase in pedestrian crashes correspond to increases in vehicle ADT, pedestrian volume, and the number of bars in the vicinity of the signalized intersections. These results are statistically significant.
2) An increase in the number of individuals who have a graduate degree near the signalized intersections corresponded to a decrease in the number of pedestrian crashes (statistically significant). While the increase in the number of lanes of the minor roadway at major-minor intersections corresponded to a decrease in pedestrian intersection crashes. It may have been because pedestrians are relatively more cautious when crossing wider minor roads.
3) The model results show that an increase in bicycle intersection crashes corresponded to an increase in the predictors: vehicle ADT, bicycle volume, the presence of bus stops, and the business land use around signalized intersections. These results are statistically significant.
4) An increase in the number of lanes in the minor roadway at major-minor intersections corresponded to a significant decrease in the number of bicycle crashes. It may have been because bicyclists are relatively more cautious when crossing wider minor roads.

Right turn lanes on major roadways at major-minor intersections corresponded to an increase in bicycle crashes at intersections.

5) The model results show that an increase in mid-block pedestrian crashes corresponded to an increase in the predictors: the number of access points, vehicle ADT, pedestrian volume and the length of the mid-block although it was statistically weak.
6) Higher posted speed limits at mid-blocks significantly corresponded to a decrease in the number of pedestrian crashes, likely as a result of diminished perception of safety and pedestrians' reluctance of crossing on high speed roads.
7) A statistically significant increase in bicycle mid-block crashes corresponded to an increase in the predictors: vehicle ADT, bicycle volume, and commuters who bicycle to work.
8) While the number of bus stops and the length of mid-blocks correspond to an increase in bicycle mid-block crashes although it was statistically weak.
9) Corridors with higher posted speed limits were shown to correspond (statistically significant) to a decrease in bicycle mid-block crashes while the presence of bicycle lanes was not a statistically significant predictor. Similar to the pedestrian case, this might be explained by reduced perception of safety by bicyclists with regard to crossing or traveling along high speed roads. Posted speed limit is correlated to the pedestrian and bike volumes. As speed limit increases, non-motorized volume decreases, hence resulting in relatively less crashes.

Chapter 6 Analysis of Cultural Factors

6.1 Introduction

Walking and bicycling are becoming more important modes of transportation. Pedestrians and bicyclists interact with automobiles, other pedestrian traffic, as well as other bicyclists in day-to-day travel. Cultural factors and understanding of rules of the road pertaining to pedestrians and bicyclists are instrumental to safe interactions among pedestrians, bicyclists and motorized traffic. This study examines, through field questionnaire surveys, whether there are cultural, perceptional, or educational differences in comprehension of these rules.

Many researchers have employed surveys in their analyses of the perceived and actual effectiveness and safety of various non-motorized facilities. Many of the studies conducted thus far attempted to show a general relationship between demographic data (such as age, gender, and education level) and survey responses related to transportation issues (Nordfjrn et al. 2012; Nordfjrn et al. 2010; Laapotti et al., 2003; Shi et al., 2010; Hassan et al., 2007; Ng et al., 2008; Jiang et al., 2011). Researchers also have attempted to establish a general relationship between various types of locations and survey responses or driver behaviors (Nordfjrn et al. 2012; Nordfjrn et al. 2010; Laapotti et al., 2003; Hatfield et al., 2007). Some of the research sought to determine if a link exists between driver attitude and driver behavior based on information collected through a survey (Nordfjrn et al. 2010; Laapotti et al., 2003; Mao et al., 2010). Not all of the established research sought out general associations, however. Many researchers chose to question subjects on specific topics, such as the understanding of traffic signs or signals (Ng et al., 2008; Hatfield et al., 2007; Kirmizioglu et al., 2012), impact of education outreach efforts (Shi et al., 2010; Hassan et al., 2007; Girasek, 2013; Currie, 2009; Nasvadi, 2007), establishment of right-of-way at signalized intersections (Hatfield et al., 2007), and understanding of free right-turn at channelized intersections (Macfarlane et al., 2011). Given their high frequency of usage in a wide spectrum of topics, surveys serve as crucial tools used by transportation researchers in their ability to examine public comprehension of right-of-way rules. The following review further elaborates on the body of work done by researchers who have drawn meaningful conclusions between responses to survey questions and the various independent characteristics discussed earlier.

With respect to the influence of various demographic traits on survey responses, research typically focuses on the impact of gender and education, as these factors tend to display the greatest impact on any variances in responses. For example, Laapotti *et al*. (2003) showed that females typically respond more positively towards traffic rules and safe driving in their analysis of drivers from both urban and rural areas, which aligns with the conclusion mad by many other research studies that males tend to act more aggressively on the road. Studies are in agreement that the level of educational attainment also plays a significant role in impacting responses with respect to transportation related questions (Nordfjrn et al. 2010; Laapotti et al., 2003; Shi et al., 2010; Hassan et al., 2007; Ng et al., 2008; Jiang et al., 2011). Nordfjrn *et al.* (2012) also analyzed the link between a heuristic measure of culture and the variability in crash involvement by comparing survey responses from Norway to those of nations in Sub-Saharan Africa. They found that cultural variables are more strongly associated with self-reported crash incidences in Sub-Saharan Africa relative to Norway, where only gender was found to factor into the variability in crashes.

Many studies have shown that resident location often influences how drivers and pedestrians perceive traffic rules and regulations when asked to participate in a survey. Nordfjrn *et al.* (2010) examined how driver behavior and attitudes varied depending on a whether a resident hailed from a rural, suburban, or urban area within Norway. In their analysis, they discovered that geographical area was associated with a significant main effect, but they also hypothesized that variations in gender, age, and education within each of the three distinct areas was likely responsible for this effect, rather than differences in roadway or traffic conditions. In their study on the effect of driver vs. pedestrian role on perception and behavior with respect to issues of right-of-way at a signalized intersection, Hatfield *at al.* (2007) found that behaviors, such as looking before crossing and waiting for traffic to stop, were strongly related to differences in area (urban vs. rural). They also found that pedestrians tended to perceive right-of-way as their own more often in urban areas in all crossing situations analyzed.

In many instances, researchers used data gathered from survey responses in conjunction with observed and self-reported traffic behaviors to determine whether a significant relationship exists between driver attitude and driver behavior. Laapotti *et al.* (2003) demonstrated that incorrect attitudes regarding traffic rules and guidelines typically resulted in increased crash involvement, regardless of location. Nordfjrn *et al.* (2010) compared survey responses according to location, and their structural equation model (SEM) analysis revealed a strong positive relationship between driver attitude and driver behavior. Specifically the difference in attitude resulted in a significant amount of the variance in driver behavior. Mao *et al.* (2010) comprehensively described a driver's attitude as his/her level of "Traffic Safety Consciousness" (TSC), and found that as TSC rises, desirable and lawful traffic behavior also rises, which leads to a lower crash rate.

As explained, data collected from surveys can serve many different functions, dependent upon the application of the analysis and the relationships of interest to the researcher. However, the review of the current body of literature shows a few areas deserving more attention. The following discussion draws attention to these issues and explains how the present work differs in its approach to using survey data as a tool in measuring the traveling public's response to relevant transportation matters. Af Wahlberg (2010) points out that much of the past research involved the use of survey responses in combination with self-reported crashes or behaviors. He further explains that this type of analysis, where both the dependent and independent variables are self-reported, will often display a common method variance (CMV) due to a desire from the respondent to not offend the interested party (social compliance), resulting in a bias in both variables. When social desirability imparts bias on both the answers of driver/pedestrian questionnaires and the self-reported crash data, statistical analysis will reveal a more significant relationship than otherwise expected, or it will indicate a significant relationship where one does not exist. With regard to previous research, in almost every case where an association is shown between perceptions or attitudes and behaviors or experiences with crashes, all data are self-reported and possibly subject to validity issues propagated by social desirability. Hatfield *et al.* (2007) avoided this problem in their analysis by visually observing how survey respondents interact with pedestrian traffic signals in the various crossing situations relevant to their research.

The study introduced a unique approach in analyzing the impact of location on bicyclists', pedestrians', and drivers' understanding of non- motorized traffic safety through its Chi-Square analyses of results from four cities across Michigan: Ann Arbor, East Lansing, Flint and Grand Rapids. One would expect little to no variation in understanding of non-motorized safety between these locations due to their relative close proximity, all under the same legislative umbrella (The Michigan Vehicle Code - MVC), with respect to the "rules of the road." Moreover, the Michigan Department of Transportation plans, operates, and maintains state roadways within each city. This work also differs from similar studies by showing how any revealed associations might relate to actual crash data, as opposed to self-reported crash involvement. In addition, results are considered with respect to subjects' perceptions of safety within each city.

When choosing to analyze responses according to location, many studies either categorized respondents according to urban vs. rural, offered other sub-classifications in a country-wide or area-wide sample (Nordfjrn et al., 2010; Laapotti et al., 2003; Hatfield et al., 2007) or performed cross-country comparisons (Nordfjrn et al., 2012). This research differs in its decision to compare survey responses in four major cities spanning the lower half of the lower peninsula of the State of Michigan, while also ensuring to gather data from a representative sample of responses from downtown areas, areas outside the downtown, as well as low-income areas from within each city. Finally, the present work builds upon similar research conducted by Hatfield *et al*. (2007) by studying the impact of location on the respondents' understanding of pedestrian versus driver right-of-way at unmarked crosswalks, uncontrolled crosswalks, midblock crossings, and crosswalks controlled by a COUNTDOWN signal.

One of the main purposes of this study was to investigate cultural, perceptional, and educational differences associated with non-motorized safety among four cities in Michigan. To achieve the objective, this study employed a questionnaire survey and compares behavioral differences. The methodology section outlines the content of the bicyclist and driver/pedestrian questionnaires, the survey procedure, and explanation of the statistical analysis of survey responses. The next section, Results & Discussion, presents associations revealed by the statistical analysis between survey responses and city. When an association is discovered, an explanation is offered with respect to the impact of educational or cultural differences according to city. The study mitigates the influence of social desirability on the statistical analysis of driver and pedestrian behavior by using crash data from the Michigan Traffic Crash Facts (MTCF) website (http://www.michigantrafficcrashfacts.org) when using associations concluded from survey responses in relation to actual traffic crashes, as opposed to the decision by previous studies to use self-reported crash involvement. This is in, opposition to decisions by previous studies to use self-reported crash involvement. Finally, the chapter wraps up with a conclusion that summarizes how city of residence influences cultural, perceptional, or educational differences with regard to non-motorized traffic safety.

6.2 Methodology

To identify cultural factors and understanding of traffic laws according to city, questionnaires for drivers, pedestrian, and bicyclists were developed. While pedestrians often drive and vice-versa, bicycles represent a form of non-motorized transportation not universally experienced. The survey questions chosen for bicyclists strived to gauge both the typical behavior of each individual, and how that individual interacts with other forms of transportation and traffic devices while riding a bike. The bicyclist survey questions included the following:

1. How often do you ride your bike?
2. How many bike trips do you make per week in good weather?
3. What is the primary purpose of bike trips?
4. Where do you most often ride?
5. Which way do you travel relative to traffic when riding in the road?
6. Do you stop at red lights when riding your bicycle if there is no traffic?
7. Do you stop at stop signs when riding your bicycle if there is no traffic?
8. Do you typically signal when making a turn on your bicycle?
9. Do you yield to pedestrians at crosswalks when riding your bicycle?

Unlike the unique experience of bicyclists, drivers can easily relate to pedestrians, since a driving trip often involves walking. The survey questions, asked of drivers and pedestrians, attempted to discover how drivers and pedestrians understand traffic rules in various crossing scenarios by asking the following questions and showing a picture of the scenario in question for clarification:

1. Who has the right-of-way (R-o-W) here, the pedestrian or the driver?
2. If there was a crash, who would be at fault?

The types of crosswalks of interest included a marked crosswalk showing a WALK signal, a marked crosswalk with a COUNTDOWN signal, a marked crosswalk showing a DON'T WALK signal, a marked crosswalk at uncontrolled location, an unmarked crosswalk at an uncontrolled location, and a midblock crossing. Copies of the survey questionnaire for bicyclists, drivers, and pedestrians are included in the appendix.

6.2.1 Survey

A survey team consisting of Western Michigan University graduate and undergraduate students attempted to intercept 100 each of pedestrians, drivers and bicyclists in four cities across Michigan: Ann Arbor, Grand Rapids, East Lansing, and Flint. Ann Arbor and East Lansing are similar in their high student populations as a result of the University of Michigan and Michigan State University respectively calling these places home. However, East Lansing's population is roughly half that of Ann Arbor. Grand Rapids is the largest metropolitan area of the four surveyed cities. Flint is a former industrial city that has been in decline in recent years due to companies relocating or shutting down operations. The survey locations were carefully selected to include low-income areas, downtown areas and areas outside the downtown. Furthermore, survey responses were specifically categorized according to subject type, area, and other factors, but the present work focuses its discussion on survey responses with respect to city of residence.

The surveys were conducted on four consecutive days between 5/13/2013 to 5/16/2013. Survey members were placed in pairs and directed to intercept 100 subjects near intersections in specific locations (low income, downtown, and an outside area). The survey administers preferred to conduct samplings of driver participants at gas stations due to the high volume of traffic and access to drivers outside of their vehicles. Pedestrians and bicyclists were intercepted whenever an opportunity presented itself; however, bicyclists tended to be less responsive due to their speed of travel and unwillingness to stop. Table 6-1 highlights survey completion percentages at each of the three locations in all four cities.

As shown, the low volume of bicyclists in the outside locations significantly reduced the total number of bicyclist surveys to 59.3 percent of anticipated completed surveys. Ultimately, a total of 908 subjects (233 bicyclists and 675 combined pedestrians and drivers) were sampled, resulting in a 76.2 percent sampling rate of 1200 total anticipated surveys.

Table 6-1 Percentage of Surveys Completed by City and Location

City	Location	Subject Type			Total
		Pedestrians	Bicyclists	Drivers	
Flint	Downtown	95.0%	67.5%	96.7%	85.5%
	Outside	30.0%	6.7%	97.5%	50.0%
	Low Income	70.0%	23.3%	83.3%	58.9%
	Total	68.0%	36.0%	93.0%	65.7%
Ann Arbor	Downtown	100.0%	102.5%	100.0%	100.9%
	Outside	100.0%	70.0%	90.0%	87.0%
	Low Income	96.7%	103.3%	100.0%	100.0%
	Total	99.0%	93.0%	96.0%	96.0%
East Lansing	Downtown	82.5%	82.5%	100.0%	87.3%
	Outside	90.0%	10.0%	100.0%	70.0%
	Low Income	96.7%	96.7%	100.0%	97.8%
	Total	89.0%	65.0%	100.0%	84.7%
Grand Rapids	Downtown	97.5%	67.5%	83.3%	82.7%
	Outside	20.0%	23.3%	40.0%	29.0%
	Low Income	83.3%	30.0%	70.0%	61.1%
	Total	70.0%	43.0%	62.0%	58.3%
Total	Downtown	93.8%	80.0%	95.0%	89.1%
	Outside	60.0%	27.5%	81.9%	59.0%
	Low Income	86.7%	63.3%	88.3%	79.4%
	Total	81.5%	59.3%	87.8%	76.2%

6.2.2 Statistical Analysis

After the responses were tabulated according to city, area, or subject type, Chi-Square tests were conducted to determine if there were differences in survey responses among the study groups. Expected values are calculated proportionally using the column total and the raw total, and compared with observed responses. The sum of the differences between observed and expected values over the sum of expected values results in the Chi-Square value, as shown in the equation below.

$$\chi^2 = \sum \frac{(observed - expected)^2}{expected}$$

Any Chi-Square value that returned a asymptotic significance greater than 0.05 was deemed insignificant and led to a conclusion that there is no difference among cities (or study groups) in the responses to the survey question of interest. While a Chi Square test with asymptotic significance less than 0.05 indicated that city somehow influences survey responses.

In the analyses of R-o-W survey responses, no difference was found in responses between drivers and pedestrians as a car trip often also involves walking to some degree and vice-versa, thus pedestrian and driver responses were combined and analyzed as one group. The analysis of the results of these survey questions and their respective Chi-Square tests revealed the manner in which resident city affects a person's behavior and responses to non-motorized traffic and traffic control.

6.3 Analysis and Evaluation of Survey Data

6.3.1 Bicyclists

<u>With Respect to Location</u>

Chi-Square tests displayed a significant relationship between responses by location for questions 1-4. Compared to bicyclists in the outside location, bicyclists in downtown and low-income locations not only tend to ride their bicycles more frequently in good weather, but also in general, as shown in Table A-1 and Table A-2 in the appendix. This result directly relates to the response most typical of bicyclists in downtown and low-income locations with regard to the primary purpose of bike trips, as shown in Table A-3 in the appendix. The majority of low income and downtown participants stated that the primary purpose of bike trips was, "to commute back and forth to work." However, 36.2 percent of outside bicyclists stated that exercise and health was the primary purpose of bike trips, while only 5.2 percent of outside bicyclists stated that they primarily commute back and forth to work by bike.

While both low income and downtown bicyclists mostly stated that commuting to work was the primary purpose of bike trips, the reasoning behind this choice may differ between locations. A downtown bicyclist may choose to commute to work by bike due to the relatively short distance between their place of work and residence; affordability likely raises the appeal, or even necessity, of bike travel for a low-income resident. In contrast, an outside bicyclist likely lives further away from work locations and will choose to drive if economically viable, resulting in the view that bike trips represent primarily a leisure activity. Significance could not be determined between location and survey responses to question 5 ("Where do you most often ride?"), concerned with typical choice of bicyclist facility. While interesting, knowledge of how often, where, and why travelers choose to take a bike may not hold the same importance in regard to non-motorized safety as the survey questions focused on a bicyclist's interaction with, and understanding of, relevant traffic rules and conditions, as seen in the next evaluation of answers to questions 5-9.

Within this subset of traffic specific questions, the Chi-Square tests determined significance in the relationship between location and the bicyclists' responses to question 7, which asked, "Do you come to a stop at stop *signs* on your bicycle if there is no traffic?" Section 257.657 of the Michigan Vehicle Code states that bicyclists must follow the same regulations as drivers, except when an exception is made in the code (Michigan Compile Laws [MCL], 2013). The code makes no special provision to bicyclists with regard to stopping at stop signs. However, more than half of low income bicyclists and outside bicyclists stated that they do not stop at stop signs, while 63 percent of downtown bicyclists stated that they do stop at stop signs. These results are displayed in Table 6-2 below. Generally, the higher volume of traffic in downtown locations compared to outside and low-income areas likely explains this behavioral difference.

Table 6-2 Location vs. Stopping at Stop Signs and Yielding to Pedestrians at Crosswalks

			Do you come to a stop at stop signs on your bicycle if there is no traffic		Do you yield to pedestrians at crosswalks when riding your bicycle	
			Yes	No	Yes	No
Location	Low income	Count	31	42	66	7
		% within Location	42.50%	57.50%	90.40%	9.60%
	Downtown	Count	80	47	107	20
		% within Location	63.00%	37.00%	84.30%	15.70%
	Outside	Count	13	20	33	0
		% within Location	39.40%	60.60%	100.00%	0.00%
Total		Count	124	109	206	27
		% of Total	53.20%	46.80%	88.40%	11.60%
Chi-sq. (Asymp. Sig) =			10.796 (0.005)		6.755 (0.034)	

When asked the same question, but replacing "stop sign" with "red light" (question 6), bicyclists from low income and outside areas join those from downtown areas in choosing to stop, as shown in Table A-4 in the Appendix. Once again, the Michigan Vehicle Code makes no exceptions for bicyclists in their duty to stop at red lights (MCL, 2013). The deployment of traffic signals, as opposed to stop signs, in areas with higher traffic volumes in low income and outside areas likely leads to this change in behavior. The differences in asymptotic significance values between questions 6 and 7 verify how location alters a bicyclist's perception of the difference between a stop sign and a red light. With regard to stopping at stop signs, the Chi Square test returned an asymptotic significance value of 0.005, indicating a strong relationship with location. However, when asked about stopping at red lights, the Chi Square test returned an asymptotic significance value of 0.361, indicating that location does not have a meaningful effect on the replies of survey respondents.

As shown in Table 6-2, statistical analysis also indicated significance between location and survey responses to question 9, concerned with yielding to pedestrians at crosswalks when riding a bicycle. All 33 bicyclists surveyed from the outside location stated that they do indeed yield to pedestrians at crosswalks, while 9.6 and 15.7 percent of bicyclists stated that they do not yield in low income and downtown locations, respectively. Chi-square tests could not determine significance between location and survey responses to questions 5 and 8. These results are shown in Table A-5 and Table A-6 in the appendix.

With Respect to City

Survey respondents were not only categorized according to location, but also with respect to the city in which they reside, namely: Ann Arbor, East Lansing, Flint and Grand Rapids. Table 6-3 summarizes the Chi-square statistics only to show what types of bicyclist behavior are different across the cities or the location types discussed previously (downtown, low income, and an outside area). The result indicates that many more significant differences are observed among cities compared to the types of locations. The study pays particular attention to any significant differences among study groups with regard to questions 5-9, as these highlight the level of respondents' understanding of bicyclist safety. As seen, the responses to three of these questions showed significance with city, compared to only one question with respect to area. However, location has a larger influence on non-safety related questions.

Bicyclists in all four cities, except Grand Rapids, tend to ride their bike almost every day in good weather and in general, with the majority of bicyclists in Grand Rapids choosing to bike several times a week instead of every day, as shown in Table A-7 and Table A-8 in the appendix. This difference in bike usage according to city appears to stem from a similar cause as the difference in bike usage according to location, namely ride purpose and typical facility usage, as explained next.

Table 6-3 Significance of Bicyclist Responses by City and Location

Survey Question	By City		By Location	
	Chi-Square Value	Asymptotic Significance	Chi-Square Value	Asymptotic Significance
1. How often do you ride your bike?	24.235	0.004*	34.822	0.000*
2. How many bike trips do you make per week in good weather?	15.544	0.077*	32.939	0.000*
3. What is the primary purpose of bike trips?	34.188	0.012*	55.948	0.000*
4. Where do you most often ride?	45.942	0.000*	10.275	0.592
5. Which way do you travel when riding in the road?	14.955	0.021*	3.343	0.502
6. Do you stop at red lights when riding your bicycle if there is no traffic?	8.213	0.042*	2.040	0.361
7. Do you stop at stop signs when riding your bicycle if there is no traffic?	3.736	0.291	3.736	0.291
8. Do you typically signal when making a turn on your bicycle?	1.680	0.641	10.796	0.005*
9. Do you yield to pedestrians at crosswalks when riding your bicycle?	7.762	0.051*	6.755	0.034

*Indicates those survey questions where statistical significance was determined in the relationship between survey responses and city or location.

In Grand Rapids, almost as many bicyclists choose to ride a bike while shopping or running errands as those who use a bike to commute to work. In East Lansing and Ann Arbor, the majority of bicyclists choose to bike as a means of commuting. In Flint, the responses “exercise and health”, “shop or run errands”, and “all” were chosen most of the time in similar quantities. Due to all the differences in opinion regarding the purpose of bike trips, a Chi Square test returned an asymptotic significance value of 0.012, indicating a strong relationship between city and popular opinion of the purpose of bike trips. This data is shown in Table A-9 in the appendix. Similarly, a Chi Square test revealed an even stronger relationship between city and bicyclists' answers to the question, "Where do you most often ride?" As seen in Table A-10 in the appendix, the majority of bicyclists in Grand Rapids ride on public roads, bicyclists in East Lansing tend to ride on sidewalks, bicyclists in Ann Arbor can be seen riding their bike in all different locations, and bicyclists in Flint mostly ride on bike paths and trails. As shown, bicyclists in each city possess their own unique characteristics in choosing where to ride, likely resulting from issues of access and availability of facilities that differ from city to city, as well as the aforementioned varying opinions pertaining to the purpose of bike trips.

As discussed earlier in the location analysis, understanding bicyclists' characteristics in regard to where, when and why they ride their bike is not as important as learning how they interact with traffic while traveling on a bike. However, differences in a bicyclist's home city appear to impact survey responses less compared to their location within the city. For example, bicyclists from all four cites mostly agree to ride in the same direction that cars are traveling (Table 6-4), stop at red lights (Table 6-4), and yield to pedestrians at crosswalks (Table A-11). Also, opinion is split quite evenly between "Yes" and "No" answers in all four cities in response to signaling when making a turn (Table A-12), as well as coming to a stop at a stop sign if there is no traffic (Table A-13).

Table 6-4 Bicycle Riding Direction and Stopping at Red Lights

			Which way do you travel when riding in the road?			Do you stop at red lights when riding your bicycle?	
			In the same direction the cars are travelling	Facing traffic(on the left side)	It does not matter. One can ride in both directions	Yes	No
City	Grand Rapid	Count	34	3	5	29	12
		% within City	81.00%	7.10%	11.90%	70.70%	29.30%
	East Lansing	Count	43	7	12	46	16
		% within City	69.40%	11.30%	19.40%	74.20%	25.80%
	Ann Arbor	Count	78	9	5	67	26
		% within City	84.80%	9.80%	5.40%	72.00%	28.00%
	Flint	Count	24	9	3	34	2
		% within City	66.70%	25.00%	8.30%	94.40%	5.60%
Total		Count	179	28	25	176	56
		% of Total	77.20%	12.10%	10.80%	75.90%	24.10%
Chi-sq. (Asymp. Sig) =			14.955 (0.021)			8.213 (0.042)	

As shown in Table 6-4 on the previous page, the Chi Square test indicated one significant relationship to the question asking, "Which way do you travel when riding in the road?" Since Section 257.634 of the Michigan Vehicle Code states that all vehicles must travel on the right half of the roadway, and no exception is made for bicyclists, a bicyclist must therefore travel in the same direction as vehicular traffic. Although bicyclists from all cities stated that they travel in the same direction as traffic the majority of the time, 25 percent of the bicyclists from Flint stated that they ride facing traffic. This deviation resulted in an asymptotic significance value of 0.021, indicating a strong relationship between city and the choice of direction while riding a bike. A possibility exists that bicyclists from Flint simply might not understand the correct direction to travel due to a lack of education on the matter.

According to data collected by the 2010 Census, among the four cities studied, the city of Flint contained the lowest proportion (79.4 percent) of residents aged 18 and older that reported their educational attainment as at least having a high school diploma or GED, compared to 82.6 percent, 97.2 percent, and 98.7 percent in Grand Rapids, Ann Arbor and East Lansing, respectively (U.S. Census Bureau, 2013). Accordingly, analysis of bicyclist responses (and later, driver/pedestrian responses) showed that survey respondents from Flint displayed the highest aggregated misunderstanding of traffic rules and regulations relative to the other three cities studied. Despite the lack in understanding of bicyclist safety in Flint, according to the crash data shown in Figure 6-1, bicyclist crash rate per 10,000 population between 2007-2011 is lowest in Flint (11.36 crashes) among the four cities studied. However, Figure 6-1 shows that Flint also has the lowest average daily bicyclist volume at signalized intersections, at 32 bicyclists.

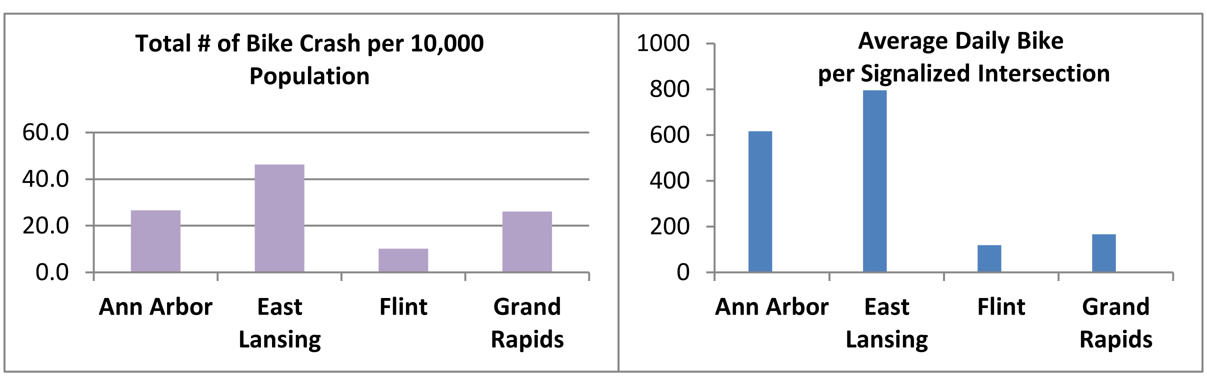


Figure 6-1 City vs. Population-based Crash Rate & Exposure-based Volumes

A second notable relationship stemmed from responses to the question asking, “Do you stop at red lights when riding your bike if there is no traffic?” Once again, bicyclists from all cities chose “Yes” the majority of the time, but Flint respondents chose “Yes” much more frequently at 94.4 percent of the 36 bicyclists surveyed. This unusual increase in affirmative answers relative to the other cities surveyed resulted in an asymptotic significance value of 0.042, as shown in Table 6-4. A possible explanation is that due to the high crime rate in Flint, law enforcement are much more likely to make a stop based on relatively smaller offences, and bicyclists want to avoid the inconvenience. In addition to low bicyclist volumes, the increased tendency to stop at red lights might explain why the crash data indicated Flint has the lowest bicyclist crash rate per 10,000 population.

With Respect to Gender

Surveyed bicyclists were also labeled according to gender, similar to location and city, in an effort to determine whether a bicyclist’s gender played any significant role in survey responses. However, unlike city and location, gender appears to have little to no effect on the behavior and decisions of a bicyclist, as Chi Square tests turned up no asymptotic significance values higher than 0.05 in any of the relationships. For this reason, gender’s impact on the results of the survey is not discussed further.

6.3.2 Driver and Pedestrians with Regard to Right-of-Way

With Respect to Location

With respect to location, survey participants in all locations agreed that pedestrians have the right-of-way at marked crosswalks with either a WALK signal or a COUNTDOWN signal, as shown in Table A-14 and Table A-15 in the appendix. Section 257.613 of the Michigan Vehicle Code specifies that pedestrians have the right-of-way when facing a signal during the WALK interval. However, the code makes no mention of right-of-way with regard to a COUNTDOWN signal, likely due to their relatively short deployment history. When the signal changes to DON’T WALK, survey respondents across all locations agreed that the R-o-W switches to the driver, which agrees with the Michigan Vehicle code, unless the pedestrian is in the process of crossing while the signal switches to DON'T WALK, resulting in pedestrian R-o-W. However, participants from downtown areas tend to choose pedestrian R-o-W more frequently in this scenario (33.5 percent of the time), resulting in an asymptotic significance value of 0.000. Table 6-5 regarding this information is shown below.

Table 6-5 Right of Way at Marked Crosswalks by Location

			Marked Crosswalk (DON'T WALK)			Marked Crosswalk (UNCONTROLLED)		
			Driver	Pedestrian	Both	Driver	Pedestrian	Both
Location	Low Income	Count	158	50	2	33	169	7
		% within Location	75.2%	23.8%	1.0%	15.8%	80.9%	3.3%
	Downtown	Count	173	88	2	67	185	8
		% within Location	65.8%	33.5%	0.8%	25.8%	71.2%	3.1%
	Outside	Count	174	27	1	27	167	9
		% within Location	86.1%	13.4%	0.5%	13.3%	82.3%	4.4%
Total		Count	505	165	5	127	521	24
		% of Total	74.8%	24.4%	0.7%	18.9%	77.5%	3.6%
Chi-sq. (Asymp. Sig.) =			25.551(0.000)			13.809(0.008)		

In the absence of a signal, known as an uncontrolled, marked crosswalk, those surveyed across all locations agreed that pedestrians possess the R-o-W. However, once again, a higher proportion of downtown residents were in disagreement, with 25.8 percent believing that drivers hold the R-o-W. This unexpected discrepancy influenced the Chi Square test on the relationship to return an asymptotic significance value of 0.008, as evidenced by Table 6-5. These results indicate that downtown residents associate any signal with pedestrian R-o-W, and without the presence of a signal, downtown residents place precedence on the driver. Also, since pedestrian traffic is higher in downtown areas when compared to the other locations, downtown residents have more experience in the pedestrian role, potentially leading to a heightened sense of entitlement with regard to pedestrian R-o-W at signalized, marked crosswalks. When crosswalks become both unmarked and uncontrolled, survey participants agreed that drivers have the R-o-W, regardless of location, as shown in Table A-16 in the appendix. At midblock crossings, the majority of participants in all locations agreed that pedestrians have the R-o-W, as shown in

Table A-17 in the appendix. Rule 706 of the Michigan Uniform Traffic Code states that pedestrians must yield the R-o-W to vehicles at any point other than a marked crosswalk at an intersection.

With Respect to City

When the covariate changes from location to city, the Chi Square tests reveal an increased occurrence of significant relationships. In almost every scenario, survey responses from at least one city tend to deviate more prominently from the status quo, establishing a link between city and driver/pedestrian behavior at traffic crossings, as verified by Chi Square tests returning asymptotic significance values less than 0.05 on these relationships. Marked crosswalks with a WALK signal (Table A-18) and midblock crossings (Table A-19) represent the only two examples where agreement exists (pedestrian R-o-W) between all cities to such a degree that significance could not be established by means of the Chi Square test. Due to the Chi Square test returning an asymptotic significance value of 0.476, there is not enough evidence to conclude with certainty that a significant relationship exists between participants who stated that pedestrians have the R-o-W at Mid-Blocks and city of residence. However, a higher amount of pedestrian crashes occur at these types of locations in Flint and East Lansing relative to Ann Arbor and Grand Rapids, as seen in Figure 5-9 in Chapter 5. This might indicate that drivers and pedestrians in Flint and East Lansing tend to act differently than they believe at Mid-Block intersections. Section 257.613 of the MVC states that pedestrians have the right-of-way when facing a signal during the WALK interval, but it does not clearly specify how pedestrians should behave at mid-block crossings.

As shown in Table 6-6, concerning marked crosswalks with a COUNTDOWN signal, subjects from all cities stated that pedestrians have the R-o-W the majority of the time; however, relatively high proportion (24.2 percent) of the participants from Flint stated that drivers have the R-o-W. In fact, the responses from the city of Flint tended to show a strong enough disagreement with the other cities to be the likely reason for a significant relationship in every crossing scenario where one exists. As posited in the bicyclist analysis, the prominence of low-income areas within Flint, and the resultant effect on traffic safety education, likely causes both the pedestrians and drivers from Flint to think and act differently in these crossing situations. In two particular examples, a sizeable portion of residents from Ann Arbor sided with residents from Flint in their relatively higher deviation from the majority opinion, namely at uncontrolled, marked crosswalks and marked crosswalks with a DON'T WALK signal, as shown in Table 6-6. A possible explanation for this result in Ann Arbor might be the city's stop ordinance and recent enforcement efforts.

Table 6-6 Right of Way at Marked Crosswalks by City

			Marked Crosswalk (COUNTDOWN SIGNAL)			Marked Crosswalk (UNCONTROLLED)			Marked Crosswalk (DON'T WALK)		
			Driver	Ped	Both	Driver	Ped	Both	Driver	Ped	Both
City	GR	Count	16	108	6	16	108	5	113	18	0
		% within City	12.3%	83.1%	4.6%	12.4%	83.7%	3.9%	86.30%	13.70%	0.00%
	EL	Count	16	166	7	30	149	9	149	38	2
		% within City	8.5%	87.8%	3.7%	16.0%	79.3%	4.8%	78.80%	20.10%	1.10%
	AA	Count	20	166	9	39	147	8	132	60	2
		% within City	10.3%	85.1%	4.6%	20.1%	75.8%	4.1%	68.00%	30.90%	1.00%
	FL	Count	39	115	7	42	117	2	111	49	1
		% within City	24.2%	71.4%	4.3%	26.1%	72.7%	1.2%	68.90%	30.40%	0.60%
Total		Count	91	555	29	127	521	24	505	165	5
		% of Total	13.5%	82.2%	4.3%	18.9%	77.5%	3.6%	74.8%	24.4%	0.70%
Chi-sq. (Asymp. Sig.) =			22.294 (0.001)			12.992 (0.043)			19.408 (0.004)		

In the case of marked crosswalks with a DON'T WALK signal, the Chi Square test returned an asymptotic significance value of 0.004, indicating a strong relationship with resident city. The survey respondents from both Flint and Ann Arbor tended to choose pedestrian R-o-W more frequently than their counterparts from Grand Rapids and East Lansing. Whereas a lack of education might explain these deviations between observed and expected results in Flint, in Ann Arbor, the opposite might be true. Respondents from Ann Arbor likely understand that drivers have R-o-W at a DON'T WALK signal, yet they act in a contrary fashion as a cultural response. Figure 6-2 displays the results of a Poisson Regression Model used to determine average daily pedestrian counts per signalized intersection in each city. As seen, pedestrian volumes are highest in Ann Arbor. An implication of these results might be that as volumes increase, pedestrians and bicyclists are conditioned to a type of "pack mentality", whereby non-motorized travelers hold priority over drivers at intersections, regardless of the status of traffic control. This type of behavior could be described as an extroverted cultural symbol exchange, as described by Nordfjrn *et al*. (2012**)**. Their research concluded that extroverted cultural behaviors might mitigate crash involvement due to the direct expression of intent by the people involved. Drivers in Ann Arbor likely react to the behavior of pedestrians near an intersection, rather than adhere to the status of the traffic signals. As seen in Figure 6-2, this cultural understanding of universal and constant pedestrian R-o-W in Ann Arbor appears to positively impact the frequency of non-motorized crashes, as Ann Arbor had the second lowest amount of both pedestrian and bicyclist crashes per 10,000 population from 2007-2011.

Interestingly, even though the majority of survey responses from Grand Rapids tend to agree with proper traffic safety guidelines and regulations, Figure 6-2 also shows that the pedestrian crash rate in Grand Rapids is second only to Flint. This result possibly indicates that pedestrians and drivers in Grand Rapids are knowledgeable of traffic safety, but shortcomings might exist in either the city's enforcement of traffic laws or the operation and maintenance of the city's pedestrian facilities, as discussed later in Chapter 8.

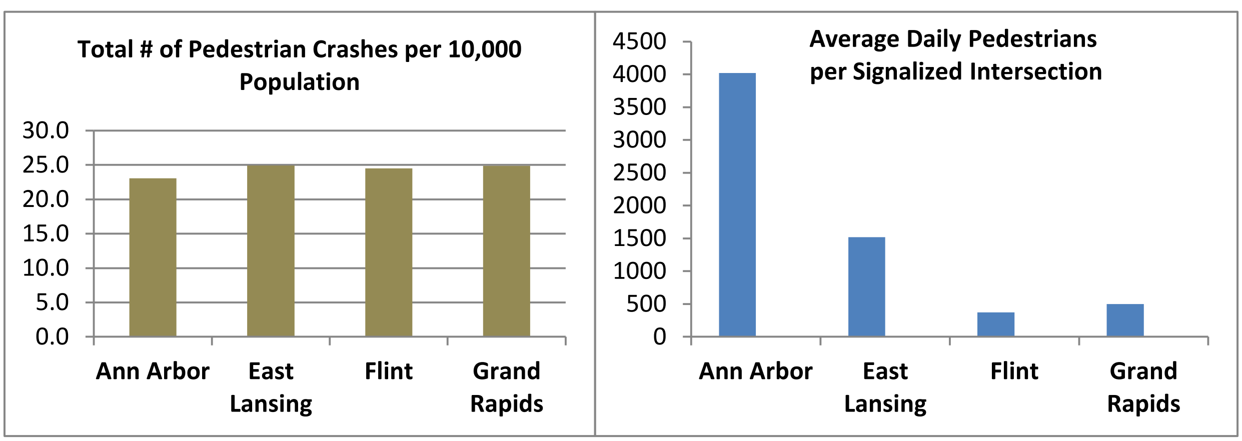


Figure 6-2 City vs. Population-based Crash Rate & Exposure-based Volumes

6.3.3 Consistency of Answers with Respect to Pedestrian vs. Driver

In the previous section, an analysis was performed on the relationship between surveyed drivers' and pedestrians' responses to questions of R-o-W at various crossing scenarios, versus resident location and city. However, a second question accompanied each R-o-W inquiry, asking who would be at fault (pedestrian or driver) in case of a crash. A comparison of answers between the first question and this crucial supplementary question aids in determining the level of consistency in survey responses. Understanding that most drivers are also pedestrians at some point, and vice-versa, it is interesting to see if participants' answers change depending on whether they answered the question from the perspective of a pedestrian, or a driver. When viewing the asymptotic significance values returned by the Chi Square tests, it becomes apparent that drivers and pedestrians are not consistent in a number of cases regarding pedestrian versus driver R-o-W at crossings and fault in case of a crash. The most notable examples include the survey questions regarding R-o-W at marked crosswalks with a COUNTDOWN signal and uncontrolled, marked crosswalks, with respective asymptotic significance values of 0.020 and 0.002, indicating the existence of a significant relationship between consistency and type of motorist (pedestrian or driver).

With regard to marked crosswalks with a COUNTDOWN signal, the overwhelming majority of both pedestrians and drivers agree that pedestrians have the R-o-W, and drivers hold responsibility in case of a crash (considered a "pedestrian-driver" response). However, the tallies of each of the three other conflicting pairs of responses ("driver-driver", "driver-pedestrian", and "pedestrian-pedestrian") show higher proportions of drivers relative to their pedestrian counterparts, as shown in Table 6-7. Since each response pair is unique, it is unlikely that a universal explanation exists which describes the increased proportion of driver contradictions in all cases. For example, a driver might choose driver-driver or pedestrian-pedestrian due to an incorrect personal belief that R-o-W also equates to fault in case of a crash. A different driver, with possibly better understanding of the difference between R-o-W and fault in a crash, would choose pedestrian fault after incorrectly choosing driver R-o-W. In all scenarios, any survey responses that don't align with the "rules of the road" (Michigan Vehicle Code) can typically be explained by a lack of regulation and education regarding proper behavior related to the COUNTDOWN signal due to the relatively short deployment history of this type of control.

Table 6-7 Consistency of Answers vs. Marked Crosswalks

			Marked Crosswalk (COUNTDOWN SIGNAL)				Marked Crosswalk (UNCTONROLLED)			
			Driver-Driver	Pedestrian-Driver	Driver-Pedestrian	Pedestrian-Pedestrian	Driver-Driver	Pedestrian-Driver	Driver-Pedestrian	Pedestrian-Pedestrian
Type of motorist	Pedestrians	Count	7	269	20	1	12	215	60	4
		% within Type of motorist	2.4%	90.6%	6.7%	0.3%	4.1%	73.9%	20.6%	1.4%
		% of Total	1.1%	43.9%	3.3%	0.2%	2.0%	35.2%	9.8%	.7%
	Drivers	Count	18	260	34	4	15	269	31	4
		% within Type of motorist	5.7%	82.3%	10.8%	1.3%	4.7%	84.3%	9.7%	1.3%
		% of Total	2.9%	42.4%	5.5%	0.7%	2.5%	44.1%	5.1%	.7%
Total		Count	25	529	54	5	27	484	91	8
		% within Type of motorist	4.1%	86.3%	8.8%	0.8%	4.4%	79.3%	14.9%	1.3%
		% of Total	4.1%	86.3%	8.8%	0.8%	4.4%	79.3%	14.9%	1.3%
Chi-sq. (Asymp. Sig.)=			9.843(0.020)				14.345(0.002)			

In the case of uncontrolled, marked crosswalks, pedestrians and drivers once again mostly converged on the "pedestrian-driver" response. Interestingly, an inconsistency was discovered pertaining to the "driver-pedestrian" response, as displayed in Table 6-7. As shown, almost twice as many pedestrians feel drivers have the R-o-W and pedestrians are at fault in case of a crash. These particular pedestrians might believe drivers have the R-o-W at an uncontrolled location due to the intersection lacking a method of directly granting or denying permission for pedestrians to cross. Accordingly, when a crash occurs, they would believe they made the wrong decision, and should be at fault.

6.3.4 Perception of Safety with Respect to City

The survey team also inquired about participant's general "feeling of safety" in the city where they reside, with four possible answers including: "not at all safe", "a little safe", "fairly safe" and "very safe". Chi-square tests revealed an apparent relationship between perception of safety and city, as shown in Table 6-8. The results show that more people in Ann Arbor tended to feel "very safe" relative to other levels of safety within Ann Arbor compared to the other cities, while those living in Flint felt "not at all safe" with a comparatively higher frequency. This variation in perception of safety with respect to city might be explained by some of the relevant crash data that the project team collected.

As shown in Figure 6-2 earlier, pedestrian crash rate per 10,000 population is highest in Flint at 25.95 crashes. This high crash rate likely influences pedestrians' survey response as increases in crash rates result in reductions in level of safety along with personal perception of safety. Even if a particular surveyed pedestrian never experienced a crash in Flint, word of mouth and local media might begin to develop a reputation that Flint is dangerous for pedestrians, which would influence their perception of safety. As displayed in Table A-20, pedestrians tend to answer that they feel "very safe" less frequently relative to other levels of safety.

However, analysis of bicycle crash rate revealed perception of safety did not decrease with an increased frequency of bicycle crashes. As shown in Figure 6-1, East Lansing maintains the highest total number of bike crashes per 10,000 population by a substantial margin. (It should be noted that the East Lansing population-based crash rate may be biased due to the influence of a high student population, whose data may not be included in the Census population data. However, Ann Arbor should show a similar bias for the same reason.) Unlike pedestrians in Flint, bicyclists in East Lansing appear to feel just as, if not more, safe than pedestrians and drivers, as shown in Table A-21. As seen, bicyclists in East Lansing answered "very safe" more often relative to drivers and pedestrians. One possible explanation might be that those responsible for transportation planning and traffic safety in East Lansing have begun to pursue and promote increased levels of bicyclist safety. For example, an "East Lansing Non-Motorized Plan Public Workshop" was held on May 27, 2009. The workshop focused on gathering the input of participants with regard to pinpointing specific trouble spots and preferred solutions related to non-motorized transportation in East Lansing. The information gathered in this public workshop helped The Greenway Collaborative, Inc. establish the roughly 200 page, “City of East Lansing Non-Motorized Transportation Plan”, submitted to the city on May 11, 2011. Among other non-motorized transportation subjects, the document covers some proposed policies and programs, design guidelines, as well as education and marketing strategies. The plan also details the many existing promotional and marketing activities from local non-motorized advocacy groups, including the City of East Lansing’s “Safe Routes to School” committee and Michigan State University’s “MSU Bikes” (City of East Lansing, 2011). Of course, a higher affluence level might afford East Lansing access to the necessary funds to pursue these types of strategies, unlike the economic situation in Flint (where no equivalent Flint-specific non-motorized transportation plan appears to exist).

Table 6-8 Perception of Safety by City

			How safe do you feel with regard to non-motorized interactions?				Total	Score
			Not at all safe	**A little safe**	**Fairly Safe**	**Very Safe**		
City	**Grand Rapids**	Count	17	44	85	27	173	2.71
		% within City	9.80%	25.40%	49.10%	15.60%	100.00%	
	East Lansing	Count	9	28	142	66	245	3.08
		% within City	3.70%	11.40%	58.00%	26.90%	100.00%	
	Ann Arbor	Count	25	48	120	91	284	2.98
		% within City	8.80%	16.90%	42.30%	32.00%	100.00%	
	Flint	Count	27	59	57	54	197	2.70
		% within City	13.70%	29.90%	28.90%	27.40%	100.00%	
Total		**Count**	78	179	404	238	899	2.89
		% of Total	8.70%	19.90%	44.90%	26.50%	100.00%	
Chi-sq = 68.578			**Sig.**= 0.000					

(Perception of Safety scores were developed by assigning a value 1-4 to each response, starting at 1 for “Not at all safe” and ending at 4 for “Very safe”. Then each value was multiplied by its respective proportion of total response within each city. Taking the Grand Rapids example, the score was calculated as follows: 1(17/173)+2(44/173)+3(85/173)+4(27/173)=2.71)

6.4 Conclusion

The survey intercepted a sample of drivers, bicyclists, and pedestrians from a multitude of different backgrounds, unconstrained by location, city, gender or any other characteristic. With respect to city, the systematic impact of city-wide education levels appeared to most greatly impact how subjects replied to many survey questions. A lack of understanding with regard to non-motorized transportation safety results in harmful beliefs and actions that counteract attempts to minimize the rate of crashes involving pedestrians and bicyclists. These crashes, as well as the prevalence of evasive pedestrian/motor vehicle conflicts, can influence a person's perception of safety. In Flint, where the pedestrian crash rate per 10,000 population was highest, surveyed pedestrians felt less safe than drivers and bicyclist; while in East Lansing, where bicyclists crash rate per 10,000 population was highest, the surveyed bicyclists' perception of safety appeared to be unaffected. However, the City of East Lansing recently developed a focused action plan to elevate the prominence and safety of non-motorized transportation in East Lansing, which likely positively influenced public opinion with regard to bicyclist safety.

Some of the Chi Square analyses on survey responses turned up relationships (or lack thereof) that did not align with observed traffic crash data. In the analyses of R-o-W survey responses with respect to city and location, it was assumed that drivers and pedestrians would respond similarly, as a car trip often also involves walking to some degree and vice-versa, so their answers were combined and treated as one group. However, an analysis of the consistency of respondents with respect to role revealed that, in certain crossing scenarios, pedestrians and drivers are not consistent with respect to issues of right-of-way and fault in case of a crash. Whenever the crash data did not seem to agree with the analysis of survey responses, it was typically rationalized that drivers and pedestrians act in contradiction to their beliefs: Most people know and understand the speed limit, but choose to speed anyways. However, it might be more likely that inconsistencies with respect to pedestrian vs. driver roles better describes these contradictions.

The analysis of survey results shows that drivers, pedestrians and bicyclists do not react with universal similarity to issues of non-motorized traffic safety, but instead often differ greatly by city, even cities within a region where one might expect general homogeneity. Variations in understanding of traffic safety rules as an effect of city-specific resident education and culture often result in higher frequencies of incorrect responses with respect to traffic rules and regulations. Analysis of relevant traffic crash data shows that understanding of lawful non-motorized traffic safety behaviors does not always directly relate to frequency of non-motorized crash involvement by city. While the general lack of understanding among all surveyed motorist types is likely responsible for the high bicyclist and pedestrian crash rates in Flint, respondents in Ann Arbor also displayed a disproportionate lack of adherence to proper right-of-way designation in certain situations, yet Ann Arbor has among the lowest non-motorized crash rates out of the four cities studied. On the other hand, while observed survey responses from Grand Rapids tended to align with the expected values, Grand Rapids has among the highest non-motorized crash rates per 10,000 population relative to the other four cities studied. Despite the deviations in understanding of non-motorized safety among cities not always being reflected in the crash data analysis, there are factors that can explain these disparities.

When survey responses are likely the result of a lack of traffic safety education (as is likely the case in Flint), officials should strive to increase awareness of issues of non-motorized safety in an effort to reduce crash rates. In Ann Arbor, the cultural idea of eternal pedestrian right-of-way appears to prove beneficial in reducing non-motorized crash rates and should likely continue to be promoted by both the users and officials of non-motorized traffic in the city, despite respondents' contradiction of conventional understanding with regard to expected or lawful survey responses. When a city appears to display an expected level of understanding, as is the case in Grand Rapids, yet crash rates are unexpectedly high, it might mean that the city is lacking in areas of law enforcement or operation and maintenance of non-motorized facilities. These evaluations are only possible through direct measurement of the public's reception to the efforts in planning, operating, and maintaining safe non-motorized facilities, as provided by surveys, in conjunction with analysis of relevant traffic crash data (as opposed to self-reported crash involvement) and actual measures of road user compliance. Discovering and analyzing how understanding of non-motorized traffic safety differs by city, and the resultant effects on actual crash data within a city, allows transportation officials to determine specific shortcomings, understand why these shortcomings exist, and appropriately develop safety-focused solutions.

Chapter 7 Before-and-After Studies

7.1 Introduction and Methodology

The objective of the before-and-after analysis is to investigate the effectiveness of previously implemented non-motorized improvements in the Michigan cities of Ann Arbor, East Lansing, Flint and Grand Rapids. A challenge inherent to these studies is that crashes are random and change from year to year, and there are many parameters that affect the safety in addition to the facility improvement. As the purpose of the before-and-after studies is to identify the impact of each treatment, there is need for taking other effects into consideration. Some of these effects include changes in exposure measures, general trends, and randomness of crash occurrence. As shown in Table 7-1, the ITE Traffic Safety Council (2009) compares methodologies for before-and-after studies. The before-and-after study that applies the Bayes method is the most capable in comparing crashes before and after an intervention is introduced, but the method is applicable only when a safety performance function for the facility is available. Therefore, in this study, the before-and-after study with a comparison group was chosen as the analysis method. This method compares the change before and after the treatment with that of comparison sites to reflect exposure and trend effects. Generally, one can always embed a before-and-after study within a mixed model to account for random effects.

Table 7-1 Methodologies for Before-and-After Study

Methodology	Ability to determine or account for:			
	Treatment Effect	Exposure Effect	Trend Effect	Random Effect
Before-and-After with Empirical Bayes	Yes	Yes	Yes	Yes
Before-and-After with Comparison Group	Yes	Yes	Yes	No
Before-and-After with Yorked Group	Yes	Yes	Potential	No
Naïve Before-and-After	Yes	Potential	No	No

Source) ITE Traffic Safety Council, 2009

In this study, a group of comparison sites is chosen from four cities to determine the trend of crash occurrences. The sites in the comparison group are those without any improvement during the analysis period (2004-2012) but with similar characteristics as the improvement sites. Similar to the corridor-level crash analysis, the non-motorized crashes that occurred on these improvement sites, as well as comparison sites, are separated into mid-block and intersection crashes in order to observe if the improvement projects are effective in promoting non-motorized safety at intersections, mid-blocks, or at both locations. Intersection crashes are defined as crashes that occurred at signalized road junctions, whereas mid-block crashes are defined as crashes that occurred between the signalized road junctions.

For the before-and-after comparison, the 9-year analysis period (2004-2012) is broken down into three 3-year spans. The period during 2004 - 2006 is regarded as a before period, and the period during 2010 - 2012 is an after period while all improvements were completed during 2007 - 2009. In the analysis, crashes that occurred during the improvement period are excluded.
The mean numbers of pedestrian, bicycle and total crashes at intersection and mid-block are analyzed before and after each improvement group. To determine if the average number of crashes for each type of improvement is significantly different between the periods before and after the improvement, a pairwise t-test is performed with a nominal 0.05 alpha level. The potential change is also compared with the trend found from the comparison sites. The trend is applied to project the number of crashes at each improvement site as if the improvement was not made. The difference between projected and actual crashes for the after-case is regarded as actual change by the improvement.

7.2 Selection of Analysis Sites and Comparison Sites

As described in Chapter 2, non-motorized improvement information was provided through personnel of the city transportation engineers, MPOs and MDOT personnel. The information received provided details related to the improvement project, such as what it entailed, the configuration of the roadway before roadway construction, street location, time period of construction and the overall cost. Among all non-motorized improvement projects compiled, analysis sites for the before-and-after studies were selected based on the projects focus and construction period. Due to the availability (2004 – 2012) of reliable crash data, projects that occurred between 2007 and 2009 were chosen for further analysis as they allow at least a three-year crash analysis for the periods before and after. The selected improvement sites were combined and classified into following four groups:

- Bicycle Sharing Marking – 5 sites
- Bicycle Lanes – 7 sites
- Sidewalk Improvements – 5 sites
- Others – individual 7 sites

"Others" include improvements with one or two cases which are treated as individual improvements rather than representing a particular type. Details on selected improvement projects are provided in a later section of this chapter, while the locations of those improvements are shown in Figure 7-1 - Figure 7-4.

The comparison corridors were selected from the list of corridors used for the corridor-level crash analysis in Chapter 5 on the basis of not having any non-motorized improvements from 2004 to 2012, and having similar roadway geometry, exposure measures and land use as compared to the improvement corridors. A total of 37 similar comparison corridors were selected with 16 corridors from Grand Rapids and 7 corridors each from Ann Arbor, East Lansing and Flint. The selected comparison corridors and improvement sites for analysis are also shown in the same figures.

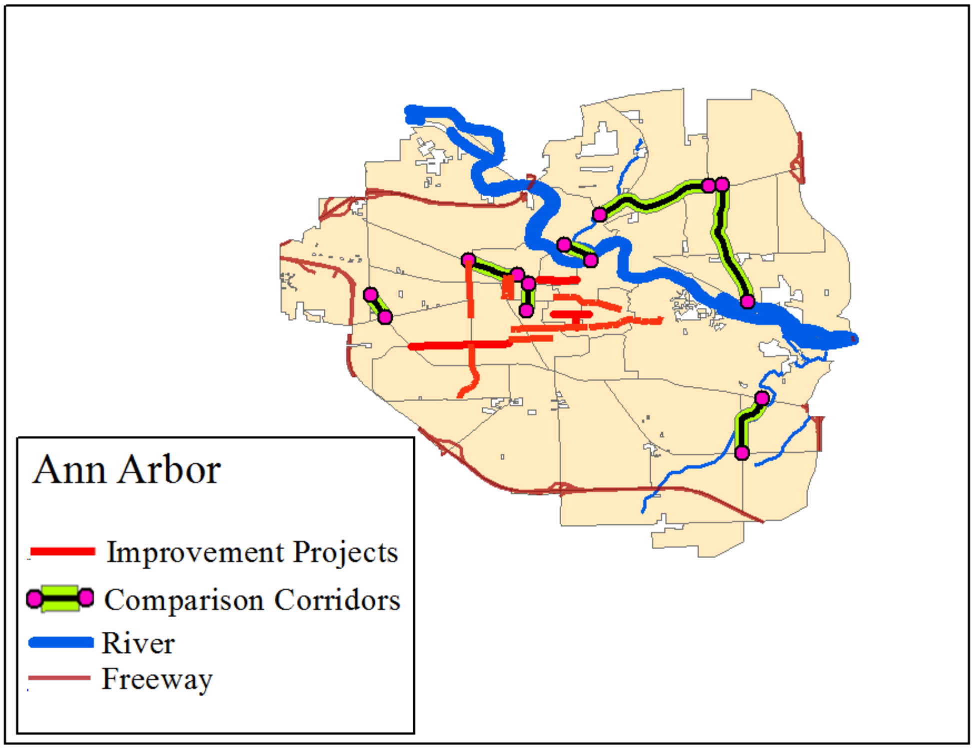


Figure 7-1 Locations of Non-motorized Improvements: Ann Arbor

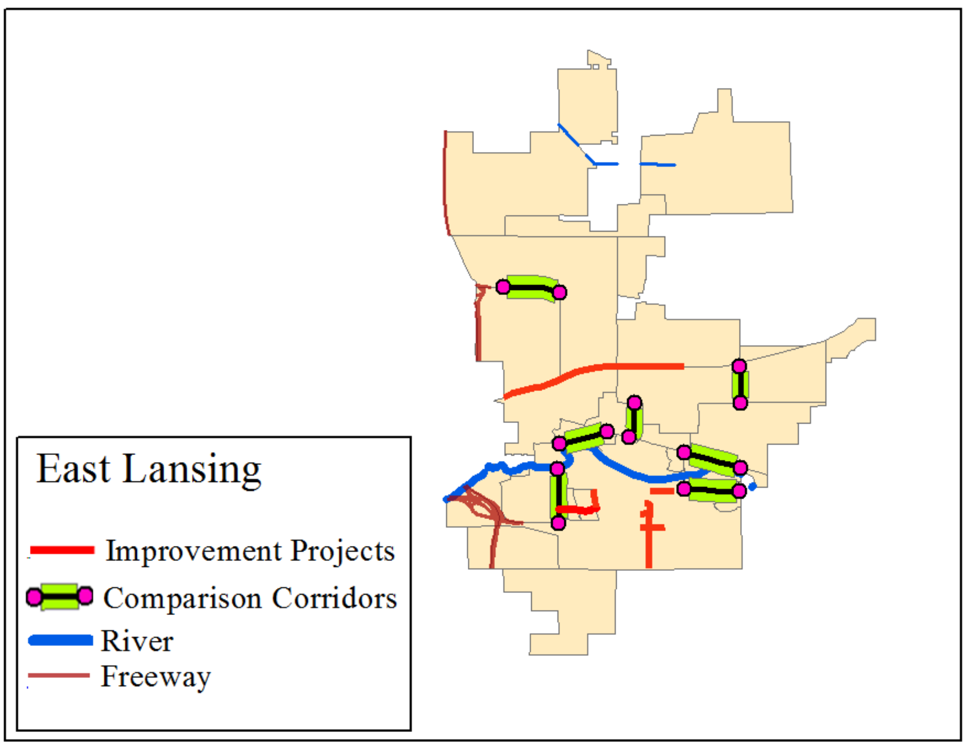


Figure 7-2 Locations of Non-motorized Improvements: East Lansing

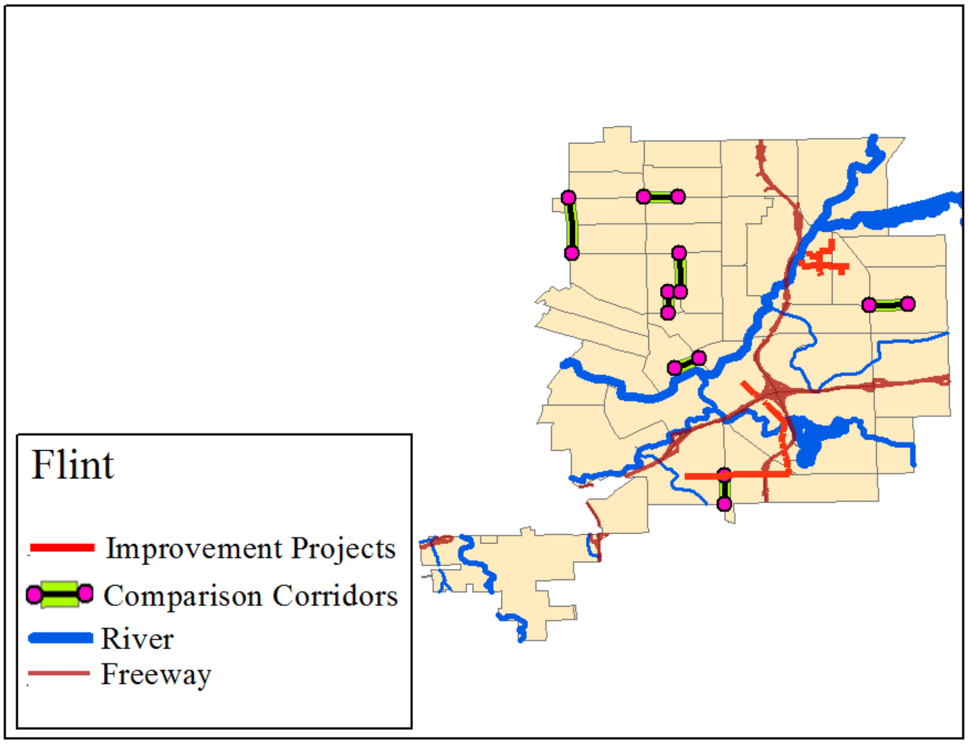


Figure 7-3 Locations of Non-motorized Improvements: Flint

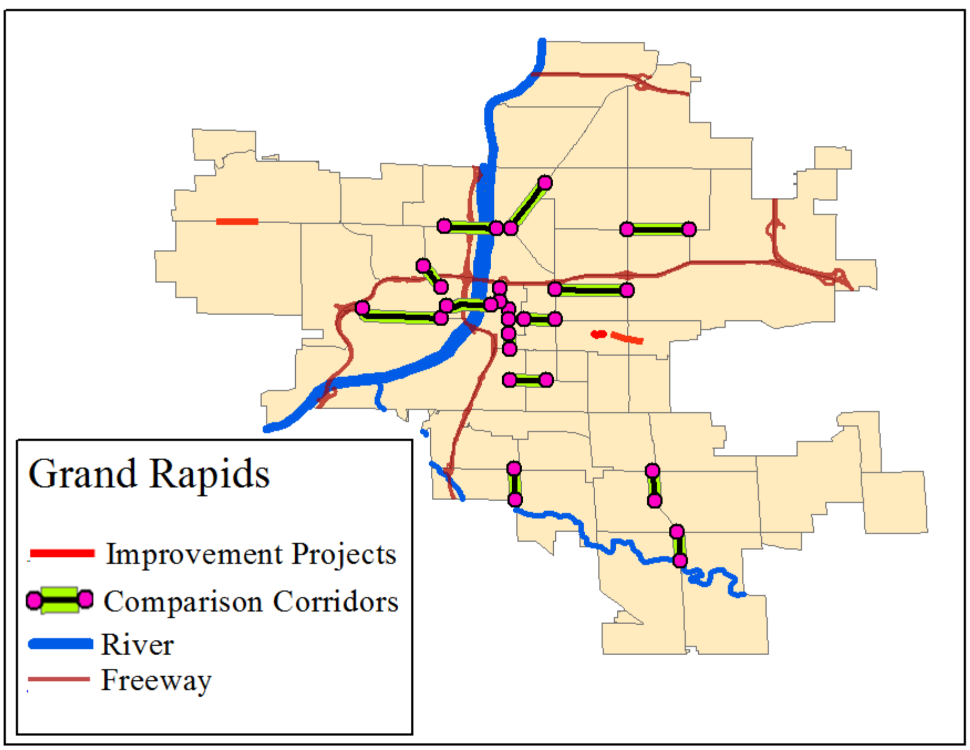


Figure 7-4 Locations of Non-motorized Improvements: Grand Rapids

7.3 Trend of Crash Occurrence in Comparison Sites

To understand overall crash trends, non-motorized crash data from four cities and comparison sites were analyzed for the before-period (2004-2006) and the after-period (2010-2012). The overall crash statistic was composed of 768 signalized intersections and 109.04 miles of mid-block roadway from the four cities. The comparison corridors were comprised of 74 comparative signalized intersections and 37 comparative mid-blocks across the four cities. Non-motorized crash data were collected and classified into crashes at midblocks or at signalized intersections.

The comparison of the two statistical data sets was performed in order to investigate the validity of the selected comparison corridor group. The number of non-motorized crashes among the combined city-wide crash statistics should be less than the comparison group, because the combined city-wide crash statistics incorporate improvement projects. From Table 7-2 and Table 7-3, it can be observed that both sets of data experience similar increasing crash pattern before and after in all categories except for mid-block bicycle crashes. The crash trend for the number of mid-block bicycle crashes is decreasing according to crash statistics for the four cities, whereas it is increasing for the comparison group statistic. However, it should be noted that the difference in the average numbers of mid-block crashes between the before and after years was not statistically significant at the 5 percent level. Nevertheless, the average for the after case of the comparison corridor group is higher in magnitude for all crash types, which makes sense because the comparison group did not include any non-motorized improvement projects. This confirms that the selected comparison group is valid for evaluation against the selected improvement projects.

Table 7-2 Overall Crash Trend for Four Cities

Intersection Crash (Crash/Intersection/3 Years)						Mid-Block Crash (Crash/Mile/3 Years)					
Pedestrian		Bicycle		Total		Pedestrian		Bicycle		Total	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
0.35	0.49	0.36	0.49	0.79	0.99	3.72	4.02	3.27	3.00	6.99	7.01

Note) Before-period: 2004-2006; After-period: 2010-2012

Table 7-3 Crash Trend for Comparison Corridors

Intersection Crash (Crash/Intersection/3 Years)						Mid-Block Crash (Crash/Mile/3 Years)					
Pedestrian		Bicycle		Total		Pedestrian		Bicycle		Total	
Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
0.57	0.91	0.74	1.03	1.31	1.93	2.68	4.31	2.84	3.17	5.52	7.48

Note) Before-period: 2004-2006; After-period: 2010-2012

7.4 Bicycle "Share the Road" Warning Signs and Shared Lane Markings

Sando et al. (2013) showed a 0.63 lateral feet increase between a bicyclist and vehicles and a 0.51 lateral feet increase between the bicyclist and the face of the curb after the installation of shared lane marking for bicycle sharing. In the study area, bicycling sharing signs and markings were placed at five locations without increasing the width of the roadway. Among them, four locations were in Ann Arbor and one in Grand Rapids. More details about these shared lane improvement projects are listed in Table 7-4.

Table 7-4 Improvement- Shared Lane Markings

Project Location	Year	Before Improvement Project	After Improvement Project	Cost
S. University Ave., Ann Arbor	2008	2 lanes of traffic	Added shared lane marking.	$3,025
Ann Street, Ann Arbor.	2008	2 lanes of traffic, one way from Division to State, 2 lanes of traffic both ways from State to Glen	Added shared lane marking.	$1,657
Pauline, Ann Arbor.	2008	3 lanes of traffic from Stadium to Virnakay, 2 lanes from Virnakay to Birk, 3 lanes from Birk to Hutchines, 2 lanes of traffic from Hutchines to Main	Added shared lane marking.	$4,504
E. University Ave., Ann Arbor	2008	2 lanes of traffic	Added shared lane marking..	$1,781
Cherry Street, Grand Rapids	2007	Brick paved road without bike sharing signs or markings.	Rehabilitation/ restoration of historic brick street and added shared lane marking.	$337,885

A three year before-and-after analysis of the improvements was performed. As shown in Table 7-5 and Table 7-6, the average number of non-motorized crashes at both intersection and midblock locations increased after installation of shared lane markings, except for midblock pedestrian crashes. Even though the average number of crashes increased, there were high variations by locations. Also, it is likely that non-motorized volumes increased as a result of provision of the shared lane markings, which may be responsible for the increased crash rate. Any future before-and-after improvement project studies should consider potential changes in non-motorized volumes. Therefore, it cannot be concluded with reasonable certainty that the shared lane markings increased non-motorized crashes.

Given the increasing trend from the comparison group analysis, the results should be compared between the number of actual crashes and that of projected crashes. The total number of crashes at intersections after treatment was higher than the projected value, while the number of crashes at mid-blocks was lower than projected, as shown in Table 7-5, Table 7-6 and also Figure 7-5. In Figure 7-5, the blue line shows changes in the average number of non-motorized crashes before and after for the improvement roadway groups, while the green dashed line indicates the expected trend if there was no treatment, based on the trend from the comparison sites. The data shows that the number of intersection crashes increased after placing shared lane markings on S. University Ave in Ann Arbor.

Table 7-5 Changes in Intersection Crashes for the Shared Lane Markings

Location	Pedestrian Crash		Bicycle Crash		Total Crash	
	Before	After	Before	After	Before	After
Pauline, AA. 2008	0	0	1	1	1	1
S. University Ave., AA. 2008	4	7	1	2	5	9
E. University Ave., AA. 2008	0	0	0	0	0	0
Ann St., AA., 2008	0	3	2	4	2	7
Cherry St., GR., 2007	0	0	0	0	0	0
Mean (Projected)	0.8	2.0 (1.28)	0.8	1.4 (1.10)	1.6	3.4 (2.35)

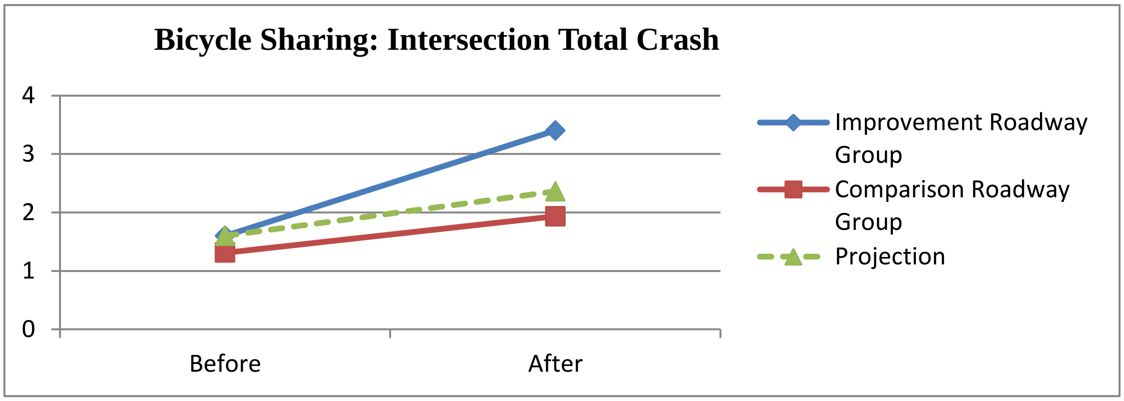
Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in ( ) are projected average number of crashes based on the trend from the comparison group

Table 7-6 Changes in Midblock Crashes for the Shared Lane Markings

(Unit: the number of crashes per midblock mile)

Location	Pedestrian Crash		Bicycle Crash		Total Crash	
	Before	After	Before	After	Before	After
Pauline, AA. 2008	0.00	2.87	0.00	0.00	0.00	2.87
S. University Ave., AA. 2008	11.52	5.76	0.00	3.84	11.52	9.60
E. University Ave., AA. 2008	0.00	0.00	0.00	0.00	0.00	0.00
Ann St., AA., 2008	4.74	0.00	0.00	0.00	4.74	0.00
Cherry St., GR., 2007	0.00	3.86	0.00	0.00	0.00	3.86
Mean (Projected)	3.25	2.50 (5.23)	0.00	0.77 (0.0)	3.25	3.27 (4.40)

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in ( ) are projected average number of crashes based on the trend from the comparison group



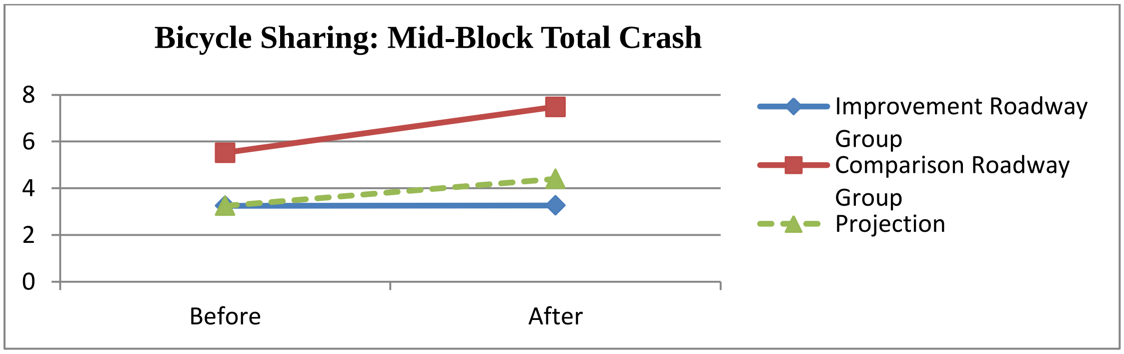


Figure 7-5 Changes in the Total Crashes for the Shared Lane Markings

To more closely investigate why the number of non-motorized crashes increased due to bicycle sharing treatments, this study scrutinized South University Avenue in Ann Arbor through visual inspection of the street and review of police crash (UD-10) reports. South University Avenue is a two-lane roadway with on-street parking on both sides of the roadway as shown in Figure 7-6. It seems that the bicycle sharing marking invited more bicyclists to the roadway, but narrowed lanes, in addition to on-street parking, caused risks to bicyclists. The bicyclists were essentially sandwiched between moving vehicles and parked vehicles, which presents a hazardous situation of a bicyclist striking the extended door of a parked vehicle.

In order to identify if adding shared lane markings increased a specific type of crash, crash typing was implemented along the South University Ave. The crash types and possible causes of the bicycle crashes were identified through police crash reports (UD-10) and the BIKESAFE website. Although no crash types occurred more than once, the bicycle crashes are somewhat related to the shared lane markings, as summarized in Table 7-7.

Figure 7-6 Bicycle Sharing Marking on S. University Ave. in Ann Arbor, MI

Table 7-7 Bicycle Crash Types and Possible Causes on S. University Ave.

	Crash Type	Before Crashes	After Crashes	Possible Cause
Intersection Crashes	Motorist Failed to Yield - Signalized Intersection	1	0	Speeding, unable to stop, or trying to get through intersection
	Bicyclist Overtaking Motorist	0	1	Overtaking bicyclist strikes parked motor vehicle or extended door
	Motorist Turned or Merged Left into Path of Bicyclist	0	1	A motorist turns or merges left across the path of a bicyclist who is traveling straight ahead.
Midblock Crashes	Motorist Failed to Yield – Non-signalized Intersection	0	1	Speeding, failing to observe correct right of way, or failing to check if bicyclists are approaching
	Bicyclist Failed to Yield – Non-signalized Intersection	0	1	Did not notice or obey sign control, did not detect approaching motorist, or did not understand right-of-way rules

There is no significant evidence that installing shard bicycle lane marking on South University Ave. promoted a certain bicycle crash type on the roadway. The increase in bicycle crashes on this roadway can probably be contributed to an increase in bicycle volume after the installation of the shared bicycle marking. The installation of shared lane markings encourages more bicyclists to utilize the main roadway for traveling instead of sidewalks. Accordingly, the exposure increases between bicyclists and vehicles and can potentially lead to a higher number of bicycle-vehicle crashes. Due to the insufficient number of cases and the lack of information on bicycle volume for the before case, no definite conclusion can be made. However, the shared lane markings, along with on-street parking on narrow lanes, could be a potential reason for the observed increasing trend in bicycle crashes. This trend could be reversed with proper media outreach to increase education and awareness of shared lane markings, paired with prolonged exposure by motorists, to reduce non-motorized crash rates over an extended analysis period after implementation.

7.5 Bicycle Lanes

Bicycle lanes improve bicycle safety by providing separate space between bicyclists and motorists while enhancing the mobility and quantity of bicycle use. Winters *et al.* (2013) found the bicyclists that use arterials and collectors with bike lanes and no vehicle parking have half the risk to be involved in an injury crash, as compared to those who travel on arterial and collector roadways with vehicle parking and no bicycle lanes. In addition, an Iowa study (Hamann and Peek-Asa, 2013) showed as much as a 60 percent decrease in crash risk through the presence of bicycle lanes or shared lane markings and a 38 percent decrease in crash risk through the presence of bicycle signage.

Bicycle lanes were added along seven corridors in Ann Arbor during the improvement period (2007-2009). These projects converted the roadways into areas with bicycle lanes by adding bicycle lane markings and signs. The width of the roadway was not increased for any of these bicycle lane improvement projects. More detailed information on the bicycle lane projects are listed in Table 7-8.

Table 7-8 Details about Bicycle Lane Improvement Projects

Project Location	Year	Before Improvement Project	After Improvement Project	Cost
1st St., Ann Arbor	2008	2 lanes of traffic, one way (Heading South), presents of parking on one side	Converted into a bike lane roadway	$2,436
Ashley St., Ann Arbor	2008	2 lanes of traffic, one way (Heading North), present of parking on one side	Converted into a bike lane roadway	$3,686
Hill Street., Ann Arbor	2008	2 lanes from Main to Division, 3 lanes from Division to Oakland, 2 lanes from Oakland to Geddes	Converted into a bike lane roadway	$5,659
N. University Ave., Ann Arbor	2008	3 lanes from State to Thayer, 4 lanes from Thayer to Washtenaw, 3 lanes from Washtenaw to Elm, 2 lanes from Elm to Oxford	Converted into a bike lane roadway	$2,897
Hoover Rd., Ann Arbor	2008	2 lanes of traffic	Converted into a bike lane roadway	$3,447
7th Street., Ann Arbor	2007	2 lanes of traffic	Converted into a bike lane roadway	
7th Street., Ann Arbor	2008	2 lanes of traffic	Converted into a bike lane roadway	

A three-year statistical analysis was performed to find the mean value of crashes before and after improvements. The intersection and mid-block crash results for bicycle lane improvements can be viewed in Table 9 and Table 10. The results show a decrease in intersection and mid-block pedestrian crashes. The mean value of bicycle and total non-motorized crashes increased for both intersections and mid-blocks. However, once again, considerations should be made with regard to changes in non-motorized volume before and after implementation of improvements in future studies performed in a similar manner.

Table 7-9 Changes in Intersection Crashes for the Bicycle Lanes

Intersection Crashes: Bicycle Lanes						
Locations	Pedestrian Crash		Bicycle Crash		Total Crash	
	Before	After	Before	After	Before	After
Hoover Ave., AA. 2008	2	1	0	0	2	1
Hill St., AA. 2008	5	3	1	4	6	7
N. University Ave., AA. 2008	5	4	2	3	7	7
Ashley St., AA., 2008	1	3	1	4	2	7
7th St., AA., 2008	3	1	1	2	4	3
7th St., AA., 2007	1	0	0	0	1	0
1st St., AA., 2008	1	0	0	2	1	2
Mean (projected)	2.57	1.71 (4.10)	0.71	2.14 (0.99)	3.29	3.86 (4.84)

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in ( ) are projected average number of crashes based on the trend from the comparison group

Table 7-10 Changes in Midblock Crashes for the Bicycle Lanes

Mid-Block Crashes: Bicycle Lanes (Crash/Mile)						
Location	Pedestrian Crash		Bicycle Crash		Total Crash	
	Before	After	Before	After	Before	After
Hoover Ave., AA. 2008	0.00	1.86	0.00	0.00	0.00	1.86
Hill St., AA. 2008	2.68	5.36	4.02	2.68	6.70	8.04
N. University Ave., AA. 2008	10.13	5.07	0.00	7.60	10.13	12.66
Ashley St., AA., 2008	0.00	0.00	0.00	0.00	0.00	0.00
7th St., AA., 2008	0.00	0.00	0.72	0.00	0.72	0.00
7th St., AA., 2007	0.00	0.00	0.00	0.00	0.00	0.00
1st St., AA., 2008	0.00	0.00	0.00	0.00	0.00	0.00
Mean (projected)	1.83	1.75 (2.94)	0.68	1.47 (0.75)	2.51	3.22 (3.40)

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in (   ) are projected average number of crashes based on the trend from the comparison group

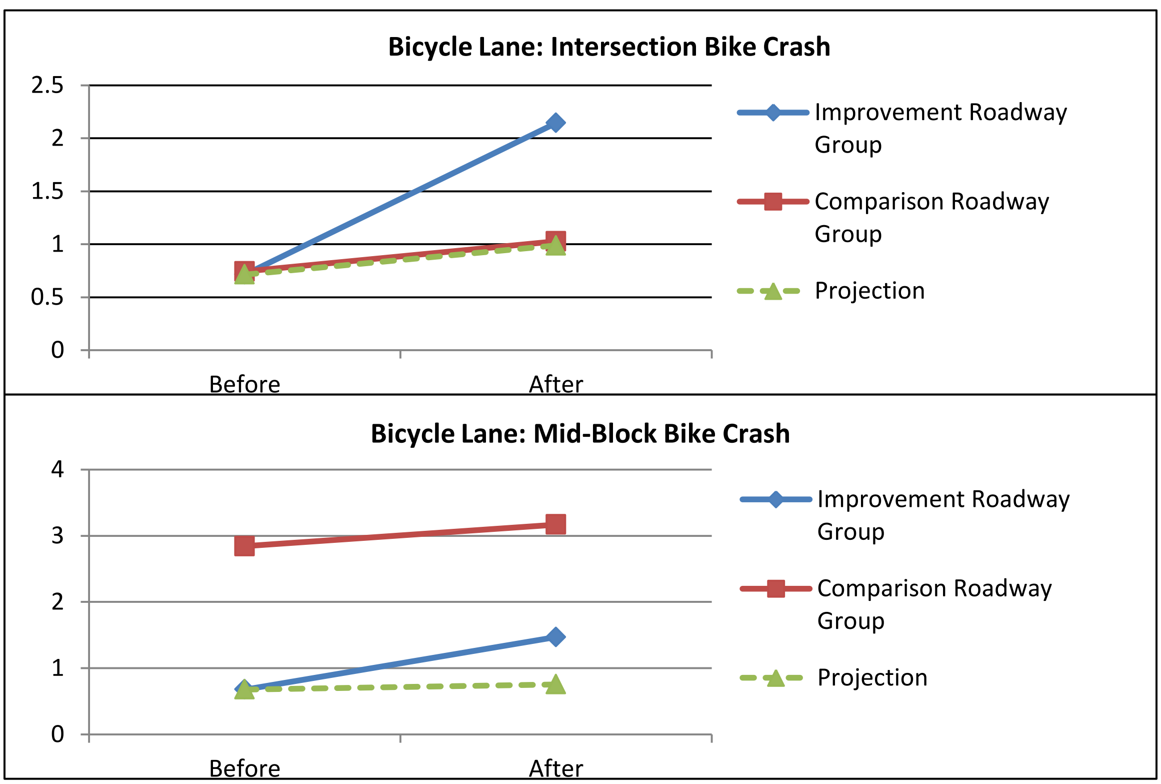


Figure 7-7 Changes in the Bicycle Crashes for the Bicycle Lanes

7.6 Sidewalk Improvements

Five sidewalk improvement projects were evaluated; four occurred in Flint, and one occurred in East Lansing. These sidewalk improvements consisted of repairing, replacing, and updating various sidewalk facilities such as the sidewalks, ramps, curbs and truncated domes. More detailed specifics for each sidewalk improvement site can be seen in seen in Table 7-11.

Table 7-11 Details about Sidewalk Improvement Projects

Project Location	Year	Before Improvement Project	After Improvement Project	Cost
Atherton Road, FL.	2008	No truncated domes in sidewalk ramps	Truncated domes were installed. Resurfaced roadway.	$ 1,100
S. Saginaw Street, FL.	2007	No truncated domes in sidewalk ramps	Truncated domes were installed. Spot curve repairs were performed. Resurfaced roadway.	*Included in total below
S. Saginaw Street, FL.	2007	No truncated domes in sidewalk ramps	Truncated domes were installed. Spot curve repairs were performed. Resurfaced roadway.	$222,500
N Franklin Ave, FL.	2009		Repair and replacement of sidewalks, ramps, curbs & gutters. Improve crosswalk pavement markings	$369,125
E. Shaw Lane, EL.	2007	Sidewalk did not have proper ramps or truncated domes	Repaved, updated sidewalk path ramps and truncated domes	$ 600,000

A three-year statistical analysis was performed to find the mean value of crashes before and after improvements. The results of this analysis can be viewed in Table 7-12 and Table 7-13. The sidewalk improvements were determined to be statistically significant in reducing bicycle crashes at intersections at a 5 percent level. When comparing the improvement projects to the projected trend line, the mean value of non-motorized crashes decreased more than expected in every scenario. The variation of non-motorized crashes can be visually observed in the intersection and mid-block graphs in Figure 7-8 and Figure 7-9.

Table 7-12 Changes in Intersection Crashes for the Sidewalk Improvements

Intersection Crashes: Sidewalk Improvement						
	Pedestrian Crash		Bicycle Crash		Total Crash	
Improvement Street Name	Before	After	Before	After	Before	After
N. Franklin Ave., FL., 2009	1	0	1	0	2	0
S. Saginaw St., FL., 2007	1	2	1	0	2	2
S. Saginaw St., FL., 2007	3	1	2	0	5	1
Atherton Rd., FL., 2008	1	2	1	0	2	2
E. Shaw Ln., EL, 2007	0	0	3	1	3	1
Mean (Projected)	1.2	1.0 (1.9)	1.6	0.2 (2.2)	2.8	1.2 (4.1)

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in (   ) are projected average number of crashes based on the trend from the comparison group

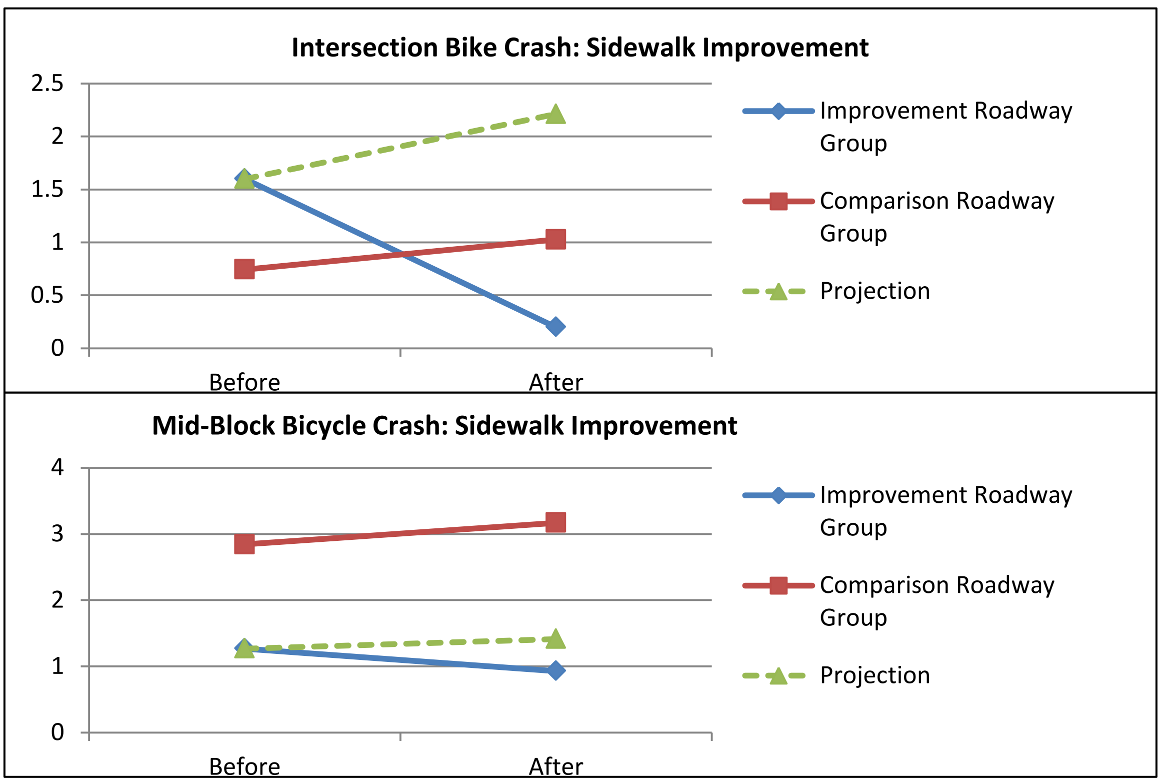


Figure 7-8 Changes in Bicycle Crashes for the Sidewalk Improvements

Table 7-13 Changes in Midblock Crashes for the Sidewalk Improvements

Mid-Block Crashes: Sidewalk Improvements (Crash/Mile)						
	Pedestrian Crash		Bicycle Crash		Total Crash	
Improvement Street Name	Before	After	Before	After	Before	After
N. Franklin Ave., FL., 2009	2.64	0.00	2.64	0.00	5.28	0.00
S. Saginaw St., FL., 2007	0.00	10.28	0.00	0.00	0.00	10.28
S. Saginaw St., FL., 2007	1.13	1.13	0.00	1.13	1.13	2.26
Atherton Rd., FL., 2008	0.00	0.00	1.94	0.00	1.94	0.00
E. Shaw Ln., EL, 2007	5.27	1.76	1.76	3.51	7.03	5.27
Mean (Projected)	1.81	2.63 (2.9)	1.27	0.93 (1.4)	3.07	3.56 (4.2)

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in ( ) are projected average number of crashes based on the trend from the comparison group

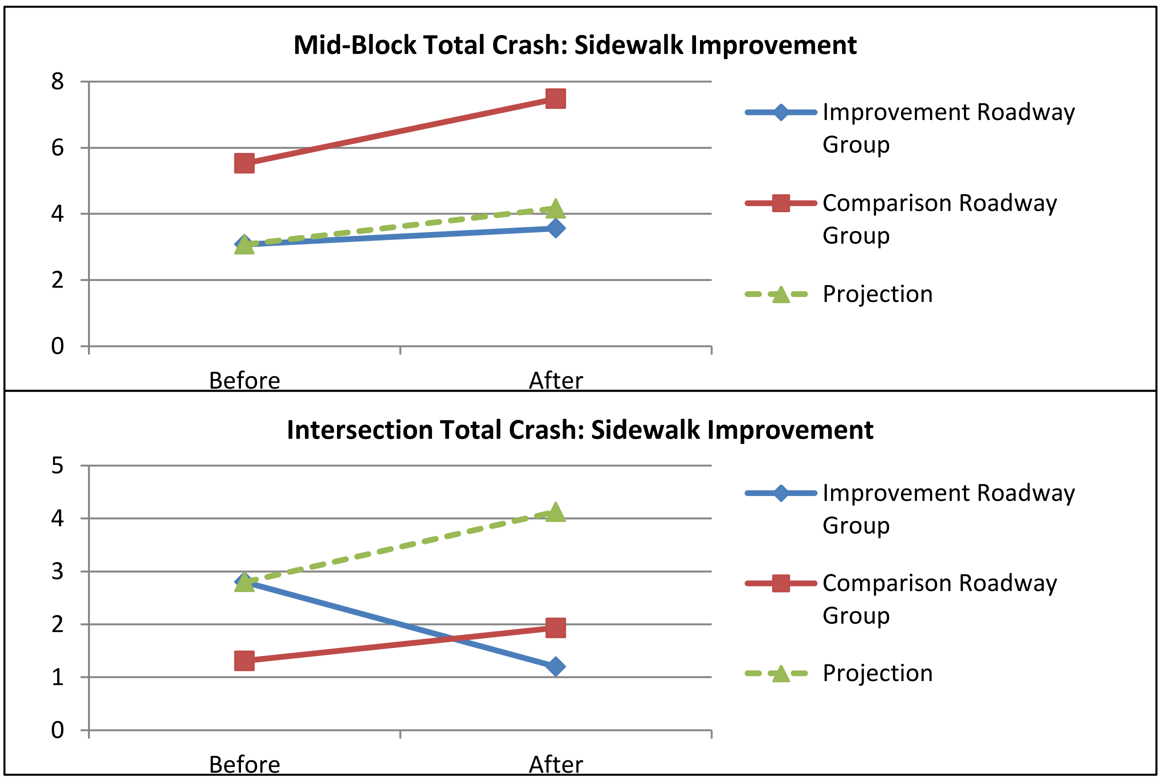


Figure 7-9 Changes in Bicycle Crashes for the Sidewalk Improvements

7.7 Additional Improvements

Additional improvements were evaluated based on their before and after mean value of crashes because a pairwise t-test could not be utilized since there were limited improvement site locations (observations). These additional improvement projects consisted of removing parking and adding bicycle lanes, Pedestrian Hybrid Beacons (PHB) also known as the HAWK (**H**igh-Intensity **A**ctivated crosswalk**)** beacon, road diets, improving connectivity, intersection conversion and road expansion. Further details pertaining to these additional improvement projects can be examined in Table 7-14.

Table 7-14 Details about Additional Improvement Projects

Improvement	Project Location	Year	Before Improvement Project	After Improvement Project	Cost
Remove Parking & Add Bicycle Lanes	Lake Drive, GR.	2010	2 lane road with parking on both sides.	Parking on 1 side was removed & bike lanes were installed. Pavement markings & signs installed for bikes.	$284,866
	Chestnut, EL.	2007	2 lane road with parking on one side	Reconstruction, addition of bike lanes and removal on-street parking	$ 880,000
Pedestrian Hybrid Beacon	Huron St., AA.	2010	4 lanes with marked pavement crosswalk on the western intersection & oversized signage	HAWK Beacon Signal	$102,561
Road Diet	Leonard Street, GR.	2008	4 lane road	Performed a road diet by converting to 3 lanes with a 5 foot shoulder.	$1,355,015
Improved Connectivity of Non-motorized Pathway	Saginaw St. (I-69), EL.	2009	Prior to construction, pathway was gapped in locations & portions of existing pathway were 5' in width.	Improvements incorporated an 8' pathway & provided connectivity along the corridor.	$1,100,000
Intersection Conversion	Wilson Rd., EL.	2009	Intersection of Wilson & Red Cedar was a roundabout. Roadway did not have bike lanes.	Roundabout removed & converted to signalized intersection with bike lanes & pedestrian signals.	$ 1,100,000
Road Expansion	Farm Lane, EL.	2008	2 lane road without bicycle lanes. 2 at-grade railroad/roadway intersections.	Intersection reconstruction, rail & road grade separation, addition of bike lanes & 2 traffic lanes.	$46,000,000

Non-motorized crashes were evaluated at both intersection and mid-block for all additional improvement projects, except for the Pedestrian Hybrid Beacon. The Pedestrian Hybrid Beacon is a high intensity activated cross-walk, which is predominately utilized on mid-block locations. Since the Pedestrian Hybrid Beacon is installed at a specific location on a mid-block roadway, non-motorized crashes that occur around it cannot be defined as being intersection or mid-block crashes. Through observing the before and after means in Table 15, Table 16 and Table 17, improved connectivity of non-motorized pathways reduced non-motorized crashes, and road expansion significantly reduced non-motorized crashes at intersections. The Pedestrian Hybrid Beacon reduced the number of bicycle crashes. The before and after mean results for the other improvement projects were determined to be inconclusive because of small crash sample size, or because no distinctive variation between the before and after crash means could be perceived.

Table 7-15 Changes in the Intersection Crashes for the Additional Improvements

Improvement Type	Location	Pedestrian Crash		Bicycle Crash		Total Crash	
		Before	After	Before	After	Before	After
Remove Parking & Add Bicycle Lanes	Chestnut, EL 2007 (2 Year Analysis)	1	0	1	2	2	2
	Lake Drive, GR 2010 (2 Year Analysis)	0	0	0	1	0	1
Pedestrian Hybrid Beacon	Huron St., AA, 2010 (2 Year Analysis)	0	0	2	0	2	0
Road Diet	Leonard St., GR, 2008 (4 Year Analysis)	0	1	0	0	0	1
Improve Connectivity	S. Saginaw St. , EL. 2009 (3 Year Analysis)	5	3	4	2	9	5
Intersection Conversion	Wilson Rd., EL, 2009 (3 Year Analysis)	0	0	2	1	2	1
Road Expansion	Farm Ln, EL., 2008 (4 Year Analysis)	3	2	13	4	16	6

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in (   ) are projected average number of crashes based on the trend from the comparison group

Table 7-16 Changes in the Midblock Crashes for the Additional Improvements

(Unit: Number of Crashes per Mile)

Improvement Type	Location	Pedestrian Crash		Bicycle Crash		Total Crash	
		Before	After	Before	After	Before	After
Remove Parking & Add Bicycle Lanes	Chestnut, EL 2007 (2 Year Analysis)	0.00	5.03	10.05	10.05	10.05	15.08
	Lake Drive, GR 2010 (2 Year Analysis)	2.10	2.10	10.49	6.30	12.59	8.39
Road Diet	Leonard St., GR, 2008 (4 Year Analysis)	0.00	0.00	0.00	0.00	0.00	0.00
Improve Connectivity	S. Saginaw St. , EL. 2009 (3 Year Analysis)	0.00	0.60	0.60	1.20	0.60	1.80
Intersection Conversion	Wilson Rd., EL, 2009 (3 Year Analysis)	0.00	0.00	0.00	0.00	0.00	0.00
Road Expansion	Farm Ln, EL., 2008 (4 Year Analysis)	0.00	0.00	0.00	0.00	0.00	0.00

Note 1) Before-period: 2004-2006; After-period: 2010-2012
Note 2) Values in (   ) are projected average number of crashes based on the trend from the comparison group

7.8 Findings

In this chapter, before-and-after studies for non-motorized improvement projects were conducted. However, due to lack of exposure measures in the before period and due to the smaller sample size of improvement sites, a naïve before-after analysis was conducted. In order to gain a better understanding of the impact of different types of improvements on non-motorized safety, a comprehensive study should be conducted. Nevertheless, some interesting points were observed through the naïve before-and-after studies.

Non-motorized crashes were shown to increase after implementation of shared lane markings. However, the results showed that the performance varied by individual sites. In the case of South University Avenue, bicycle crashes could be contributed to the on-street parallel parking along the roadway and drivers' distraction and lack of understanding of shared lane markings while bicycle volume increased in the corridor. Therefore, this study recommends that education campaigns should accompany installation of shared lane markings as the cultural and educational awareness of mutual bicyclist presence is not naturally inherent to these installations.

Sites with newly added bicycle lanes exhibited an increased number of bicycle crashes, while they had a decrease in pedestrian crashes at both intersections and midblock segments. The decrease in pedestrian crashes can be interpreted as a result of the buffer introduced between vehicle traffic and pedestrians. The increase in bicycle crashes can be summarized by two possible explanations. First, it may have been due to increases in bicycle volume along the highways, although the lack of bicycle volume data for the before case hinders this explanation. Second, unsafe bicycle lane treatment at intersections may have led to more bicycle crashes. In fact, the number of bicycle crashes at intersections may increase after installing the bicycle lanes due to increased bicycle volume even though overall bicycle safety was enhanced.

Sidewalk improvement projects aim to provide a better walking environment. The before-and-after analysis for the sidewalk improvement clearly shows that both pedestrian and bicycle crashes were decreased after the improvements when compared with the projected number of crashes. It may have been due to the orderly arrangement of the non-motorized environment. Therefore, it can be concluded that sidewalk improvements contribute to enhancing non-motorized safety.

The additional improvement projects include various types of improvements. Most projects contributed to enhancing non-motorized safety. Road expansion from 2-lanes to 4-lanes certainly reduced pedestrian and bicycle crashes at both intersections and mid-blocks. The additional traffic lane in each direction increases the capacity of the roadway and allows vehicles to provide more lateral separation when overtaking a bicyclist. Also, travel speed increases often accompany road expansions, which may reduce the perception of safety among non-motorized travelers, causing them to avoid these corridors. Therefore, the researchers stress the importance to consider potential non-motorized volume changes as a result of the implementation of any improvement projects to accurately reflect exposure-based crash frequency and severity. Other improvements also showed positive impacts on non-motorized safety. They include improving connectivity of pathways, converting intersections to proper type, removing on-street parking, and Pedestrian Hybrid Beacons. The Pedestrian Hybrid Beacon was successful in reducing non-motorized crashes because has been shown to have a vehicle yielding rate of 97 to 99 percent (Turner, Fitzpatrick, Brewer & Park, 2006). Furthermore, the Pedestrian Hybrid Beacon was found to reduce pedestrian delay by as high as 50 percent (Li & Zhang, 2011). The improved connectivity of non-motorized pathways reduced non-motorized crashes through providing non-motorized users with a larger and more continuous separated pathway to their destination.

Even though there have been many non-motorized improvement projects in the four cities, more improvements are needed to enhance non-motorized safety. However, prior to implementation, transportation planners should consider how improvement projects will alter the existing conditions with regard to non-motorized safety. Additionally, improvement projects intended to improve one mode may have unforeseen positive impacts on the other mode, as observed when installing bicycle lanes. Ultimately, improvement projects should strive to reinforce safe transportation engineering practice and promote non-motorized mode usage by reducing the potential for hazardous conflicts with vehicle traffic on urban roadways.

The quantity of improvement sites and the frequency of crashes on the improvement projects were not as substantial as desired, which could lead to diminished statistical significance in the results. Additionally, the number of improvement site locations is mainly influenced by quantity and quality of information provided by transportation governmental personnel. The quantity and quality of information provided may have diminished because of the wide scope of possible non-motorized improvement projects. Future studies should focus on specific non-motorized improvement types in order to enhance improvement project information. Additionally, non-motorized volume data before and after improvement projects should be collected, and considered in tandem with crash frequency and severity, in order to accurately reflect the changes in exposure-based crash rates.

Non-motorized crashes are rare due to low mode utilization. Due to the low frequency of non-motorized crashes, a larger time frame of data collection may be required to develop a more definitive result. However, the only real means to accomplish this is to collect future non-motorized crash data and revaluate implemented non-motorized improvement projects over a greater time frame. It is also important to take into consideration that there could be many unreported non-motorized crashes in case they are not vehicle-related.

Chapter 8 Performance Measures

8.1 Introduction and Methodology

Performance measures for non-motorized traffic are important especially in guiding selection and implementation of countermeasures for pedestrian and bicycle safety. Most past research have developed performance measures based on population. This has been mainly due to the lack of exposure data (pedestrian and bicycle volumes) needed to develop exposure-based measures. In this study, great efforts to obtain reliable pedestrian and bicycle volume data were made. This study analyzed safety performances in three levels: city, census tract level, and corridor. This chapter presents performance measures developed at two levels: city-wide and corridor. In addition to developing performance measures for non-motorized traffic, this chapter documents the approach for selecting countermeasures.

City-wide Performance Measures and Countermeasures

This study categorized city-wide non-motorized traffic performance into four groups, which consist of infrastructure performance, exposure performance, education/enforcement performance, and crash performance. The infrastructure, exposure, and education/enforcement performance groups can be seen as distinct and mostly independent of each other; however crash performance depends on each of these groups. A number of performance measures were selected for investigation of each performance measure group. Upon selection of meaningful performance measures, appropriate performance goals and objectives were determined. The focus of this study was not to identify and introduce every possible performance goal and objective, as these can vary widely by city, and criteria used are subject to the scrutiny of the jurisdiction tasked with improving non-motorized safety performance. Instead, this report identifies a few potential performance objectives according to the results of this study, which can be used as a guideline for future applications.

Following identification of pertinent performance objectives, a number of countermeasure alternatives can be evaluated according to the performance objective of interest. Once again, the focus of this study was not to introduce new or never-before-seen countermeasure treatments, but instead formulate the countermeasure development process, beginning with analysis of non-motorized safety performance and ending with a selection of appropriate countermeasures according to desired performance goals or objectives.

Corridor-level Performance Measures & Countermeasures

City-wide performance objectives and countermeasures strive to improve safety on a broad and general scale. However, many of the city-wide countermeasures might have little impact on non-motorized safety upon high-risk corridors as they do not target the specific conditions that potentially cause crashes on mid-blocks and intersections within the corridor. Thus, a different approach was needed to identify problematic corridors within a city and evaluate individual crashes on the corridor to determine focused countermeasure improvements.

Corridor-level performance analysis began with identifying regions within the city that likely contain particularly unsafe corridors. Two methods were used to accomplish this task, which include developing (1) a city-wide crash density map and (2) a crash frequency map by census tract. Once regions within the corridor have been targeted, individual corridors within those regions were selected for performance analysis and ranked accordingly. In this study, corridors were evaluated against five performance measures, including crash frequency and severity at both signalized intersection as well as mid-blocks. Corridors that perform most poorly over the widest range of measures display the greatest urgency for countermeasure improvement. Countermeasures intended to improve corridor performance can be developed in two different ways, either according to Highway Capacity Manual (HCM) Level-of-Service (LOS) analysis or "crash-typing."

8.2 City-wide Performance Measures

8.2.1 Infrastructure Performance

Measuring non-motorized safety performance from a city-wide infrastructure perspective requires evaluation of many different facility components. This study focused on aspects such as sidewalk coverage, bike lane coverage, number of marked crossings per mile, and number of access points per mile. The performance of each city was determined with regard to each of these measures, and results were analyzed to determine any possible city-specific infrastructure short-comings.

Another possible method to evaluate city-wide infrastructure performance in a more comprehensive manner is through administration of "walkability" or "bikeability" checklists to candidate communities throughout the city. These checklists ask non-motorized travelers to answer a number of questions pertaining to their experience on an individual walking or biking trip. Example questions from the Safe Routes to School walkability checklist include:

- "Did you have room to walk?"
- "Was it easy to cross streets?"

Participants are further asked to rate the performance of each question according to the severity of problems afflicting their experience as a non-motorized traveler. After rating each question individually, the scores are tallied and compared against a scale to determine the relative performance of the community with regard to walkability or bikeability. In addition, the Safe Routes to School checklists provide a number of citizen-action solutions, which participants can implement to help improve their neighborhood's walkability or bikeability rating. Currently, in most states these checklists are used as self-help resources to inform interested travelers about the state of non-motorized safety within their communities, and results aren't typically collected or viewed by transportation officials within the community. However, in Michigan, part of the SRTS planning process requires local agencies to be involved in the planning and the checklists are shared. Also, the local agencies are required to approve the projects.

Table 8-1 City-wide Infrastructure Performance Measures

1. Infrastructure	**AA**	**EL**	**FL**	**GR**
Sidewalks Coverage (%)	98.8	84.2	83.4	93.8
Bike Lane Coverage (%)	35.3	30.3	3.7	9.6
Marked Crossings (number per mile)	1.4	3.1	0.5	0.5
Access points (number per mile)	8.4	6.8	9.3	9.9
Number of Marked Crossings per Access points	0.17	0.46	0.05	0.05

Note) Statistics were based on arterials and collectors

Table 8-1 below summarizes the infrastructure performance of each of the four cities. As stated earlier, performance measures investigated in this study were sidewalk coverage, bike lane coverage, number of marked crossings per mile, and number of access points per mile. As seen, all four cities have sidewalk coverage in excess of 80%, with Ann Arbor and Grand Rapids harboring the greatest sidewalk coverage at 98.8% and 93.8% respectively.

Compared to sidewalk coverage, bike lane coverage appears to be sorely lacking in all four cities, with no city displaying bike lane coverage in excess of 40 percent. Bike lane coverage in Flint and Grand Rapids is very low, at 3.7 percent and 9.6 percent, respectively. The number of marked crossings per mile of roadway varies between 0.5 (Flint and Grand Rapids) and 3.1 (East Lansing), and the number of access points per mile of roadway varies between 6.8 (East Lansing) and 9.9 (Grand Rapids). Ideally, the number of marked crossings would vary directly with the number of access points. When the opposite occurs, as the results show, it indicates that a high portion of the city's roadways and intersections have unmarked crossings. This is a particularly troubling trend, because as seen in Chapter 6 and also Table 8-4, travelers tend to display a high degree of misunderstanding with regard to right-of-way at unmarked crossings compared to marked crossings.

Performance Objective

Among the four cities, sidewalk coverage appears satisfactory; however, it should be noted that the data did not include local streets due to the lack of information. Therefore, there is still need for further investigating a performance objective at the local street level. While bike lanes in all four cities do not meet the same level of coverage as sidewalks, only Flint and Grand Rapids appear to be comparatively lacking in bike lane coverage, so it might be prudent to set an objective to improve bike lane coverage in these two cities.

Having excluded sidewalk and bike lane coverage as optimal city-wide infrastructure performance objective candidates, the remaining performance measures of "number of marked crossings per mile" and "number of access points per mile" were evaluated. As explained earlier, the results from the four cities revealed a trend that the number of marked crossings decreases as the number of access points increases. A potential performance objective in this case would seek to increase the number of marked crossings per access point. The number of access points has been identified as a key factor increasing more non-motorized crashes as investigated in the crash analysis in Chapter 5. Therefore, a suitable infrastructure objective in the other three cities would be to increase the ratio of marked crosswalks over the number of access points or to reduce the number of access points. However, vehicle travel speed, number of lanes, and ADT all need to be considered prior to adding a marked crosswalk. On multilane roads with high ADT, it would be prudent to install enhanced crosswalks.

8.2.2 Exposure Performance

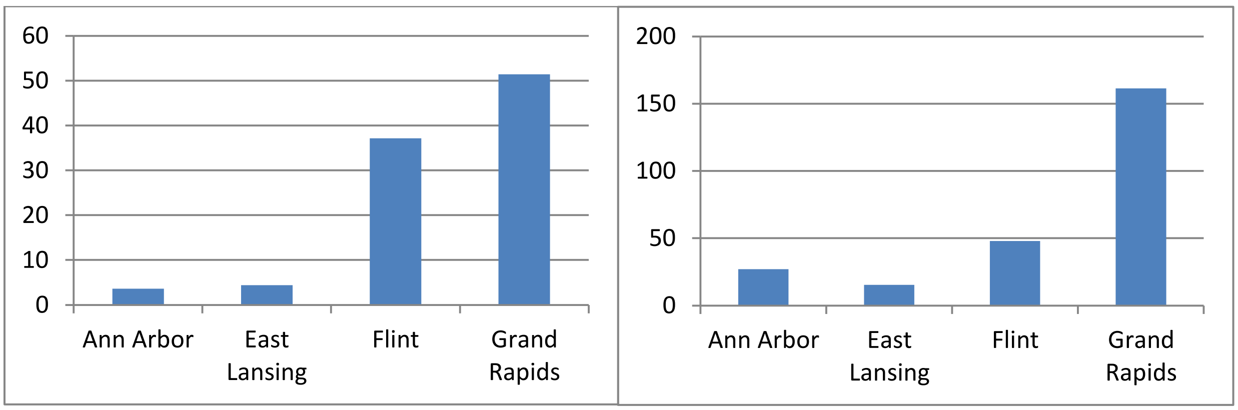
An analysis of non-motorized exposure performance must consider the interaction between non-motorized and motorized traffic from the perspective of both modes of travel. Bicyclists and pedestrians are exposed to vehicles and drivers are exposed to bicyclists and pedestrians. Clearly, as the number of pedestrian, transit, and bicycle commuters increases within a city, non-motorized exposure to vehicle traffic will also increase. Logically, for pedestrians or bicyclists, greater exposure to vehicles would also lead to heightened risk of crash occurrence. One would also expect areas with high non-motorized exposure to vehicles to display a high rate of crashes with K-A severity. However, results from the present research contradict both of these reasonable expectations, as discussed below.

Figure 4-3 - Figure 4-6 in Chapter 4 show the average daily bicycle and pedestrian volumes at signalized intersections in all four cities. As seen, the volumes for both non-motorized modes in Ann Arbor and East Lansing greatly exceed the volumes in Flint and Grand Rapids. Also, as seen in Table 8-2 below, the proportion of commuters who either take public transit, walk, or bike is highest in Ann Arbor and East Lansing.

Table 8-2 City-wide Exposure Performance Measures

2. Exposure Measures	AA	EL	FL	GR
% of Public Transportation and Walk Commuters	25.5	32.6	7.6	7.0
% of Bike Commuters	3.2	7.3	0.1	0.9
Average 12-hr Pedestrian Volume at Intersection	4,020	1,518	370	499
Average 12-hr Bike Volume at Intersection	617	796	120	167

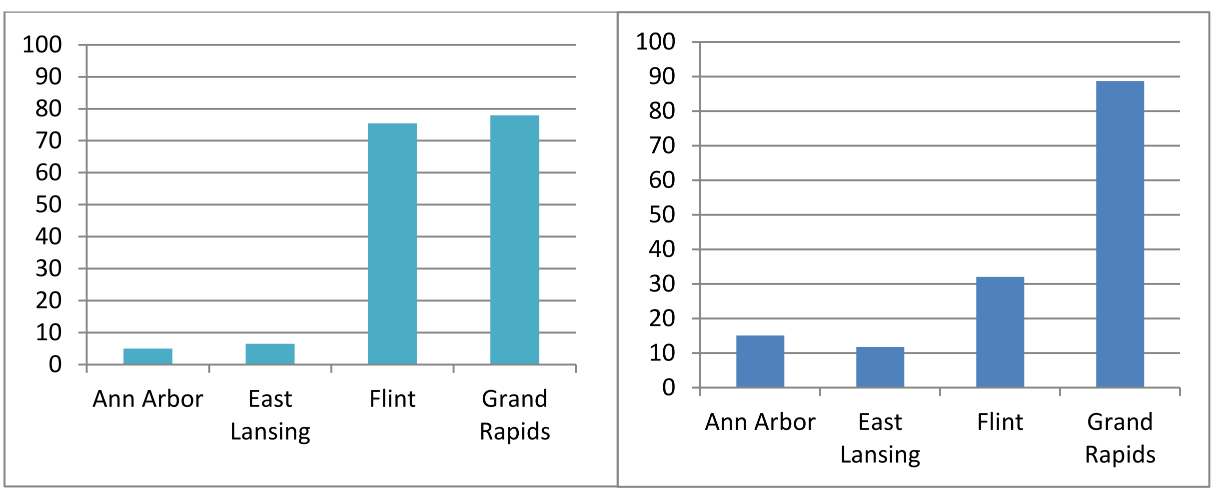
Surprisingly, as seen in Figure 8-1, the number of pedestrian crashes per 100,000 pedestrians and bicycle crashes per 100,000 bicyclists at signalized intersections is miniscule in Ann Arbor and East Lansing compared to Flint and Grand Rapids. These results indicate that among the four cities investigated, non-motorized crash rates decrease with increased exposure. Additionally, as seen in Figure 8-2, the frequency of non-motorized K-A crashes in Flint and Grand Rapids overshadows those seen in Ann Arbor and East Lansing.



(a) Number of Pedestrian Crashes per 100K Pedestrians at Signalized Intersections

(b) Number of Bike Crashes per 100K Bicyclists at Signalized Intersections

Figure 8-1 Exposure-based Performance Measures



(a) K-A Pedestrian Crashes per 1M Pedestrians at Signalized Intersections

(b) K-A Bicycle Crashes per 1M bicyclists at Signalized Intersections

Figure 8-2 Exposure-based Severe Crash Performance Measures

Rather than crash frequency and severity tending to increase alongside increases in exposure, these results appear to indicate the opposite: that non-motorized safety increases as pedestrian-driver and bicycle-driver interactions occur more frequently. As discussed earlier, exposure-based performance must be evaluated from both the perspectives of non-motorized travelers as well as motorized traffic. As motorized traffic interacts more frequently with pedestrians and bicyclists, drivers likely begin to expect a non-motorized presence in the roadways and become accustomed to the behaviors and intentions of non-motorized travelers. As explained in the analysis of survey results in Chapter 6, when non-motorized exposure reaches a certain threshold in a particular area, as in Ann Arbor, a cultural mentality towards non-motorized R-o-W priority can start building and drivers will yield to pedestrians and bicyclists even in situations where the law does not require them to do so.

Performance Objective

Understanding that increasing non-motorized exposure will improve non-motorized safety, an appropriate exposure-based performance objective for transportation authorities in Flint and Grand Rapids would be to strive to raise non-motorized exposure to a similar degree experienced in Ann Arbor and East Lansing. Of course, Flint and Grand Rapids lack the luxury of housing a major university campus similar to Ann Arbor and East Lansing, each of which benefit from the impact of high-student populations on utilization of non-motorized modes of travel. Nonetheless, while it may be ambitious to expect matching exposure levels of non-motorized travel in Flint and Grand Rapids, transportation authorities should at minimum set an acceptable and attainable goal with regard to increasing non-motorized commuting in these two cities in the future.

8.2.3 Education/Enforcement Performance

The first city-wide performance group discussed was infrastructure-based performance, which evaluates the success of the efforts in planning, designing, operating, and maintaining safe and effective facilities for non-motorized travelers. The second city-wide performance group was concerned with exposure-based performance, and a conclusion was drawn that non-motorized safety varies directly with non-motorized exposure. This conclusion, followed to its utmost extreme, would allow one to predict complete safety for pedestrians and bicyclists when not a single vehicle occupies the same roadway. Taking both of these performance groups into consideration, in the ideal case, engineers would design the safest possible transportation facility for use primarily by non-motorized travelers and reasonably expect little to no crashes between vehicles and non-motorized travelers. However, any shortcomings in non-motorized safety understanding or behavior and/or enforcement of traffic safety laws would compromise these lofty efforts and ultimately result in otherwise avoidable crashes. Accordingly, education and enforcement performance measures considered in this research are travelers' understanding of right-of-way, percentage of schools in the Safe Routes to School program, number of police officers per 10,000 population, number of crossing guards, and yielding rate at midblock crossings.

Table 8-3 City-wide Education/Enforcement Performance Measures

3. Education/Enforcement	**AA**	**EL**	**FL**	**GR**
Understanding right-of-way (%)	64.2	60.5	56.8	63.3
% of schools in SRTS (%)	23.3	100.0	7.7	9.3
Police officer per 10,000 people	14.83	26.36	15.91	16.91
Number of crossing guards[1)]	N/A	N/A	N/A	N/A
Yielding Rate at Midblock Crossing[1)]	N/A	N/A	N/A	N/A

1) These measures were proposed but not available in this study.

Table 8-4 Understanding of Right-of-Way from Survey Results

Understanding of right-of-way	**AA**	**EL**	**FL**	**GR**
Average Score	**64.2**	**60.5**	**56.8**	**63.3**
- ROW at Countdown Signal	85.1	87.8	71.4	83.1
- ROW at Marked Uncontrolled Crossing	75.8	79.3	72.7	83.7
- ROW at Unmarked Uncontrolled Crossing	20.0	22.2	28.5	16.0
- Direction of walking (Facing)	55.1	43.7	44.9	52.9
- Direction of bicycling (Same as car)	84.8	69.4	66.7	81.0

Note) Scores were the percentage of correct answers in the survey.

The research results concerned with education and enforcement performance will be discussed below. As discussed in an earlier chapter, this research gauged traveler's understanding of R-o-W through administration of field surveys to a representative sample of drivers, bicyclists, and pedestrians in various locations in all four cities. Right-of-Way understanding by city varied according to the question under consideration and the characteristics of the respondents as shown in Table 8-4.

Many factors could contribute to a lack of non-motorized safety understanding among travelers; however, limited exposure to traffic as well as traffic safety education among the nation's youth represents one of the most likely culprits. The Safe Routes to School (SRTS) program seeks to alleviate this issue. Safe Routes to School is a national movement whose goal is to promote safe bicycling and walking among school-aged children through education in an effort to enhance the well-being of communities throughout the United States (National Center for Safe Routes to School, 2013). As seen in Table 8-3, partnership with SRTS among elementary and middle schools in the four cities is very low, except in East Lansing, which shows 100% acceptance. One caveat of the percentage of schools in SRTS performance measure lies in the fact that schools can sign-on for inclusion, while not being required to actively follow the program. With this in mind, unless the researcher inquires further about the level of active participation in SRTS by each school district, measuring the percentage of schools merely signed-up for the program holds little meaning.

The performance measures of right-of-way understanding and percentage of schools in SRTS fall under the education performance group, while police officers per 10,000 people, number of crossing guards, and yielding rate at midblock crossings represent performance measures that evaluate enforcement efforts in the four cities. The number of police officers per 10,000 people evaluates general enforcement capability within a city, but cannot truly capture how non-motorized safety efforts are performing, specifically. While determining the number of crossing guards in a city would directly measure non-motorized safety enforcement performance, obtaining this value is difficult due to the need to compile the information from each individual school district within the city. For this reason, this performance measure was not calculated in the present research. Although not part of this study, observing yielding rate at midblock crossings would allow researchers to measure both education performance as well as enforcement performance. Additionally, field observations of yielding behavior could be used to verify survey results concerned with measuring Right-of-Way understanding among travelers. For these reasons, this report recommends that any future studies of similar scope include evaluation of yielding rate at mid-blocks as an integral component of measuring education and enforcement performance.

Performance Objective

Given that every other performance measure either suffers from lack of meaningful data or presently gathered information, the optimal education performance measure to evaluate by each city is the understanding of right-of-way. This applies to road users of each mode according to field survey results. Survey administration could occur on an annual basis to judge yearly education performance efforts, or continuously efforts, if users are allowed to access the survey online at an appropriate web location. Each city should strive to improve general non-motorized safety understanding (not just right-of-way) among its citizens to a specific comprehension level by an acceptable timeline. As shown in Table 8-4, this goal would best be accomplished by raising comprehension in specific areas of reduced safety understanding, such as issues of R-o-W at unmarked, uncontrolled crossings as well as proper travel direction when walking or biking.

8.2.4 Safety Performance

Non-motorized safety performance largely depends on the performance of each of the previously discussed aspects of infrastructure, exposure, and education/enforcement. City-wide non-motorized safety performance must be evaluated according to crash severity as well as crash frequency. Crash frequency performance measures can be investigated from a population-based perspective or an exposure-based perspective. The following discussion will introduce chosen crash performance measures for both pedestrians and bicyclists.

This research pinpointed six performance measures of importance concerning the pedestrian mode, including three crash frequency measures and three crash severity measures. The population-based crash frequency performance measure of interest is the number of crashes per 100,000 people. Exposure-based crash frequency performance measures include the number of crashes per 1000 transit/walk commuters as well as the number of crashes per one million exposures. Pedestrian crash severity performance measures include the proportion of K-A crashes among all crashes, the fraction of K-A crashes at intersections, and the fraction of K-A crashes at night. While numerous, evaluation of each of these measures in concern will provide a clear picture of how a city performs with regard to pedestrian crashes.

Concerning the bicycle mode, seven important performance measures were identified. These include the same three crash frequency measures as the pedestrian mode as well as the same three crash severity measures as the bicycle mode. However, bicycle safety performance includes one additional performance measure - number of crashes per bike lane mile, which evaluates crash performance as it relates to infrastructure performance. Once again, exclusion of any one of these performance measures might result in some degree of loss in complete understanding of city-wide bicycle safety performance.

Non-motorized crash data was gathered from each city between the years of 2004 to 2012. An important issue to always keep under consideration is that the majority of non-motorized crashes go unreported. Thus, performance measures are created under the basis of reported crashes only. As seen in Table 8-5 below, each city struggles in at least one measure of pedestrian safety performance.

Table 8-5 City-wide Pedestrian Safety Performance Measures

Pedestrian Safety	AA	EL	FL	GR
1. # of crashes / 100,000 people	46.2	49.8	49.0	49.8
2. # of crashes / 1000 transit or walk commuters	3.8	3.7	23.1	16.2
3. # of crashes / 1 million pedestrian exposure	35.9	43.7	371.4	513.8
4. Total KA Crashes / Total Crashes (%)	14.1	14.9	20.3	15.2
5. % of KA Crashes at Intersection	88.6	88.9	80.4	78.1
6. % of KA Crashes at Night Time	45.9	33.3	62.7	54.9

The results show that the four cities perform fairly similar with regard to the number of crashes per 100,000 people population-based crash frequency measure; however, among the two exposure-based measures, Flint and Grand Rapids display poor performance. Concerning the number of crashes per 1,000 transit/walk commuters, it is necessary to keep in mind that the “number of crashes” represents all reported pedestrian crashes rather than just crashes experienced by commuters. For this reason, cities such as Flint and Grand Rapids with low commuter populations will inherently experience lower performance unless the researcher can extract commuter-only crashes and determine a more accurate value – which is difficult to achieve. Due to this issue, the number of crashes per one million exposures performance measure may portray a more accurate representation of exposure-based crash performance as it does not differentiate between the commuter versus non-commuter role. With regard to pedestrian severity-based crash performance, overall crash severity is highest in Flint at 20 percent of all crashes resulting in K-A severity. Ann Arbor and East Lansing display the worst performance when evaluating the fraction of K-A crashes at intersections in particular, while Flint and Grand Rapids show high nighttime crash severity.

Table 8-6 City-wide Bicycle Safety Performance Measures

Bicycle Safety	AA	EL	FL	GR
1. # of crashes / 100,000 people	53.4	92.7	20.5	52.2
2. # of crashes / Bike lane mile	1.8	3.3	3.7	5.4
3. # of crashes / 1000 bike commuters	35.2	30.7	1,050.0	128.5
4. # of crashes / 1 million bicycle exposure	270.1	154.9	480.4	1,612.9
5. Total KA Crashes / Total Crashes (%)	5.6	7.6	6.7	5.5
6. % of KA Crashes at Intersection	82.4	76.5	85.7	76.9
7. % of KA Crashes at Night Time	5.9	17.6	71.4	29.6

Table 8-6 highlights bicycle safety performance by city. As shown, East Lansing has a high population-based crash rate; however, this is likely explained by East Lansing maintaining a high bicycle-travel oriented community (alongside Ann Arbor), which as previously explained, likely results from housing a high student population. As in the pedestrian example, Flint and Grand Rapids display the poorest exposure-based bicycle safety performance. At first glance, Flint's value of 1,050 bicycle crashes per 1,000 bicycle commuters may appear unreasonable or invalid, but this result stems from the limitation of this particular performance measure as explained in the pedestrian analysis. In detail, according to the 2010 Census data, Flint contains only 20 bicycle commuters, and such a small commuter sample population will profoundly influence the accuracy of the result. With regard to crash severity, unlike the pedestrian case, East Lansing exhibits a high proportion of K-A crashes among all crashes, but low K-A bicycle crashes specifically at intersections. This inconsistency in results between pedestrian and bicycle modes might indicate that mid-block crossing locations in East Lansing are more hazardous for bicyclists than pedestrians and should be investigated accordingly. Once again, as in the pedestrian case, K-A crashes are quite prominent at night in Flint and Grand Rapids.

Performance Objectives

Due to the nature of safety performance measures relying on the success of performance objectives tasked with improving infrastructure, exposure, and education/enforcement performance, any objectives suited to improving those three performance groups should be explored first. However, transportation authorities can glean additional performance objectives based on the analysis of safety performance measures outlined in this study, which might include the following:

- Improve pedestrian intersection safety in Ann Arbor and East Lansing
- Improve night-time pedestrian safety in Flint and Grand Rapids
- Improve mid-block safety for bicyclists in East Lansing
- Improve night-time bicyclist safety in Flint and Grand Rapids

8.2.5 Summary of Countermeasures Based on Selected Performance Objectives

The summary of possible countermeasures based on the performance objectives selected in each performance measure group is shown in Table 8-7. The chosen countermeasures only serve as a guideline, and more representative improvements might be chosen at the discretion of the concerned agency. As explained, crash performance depends on the performance of the three other performance groups and would likely be improved by meeting the particular objectives of those groups.

Table 8-7 Summary of City-Wide Countermeasures According to Performance Objectives

Performance Measure Group	Performance Objective	Possible Countermeasures
1. Infrastructure	• Attain at least 50% coverage of marked crosswalks per access point in AA, FL, and GR	• Delineate existing crosswalks • Reduce/control access points if possible
2. Exposure	• Improve rates of non-motorized commuting in FL and GR	• Media-outreach efforts • Improve or increase non-motorized facilities • Enhance city-wide education/enforcement
3. Education/Enforcement	• Increase levels of non-motorized safety understanding among travelers in FL and GR	• Promote non-motorized safety in public relations and marketing plans • Signage • Training of transportation officials and police officers in non-motorized safety • Increase police presence near school zones
4. Safety	Improve: • Pedestrian intersection safety in AA and EL • Night-time pedestrian safety in FL and GR • Mid-block bicyclist safety in EL • Night-time bicyclist safety in FL and GR	• In addition to previously listed countermeasures: • Implement or enhance night-time lighting of non-motorized facilities in FL and GR

8.2.6 Implementation of City-Wide Performance Measure

In order to more clearly convey the individual level of city-wide performance, radar graphs were developed which rate each city on a scale from 0 to 100 based on both pedestrian and bicycle performance. The ratings are based on the performance of each city with regard to the early discussed infrastructure, exposure, education/enforcement and safety performance measures. As a demonstration, a fictitious city was used.

This study categorized city-wide non-motorized performance measures into four groups, such as infrastructure, exposure, education and safety performance. Among many performance measures in each category as in previous sections, easily applicable performance measures were selected as shown in Table 8-8 for easiness of implementation.

Table 8-8 Easily Applicable Performance Measures by Category

Category	**Pedestrian**	**Bicycle**
Infrastructure	Sidewalks Coverage (%)	Bike Lane Coverage (%)
	Number of access points (number per mile)	Number of access points (number per mile)
Exposure	% of public transportation & walk commuters	% of bike commuters
Education	Understanding Right-of-way (Survey)	Understanding Right-of-way (Survey)
	Driver yielding rate at mid-block Crossing	Driver yielding rate at mid-block Crossing
Safety	# of ped crash / 100,000 people	# of bike crash / 100,000 people
	# of ped crash / 1,000 transit or walk commuters	# of bike crash / bike commuters

Among performance measures listed in Table 8-8, the yielding rate at mid-block crossing has not been measured in this research although it is recommended here. Understanding the right-of-way is measured using the following five survey questions in Table 8-9.

Table 8-9 Selected Survey Questions

Show Traffic Signal Location with a Marked Crosswalk showing COUNTDOWN SIGNAL sign and a pedestrian crossing the street with a turning vehicle.

Who has the right-of-way here - the pedestrian or the driver?

Driver _________ Pedestrian _________ Both _________

Show a Marked Crosswalk location with a pedestrian starting to cross the street with a vehicle approaching.

Who has the right-of-way here - the pedestrian or the driver?

Driver _________ Pedestrian _________ Both _________

Show an unmarked crosswalk location with a pedestrian crossing an uncontrolled leg of the intersection.

Who has the right-of-way here - the pedestrian or the driver?

Driver _________ Pedestrian _________ Both _________

When walking on or along the roadway which way do you face? (for pedestrian)

a. In the same direction the cars are traveling (on the right side)
b. Facing traffic (on the left side)
c. It does not matter which direction you face.

Which way do you travel when riding in the road? (for bicyclists)

a. In the same direction the cars are traveling (on the right side)
b. Facing traffic (on the left side)
c. It does not matter - one can ride on either direction

After compiling all data, the performance goals for individual measures have to be set by the city. Based on the goal, performance index for each measure is computed using the equation below:

$\mathrm{PI}_k = \frac{t_k}{pm_k} \times 100$ if smaller values indicate better performance

(e.g., # of crash per 100,000 people is 45 when the goal is 30, and then the performance measure is 30/45x100 = 66.7)

or $\mathrm{PI}_k = \frac{pm_k}{t_k} \times 100$ if larger values indicate better performance

(e.g., % of bike commuters is 3% when the goal is 10%, and then the performance measures is 3/10x100 = 30.0)

After computing individual performance indices, the perform indices in four categories are computed by averaging performance indices in each category.

$$PI\ (i) = \frac{1}{K} \sum_{all\ k} PI_k$$

where

i = performance category
K = the number of measures in category i
t_k= target value (goal) for measure k in category i
pm_k= performance of measure k in category i

The performance index in each category can be depicted by the radar graph as in Figure 1. The graph visualizes the category needing more improvement. For example, for the city depicted in this figure, education needs relatively more improvements.

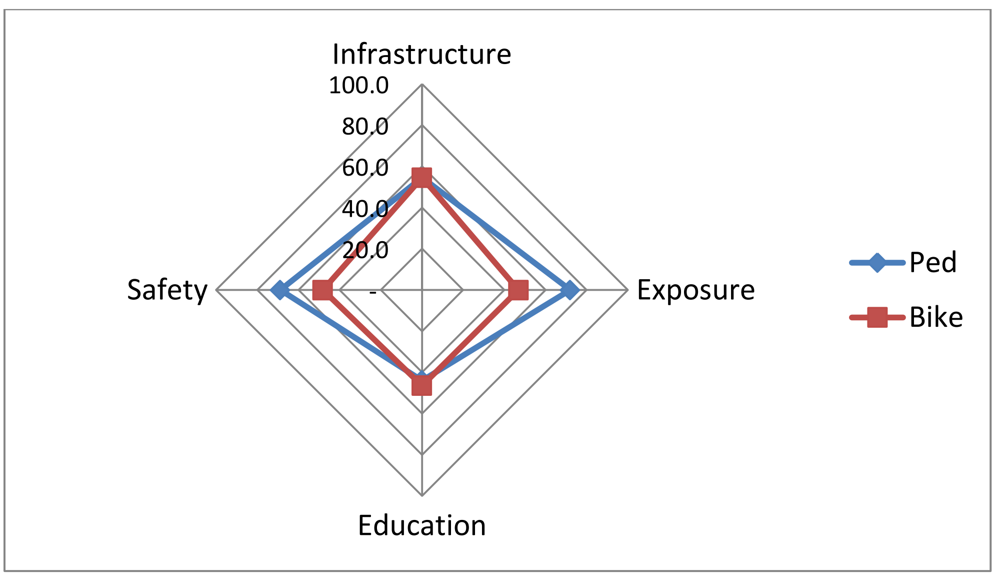


Figure 8-3 Radar Graph for City-wide Performance Index by Category

8.3 Corridor-Level Performance Measures and Countermeasures

8.3.1 Corridor-Level Performance

Identification of High-Risk Areas

Two different methods can be utilized to narrow down areas within a city that likely contain at-risk corridors. The first method is to construct a city-wide crash density map through use of a GIS software application. A crash density map forms color contours based on the amount of crashes within a particular space. Lighter gradients of the map represent locations of low crash density, while darker gradients indicate areas with high crash density. The second method used in the present study is based on crash frequency within individual census tracts. Once again, a color scale can be developed that allows the researcher to identify census tracts of high crash frequency. The two methods should be used in conjunction to verify results.

Identification and Evaluation of High-Risk Corridors

Once problematic areas within the city have been identified, individual corridors within the chosen regions can be evaluated and ranked according to a number of different crash frequency and severity performance measures. Although roughly 85% of non-motorized crashes occur at intersections, corridor safety should be evaluated on the basis of both mid-block crashes as well as signalized intersection crashes, as countermeasures can differ based on the location of crashes along a specific corridor. The performance measures used to determine corridors in greatest need of countermeasures include the following (for both pedestrians and bicyclists):

- Signalized Intersection Performance
    - Difference between Crashes Observed and Crashes Predicted
    - Yearly Crashes per One Million Exposure
    - Equivalent Property Damage Only
- Mid-Block Performance
    - Difference between Crashes Observed and Crashes Predicted per Mile
    - Equivalent Property Damage Only per Mile

The "Difference between crashes observed and crashes predicted" simply means the difference between actual crashes observed on the corridor during the analysis period and the expected number of crashes on the corridor based on the Safety Performance Function (SPF) discussed in this report. A higher value indicates that the corridor experienced more crashes than predicted by the SPF. "Yearly Crashes per One Million Exposure" is the same performance measure as used in the city-wide performance evaluation, only on the corridor level instead. "Equivalent Property Damage Only" is a common measure used in traffic safety analysis that calculates crash severity based on the cost of a Property Damage Only (PDO) crash. The EPDO equation is shown below:

$$EPDO = (K + A)\,X + (B + C)\,Y + O$$

Where K,A,B,C, and O represent the number of crashes of each respective crash severity, X represents the K-A EPDO constant, and Y represents the B-C EPDO constant. EPDO constants were calculated using the unit cost for each crash type according to the University of Michigan's "Societal Costs of Traffic Crashes and Crime in Michigan: 2011 Update" (Kostyniuk et al, 2011) and collected crash data from all four cities considered. Table 8-10 summarizes EPDO constant calculations.

Table 8-10 Crash Costs and Calculation of Equivalent Property Damage Only

	Fatal (K)	Incapacitated Injury (A)	Evident Injury (B)	Possible Injury (C)	PDO (O)
NSC (2011)[1)]	$4,459,000	$225,100	$57,400	$27,200	$2,400
FHWA (2005)[2)]	$4,008,900	$216,000	$79,000	$44,900	$7,400
Michigan (2010)[3)]	$3,611,958	$229,646	$68,431	$39,910	$3,690
% of non-motorized crashes in four cities (04-12)	1.7%	10.0%	31.4%	44.9%	12.0%
Average Cost[4)]	708,490		51,631		3,690
EPDO	192.0		14.0		1.0

1) National Safety Council, Estimating the Costs of Unintentional Injuries, 2011
2) FHWA, Crash Cost Estimation by Maximum Police-Report Injury Severity within Selected Crash Geometries, FHWA-HRT-05-051, 2005
3) Kostyniuk, et al., Societal Costs of Traffic Crashes and Crime in Michigan: 2011 Update, UMTRI-2011-21, June 2011
4) Weight average based on Michigan crash costs and crash data from four study cities

After ranking the corridors according to these performance measures, it is possible to identify candidate corridors for countermeasure selection. The need for countermeasures is developed on the basis of the corridors which perform most poorly. Countermeasures can be developed in one of two ways, either through Level-of-Service analysis or by “crash-typing”.

8.3.2 Highway Capacity Manual Level-of-Service Countermeasure Development

Introduction

The 2010 edition of the Highway Capacity Manual (HCM) includes a comprehensive methodology to determine the level of service (LOS) for non-motorized modes of traffic on urban street facilities. Chapters 16-18 of HCM discuss the input data needed and the proper procedure to determine the LOS for three “non-automobile” modes, which include pedestrians, bicyclists, and transit. The HCM further differentiates between three different analysis levels that require varying degrees of input data. These levels include: operational analysis, design level analysis, and planning and preliminary engineering analysis. Operational analysis requires the most encompassing information with regard to all traffic, geometric and signalization conditions, while planning and preliminary engineering analysis needs comparatively rudimentary information with regard to these conditions. This includes, taking advantage of default input data as provided by the HCM when the data is either unknown or too resource costly to obtain.

LOS Analysis

The HCM defines an urban facility as the length of roadway consisting of continuous segments, commonly known as urban arterial or collector streets. Segments represent the operational combination of links and their boundary intersections (or points) on either side. The bicycle LOS methodology evaluates travel along one direction of the roadway, while the pedestrian LOS methodology includes both sidewalk (when present) and street conditions on one side of the segment. The LOS for both travel modes is based on research that gauged travelers’ perception of the quality of service provided by urban street facilities with various conditions. A rating of “A” was associated with a trip under ideal conditions as perceived by the traveler, while a rating of “F” represented the poorest perception of quality of service according to the traveler. Using these answers, researchers were able to determine which conditions travelers gravitate towards as desirable or ideal when making a trip on an urban street facility. The conditions can be described as performance measures that quantify the operational health of a facility as experienced by the various road users, and include: travel speed, space, and perception score. The comprehensive evaluation of these performance measures forms the basis of the calculation of both urban street segment LOS and signalized intersection LOS for all travel modes. The performance measures for each segment and boundary intersection along a given travel direction must first be evaluated separately, and the calculation of a segment length-weighted average follows for each condition, which determines the overall facility LOS.

Countermeasures Based on LOS

Upon completion of the evaluation of facility LOS, focused countermeasures can be developed to alleviate any shortcomings spotted during the LOS development process. The FHWA Pedestrian and Bicycle Information Center (PEDSAFE/BIKESAFE) developed the web-based “Pedestrian Safety Guide and Countermeasure Selection System” which includes a number of useful tools to select appropriate countermeasures according to specific performance measure goals. One of these tools is an interactive “Performance Objective Matrix”, which charts a list of performance objectives against various countermeasure classifications (US Department of Transportation Federal Highway Administration [USDOT FHWA], 2013). Images of both pedestrian and bicyclist matrices as found on the PEDSAFE/BIKESAFE websites, are included in the appendix. Upon choosing the appropriate Performance Objective-Countermeasure grid pair, a list of candidate countermeasures is presented with additional details for each particular solution.

8.3.3 PEDSAFE & BIKESAFE Crash-typing Countermeasure Development

Introduction

In the 1970s, the National Highway Traffic Safety Administration (NHTSA) developed a non-motorized crash typing methodology. Later, in the 1990s, Hunter et al. (1996) applied the NHTSA methodologies to more than 8,000 non-motorized crashes in an effort to summarize different crash types. Currently, the Pedestrian and Bicycle Information Center funded by FHWA provides the PBCAT (Pedestrian and Bicycle Crash Analysis Tool) version 2.0 to help agencies more quickly and efficiently identify appropriate countermeasures based on 12 crash-type groups. PBCAT analyzes given input data, including information obtained from crash reports, by crash-type, dependent on a database of previous research.

Crash-type Countermeasures Methodology

In order to perform non-motorized crash-typing, the analyst must first identify current or future high-crash locations in at least one of three ways: GIS mapping of reported incidents, walkability/bikeability checklists, and calculating non-motorized LOS. Secondly, an investigation of the behaviors and events preceding the crash must be performed, according to the police crash report. Next, the crash must be defined according to one of the 12 crash-type groups. Finally, countermeasures must be prescribed according to the defined crash-type, as shown in the image of the interactive PEDSAFE/BIKESAFE Crash-Typing matrices (USDOT FHWA, 2013), included in the appendix.

8.3.4 Case Example of Corridor-Level Analysis

Study City

The city under investigation for the case example of corridor-level performance analysis is Grand Rapids. Grand Rapids was chosen for the following reasons:

- **City-wide Infrastructure Performance**
    - Grand Rapids has the lowest number of marked crossings per access point among the four cities, possibly impacting corridor-level safety performance.
- **City-wide Exposure Performance**
    - Grand Rapids has the highest non-motorized crash frequency and severity at signalized intersections among the four cities, likely indicating safety issues at the corridor level.
- **City-wide Education/Enforcement Performance**

    - Survey respondents from Grand Rapids tended to properly understand non-motorized safety, so city-wide education and enforcement related countermeasures are not a top priority.
- **City-wide Crash Performance**
    - Along with Flint, Grand Rapids displays high crash frequency and severity for both pedestrians and bicyclists.

<u>City Regional Safety Analysis</u>

As explained in the methodology section, two methods (the crash density graph and census tract crash frequency map) should be utilized to determine specific locations within the city that likely contain corridors of high-risk. Using the gathered crash data, a crash density map was developed in ArcGIS, which is displayed in Figure 8-4.

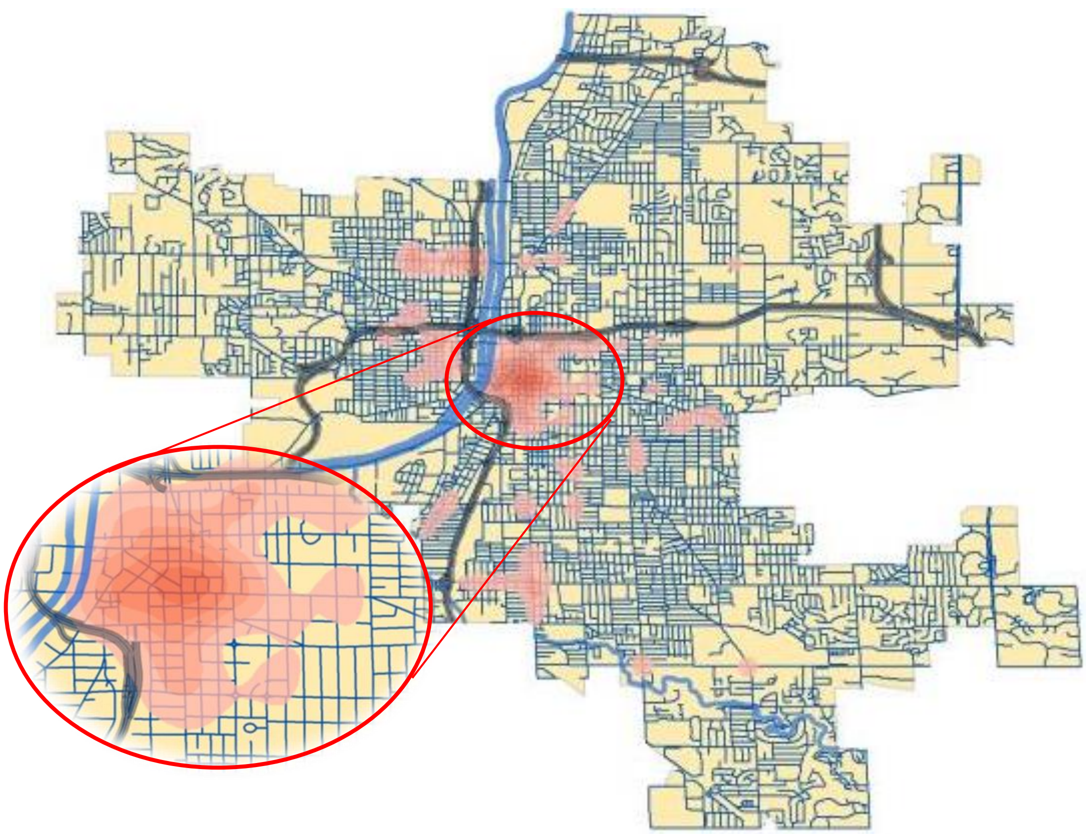


Figure 8-4 Grand Rapids Crash Density Map

The circled location represents the region of the city most likely to include high-risk corridors. In order to verify the selected region, a crash frequency by census tract map was constructed and is shown in Figure 8-5. The census tract map also serves another useful purpose in that it allows faster extraction of candidate corridors, as corridors are labeled according to census tract ID. Census tracts were chosen on the basis of meeting or exceeding 0.004773 pedestrian crashes per census tract population and containing at least one of the 51 corridors under study in this report. As seen, five census tracts meet these criteria, and all but Census Tract 0008 are within the high-risk region determined by the crash density map.

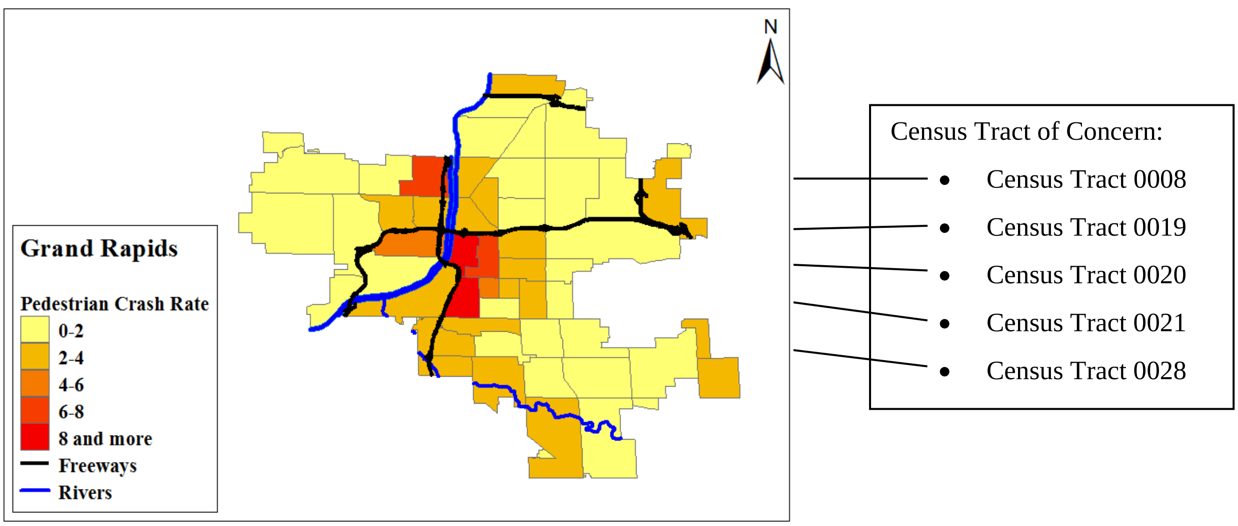


Figure 8-5 Census Tract Crash Frequency Map

Corridor Level Performance Analysis

After narrowing down the scope of performance analysis to high-risk census tracts, individual corridors within the census tracts can be evaluated and ranked according to the five performance measures discussed in Section 7.3.1. Nine of the fifty-one corridors investigated in this report fall within the five census tracts previously identified as high-risk. These corridors are shown in the image of the ArcGIS map on the following page.

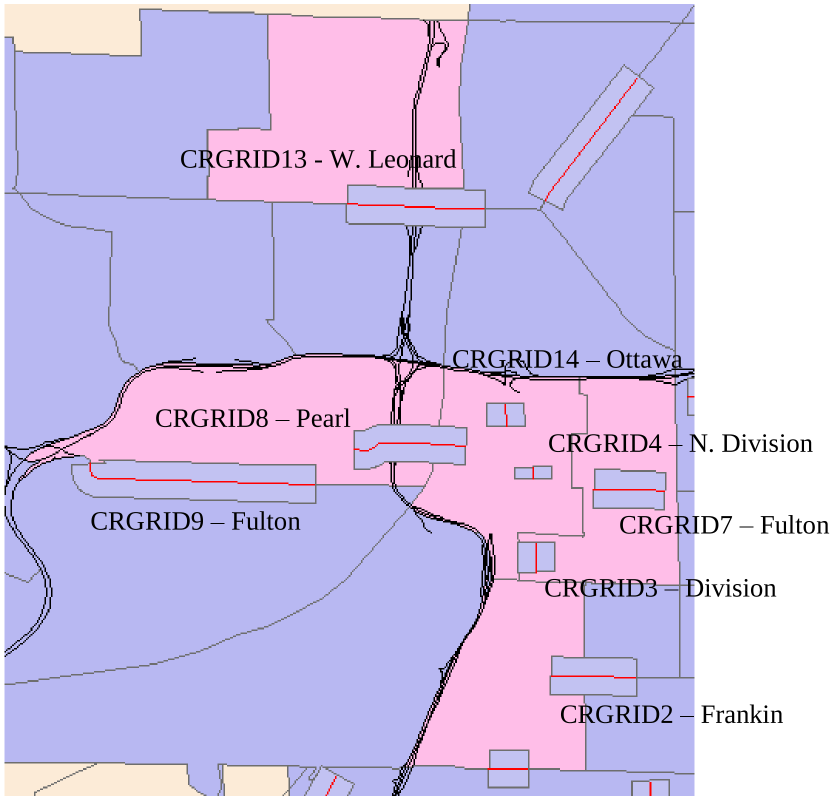


Figure 8-6 Candidate Corridors for Performance Analysis

As seen in Figure 8-7, Corridor ID #15 (Ottawa) displays the poorest aggregated performance with regard to each signalized intersection pedestrian performance measure. Concerning crash frequency at the Ottawa corridor, 4.297 more pedestrian crashes were observed than predicted by the SPF during the analysis period and the corridor would experience 6.284 pedestrian crashes per one million exposures per year, higher than any other corridor investigated. Also, pedestrian EPDO at Ottawa was highest (along with Corridor ID #8) among the candidate corridors at 276 EPDO. Corridor mid-block performance analysis follows signalized intersection analysis, and the results are shown on the following page.

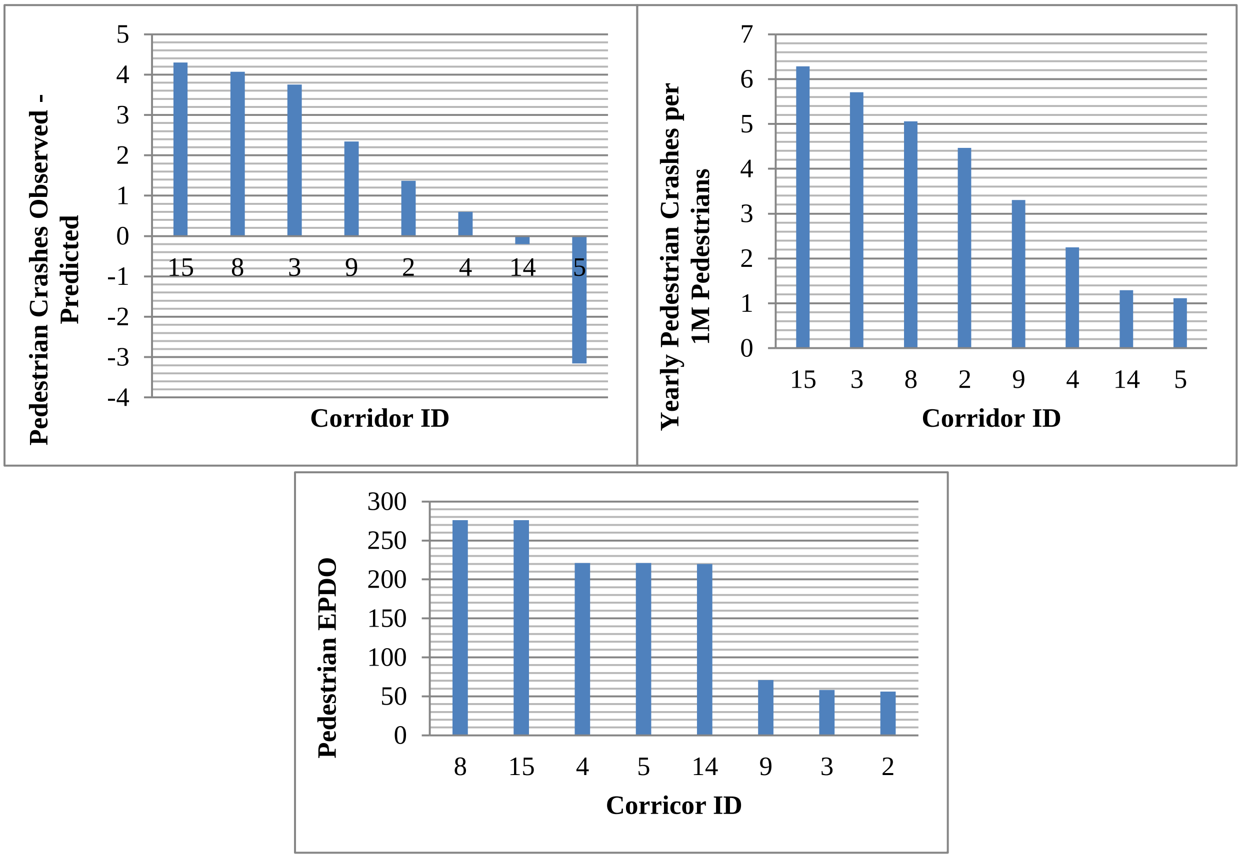


Figure 8-7 Candidate Corridor Performance Measures at Signalized Intersections

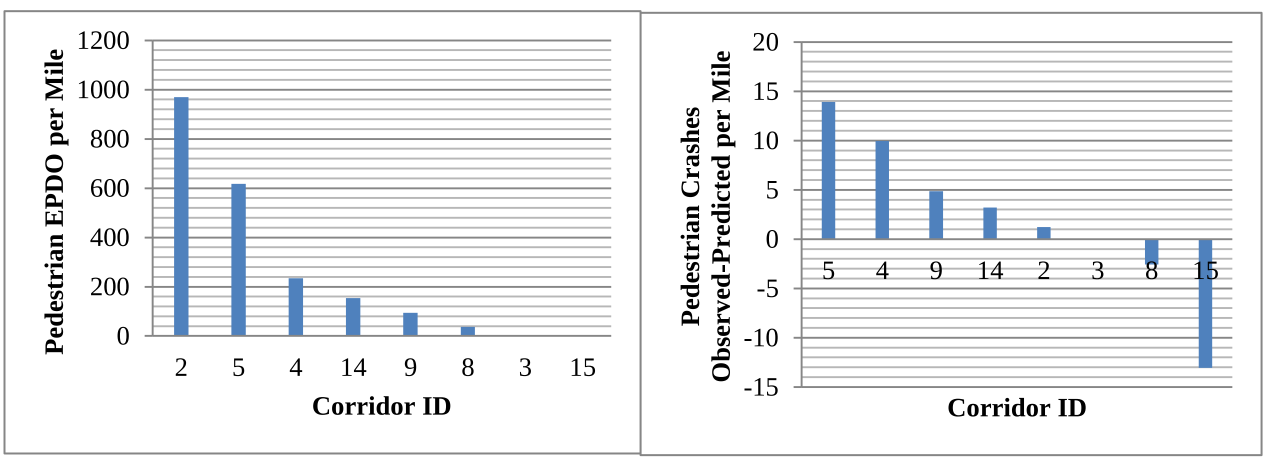


Figure 8-8 Candidate Corridor Performance Measures at Mid-Blocks

Figure 8-8 reveals that Corridor ID #15 displays the best performance of all corridors with regard to mid-block safety. Given that the corridor performs the worst at signalized intersections, this gives strong indication that countermeasures should focus on improving the signalized intersections on the Ottawa corridor. As discussed, crash-typing can be used to finalize which particular countermeasures should be implemented. The following section discusses the crash-typing results.

Corridor-Level Crash-typing & Countermeasures

Crash-typing is based on the information provided in police crash reports, as found at the Michigan Traffic Crash Facts (MTCF) website. The MTCF Data Query Tool is used to locate the crashes of interest (Michigan Traffic Crash Facts, 2013). After building a query, crash information is provided in many different formats, including maps, tables, lists, and charts. Figure 8-9 on the following page depicts the location of crashes on the Ottawa corridor. The image on the left-side shows the single crash that occurred on the intersection with Michigan St. NW, while the image on the right-side displays the six crashes that occurred on the intersection with Lyon St. NE. Table 8-11, below the images summarizes the crash-typing analysis and appropriate countermeasures for the Ottawa corridor.

Figure 8-9 Crash Locations on Ottawa Corridor

Table 8-11 Ottawa Corridor Crash-Typing and Countermeasures

Lyon St. NE Intersection			
Crash Type	**Crash IDs**	**Possible Causes**	**Possible Countermeasures**
2.Multiple Threat/Trapped	7516938	1. Pedestrian struck by vehicle traveling in same direction as stopped vehicle	• Install barriers or signs which prohibit crossing • Enforce crosswalk laws
6. Turning vehicle	8400568 8147428 8200948 7212593	1. Conflict between pedestrian and left-turning vehicle	• Provide separate left-turn and WALK/DON'T WALK signals • Prohibit left turns
	6976002	1. Conflict between pedestrian and left-turning vehicle	• Install raised pedestrian crossing
Michigan St. NW Intersection			
Crash Type	**Crash IDs**	**Possible Causes**	**Possible Countermeasures**
6. Turning vehicle	7131070	1. Conflict between pedestrian and left-turning vehicle	• Install raised pedestrian crossing • Install warning signs for pedestrians and/or motorists

8.4 Conclusion

This section began with an introduction summarizing non-motorized performance measures as developed by other transportation agencies and organizations. Many agencies have developed performance measures in recent years in an effort to evaluate the nature and status of non-motorized safety within their particular area of operation. Established performance measures vary widely in focus, and include evaluation of crash rate/quantity, education/enforcement, cultural factors, and cost, among others. This research studied many of these performance measures and used them as inspiration in determining the best practice of measuring non-motorized safety. A review of previous literature proved instrumental in developing the methodology to develop performance measures and related countermeasures in the State of Michigan.

The methodology developed to effectively measure non-motorized safety performance in Michigan has two stages, beginning with a city-wide analysis and progressing into a corridor-level analysis. The purpose of city-wide evaluation of non-motorized safety is to establish a baseline and identify any general performance issues within a city on a large-scale. The study found that performance can best be summarized into four different groups: infrastructure performance, exposure performance, education/enforcement performance, and crash performance. City-wide crash performance depends on the supplementary performance measures of each of the other three groups. The study found that Flint and Grand Rapids display the worst crash performance as a whole among the four cities under investigation. A number of factors, many concerning the infrastructure, exposure and education/enforcement performance groups, are likely responsible for this result.

City-wide Analysis

Beginning with infrastructure performance, every city displays roughly the same proportion of sidewalk coverage, ranging from between about 80% in Flint to almost full coverage in Ann Arbor. With regard to bike lane coverage, Ann Arbor and East Lansing show the best coverage at nearly 40% in both cities, while Flint and Grand Rapids have very few bike lanes, unable to exceed 10% coverage. However, bicycling in Flint and Grand Rapids does not enjoy the same amount of utility compared to the campus towns of East Lansing and Ann Arbor, so these cities likely do not require an equivalent level of bike lane coverage. Ultimately, a combination of the two performance measures concerned with the number of access points and marked crossings portrays the clearest picture of non-motorized infrastructure performance on a city-wide basis. As shown, East Lansing has the most marked crossings per access point, at nearly 50% coverage, while the other three cities vary between roughly 5% to 15% coverage. Therefore, East Lansing should at least maintain this level of marked crosswalk coverage, and the other three cities should strive to meet this benchmark of performance. Improving the number of marked crosswalks can be accomplished either by providing delineation of existing crosswalks or removing access points when possible.

Analysis of city-wide non-motorized exposure safety performance followed the evaluation of infrastructure performance. One would expect that, as the volume of pedestrians and bicyclists increase in a city, the number of non-motorized crashes would increase accordingly. However, the present research observed that, in fact, the opposite occurs. Ann

Arbor and East Lansing display the highest volumes of non-motorized travel, but also experience the lowest frequency and severity of non-motorized crashes based on exposure among the four cities under investigation. While surprising, this result can likely be attributed to cultural reasons. First, as a result of high non-motorized volumes, drivers in Ann Arbor and East Lansing have grown to expect and anticipate the presence of non-motorized travelers on city roadways. As drivers increasingly become exposed to pedestrians and bicyclists and vice-versa, a culture of non-motorized priority manifests, and practitioners of these modes can reliably expect a heightened sense of awareness from drivers. For this reason, pedestrians and bicyclists also tend to feel safer in Ann Arbor and East Lansing, as shown in the analysis of survey results in this report. Thus, in order to improve exposure-related non-motorized performance in Flint and Grand Rapids, these cities should seek to increase promotion and accommodation for pedestrian and bicyclist commuters as an initial objective. Strategies to accomplish this goal might include media-outreach efforts, improving non-motorized facilities, and enhancing city-wide education/enforcement of non-motorized safety.

City-wide education/enforcement performance measures under investigation in this report included understanding of non-motorized safety, the number of schools in the Safe Routes to School program, and the number of police officers per 10,000 population. The results indicate that understanding of non-motorized safety is highest in Ann Arbor and lowest in Flint. These particular results were discussed briefly in this chapter, but a more comprehensive analysis can be found in the chapter discussing the survey conducted as part of the research. With regard to the number of schools in the SRTS program, East Lansing shows the highest participation at 100% and the rest of the cities vary between roughly 10% to 20% participation. However, as mentioned, this number can be deceiving as schools can sign-up for the program and not be obligated to actively enact any of the initiatives set forth by SRTS. The performance measure concerned with population-based police coverage is useful in measuring general law enforcement within a city, but it does not accurately gauge non-motorized safety enforcement specifically. The report also recommends the enforcement measures of "number of crossing guards" and "yielding rate at midblock crossings" for future studies, as these measures, although difficult to obtain, might provide direct insight into city-wide education/enforcement performance of non-motorized modes. Ultimately, the understanding of non-motorized R-o-W by travelers as indicated by field survey results serves as the most useful and accessible measure of non-motorized education/enforcement. Accordingly, increasing non-motorized safety understanding throughout the populace is the primary education/enforcement related performance objective recommended in this report. Methods to accomplish this goal include promotion of non-motorized safety in public relation and marketing plans, signage, training of transportation officials and police officers in non-motorized safety, and increasing police presence near school zones.

The final city-wide performance measure is overall crash performance for both pedestrians and bicyclists. The results indicate that the status of crash performance depends on each other performance measure group. Crash performance is evaluated according to both crash frequency and severity based on general population as well as actual exposure. Throughout analysis of infrastructure, exposure, and education/enforcement performance, the cities of Flint and Grand Rapids displayed low performance relative to Ann Arbor and East Lansing. Accordingly, Flint and Grand Rapids display relatively worse crash performance in most of the measures under investigation in this report, including the following:

- Pedestrian Mode:
  - Number of crashes /1000 transit/walk commuters (Flint & Grand Rapids)
  - Number of crashes / 1M exposure (Flint & Grand Rapids)
  - Total KA crashes / Total crashes per year (Flint)
  - Fraction of KA crashes at night time (Flint & Grand Rapids
- Bicycle Mode:
  - Number of crashes / 1000 bike commuters (Flint & Grand Rapids)
  - Number of crashes / 1M exposure (Flint & Grand Rapids)
  - Total KA crashes / Total crashes per year (Flint)

However, East Lansing and Ann Arbor perform poorly with regard to a handful of indicators. In particular, East Lansing struggles with the fraction of K-A pedestrian crashes at intersections, the number of bicycle crashes per 100,000 population, and the proportion of K-A bicycle crashes among all bicycle crashes. Ann Arbor similarly displays poor performance with regard to the fraction of K-A pedestrian crashes at intersections.

Given these evaluations, each city has some room for improvement with regard to city-wide crash performance. In addition to setting and meeting performance objectives for each of the three other performance groups, Flint and Grand Rapids need to improve night-time safety for both pedestrians and bicyclists. Countermeasure treatment projects in these two cities should include implementation or improvement of night-time lighting throughout non-motorized facilities. In Ann Arbor and East Lansing, transportation officials should strive to enhance intersection safety for pedestrians. Also, authorities in East Lansing might want to further assess midblock safety for bicyclists. City-wide countermeasure alternatives to improve these aspects of non-motorized safety might include some of the education/enforcement strategies discussed earlier.

Corridor-Level Analysis

The corridor-level analysis covered in this report presents a more targeted approach to measuring non-motorized performance and developing focused countermeasures according to the corridor scale. Selection of corridors for performance analysis begins with narrowing down regions of high-risk within the city through both crash density maps as well as crash frequency by census-tract. Once these regions have been identified, corridors can be evaluated and ranked according to various performance measures of interest, among which this report specifically studied the following:

- Signalized Intersection Performance
  - Difference between observed and predicted crashes
  - Yearly Crashes per One Million Exposure
  - Equivalent Property Damage Only
- Mid-Block Performance
  - Difference between observed and predicted crashes per Mile
  - Equivalent Property Damage Only per mile

Upon ranking of candidate corridors according to these performance measures, the corridor(s) that display the poorest performance can be selected for countermeasure treatments. Countermeasures can be chosen through two different approaches, including HCM LOS analysis and PEDSAFE/BIKESAFE "crash-typing." In an effort to conceptualize this process more clearly, this report conducted a corridor-level analysis with respect to pedestrian safety in the City of Grand Rapids.

Within Grand Rapids, both the crash density map as well as the crash frequency by census tract map revealed that the Southeast quadrant of the intersection of I-196 and US-131 displayed the highest risk for pedestrian safety. Nine of the corridors investigated in this report fell within this region, and were ranked according to the performance measures listed above. Among these corridors, the stretch of Ottawa Avenue between Michigan Street and Lyon Street performed most poorly during the analysis period. Specifically, the Ottawa-Lyon intersection pedestrian safety performance was most concerning with regard to both crash frequency and severity. Finally, appropriate countermeasures were recommended according to the crash-typing methodology described by the FHWA. It is recommended that transportation agencies review, and if necessary, expand upon, this case example to refine the process of identifying high-risk corridors with respect to non-motorized safety and responsively develop appropriate countermeasures.

Chapter 9 Conclusion

9.1 Summary of Research

This study presented performance measures for non-motorized (pedestrian and bicyclists) traffic safety for four Michigan cities. Based on the data collected from four Michigan cities (Ann Arbor, East Lansing, Flint, and Grand Rapids), the study analyzed non-motorized safety in three levels (city level, census tract level, and corridor level). This research also concerned about non-motorized volumes as exposure measures and developed models to estimate pedestrian and bicycle volumes at signalized intersections in Chapter 4. The volume models allowed the research team estimating exposure measures where observed volumes were unavailable.

In Chapter 5, non-motorized crash frequency and severity were analyzed. The census tract-level analysis revealed that the number of access points, higher population with lower education, and higher exposure measures tended to increase non-motorized crashes. Through detailed corridor-level analyses, safety performance functions (SPF) for intersections and midblock segments were developed. The intersection SPFs showed that higher average daily traffic (ADT), more number of bars, and fewer number of lanes on minor approaches increased pedestrian crashes while the presence of right turn lanes and bus stops increased bicycle crashes. Midblock SPFs also revealed that ADT, the number of access points, and the number of bus stops were factors leading to more non-motorized crashes. The non-motorized safety performance functions not only help researcher and engineers understand what factors are associated with crashes but also identify locations with high non-motorized crash risk by comparing the estimate with the actual number of non-motorized crashes. In addition, intersection level of safety (LOS) indices for pedestrian and bicycle were developed to determine the level of safety by integrating both the number of crashes and the level of non-motorized volume.

Realizing that cultural and educational factors play a large role on non-motorized safety, a field survey was conducted. In Chapter 6, the survey and analysis results were discussed. The survey intercepted motorized as well as non-motorized travelers from locations throughout the cities in an effort to comprehensively sample a representative population. Survey responses were analyzed using statistical analysis to determine the impact of various characteristics (location, gender, age, etc.) on traffic safety understanding. The results show that these characteristics often significantly affect certain aspects of non-motorized safety understanding.

In Chapter 7, before-and-after studies were performed to evaluate the performance of previous non-motorized safety countermeasures at the corridor-level. A set of comparison corridor groups was chosen throughout all four cities to identify the expected trend of crash frequency without treatment implementation. The improvement types included shared bicycle lane markings, bicycle lanes, sidewalk improvements and others. Although the result cannot be generalized, non-motorized crashes were shown to increase after implementation of shared lane markings perhaps because of drivers' distraction and lack of understanding of shared lane markings. Installation of shared lane markings should be accompanied by education campaigns as the cultural and educational awareness of mutual bicyclist presence is not naturally inherent to these installations. In the before-and-after studies, importance of non-motorized volume data for both before and after periods was identified. Bicycle volume data were essential when analyzing impacts of bicycle lanes. It is because bike lanes increase bicycle volume and the increased volume could also lead to more crashes although bike lanes enhance bicycle safety. This issue could be alleviated in future studies by ensuring that before and after non-motorized volume data is collected and considered in conjunction with the before and after crash data to more gauge the change in exposure-based crash frequency and severity.

In Chapter 8, performance measures in two stages (city-wide analysis and corridor-level analysis) were addressed. City-wide performance measures gauge non-motorized safety on a large-scale, and include infrastructure performance, exposure performance, education/enforcement performance, and crash performance. These performances are depicted via radar graphs which rate each city on a scale from 0 to 100 based on both pedestrian and bicycle performance. The graph visualizes the category needing more improvement. The corridor-level performance measures developed by the research team evaluate non-motorized crash frequency and severity at intersections as well as mid-blocks. In a case study, corridors were ranked according to these measures, and the corridor which performed most poorly was selected for countermeasure treatment. Countermeasures were identified based on crash-typing.

9.2 Conclusions and Recommendations

This research covered various issues in non-motorized safety as described in Section 9.1. Research agenda dealt in this research can be summarized into following seven categories.

1. Non-motorized volume modeling
2. Non-motorized data processing and visualization
3. Non-motorized safety performance functions
4. Non-motorized intersection level of safety
5. Cultural and educational factors in non-motorized safety
6. Before-and-after studies on improvement projects
7. Non-motorized performance measures

Each of these topics can be an independent research project. Even though each topic was dealt as detailed as possible in this project, it was difficult to deliver final outputs for all topics. Hence, this research should be viewed as an initiative research to discover current research agendas in non-motorized safety in Michigan. It is recommended to conduct focused independent research in each of these topics. Followings are specific recommendations for non-motorized safety and mobility.

1) Non-motorized volume models were developed in this research. The model is applicable to similar cities as four study cities. However, the models were based on limited observed volume data. In order to develop more precise models, it is recommended to conduct a comprehensive study with more non-motorized data. It is also proposed to develop a non-motorized data collection policy and an inventory program to manage collected data. As pointed out many times, the lack of non-motorized volume data was one of key difficulties in determining impacts of non-motorized improvements. Even though there are high needs for collecting non-motorized volumes, there are still technological challenges and cost-effectiveness concerns.
2) Non-motorized safety performance functions were developed for intersection safety as well as midblock segments. The models are capable of predicting the number of crashes. However, its transferability is limited to those areas with similar size and

characteristics as the study cities. Further studies are needed to enhance accuracy and transferability. It is also recommended to develop models that can handle non-motorized volume and non-motorized safety simultaneously.

3) Non-motorized level of safety index has been developed in this study. The index was developed by integrating both non-motorized volume and crashes. However, this approach does not involve pedestrians and bicyclists' perception on the safety. Future research has to incorporate user perception on the safety as well as other measures in order to determine the level of safety for pedestrians and bicyclists.
4) To study cultural and educational factors influencing non-motorized safety, a survey was conducted and the results were analyzed in this study. However, the survey was lacking in reflecting behavioral aspects. A corresponding behavioral data should be collected and compared with the survey result. An example is yielding behavior that was recommended as a way of determining educational performance in Chapter 8. Understanding current educational and cultural factors will guide what to be done to enhance non-motorized safety.
5) The research team has identified that the number of access points are one of the main contributors for non-motorized crashes. Therefore, there is a need for investigating problems associated with access points and developing a guideline to manage access points.
6) Shared lane markings have become popular in Michigan, but their effectiveness depends on drivers' awareness and understanding. The research team observed a lack of awareness and understanding of shared lane markings by drivers. Therefore, it is imperative to develop an educational program to enhance effectiveness of shared lane markings. Installation of shared lane markings coupled with educational program is expected to enhance bicycle safety and mobility.
7) Paradigm is now shifting from vehicle-centric transportation to people-centric. One of the most important elements in this context is providing walkable and bikeable environment to encourage walking and bicycling. As its first step, there is a need for developing a diagnostic tool to analyze walkability and bikeability. The measures of walkability and bikeability are keywords for non-motorized safety and mobility.

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Appendix

Appendix 1: Locations of Analysis Corridors (51 corridors)

No.	Street Name	City	Length (mile)	1st Intersection	2nd Intersection
1	University	Ann-Arbor	0.52	Washtenaw_University	State_University
2	N-Huron	Ann-Arbor	1.37	Huron_Fuller	Huron_Plymouth
3	Hill	Ann-Arbor	0.75	Washtenaw_Hill	State_Hill
4	S-Huron	Ann-Arbor	0.70	Huron_Washtenaw	Platt_Packard
5	7th	Ann-Arbor	0.15	7th_Stadium	7th_Pauline
6	Packard	Ann-Arbor	1.24	Packard_Eisenhower	Packard_Stadium
7	Plymouth	Ann-Arbor	1.59	Nixon_Plymouth	Barton_Plymouth
8	Maiden	Ann-Arbor	0.36	Maiden_Fuller	Moore_Plymouth
9	1st	Ann-Arbor	0.03	1st_Liberty	1st_Huron
10	Miller	Ann-Arbor	0.63	Main_Miller	7th_Miller
11	5th	Ann-Arbor	0.23	5th_Huron	5th_Packard
12	Stadium	Ann-Arbor	0.25	Stadium_Liberty	Maple_Stadium
13	Geddes	Ann-Arbor	0.39	Washtenaw_Geddes	State_University
14	Farm	East-Lansing	0.14	Farm_Shaw	Farm_Trowbridge
15	Saginaw	East-Lansing	0.58	Abbot_Saginaw	Harrison_Saginaw
16	W-Lake_Lansing	East-Lansing	0.59	Harrison_Lake-Lansing	Coolidge_Lake-Lansing
17	Michigan	East-Lansing	0.45	Grand-River_Michigan	Harrison_Michigan
18	N-Hagadorn	East-Lansing	0.22	Hagadorn_Burcham	Hagadorn_Haslett
19	Grand-River	East-Lansing	0.56	Grand-River_Hagadorn	Grand-River_Bogue
20	S-Harrison	East-Lansing	0.38	Harrison_Trowbridge	Harrison_Kalamazoo
21	Saginaw	Flint	0.10	Saginaw_Court	Saginaw_2nd
22	Fenton	Flint	0.31	Fenton_Hemphill	Fenton_Atherton
23	S-Saginaw	Flint	0.89	Saginaw_Atherton	Saginaw_12th
24	Dort	Flint	0.97	Dort_Atherton	Dort_Lapeer
25	N-Saginaw	Flint	0.67	Saginaw_Pierson	Saginaw_Carperter
26	Pierson	Flint	0.50	MLK_Pierson	Dupont_Pierson
27	Clio	Flint	0.66	Clio_Pierson	Clio_Pasadena
28	Franklin	Flint	0.38	Franklin_Leith	Dort_Franklin
29	Detroit	Flint	0.45	Detroit_Hamilton	Detroit_Pasadena
30	Mason	Flint	0.20	Mason_Welch	Mason_Hamilton
31	Davison	Flint	0.56	Averill_Davison	Dort_Davison
32	University	Flint	0.33	Grand-Traverse_Univ.	Stevenson_Univ.
33	Lake	Grand-Rapids	0.48	Lake_Wealthy	Fuller_Lake
34	N-Division	Grand-Rapids	0.05	Division_Fulton	Division_Fountain
35	Fulton	Grand-Rapids	0.38	College_Fulton	Jefferson_Fulton
36	Cherry	Grand-Rapids	0.26	Lake_Cherry	Eastern_Cherry

37	Franklin	Grand-Rapids	0.45	Madison_Franklin	Division_Franklin
38	Grandville	Grand-Rapids	0.31	Grandville_Hall	Clyde-Park_Grandville
39	Hall	Grand-Rapids	0.21	Division_Hall	Buchanan_Hall
40	Madison	Grand-Rapids	0.64	Madison_Button	Madison_Hall
41	S-Division	Grand-Rapids	0.30	Division_Alger	Division_Button
42	N-Kalamazoo	Grand-Rapids	0.30	Kalamazoo_Alger	Kalamazoo_Button
43	Plainfield	Grand-Rapids	0.70	Plainfield_Ann	Leonard_Plainfield
44	S-Kalamazoo	Grand-Rapids	0.28	Kalamazoo_32nd	Kalamazoo_28th
45	W-Leonard	Grand-Rapids	0.73	Monroe_Leonard	Seward_Leonard
46	Division	Grand-Rapids	0.12	Division_Wealthy	Division_Cherry
47	E-Leonard	Grand-Rapids	0.89	Plymouth_Leonard	Fuller_Leonard
48	Ottawa	Grand-Rapids	0.09	Ottawa_Lyon	Ottawa_Michigan
49	Michigan	Grand-Rapids	1.06	Fuller_Michigan	College_Michigan
50	Pearl	Grand-Rapids	0.60	Monroe_Pearl	Lake-Michigan_Seward
51	Fulton	Grand-Rapids	1.24	Lexington_Fulton	Lake-Michigan_Fulton

Appendix 2: Data Processed at Census Tract Level (168 observations)

Definition		Min	Max	Median	Mean	Standard Deviation
Total population in the quarter mile buffer		0	7,329	2,744	2,700	1,728
Number of households in the quarter mile buffer		0	3,140	1254	1,177	783
African American population in the quarter mile buffer		0	3,479	361	651	801
Hispanic population in the quarter mile buffer		0	3,146	105	236	446
Total white population in the quarter mile buffer		0	5,974	1,583	1,676	1,439
Children 14 and below in the quarter mile buffer		0	1,341	417	442	360
Age 15 to 19 in the quarter mile buffer		0	4,826	193	280	531
Age 20 to 59 in the quarter mile buffer		0	4,973	1,561	1,532	1,024
Age 60 and older in the quarter mile buffer		0	1,860	337	384	362
Median age of both sex		16	60	34	33	8
Median age of males		16	60	31	32	7
Median age of females		13	60	34	34	8
Households with one or more people 60 years and over		0	1,363	258	282	251
Households with no people 60 years and over		0	2,149	774	758	531
Total male population		0	3,451	1,355	1,314	846
Total female population		0	4,035	1,390	1,386	893
Proportion of housing units that are vacant		0	545	110	138	125
Households owner occupied		0	2,123	498	558	501
Household renter occupied		0	1,757	426	482	405
Family households		0	1,762	583	539	413
Nonfamily households		0	2,099	449	501	424
Means of Transportation to Work	Car, truck, or van "motorized commuters"	0	2,904	890	963	780
	Drove alone	0	2701	722	773	650
	Carpooled	0	1,891	105	260	402
	Public transportation excluding taxicab	0	456	29	59	79
	Bus or trolley bus	0	456	29	59	79
	Bicycle	0	222	0	22	41
	Walked	0	1,741	19	100	228
	Other means	0	94	0	5	12
	Work at home	0	493	29	51	69
Means of	No vehicle available	0	403	22	50	67

Transportation to Work by Vehicle Available	1 vehicle available	0	1,232	315	314	244
	2 vehicles available	0	1,977	397	446	402
	3 or more vehicles available	0	1,628	155	218	249
Income in the past 12 months below poverty level		0	4,392	536	659	670
Income in the past 12 months above the poverty level		0	5,845	1,646	1,729	1,377
Average percentage income in past 12 months below poverty level		0	1	0	0	0
Household Low Income in the Past 12 Months	Less than $10,000	0	627	113	140	134
	$10,000 to $14,999	0	396	66	77	72
	$15,000 to $19,9999	0	343	59	68	67
Number of house hold units		0	3,140	883	856	817
Employment Status for the Population 16 Years and Over	Employed	0	3,132	1,064	1,085	816
	Unemployed	0	500	111	145	130
	Not in labor force	0	5,528	743	803	707
Educational Attainment for 18 years and Older	No high school diploma or GED	0	1,600	156	258	310
	High school diploma or GED	0	1,933	375	467	414
	Some college or associate's degree	0	5,979	561	747	864
	Bachelor's degree	0	1,554	219	337	354
	Graduate degree or higher	0	1878	70	249	367
Median household income in the past 12 months		0	130,257	28,177	29,377	23,488
Student Enrollment Status	8th grade and lower	0	1,208	314	327	285
	9th to 12th grade	0	1,187	125	172	196
	College or professional school	0	8,452	191	411	982
	Not enrolled	0	4,752	1453	1,454	1,202
1- unit structure		0	2,127	599	629	564
2-unit structure		0	2,081	167	293	367
Mobile homes		0	936	0	37	143
Crime number		0	529	54	105	122
Crime rate		0	244	19	36	46
Total Road length		0	50,791	16,899	16,424	11,335
Total local road length		0	36,670	10,854	10,576	8,099
Total collectors road length		0	6,359	816	1,232	1,424
Total minor arterials road length		0	11,465	1,517	2,042	2,088
Total principal road length		0	8,963	930	1,393	1,605

Total freeway road length		0	4,407	0	272	810
Total interstate road length		0	12,079	0	987	2,035
Total bike lane length		0	23,296	0	1,563	3,353
Total bike lane length in principal arterials		0	5,801	0	287	884
Total bike lane length in minor arterials		0	5,223	0	449	926
Total bike lane length in collectors		0	6,890	0	305	899
Total bike lane length in local roads		0	6,108	0	522	996
Number of churches		0	12	2	3	3
Number of libraries		0	14	0	0	1
Number of terminals		0	2	0	0	0
Number of museums		0	8	0	0	1
Number of hospital and clinics		0	9	0	1	1
Number of governmental offices		0	93	0	2	10
Length of sidewalks in principal arterials		0	8,963	878	1,285	1,506
Length of sidewalks in minor arterials		0	10,836	1,328	1,820	1,956
Number of signalized crossings		0	66	3	5	7
Number of midblock crossings of major roads		0	19	1	3	4
Number of midblock crossings of minor roads		0	155	1	3	13
Number of access points		0	94	23	26	22
Number of signalized intersections		0	55	3	5	6
Total number of pedestrian volumes in signalized intersections		0	384,114	934	5,862	31,684
Total number of bike volumes in signalized intersections		0	33,002	361	1,368	3,826
Pedestrian Crash	Total number of crashes from 2008-2012	0	78	4	7	10
	Number of crashes on weekends from 2008-2012	0	14	1	1	2
	Number of crashes on work days from 2008-2012	0	64	3	5	8
	Number of day time crashes from 2008-2012	0	56	2	4	6
	Number of night time crashes from 2008-2012	0	27	1	3	4
	Total KA crashes (2008-2012)	0	11	1	1	2
	Total KA injuries (2008-2012)	0	12	1	1	2
	Total KAB crashes (2008-2012)	0	28	2	3	4
	Total KAB injuries (2008-2012)	0	29	2	3	4
	Number of fatalities from 2008-2012	0	3	0	0	1
	Number of incapacitating injuries from	0	12	0	1	1

	2008-2012					
	Number of non-incapacitating injuries from 2008-2012	0	24	1	2	3
	Number of C= possibly injuries from 2008-2012	0	53	2	3	6
	Number of property damages only crashes from 2008-2012	0	11	0	1	1
	Number of crashes in dark situations from 2008-2012	0	5	0	0	1
	Number of crashes in non dark situations” day-light, dark but lighted, dawn, dusk" from 2008-2012	0	77	4	6	10
	Number of crashes which signal was at the site of the crash	0	47	1	2	5
	Number of crashes which stop sign was at the site of the crash	0	14	0	1	2
	Number of crashes which yield sign was at the site of the crash	0	3	0	0	0
	Number of crashes which there is no sign nor signal at the site of the crash	0	19	2	3	4
	Number of crashes that happened on the road. from 2008-2012	0	74	4	6	9
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	3	0	0	1
	Number of crashes that happened on dry and clear roads from 2008-2012	0	60	3	5	7
	Number of crashes that happened on non dry and non clear roads “wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	20	1	2	3
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	4	0	0	1
	Number of crashes which happened on roads with less than 45 mi/h speed limit	0	77	4	6	10
	Number of crashes involving alcohol	0	9	0	1	2
	Number of crashes involving drugs	0	2	0	0	0
	Number of crashes with fatal injuries as the greatest injury severity	0	3	0	0	0
	Number of crashes with incapacitating injuries as the greatest injury severity	0	11	0	1	1
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	23	1	2	3
	Number of crashes with possible injury	0	47	2	3	5

	as the greatest injury severity					
	Number of crashes with property damage only loss as the greatest injury severity	0	11	0	1	1
Bike Crash	Total number of crashes from 2008-2012	0	87	3	7	11
	Number of crashes on weekends from 2008-2012	0	12	0	1	2
	Number of crashes on work days from 2008-2012	0	83	3	6	9
	Number of day time crashes from 2008-2012	0	77	2	5	9
	Number of night time crashes times from 2008-2012	0	13	1	2	3
	Total KA crashes (2008-2012)	0	5	0	0	1
	Total KA injuries (2008-2012)	0	5	0	0	1
	Total KAB crashes (2008-2012)	0	35	1	3	4
	Total KAB injuries (2008-2012)	0	36	1	3	4
	Number of fatalities from 2008-2012	0	2	0	0	0
	Number of incapacitating injuries from 2008-2012	0	5	0	0	1
	Number of non-incapacitating injuries from 2008-2012	0	31	1	2	4
	Number of C=possibly injuries from 2008-2012	0	34	1	3	5
	Number of property damages only crashes from 2008-2012	0	18	0	1	2
	Number of crashes in dark situations from 2008-2012	0	2	0	0	0
	Number of crashes in non dark situations" day-light, dark but lighted, dawn, dusk" from 2008-2012	0	86	3	7	11
	Number of crashes which signal was at the site of the crash	0	47	1	3	6
	Number of crashes which stop sign was at the site of the crash	0	14	1	2	2
	Number of crashes which yield sign was at the site of the crash	0	3	0	0	0
	Number of crashes which there is no sign nor signal at the site of the crash	0	25	1	2	3
	Number of crashes that happened on the road from 2008-2012	0	83	3	6	10
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	5	0	0	1

	Number of crashes that happened on dry and clear roads from 2008-2012	0	69	3	6	9
	Number of crashes that happened on non dry and non clear roads "wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	18	0	1	2
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	1	0	0	0
	Number of crashes which happened on roads with less than 45 mi/h speed limit	0	85	3	7	11
	Number of crashes involving alcohol	0	8	0	0	1
	Number of crashes involving drugs	0	1	0	0	0
	Number of crashes with fatal injuries as the greatest injury severity	0	2	0	0	0
	Number of crashes with incapacitating injuries as the greatest injury severity	0	5	0	0	1
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	30	1	2	4
	Number of crashes with possible injury as the greatest injury severity	0	34	1	3	5
	Number of crashes with property damage only	0	18	0	1	2

Appendix 3: Variables Used for Intersection Crash Analysis (102 observations)

	Definition	Min	Max	Median	Mean	Standard Deviation
	A dummy variable for existence of bus stops in 250 feet around the intersections	0	1	1	0.7	0.46
	A dummy variable for existence of bus stops in 0.1 mile around the intersections	0	1	1	0.8	0.37
	A dummy variable for existence of bus stops in 0.25 mile around the intersections	0	1	1	1.0	0.17
	Final pedestrian volume	59	40,718	355	1,725.0	5,505.32
	Final bicycle volume	27	5,066	196	339.2	606.69
	ADT of the corridor	2,469	47,024	16,752	18,582.1	8,660.36
	ADT of the road which intersects within the corridor	392	49,237	13,927	15,122.2	10,020.58
	Total ADT	2861	96,261	32,028	33,704.3	15,269.17
Half Mile Buffer	Area (feet^20) of business land use type	0	11,000,000	1,850,000	2,470,505.7	2,436,280.01
	Area (feet^20) of mixed land use type	0	2,000,000	0	136,780.8	349,684.02
	Area (feet^20) of other land use type	0	6,400,000	1,650,000	2,048,704.7	1,782,300.09
	Area (feet^20) of undeveloped land use type	0	11,000,000	1,100,000	1,669,025.8	1,998,973.22
	Area (feet^20) of residential land use type	339,292	17,000,000	8,250,000	8,665,091.1	4,057,674.72
	Area (feet^20) of industrial land use type	0	8,500,000	280,046	1173556.2	2,068,020.69
	Area (feet^20) of campus land use type	0	17,000,000	0	1,325,837.0	2,720,520.05
	Dummy variable for business land use as the dominant land use	0	1	0	0.1	0.34
	Dummy variable for mix land use as the dominant land use	0	0	0	0.0	0.00
	Dummy variable for other land use as the dominant land use	0	1	0	0.0	0.17
	Dummy variable for undeveloped land use as the dominant land use	0	1	0	0.0	0.14
	Dummy variable for residential land use as the dominant land use	0	1	1	0.7	0.44
	Dummy variable for industrial land use as the dominant land use	0	1	0	0.0	0.22
	Dummy variable for campus land use as the dominant land use	0	1	0	0.0	0.20
	Number of households in the quarter mile buffer	0	4,474	1,700	1,886.4	989.11
	Total population in the quarter mile buffer	688	14,760	3,624	4,572.6	2,944.61
	African american population in the	15.1	5,174	235	475.8	724.16

	quarter mile buffer						
	Hispanic population in the quarter mile buffer		30	7,348	1,298	1,737.9	1,720.57
	Total white population in the quarter mile buffer		0	11,363	779	1,721.2	2,552.77
	Children 14 and below in the quarter mile buffer		40	4,002	269	427.9	614.64
	Age 15 to 19 in the quarter mile buffer		43	6,921	1,859	2,060.5	1,444.89
	Age 20 to 59 in the quarter mile buffer		0	9,540	492	1,340.9	2,095.32
	Age 60 and older in the quarter mile buffer		20	774	34	136.2	206.32
	Median Age	Both sexes	20	46	31	30.6	5.58
		Male	20	47	32	31.3	5.85
		Female	21	596	246	245.4	173.24
	Households with one or more people 60 years and over		0	3,240	802	922.0	648.84
	Households with no people 60 years and over		293	4,786	1,744	1,970.1	1,007.24
	Total male population		345	7,440	1,856	2,280.4	1,485.18
	Total female population		0	7,320	321	1,018.6	1,706.30
	Proportion of housing units that are vacant		0	1,326	395	457.5	338.82
	Households owner occupied		0	4,020	796	1,090.9	897.66
	Household renter occupied		0	1,770	581	629.0	339.68
	Family households		0	1,061	271	318.8	203.32
	Family households 2-person		0	524	161	186.1	109.19
	Family households 3-person		0	395	112	119.3	74.17
	Family households 4-person		0	328	65	72.9	57.17
	Family households 5-person		0	188	26	32.9	30.75
	Family households 6-person		0	210	12	25.4	33.72
	Family households 7-person		0	2,900	445	588.1	624.24
	Nonfamily households		0	4,000	484	859.2	910.37
	Nonfamily households 1-person		0	2,165	190	381.1	522.05
	Nonfamily households 2-person		0	996	37	133.6	219.93
	Nonfamily households 3-person		0	396	17	57.6	91.24
	Nonfamily households 4-person		0	313	4	30.3	64.55
	Nonfamily households 5-person		0	199	1	13.8	34.42
	Nonfamily households 6-person		0	207	1	13.5	35.82
	Nonfamily households 7-person		0	173	0	9.9	30.64
	Means of Transportation to Work	Car, truck, or van "motorized commuters"	22	4,419	1,007	1,346.3	958.71

		Drove alone	1	1,594	147	385.6	448.50
		Carpooled	5	1,436	100	302.3	410.61
		Public transportation excluding taxicab	5	381	93	107.2	82.31
		Bus or trolley bus	0	380	37	74.7	92.82
		Bicycle	0	1,443	62	170.3	269.36
		Walked	0	2,381	8	225.3	537.25
		Other means	0	215	27	50.5	53.25
		Work at home	0	344	90	110.0	79.11
	Means of Transportation to Work by Vehicle Available	No vehicle available	0	1,191	340	371.1	235.53
		1 vehicle available	0	1,530	545	562.2	303.55
		2 vehicles available	0	1,037	355	382.4	272.20
		3 or more vehicles available	2	2,354	927	982.5	536.01
	Household Low Income in the Past 12 Months	Less than $10,000	0	813	112	189.8	186.65
		$10,000 to $14,999	1	398	91	116.0	81.58
		$15,000 to $19,9999	0	3,667	1,179	1,199.9	861.26
	Employment Status for the Population 16 Years and Over	Employed	159	3,719	1523	1,653.6	841.83
		Unemployed	19	576	221	243.7	141.83
		Not in labor force	351	5,658	999	1,372.0	1,083.62
	Educational Attainment for 18 years and Older	No high school diploma or GED	0	1,656	328	367.7	316.21
		High school diploma or GED	62	1,600	663	681.8	341.64
		Some college or associate's degree	202	7,673	822	1,557.8	1,776.97
		Bachelor's degree	3	1,666	452	533.4	429.40
		Graduate degree or higher	3	1,303	240	340.7	323.75
	Student Enrollment Status	8th grade and lower	0	240,000,000	950,353	59,989,365.3	69,969,071.49

		9th to 12th grade	1	895	174	222.9	189.09
		College or professional school	0	10,186	287	1,160.9	2,315.13
		Not enrolled	0	4,369	1,973	1,836.2	997.94
	Income in the past 12 months below poverty level		0	5,237	1,892	1,954.3	1,140.31
	Income in the past 12 months above the poverty level		0	3,649	0	664.4	1,197.55
	Average percentage income in past 12 months below poverty level		0	698	170	186.6	172.81
	Median household income in the past 12 months		0	86,964	28,957	31,595.6	14,991.66
	1- unit structure		0	1,444	710	703.5	410.94
	2-unit structure		0	2,387	368	639.1	672.78
	Mobile homes		0	819	4	64.3	172.02
	Weighted crime rate based on the population		3	165	43	54.8	45.14
	Number of crimes		0	650	183	225.1	187.72
	Number of libraries		0	17	0	2.0	3.75
	A dummy variable for presence of library		0	1	0	0.4	0.50
	A dummy variable for presence of bike lane		0	1	1	0.6	0.48
	Number of liquor stores		0	10	1	1.8	2.37
	A dummy variable for presence of park		0	1	1	0.8	0.43
	Number of bars		0	48	2	7.7	13.77
	Number of retail stores		0	115	10	18.8	24.87
	Number of schools		0	4	1	1.0	0.98
Quarter Mile Buffer	Area (feet^20) of business land use type		0	4,600,000	667,251	935,427.2	1,025,700.64
	Area (feet^20) of mixed land use type		0	648,789	0	49,117.2	135,577.11
	Area (feet^20) of other land use type		0	2,700,000	301,892	469,258.7	552,552.71
	Area (feet^20) of undeveloped land use tyep		0	3,100,000	47,016	335,368.3	596,133.30
	Area (feet^20) of residential land use type		0	4,700,000	2,050,000	2,005,362.8	1,294,986.00
	Area (feet^20) of industrial land use type		0	3,500,000	0	283,676.8	649,431.66
	Area (feet^20) of campus land use type		0	4,700,000	0	330,770.0	812,884.87
	Dummy variable for business land use as the dominant land use		0	1	0	0.2	0.37
	Dummy variable for mix land use as the dominant land use		0	0	0	0.0	0.00

	Dummy variable for other land use as the dominant land use		0	1	0	0.0	0.17
	Dummy variable for undeveloped land use as the dominant land use		0	1	0	0.0	0.20
	Dummy variable for residential land use as the dominant land use		0	1	1	0.6	0.49
	Dummy variable for industrial land use as the dominant land use		0	1	0	0.1	0.24
	Dummy variable for campus land use as the dominant land use		0	1	0	0.1	0.27
	Number of households in the quarter mile buffer		0	1,297	451	483.0	313.09
	Total population in the quarter mile buffer		0	5,566	952	1,193.8	1,005.61
	African american population in the quarter mile buffer		0	1,260	132	236.2	277.78
	Hispanic population in the quarter mile buffer		0	1,698	49	128.3	256.68
	Total white population in the quarter mile buffer		0	4,303	539	755.3	815.99
	Children 14 and below in the quarter mile buffer		0	731	94	131.5	137.36
	Age 15 to 19 in the quarter mile buffer		0	1,896	60	190.5	374.11
	Age 20 to 59 in the quarter mile buffer		0	3,441	564	723.8	622.93
	Age 60 and older in the quarter mile buffer		0	254	89	99.4	63.65
	Median Age	Both sexes	0	53	32	31.4	7.53
		Male	0	50	30	30.9	7.22
		Female	0	55	33	31.9	8.08
	Households with one or more people 60 years and over		0	233	67	78.2	52.89
	Households with no people 60 years and over		0	1,164	281	346.5	269.92
	Total male population		0	2,967	483	608.3	517.00
	Total female population		0	2,599	469	585.5	494.77
	Proportion of housing units that are vacant		0	189	42	58.3	46.53
	Households owner occupied		0	1,163	144	205.8	238.97
	Household renter occupied		0	998	153	218.9	208.66
	Family households		0	494	123	149.5	102.61
	Family households 2-person		0	178	56	61.0	35.95
	Family households 3-person		0	112	30	34.5	24.07
	Family households 4-person		0	104	20	26.4	23.62
	Family households 5-person		0	96	8	14.0	16.05
	Family households 6-person		0	57	3	7.2	10.65
	Family households 7-person		0	67	2	6.3	11.54

	Nonfamily households		0	1,122	163	275.2	280.75
	Nonfamily households 1-person		0	855	117	176.6	179.62
	Nonfamily households 2-person		0	326	29	56.9	67.10
	Nonfamily households 3-person		0	139	6	16.7	26.62
	Nonfamily households 4-person		0	225	2	13.6	31.32
	Nonfamily households 5-person		0	73	1	5.1	11.77
	Nonfamily households 6-person		0	72	0	3.4	10.89
	Nonfamily households 7-person		0	59	0	3.0	9.49
	Means of Transportation to Work	Car, truck, or ban "motorized commuters"	1	1,192	276	367.8	252.76
		Drove alone	1	796	232	251.5	141.79
		Carpooled	0	392	38	88.0	98.61
		Public transportation excluding taxicab	0	105	21	27.8	23.34
		Bus or trolley bus	0	105	21	27.6	23.16
		Bicycle	0	149	6	15.5	24.06
		Walked	0	680	22	95.6	158.07
		Other means	0	12	1	1.8	2.10
		Work at home	0	105	15	24.1	24.14
	Means of Transpiration to Work by Vehicle Available	No vehicle available	0	192	22	32.5	33.28
		1 vehicle available	0	354	107	124.1	67.75
		2 vehicles available	0	427	133	141.0	83.83
		3 or more vehicles available	0	567	61	88.4	94.61
	Household Low Income in the Past 12 Months	Less than $10,000	0	257	54	75.2	61.47
		$10,000 to $14,999	0	130	27	36.5	28.73
		$15,000 to $19,9999	0	146	23	27.6	23.56
	Employment Status for the Population 16 Years and Over	Employed	7	1,095	366	423.0	242.06
		Unemployed	1	167	54	62.5	39.29
		Not in labor force	12	1,602	256	368.3	344.99
	Educational Attainment for 18 years and Older	No high school diploma or GED	0	431	82	92.9	82.08

		High school diploma or GED	1	771	169	180.3	117.72
		Some college or associate's degree	27	2,282	191	424.2	574.58
		Bachelor's degree	0	512	108	134.2	114.12
		Graduate degree or higher	0	372	61	84.4	82.30
	Student Enrollment Status	8th grade and lower	0	348	91	95.0	63.83
		9th to 12th grade	0	280	41	55.8	54.29
		College or professional school	0	2,928	80	308.0	654.55
		Not enrolled	0	1,229	497	464.8	268.90
	Median household income in the past 12 months		0	87,673	27,928	30,536.2	15,562.23
	Income in the past 12 months below poverty level		0	1,577	277	330.7	276.55
	Income in the past 12 months above the poverty level		0	1,317	492	549.2	260.34
	Average percentage income in past 12 months below poverty level		0	1	0	0.3	0.16
	1- unit structure		0	386	182	173.9	110.05
	2-unit structure		0	798	87	170.0	189.66
	Mobile homes		0	206	1	16.7	44.91
	Weighted crime rate based on the population		3	244	44	60.8	55.89
	Number of crimes		0	331	50	72.8	73.71
	Number of libraries		0	9	0	0.8	1.71
	A dummy variable for presence of library		0	1	0	0.2	0.43
	A dummy variable for presence of bike lane		0	1	1	0.5	0.50
	Number of liqour stores		0	4	0	0.7	1.01
	A dummy variable for presence of park		0	1	0	0.4	0.49
	Number of bars		0	31	0	3.0	6.66
	Number of retail stores		0	81	4	8.2	12.46
	Number of schools		0	2	0	0.3	0.48
Tenth Mile	Area (feet^20) of business land use type		0	871,381	183,857	246,108.0	232,243.78
	Area (feet^20) of mixed land use type		0	173,166	0	9,838.2	30,472.00

	Area (feet^20) of other land use type		0	535,845	20,377	80,073.8	117,399.01
	Area (feet^20) of undeveloped land use type		0	467,433	0	43,768.9	110,033.30
	Area (feet^20) of residential land use type		0	871,386	246,195	243,566.4	208,691.78
	Area (feet^20) of industrial land use type		0	789,580	0	36,997.6	121,093.25
	Area (feet^20) of campus land use type		0	841,132	0	46,192.7	140,598.01
	Dummy variable for business land use as the dominant land use		0	1	0	0.4	0.49
	Dummy variable for mix land use as the dominant land use		0	0	0	0.0	0.00
	Dummy variable for other land use as the dominant land use		0	1	0	0.1	0.27
	Dummy variable for undeveloped land use as the dominant land use		0	1	0	0.0	0.20
	Dummy variable for residential land use as the dominant land use		0	1	0	0.4	0.49
	Dummy variable for industrial land use as the dominant land use		0	1	0	0.0	0.22
	Dummy variable for campus land use as the dominant land use		0	1	0	0.1	0.24
	Number of households in the quarter mile buffer		0	309	62	72.0	66.85
	Total population in the quarter mile buffer		0	1331	133	173.5	194.71
	African american population in the quarter mile buffer		0	197	14	32.4	43.64
	Hispanic population in the quarter mile buffer		0	308	6	19.1	44.50
	Total white population in the quarter mile buffer		0	963	71	109.5	147.14
	Children 14 and below in the quarter mile buffer		0	121	10	17.2	20.71
	Age 15 to 19 in the quarter mile buffer		0	755	6	25.5	80.93
	Age 20 to 59 in the quarter mile buffer		0	679	74	109.1	121.50
	Age 60 and older in the quarter mile buffer		0	104	11	13.8	14.14
	Median Age	Both sexes	0	71	32	31.9	10.59
		Male	0	69	31	31.2	10.29
		Female	0	72	32	31.9	11.55
	Households with one or more people 60 years and over		0	94	8	10.8	12.30
	Households with no people 60 years and over		0	296	35	52.1	58.29
	Total male population		0	705	69	90.0	104.07
	Total female population		0	626	65	83.5	92.72

	Proportion of housing units that are vacant		0	52	5	9.1	9.35
	Households owner occupied		0	297	17	31.0	52.40
	Household renter occupied		0	199	20	32.0	37.93
	Family households		0	76	15	20.2	16.27
	Family households 2-person		0	35	8	8.6	7.01
	Family households 3-person		0	18	3	4.5	4.03
	Family households 4-person		0	18	2	3.3	3.66
	Family households 5-person		0	14	1	1.9	2.58
	Family households 6-person		0	9	0	0.9	1.50
	Family households 7-person		0	13	0	0.9	1.89
	Nonfamily households		0	285	20	42.7	58.74
	Nonfamily households 1-person		0	190	16	27.6	36.43
	Nonfamily households 2-person		0	83	4	8.8	14.43
	Nonfamily households 3-person		0	43	1	2.5	5.85
	Nonfamily households 4-person		0	45	0	2.0	5.92
	Nonfamily households 5-person		0	16	0	0.8	2.42
	Nonfamily households 6-person		0	18	0	0.6	2.42
	Nonfamily households 7-person		0	12	0	0.3	1.62
	Means of Transportation to Work	Car, truck, or van "motorized commuters"	0	240	45	59.3	42.11
		Drove alone	0	128	37	40.7	24.15
		Carpooled	0	65	6	14.1	16.07
		Public transportation excluding taxicab	0	22	3	4.5	4.19
		Bus or trolley bus	0	22	3	4.5	4.16
		Bicycle	0	39	1	2.6	5.18
		Walked	0	144	3	15.8	28.13
		Other means	0	2	0	0.3	0.36
		Work at home	0	23	2	4.0	4.52
	Means of Transportation to Work by Vehicle Available	No vehicle available	0	31	3	5.5	6.24
		1 Vehicle Available	0	57	17	20.1	11.34
		2 vehicles available	0	68	21	22.5	14.07
		3 or more vehicles available	0	134	9	14.3	18.58
	Household Low	Less than	0	52	8	12.7	11.61

	Income in the Past 12 Months	$10,000					
		$10,000 to $14,999	0	22	4	6.1	5.22
		$15,000 to $19,9999	0	24	4	4.6	4.18
	Employment Status for the Population 16 Years and Over	Employed	1	213	58	68.6	42.70
		Unemployed	0	28	9	10.2	6.79
		Not in labor force	2	317	41	61.6	65.10
	Educational Attainment for 18 years and Older	No high school diploma or GED	0	76	15	15.2	13.66
		High school diploma or GED	0	149	27	29.7	23.31
		Some college or associate's degree	4	543	30	72.1	109.16
		Bachelor's degree	0	106	16	21.6	19.85
		Graduate degree or higher	0	59	9	13.0	12.87
	Student Enrollment Status	9th to 12th grade	0	51	7	9.1	9.51
		College or professional school	0	501	13	50.9	110.56
		Not enrolled	0	197	79	75.1	44.21
	Income in the past 12 months below poverty level		0	362	43	55.1	55.50
	Income in the past 12 months above the poverty level		0	211	79	88.0	44.17
	Average percentage income in past 12 months below poverty level		0	1	0	0.3	0.16
	Median household income in the past 12 months		0	87,713	27,147	30,079.8	15,883.42
	1-unit structure		0	64	29	27.7	18.50
	2-unit structure		0	134	14	28.3	33.66
	Mobile homes		0	33	0	2.7	7.21
	Weighted crime rate based on the population		4	244	45	63.3	60.15
	Number of crimes		0	126	12	20.4	24.89
	Number of libraries		0	5	0	0.1	0.60
	A dummy variable for presence of library		0	1	0	0.1	0.29
	A dummy variable for presence of bike lane		0	1	0	0.4	0.50
	Number of liquor stores		0	4	0	0.3	0.74

	A dummy variable for presence of park	0	1	0	0.1	0.36
	Number of bars	0	12	0	0.8	1.96
	Number of retail stores	0	22	1	2.5	3.41
	Number of schools	0	2	0	0.1	0.28
Pedestrian Crash (250 feet buffer)	Total number of crashes from 2008-2012	0	7	1	1.4	1.58
	Number of crashes on weekends from 2008-2012	0	6	1	1.1	1.34
	Number of crashes on work days from 2008-2012	0	4	0	0.3	0.68
	Number of day time crashes 2008-2012	0	6	1	0.9	1.20
	Number of night time crashes from 2008-2012	0	3	0	0.5	0.81
	Number of fatalities from 2008-2012	0	2	0	0.0	0.44
	Number of incapacitating injuries from 2008-2012	0	2	0	0.2	0.44
	Number of non-incapacitating injuries from 2008-2012	0	5	0	0.5	0.94
	Number of K= fatal & A= incapacitating crashes from 2008-2012	0	6	0	0.2	1.04
	Number of K= fatal & A= incapacitating injuries from 2008-2012	0	1	0	0.2	0.14
	Number of K= fatal & A= incapacitating & B= non-incapacitating crashes from 2008-2012	0	2	0	0.6	0.42
	Number of K= fatal & A= incapacitating & B= non-incapacitating injuries from 2008-2012	0	5	0	0.6	0.89
	Number of C= possibly injuries from 2008-2012	0	5	0	0.7	1.09
	Number of property damages only crashes from 2008-2012	0	2	0	0.2	0.41
	Number of crashes in dark situations from 2008-2012	0	1	0	0.0	0.14
	Number of crashes which signal was at the site of the crash	0	7	1	1.4	1.58
	Number of crashes which signal was at the site of the crash	0	5	0	1.0	1.29
	Number of crashes which stop sign was at the site of the crash	0	4	0	0.1	0.42
	Number of crashes which yield sign was at the site of the crash	0	1	0	0.0	0.10
	Number of crashes which there is no sign nor signal at the site of the crash	0	3	0	0.4	0.65

	Number of crashes that happened on the road from 2008-2012	0	7	1	1.3	1.51
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	2	0	0.1	0.35
	Number of crashes that happened on dry and clear roads from 2008-2012	0	6	1	1.0	1.22
	Number of crashes happened on non dry and non clear roads" wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	4	0	0.4	0.71
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	0	0	0.0	0.00
	Number of crashes which happened on roads with less than 45 mi/h speed limit	0	7	1	1.4	1.54
	Number of crashes involving alcohol	0	2	0	0.2	0.42
	Number of crashes involving drugs	0	1	0	0.0	0.17
	Number of crashes with fatal injuries as the greatest injury severity	0	1	0	0.0	0.14
	Number of crashes with incapacitating injuries as the greatest injury severity	0	2	0	0.2	0.42
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	4	0	0.4	0.80
	Number of crashes with possible injury as the greatest injury severity	0	5	0	0.6	0.96
	Number of crashes with property damage only	0	2	0	0.2	0.41
Bike Crash (250 feet buffer)	Total number of crashes from 2008-2012	0	12	1	1.6	1.99
	Number of crashes on weekends from 2008-2012	0	11	1	1.3	1.73
	Number of crashes on work days from 2008-2012	0	3	0	0.3	0.68
	Number of day time crashes 2008-2012	0	12	1	1.2	1.82
	Number of night time crashes from 2008-2012	0	3	0	0.4	0.66
	Number of fatalities from 2008-2012	0	2	0	0.0	0.35
	Number of incapacitating injuries from 2008-2012	0	2	0	0.1	0.35
	Number of non-incapacitating injuries from 2008-2012	0	6	0	0.4	0.85

	Number of K= fatal & A= incapacitating crashes from 2008-2012	0	6	0	0.1	0.86
	Number of K= fatal & A= incapacitating injuries from 2008-2012	0	1	0	0.1	0.10
	Number of K= fatal & A= incapacitating & B= non-incapacitating crashes from 2008-2012	0	2	0	0.5	0.34
	Number of K= fatal & A= incapacitating & B= non-incapacitating injuries from 2008-2012	0	4	0	0.5	0.69
	Number of C= possibly injuries from 2008-2012	0	5	0	0.8	1.09
	Number of property damages only crashes from 2008-2012	0	5	0	0.3	0.71
	Number of crashes in dark situations from 2008-2012	0	1	0	0.0	0.10
	Number of crashes which signal was at the site of the crash	0	12	1	1.6	1.99
	Number of crashes which signal was at the site of the crash	0	9	1	1.1	1.66
	Number of crashes which stop sign was at the site of the crash	0	1	0	0.1	0.31
	Number of crashes which yield sign was at the site of the crash	0	2	0	0.0	0.20
	Number of crashes which there is no sign nor signal at the site of the crash	0	4	0	0.3	0.76
	Number of crashes that happened on the road. from 2008-2012	0	11	1	1.5	1.89
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	2	0	0.1	0.41
	Number of crashes that happened on dry and clear roads from 2008-2012	0	11	1	1.5	1.88
	Number of crashes that happened on non dry and non clear roads "wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	1	0	0.2	0.37
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	1	0	0.0	0.10
	Number of crashes which happened on roads with less than 45 mi/h speed limit	0	12	1	1.6	1.92
	Number of crashes involving alcohol	0	1	0	0.0	0.20
	Number of crashes involving	0	1	0	0.0	0.10

	drugs					
	Number of crashes with fatal injuries as the greatest injury severity	0	1	0	0.0	0.10
	Number of crashes with incapacitating injuries as the greatest injury severity	0	2	0	0.1	0.34
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	4	0	0.4	0.69
	Number of crashes with possibly injury as the greatest injury severity	0	5	0	0.8	1.09
	Number of crashes with property damage only loss as the greatest injury severity	0	5	0	0.3	0.71
A dummy variable for presence of left turn on the major road		0	1	1	0.7	0.45
A dummy variable for presence of right turn on the major road		0	1	0	0.2	0.42
Total lane number of the major road		2	14	8	8.2	2.29
A dummy variable for presence of left turn on the minor road		0	12	1	0.9	1.28
A dummy variable for presence of right turn on the minor road		0	1	0	0.2	0.41
Total lane number of the minor road		0	12	8	7.6	2.69

Appendix 4: Variables Used for Midblock Crash Analysis (51 observations)

Definition		Min	Max	Median	Mean	Standard Deviation
Average of pedestrian volume of both ends		85	20,953	472	1,724.8	4,059.1
Average of bike volume of both ends		26	3,211	171	320.1	498.0
Ownership type of the corridor "1:Trunkline, 2:County primary, 3:County local, 4:City major, 5:City local, 6: Federal owned"		1	5	4	3.6	1.1
Posted speed in the corridor		25	45	30	30.1	5.0
Corridor length		0	2	0	0.5	0.3
Corridor area		0	0	0	0.1	0.1
ADT		4,209	39,476	18,453	18,582.1	7,837.2
Actual number of crimes		0	180	18	31.6	40.3
Rate of crime		4	244	45	60.6	57.8
Number of all types of roads which intersect with the corridor		0	31	7	9.1	7.0
Number of all of other accesses to the corridor		0	106	16	24.7	22.3
Total number of any access to the corridor		0	114	27	33.8	26.1
Dummy variable for existence of medians in the corridor		0	1	0	0.2	0.4
Total medians length in the corridor		0	6,620	0	297.5	1,033.6
Dummy variable for existence of shared lanes in the corridor		0	3,351	0	79.7	477.8
Total shared lanes length in the corridor		0	1	0	0.0	0.2
Number of bus stops in the corridor		0	15	3	3.7	3.5
Number of signalized crossings in the corridor		0	5	1	1.1	1.1
Number of unsignalized crossings in the corridor		0	6	0	1.0	1.4
Total number of any crossing in the corridor		0	7	2	2.1	1.8
Pedestrian	Total number of crashes from 2008-2012	0	12	2	2.4	2.7
	Number of crashes on weekends from 2008-2012	0	3	0	0.5	0.8
	Number of crashes on work days from 2008-2012	0	10	1	1.9	2.3
	Number of day time crashes from 2008-2012	0	6	1	1.5	1.7
	Number of night time crashes time from 2008-2012	0	6	0	0.9	1.4
	Number of K= fatal & A= incapacitating crashes from 2008-2012	0	5	0	0.4	0.9
	Number of K= fatal & A=	0	5	0	0.4	0.9

	incapacitating injuries from 2008-2012					
	Number of K= fatal & A= incapacitating & B= non-incapacitating crashes from 2008-2012	0	7	1	1.1	1.4
	Number of K=fatal & A= incapacitating & B= non-incapacitating injuries from 2008-2012	0	7	1	1.1	1.5
	Number of fatalities from 2008-2012	0	2	0	0.1	0.3
	Number of incapacitating injuries from 2008-2012	0	3	0	0.3	0.7
	Number of non-incapacitating injuries from 2008-2012	0	5	0	0.7	1.1
	Number of C= possibly injuries from 2008-2012	0	8	1	1.3	1.8
	Number of property damages only crashes from 2008-2012	0	2	0	0.3	0.5
	Number of crashes in dark situations from 2008-2012	0	1	0	0.1	0.2
	Number of crashes which signal was at the site of the crash	0	12	2	2.3	2.7
	Number of crashes which signal was at the site of the crash	0	5	0	0.6	1.2
	Number of crashes which stop sign was at the site of the crash	0	5	0	0.5	1.1
	Number of crashes which yield sign was at the site of the crash	0	1	0	0.0	0.1
	Number of crashes which there is no sign nor signal at the site of the crash	0	10	1	1.3	1.9
	Number of crashes that happened on the road. from 2008-2012	0	12	1	2.3	2.7
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	1	0	0.1	0.3
	Number of crashes that happened on dry and clear roads from 2008-2012	0	7	1	1.6	1.7
	Number of crashes that happened on non dry and non clear roads" wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	5	0	0.8	1.2
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	0	0	0.0	0.0
	Number of crashes which happened on roads with less than 45 mi/h speed limit	0	12	2	2.4	2.7
	Number of crashes involving alcohol	0	5	0	0.5	1.1
	Number of crashes involving drugs	0	3	0	0.1	0.4
	Number of crashes with fatal injuries as the greatest injury severity	0	2	0	0.1	0.3

	Number of crashes with incapacitating injuries as the greatest injury severity	0	3	0	0.3	0.7
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	4	0	0.6	0.9
	Number of crashes with possible injury as the greatest injury severity	0	6	1	1.0	1.4
	Number of crashes with property damage only loss as the greatest injury severity	0	2	0	0.3	0.5
Bike	Total number of crashes from 2008-2012	0	15	2	2.5	3.0
	Number of crashes on weekends from 2008-2012	0	3	0	0.4	0.8
	Number of crashes on work days from 2008-2012	0	13	1	2.1	2.5
	Number of day time crashes from 2008-2012	0	12	1	2.0	2.5
	Number of night time crashes time from 2008-2012	0	3	0	0.5	0.8
	Number of K= fatal & A= incapacitating crashes from 2008-2012	0	1	0	0.1	0.3
	Number of K= fatal & A= incapacitating injuries from 2008-2012	0	1	0	0.1	0.3
	Number of K= fatal & A= incapacitating & B= non-incapacitating crashes from 2008-2012	0	6	0	0.9	1.3
	Number of K=fatal & A= incapacitating & B= non-incapacitating injuries from 2008-2012	0	8	0	1.0	1.5
	Number of fatalities from 2008-2012	0	0	0	0.0	0.0
	Number of incapacitating injuries from 2008-2012	0	1	0	0.1	0.3
	Number of non-incapacitating injuries from 2008-2012	0	8	0	0.9	1.5
	Number of C=possibly injuries from 2008-2012	0	5	1	1.1	1.4
	Number of property damages only crashes from 2008-2012	0	7	0	0.5	1.1
	Number of crashes in dark situations from 2008-2012	0	1	0	0.0	0.2
	Number of crashes which signal was at the site of the crash	0	15	1	2.5	3.0
	Number of crashes which signal was at the site of the crash	0	12	0	1.0	2.0
	Number of crashes which stop sign was at the site of the crash	0	6	0	0.8	1.2

	Number of crashes which yield sign was at the site of the crash	0	0	0	0.0	0.0
	Number of crashes which there is no sign nor signal at the site of the crash	0	4	0	0.8	1.0
	Number of crashes that happened on the road from 2008-2012	0	14	1	2.3	2.8
	Number of crashes that happened off the road "shoulder, median, out of shoulder, gore,.." from 2008-2012	0	2	0	0.2	0.5
	Number of crashes happened on dry and clear roads from 2008-2012	0	15	1	2.4	2.9
	Number of crashes happened on non dry and non clear roads" wet, icy, muddy, snowy, slushy, debris" from 2008-2012	0	2	0	0.2	0.5
	Number of crashes which happened on roads with more than 50 mi/h speed limit	0	0	0	0.0	0.0
	Number of crashes which happened on Roads with less than 45 mi/h speed limit	0	15	2	2.5	3.0
	Number of crashes involving alcohol	0	1	0	0.1	0.2
	Number of crashes involving drugs	0	0	0	0.0	0.0
	Number of crashes with fatal injuries as the greatest injury severity	0	0	0	0.0	0.0
	Number of crashes with incapacitating injuries as the greatest injury severity	0	1	0	0.1	0.3
	Number of crashes with non-incapacitating injuries as the greatest injury severity	0	6	0	0.8	1.3
	Number of crashes with possible injury as the greatest injury severity	0	5	1	1.1	1.4
	Number of crashes with property damage only loss as the greatest injury severity	0	7	0	0.5	1.1
Number of households in the corridor		0	739	201	225.3	180.5
Total population		0	2,813	409	527.8	538.3
African american population		0	513	53	94.9	129.1
Hispanic population		0	532	19	56.2	105.8
Total white population		0	2297	177	331.3	437.4
Children 14 and below		0	233	45	62.4	64.8
Age 15 to 19		0	811	19	59.2	131.7
Age 20 to 59		0	1,524	218	341.4	361.8
Age 60 and older		0	191	37	44.0	39.9
Age of both sexes		0	58	33	33.6	9.3
Age of male population		0	57	32	32.7	9.2

Age of female population		0	55	35	34.2	9.4
Means of Transportation to Work	Car, truck, or van	1	535	129	157.0	123.5
	Drove alone	1	434	95	110.4	85.5
	Carpooled	0	247	16	38.3	52.8
	Public transportation excluding taxicab	0	154	9	15.7	24.9
	Bus or trolley bus	0	149	9	15.5	24.3
	Bicycle	0	44	2	5.9	9.2
	Walked	0	289	9	35.2	68.9
	Other means	0	8	0	0.9	1.4
	Work at home	0	43	6	10.6	10.9
Means of Transportation to Work by Vehicle Available	No vehicle available	0	108	8	13.6	18.4
	1 vehicle available	0	187	45	54.5	42.8
	2 vehicles available	0	272	49	63.7	54.6
	3 or more vehicles available	0	160	24	35.1	35.5
Household Low Income in the Past 12 Months	Less than $10,000	0	191	21	31.6	33.2
	$10,000 to $14,999	0	46	11	13.3	10.1
	$15,000 to $19,9999	0	42	10	11.7	9.5
Employment Status for the Population 16 Years and Over	Employed	4	590	153	182.6	139.8
	Unemployed	0	85	22	24.8	17.6
	Not in labor force	7	732	105	158.6	167.6
Educational Attainment for 18 years and Older	No high school diploma or GED	0	163	22	39.6	41.1
	High school diploma or GED	1	309	57	77.5	65.7
	Some college or associate's degree	9	1,290	82	179.8	290.7
	Bachelor's degree	0	199	34	56.3	56.8
	Graduate degree or higher	0	246	15	39.1	56.5
Student Enrollment Status	8th grade and lower	0	138	32	4163.7	40.1
	9th to 12th grade	0	362	17	47.0	54.7
	College or professional school	0	1,494	30	32.4	278.1
	Not enrolled	0	696	186	123.9	156.2
Median household income in the past 12 months		0	11,439	3,345	195.6	2,939.6
Households with one or more people 60 years and over		0	149	27	34.3	31.8
Households with no people 60 years and over		0	638	117	162.7	154.9
Total male population		0	1,165	196	263.1	255.1

Total female population	0	1,648	207	264.7	290.3
Proportion of housing units that are vacant	0	22	4	5.0	4.7
Households owner occupied	0	648	50	101.5	133.8
Household renter occupied	0	530	67	95.5	104.5
Family households	0	261	51	72.2	63.7
Nonfamily households	0	539	67	124.9	142.9
Income in the past 12 months below poverty level	0	769	98	142.7	151.2
Income in the past 12 months above the poverty level	0	777	225	243.2	171.7
Average percentage income in past 12 months below poverty level	0	1	0	0.3	0.2
1- unit structure	0	293	80	77.2	66.8
2-unit structure	0	298	26	59.0	68.8
Mobile homes	0	119	0	10.0	28.2
Number of retail stores	0	21	2	3.5	4.3
Number of liquor stores	0	21	2	0.5	4.3
Number of bars	0	4	0	3.5	0.9
Closest distance to a school	161	6,131	1,663	1,862.8	1,211.6
A dummy variable for existence of bike lane in the corridor	0	1	0	0.3	0.5
A dummy variable for existence of park in the corridor	0	1	0	0.2	0.4
Number of lanes	2	4	4	3.5	0.9
Amount of business land use type of the corridor (feet^2)	0	18,251,130	878,301	2,127,080.5	3,451,728.1
Amount of mix land use type of the corridor (feet^2)	0	351,508	0	35,740.2	79,198.2
Amount of insignificant land use type of the corridor (feet^2)	0	20,998,566	67,575	1,230,706.4	3,778,688.3
Amount of undeveloped land use type of the corridor (feet^2)	0	6,008,570	0	691,166.8	1,274,631.9
Amount of residential land use type of the corridor (feet^2)	0	124,844,429	2,338,636	24,203,817.9	42,055,942.7
Amount of industrial land use type of the corridor (feet^2)	0	11,141,187	0	872,906.5	2,291,048.6
Amount of campus land use type of the corridor (feet^2)	0	23,242,569	0	1,434,668.1	4,550,667.8
Dummy variable for business land use as the dominant land use	0	1	0	0.2	0.4
Dummy variable for mix land use as the dominant land use	0	0	0	0.0	0.0
Dummy variable for insignificant land use as the dominant land use	0	1	0	0.1	0.3
Dummy variable for undeveloped land use as the dominant land use	0	1	0	0.1	0.3
Dummy variable for residential land use as	0	1	0	0.5	0.5

the dominant land use					
Dummy variable for industrial land use as the dominant land use	0	1	0	0.0	0.2
Dummy variable for campus land use as the dominant land use	0	1	0	0.1	0.3

Appendix 5: Survey Questionnaire

Bicyclists Answer Key

Location ____ City ___________________________________

Do you ride your bicycle in this area? (Stop if the person says no.)

Male_____ Female______

AGE: 16-23 _____ 24-35_____ 36-55 _____ 56-70 _____ Over 70 _____

Ethnic: White _____ Black _____ Hispanic _____ Asian _____ Others_______

How often do you ride your bike?

a. Less than once a month b. Several times per month
c. Several times per week d. Daily

How many bike trips do you make per week in good weather?

a. less than 1 b. about 1 per week
c. 2 or 3 per week d. almost everyday

What is the primary purpose of bike trips?

a. Exercise and health b. Recreational trips
c. To commute back and forth to work d. To shop or run errands

Which way do you travel when riding in the road?

d. In the same direction the cars are traveling (on the right side)
e. Facing traffic (on the left side)
f. It does not matter. One can ride in both directions

Where do you most often ride?

a. On public roads b. On the sidewalk
c. On bicycle paths or trails

How safe do you feel when riding your bike in terms of having a crash with a motor vehicle?

a. Not at all safe b. A little safe
c. Fairly safe d. Very safe

Do you stop at red lights when riding your bicycle if there is no traffic?

Yes_______ No________

Do you come to a stop at stop signs on your bicycle if there is no traffic?

Yes_______ No________

Do you typically signal when making a turn on your bicycle?

Yes_______ No________

Do you yield to pedestrians at crosswalks when riding your bicycle?

Yes_______ No________

<u>Drivers Answer Key</u>
Location ____ City _______________________________

<u>Are you a driver?</u> (Stop if the person says no.)

<u>Do you live in this city?</u> (Stop if the person says no.)
Male_____ Female______

AGE: 16-23 _____ 24-35_____ 36-55 _____ 56-70 _____ Over 70 _____

Ethnic: White _____ Black _____ Hispanic _____ Asian _____ Others_______

1. **How long have you had a driver's license? ______________**Years

2. **What type of vehicle do you drive most often?**

Passenger car ______ Pick-up truck ______ SUV ______ Van ______ Fleet vehicle ______

CROSSWALKS AT TRAFFIC SIGNALS

Show Traffic Signal Location with a Marked Crosswalk showing WALK sign and a pedestrian crossing the street within the crosswalk with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

Show Traffic Signal Location with a Marked Crosswalk showing COUNTDOWN SIGNAL sign and a pedestrian crossing the street within the crosswalk with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

Show Traffic Signal Location with a Marked Crosswalk showing DON'T WALK sign and a pedestrian crossing the street within the crosswalk with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

MARKED CROSSWALKS AT UNCONTROLLED LOCATION
Show a Marked Crosswalk location with a pedestrian starting to cross the street in the crosswalk with a vehicle approaching.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

UNMARKED CROSSWALK AT AN UNCONTROLLED INTERSECTION

Show an unmarked crosswalk location with a pedestrian crossing an uncontrolled leg of the intersection.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

MIDBLOCK CROSSING

Show a picture of a midblock location without a median island.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

BIKE LANE/PEDESTRIAN QUESTIONS

When can you drive in a bike lane?

a. Never b. Anytime
c. Just before making a right turn

How do you feel about your interaction with non-motorized traffic (bicyclists and pedestrians) in terms of your and their safety?

a. Not at all safe b. A little safe
c. Fairly safe d. Very safe

<u>Pedestrian Answer Key</u>
Location ____ City ___________________________________

<u>Do you typically walk in this area?</u> (Stop if the person says no.)
Male_____ Female______

AGE: 16-23 _____ 24-35_____ 36-55 _____ 56-70 _____ Over 70 _____

Ethnic: White _____ Black _____ Hispanic _____ Asian _____ Others_______

CROSSWALKS AT TRAFFIC SIGNALS

Show Traffic Signal Location with a Marked Crosswalk showing WALK sign and a pedestrian crossing the street with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver _________ Pedestrian _________ Both _________

If there was a crash, who would be at fault?
Driver _________ Pedestrian _________ Both _________

Show Traffic Signal Location with a Marked Crosswalk showing COUNTDOWN SIGNAL sign and a pedestrian crossing the street with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver _________ Pedestrian _________ Both _________

If there was a crash, who would be at fault?
Driver _________ Pedestrian _________ Both _________

Show Traffic Signal Location with a Marked Crosswalk showing DON'T WALK sign and a pedestrian crossing the street with a turning vehicle.

Who has right-of-way here the pedestrian or the driver?
Driver _________ Pedestrian _________ Both _________

If there was a crash, who would be at fault?
Driver _________ Pedestrian _________ Both _________

MARKED CROSSWALKS AT UNCONTROLLED LOCATION

Show a Marked Crosswalk location with a pedestrian starting to cross the street with a vehicle approaching.

Who has right-of-way here the pedestrian or the driver?
Driver _________ Pedestrian _________ Both _________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

UNMARKED CROSSWALK AT AN UNCONTROLLED INTERSECTION

Show an unmarked crosswalk location with a pedestrian crossing an uncontrolled leg of the intersection.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

MIDBLOCK CROSSING
Show a picture of a midblock location without a median island.

Who has right-of-way here the pedestrian or the driver?
Driver ________ Pedestrian ________ Both ________

If there was a crash, who would be at fault?
Driver ________ Pedestrian ________ Both ________

WALKING ALONG THE ROADWAY
When walking in or along the roadway which way do you face?

d. In the same direction the cars are traveling (on the right side)
e. Facing traffic (on the left side)
f. It does not matter which direction you walk.

How safe do you feel when walking in terms of being struck by a vehicle?

b. Not at all safe
b. A little safe
c. Fairly safe
d. Very safe

Appendix 6: Summary of Survey Results

Table A-1: Location vs. "How often do you ride your bike?"

			How often do you ride your bike?				Total
			Less than once a month	Several times per month	Several times per week	Almost everyday	
Location	Low income	Count	5	5	22	40	72
		% within Location	6.90%	6.90%	30.60%	55.60%	100.00%
	Downtown	Count	4	16	40	67	127
		% within Location	3.10%	12.60%	31.50%	52.80%	100.00%
	Outside	Count	2	13	15	2	32
		% within Location	6.20%	40.60%	46.90%	6.20%	100.00%
Total		Count	11	34	77	109	231
		% of Total	4.80%	14.70%	33.30%	47.20%	100.00%

Chi-sq = 34.822 Asymp. Sig = 0.000

Table A-2: Location vs. "How many bike trips do you make per week in good weather?"

			How many bike trips do you make per week in good weather?				Total
			Less than 1	About 1 per week	2 or 3 per week	Almost everyday	
Location	Low income	Count	3	5	16	49	73
		% within Location	4.10%	6.80%	21.90%	67.10%	100.00%
	Downtown	Count	3	10	27	87	127
		% within Location	2.40%	7.90%	21.30%	68.50%	100.00%
	Outside	Count	5	7	15	6	33
		% within Location	15.20%	21.20%	45.50%	18.20%	100.00%
Total		Count	11	22	58	142	233
		% of Total	4.70%	9.40%	24.90%	60.90%	100.00%

Chi-sq = 32.939 Asymp. Sig = 0.000

Table A-3: Location vs. "What is the primary purpose of bike trips?"

			What is the primary purpose of bike trips?							Total
			Exercise and health	Recreational trips	To commute back and forth to work	To shop or run errands	All	Exercise, health and recreational trips	Exercise, health and to commute to work	
Location	Low income	Count	9	3	39	13	7	1	1	73
		% within Location	12.30%	4.10%	53.40%	17.80%	9.60%	1.40%	1.40%	100.00%
	Downtown	Count	21	5	52	19	22	1	7	127
		% within Location	16.50%	3.90%	40.90%	15.00%	17.30%	0.80%	5.50%	100.00%
	Outside	Count	17	8	5	2	0	0	1	33
		% within Location	51.50%	24.20%	15.20%	6.10%	0.00%	0.00%	3.00%	100.00%
Total		Count	47	16	96	34	29	2	9	233
		% of Total	20.20%	6.90%	41.20%	14.60%	12.40%	0.90%	3.90%	100.00%

Chi-sq = 55.948 Asymp. Sig = 0.000

Table A-4: Location vs. "Do you stop at red lights when riding your bicycle if there is no traffic?'

			Do you stop at red lights when riding your bicycle if there is no traffic?		Total
			Yes	No	
Location	Low income	Count	55	18	73
		% within Location	75.30%	24.70%	100.00%
	Downtown	Count	99	27	126
		% within Location	78.60%	21.40%	100.00%
	Outside	Count	22	11	33
		% within Location	66.70%	33.30%	100.00%
Total		Count	176	56	232
		% of Total	75.90%	24.10%	100.00%

Chi-sq = 2.040 Asymp. Sig = 0.361

Table A-5: Location vs. "Which way do you travel when riding in the road?"

			Which way do you travel when riding in the road?			Total
			In the same direction the cars are travelling	Facing traffic(on the left side)	It does not matter. One can ride in both directions	
Location	Low income	Count	58	5	10	73
		% within Location	79.50%	6.80%	13.70%	100.00%
	Downtown	Count	96	18	12	126
		% within Location	76.20%	14.30%	9.50%	100.00%
	Outside	Count	25	5	3	33
		% within Location	75.80%	15.20%	9.10%	100.00%
Total		Count	179	28	25	232
		% of Total	77.20%	12.10%	10.80%	100.00%

Chi-sq = 3.343 Asymp. Sig = 0.502

Table A-6: Location vs. "Do you typically signal when making a turn on your bicycle?"

			Do you typically signal when making a turn on your bicycle?		Total
			Yes	No	
Location	Low income	Count	37	36	73
		% within Location	50.70%	49.30%	100.00%
	Downtown	Count	75	52	127
		% within Location	59.10%	40.90%	100.00%
	Outside	Count	14	19	33
		% within Location	42.40%	57.60%	100.00%
Total		Count	126	107	233
		% of Total	54.10%	45.90%	100.00%

Chi-sq = 3.410 Asymp. Sig = 0.182

Table A-7: City vs. "How often do you ride your bike?"

			How often do you ride your bike?				Total
			Less than once a month	Several times per month	Several times per week	Almost everyday	
City	Grand Rapid	Count	1	8	23	10	42
		% within City	2.40%	19.00%	54.80%	23.80%	100.00%
	East Lansing	Count	2	5	17	37	61
		% within City	3.30%	8.20%	27.90%	60.70%	100.00%
	Ann Arbor	Count	6	15	32	39	92
		% within City	6.50%	16.30%	34.80%	42.40%	100.00%
	Flint	Count	2	6	5	23	36
		% within City	5.60%	16.70%	13.90%	63.90%	100.00%
Total		Count	11	34	77	109	231
		% of Total	4.80%	14.70%	33.30%	47.20%	100.00%

Chi-sq = 24.235 Asymp. Sig = 0.004

Table A-8: City vs. "How many bike trips do you make per week in good weather?"

			How many bike trips do you make per week in good weather?				Total
			Less than 1	About 1 per week	2 or 3 per week	Almost everyday	
City	Grand Rapid	Count	1	6	18	17	42
		% within City	2.40%	14.30%	42.90%	40.50%	100.00%
	East Lansing	Count	1	5	14	42	62
		% within City	1.60%	8.10%	22.60%	67.70%	100.00%
	Ann Arbor	Count	7	8	17	61	93
		% within City	7.50%	8.60%	18.30%	65.60%	100.00%
	Flint	Count	2	3	9	22	36
		% within City	5.60%	8.30%	25.00%	61.10%	100.00%
Total		Count	11	22	58	142	233
		% of Total	4.70%	9.40%	24.90%	60.90%	100.00%

Chi-sq = 15.544 Asymp. Sig = 0.077

Table A-9: City vs. "What is the primary purpose of bike trips?"

			What is the primary purpose of bike trips?							Total
			Exercise and health	Recreational trips	To commute back and forth to work	To shop or run errands	All	Exercise, health and recreational trips	Exercise, health and to commute to work	
City	Grand Rapid	Count	8	4	13	11	3	1	2	42
		% within City	19.00%	9.50%	31.00%	26.20%	7.10%	2.40%	4.80%	100.00%
	East Lansing	Count	13	3	36	6	4	0	0	62
		% within City	21.00%	4.80%	58.10%	9.70%	6.50%	0.00%	0.00%	100.00%
	Ann Arbor	Count	18	7	41	8	14	1	4	93
		% within City	19.40%	7.50%	44.10%	8.60%	15.10%	1.10%	4.30%	100.00%
	Flint	Count	8	2	6	9	8	0	3	36
		% within City	22.20%	5.60%	16.70%	25.00%	22.20%	0.00%	8.30%	100.00%
Total		Count	47	16	96	34	29	2	9	233
		% of Total	20.20%	6.90%	41.20%	14.60%	12.40%	0.90%	3.90%	100.00%

Chi-sq = 34.188 Asymp. Sig = 0.012

Table A-10: City vs. "Where do you most often ride?"

			Where do you most often ride?							Total
			On public roads	On the sidewalk	On bicycle path or trails	On public roads and on side walks	On public roads and on bicycle paths and trails	On the sidewalk and on public roads	All	
City	Grand Rapid	Count	21	7	7	1	4	0	2	42
		% within City	50.00%	16.70%	16.70%	2.40%	9.50%	0.00%	4.80%	100.00%
	East Lansing	Count	11	30	18	1	0	2	0	62
		% within City	17.70%	48.40%	29.00%	1.60%	0.00%	3.20%	0.00%	100.00%
	Ann Arbor	Count	30	28	28	2	3	1	1	93
		% within City	32.30%	30.10%	30.10%	2.20%	3.20%	1.10%	1.10%	100.00%
	Flint	Count	5	9	20	0	1	1	0	36
		% within City	13.90%	25.00%	55.60%	0.00%	2.80%	2.80%	0.00%	100.00%
Total		Count	67	74	73	4	8	4	3	233
		% of Total	28.80%	31.80%	31.30%	1.70%	3.40%	1.70%	1.30%	100.00%

Chi-sq = 45.942 Asymp. Sig = 0.000

Table A-11: City vs. "Do you yield to pedestrians at crosswalks when riding your bike?"

			Do you yield to pedestrians at crosswalks when riding your bicycle?		Total
			Yes	No	
City	Grand Rapid	Count	39	3	42
		% within City	92.90%	7.10%	100.00%
	East Lansing	Count	50	12	62
		% within City	80.60%	19.40%	100.00%
	Ann Arbor	Count	87	6	93
		% within City	93.50%	6.50%	100.00%
	Flint	Count	30	6	36
		% within City	83.30%	16.70%	100.00%
Total		Count	206	27	233
		% of Total	88.40%	11.60%	100.00%

Chi-sq = 3.736 Asymp. Sig = 0.291

Table A-12: City vs. "Do you typically signal when making a turn on your bicycle?"

			Do you typically signal when making a turn on your bicycle?		Total
			Yes	No	
City	Grand Rapid	Count	21	21	42
		% within City	50.00%	50.00%	100.00%
	East Lansing	Count	31	31	62
		% within City	50.00%	50.00%	100.00%
	Ann Arbor	Count	55	38	93
		% within City	59.10%	40.90%	100.00%
	Flint	Count	19	17	36
		% within City	52.80%	47.20%	100.00%
Total		Count	126	107	233
		% of Total	54.10%	45.90%	100.00%

Chi-sq = 1.680 Asymp. Sig = 0.641

Table A-13: City vs. "Do you come to a stop at stop signs on your bicycle if there is no traffic?"

			Do you come to a stop at stop signs on your bicycle if there is no traffic?		Total
			Yes	No	
City	Grand Rapid	Count	20	22	42
		% within City	47.60%	52.40%	100.00%
	East Lansing	Count	30	32	62
		% within City	48.40%	51.60%	100.00%
	Ann Arbor	Count	50	43	93
		% within City	53.80%	46.20%	100.00%
	Flint	Count	24	12	36
		% within City	66.70%	33.30%	100.00%
Total		Count	124	109	233
		% of Total	53.20%	46.80%	100.00%

Chi-sq = 3.736 Asymp. Sig = 0.291

Table A-14: Location vs. Marked Crosswalk (WALK)

			Marked Crosswalk(WALK sign)			Total
			Driver	Pedestrian	Both	
Location	Low income	Count	1	209	0	210
		% within Location	0.5%	99.5%	0.0%	100.0%
	Downtown	Count	4	259	0	263
		% within Location	1.5%	98.5%	0.0%	100.0%
	Outside	Count	1	199	3	203
		% within Location	0.5%	98.0%	1.5%	100.0%
Total		Count	6	667	3	676
		% of Total	0.9%	98.7%	0.4%	100.0%

Chi-sq= 8.961 Asymp. Sig.= 0.062

Table A-15: Location vs. Marked Crosswalk (COUNTDOWN)

			Marked Crosswalk (COUNTDOWN SIGNAL)			Total
			Driver	Pedestrian	Both	
Location	Low income	Count	27	170	13	210
		% within Location	12.9%	81.0%	6.2%	100.0%
	Downtown	Count	32	225	5	262
		% within Location	12.2%	85.9%	1.9%	100.0%
	Outside	Count	32	160	11	203
		% within Location	15.8%	78.8%	5.4%	100.0%
Total		Count	91	555	29	675
		% of Total	13.5%	82.2%	4.3%	100.0%

Chi-sq= 7.737 Asymp. Sig= 0.102

Table A-16: Location vs. Unmarked Crosswalk (UNCONTROLLED)

			Unmarked Crosswalk(UNCONTROLLED Intersection)			Total
			Driver	Pedestrian	Both	
Location	Low income	Count	143	46	12	201
		% within Location	71.1%	22.9%	6.0%	100.0%
	Downtown	Count	203	54	4	261
		% within Location	77.8%	20.7%	1.5%	100.0%
	Outside	Count	140	44	12	196
		% within Location	71.4%	22.4%	6.1%	100.0%
Total		Count	486	144	28	658
		% of Total	73.9%	21.9%	4.3%	100.0%

Chi-sq.= 8.733 Asymp. Sig.= 0.068

Table A-17: Location vs. Midblock

			Midblock Crossing			
			Driver	Pedestrian	Both	Total
Location	Low income	Count	8	200	1	209
		% within Location	3.8%	95.7%	0.5%	100.0%
	Downtown	Count	22	234	5	261
		% within Location	8.4%	89.7%	1.5%	100.0%
	Outside	Count	18	181	4	203
		% within Location	8.9%	89.2%	2.0%	100.0%
Total		Count	48	615	10	673
		% of Total	7.1%	91.4%	1.3%	100.0%

Chi-Sq.= 7.368 Asymp. Sig.= 0.1177

Table A-18: City vs. Marked Crosswalk (WALK)

			Marked Crosswalk(WALK sign)			Total
			Driver	Pedestrian	Both	
City	Grand Rapids	Count	3	128	0	131
		% within City	2.30%	97.70%	0.00%	100.00%
	East Lansing	Count	1	188	0	189
		% within City	0.50%	99.50%	0.00%	100.00%
	Ann Arbor	Count	2	190	3	195
		% within City	1.00%	97.40%	1.50%	100.00%
	Flint	Count	0	161	0	161
		% within City	0.00%	100.00%	0.00%	100.00%
Total		Count	6	667	3	676
		% of Total	0.90%	98.70%	0.40%	100.00%

Chi-sq = 12.131 Asymp. Sig = 0.059

Table A-19: City vs. Midblock

Observed			Midblock Crossing			Total
			Driver	Pedestrian	Both	
City	Grand Rapids	Count	12	115	3	130
		% within City	9.20%	88.50%	2.30%	100.00%
	East Lansing	Count	14	173	0	187
		% within City	7.50%	92.50%	0.00%	100.00%
	Ann Arbor	Count	11	180	4	195
		% within City	5.60%	92.30%	2.10%	100.00%
	Flint	Count	11	147	3	161
		% within City	6.80%	91.30%	1.90%	100.00%
Total		Count	48	615	10	673
		% of Total	7.10%	91.40%	1.50%	100.00%

Chi-sq = 5.545 Asymp. Sig = 0.476

Table A-20: Perception of Safety in Flint

			How safe do you feel with interaction with non-motorized traffic?				Total
			Not at all safe	A little safe	Fairly Safe	Very Safe	
Type of motorist	Bicyclist	Count	5	13	7	11	36
		% within Type of motorist	13.9%	36.1%	19.4%	30.6%	100.0%
	Pedestrians	Count	10	24	19	16	69
		% within Type of motorist	14.5%	34.8%	27.5%	23.2%	100.0%
	Drivers	Count	12	22	31	27	92
		% within Type of motorist	13.0%	23.9%	33.7%	29.3%	100.0%
Total		Count	27	59	57	54	197
		% of Total	13.7%	29.9%	28.9%	27.4%	100.0%

Table A-21: Perception of Safety in East Lansing

			How safe do you feel with interaction with non-motorized traffic?				Total
			Not at all safe	A little safe	Fairly Safe	Very Safe	
Type of motorist	Bicyclist	Count	0	7	36	18	61
		% within Type of motorist	0.0%	11.5%	59.0%	29.5%	100.0%
	Pedestrians	Count	4	5	53	24	86
		% within Type of motorist	4.7%	5.8%	61.6%	27.9%	100.0%
	Drivers	Count	5	16	53	24	98
		% within Type of motorist	5.1%	16.3%	54.1%	24.5%	100.0%
Total		Count	9	28	142	66	245
		% of Total	3.7%	11.4%	58.0%	26.9%	100.0%

Appendix 7: Countermeasures (PBCAT)

Objective	Pedestrian Facility Design	Roadway Design	Intersection Design	Traffic Calming	Traffic Management	Signals and Signs	Other Measures
1. Reduce Speed of Motor Vehicles	●	●	●	●		●	●
2. Improve Sight Distance and Visibility for Motor Vehicles and Pedestrians	●	●		●		●	
3. Reduce Volume of Motor Vehicles		●		●	●		
4. Reduce Exposure for Pedestrians	●	●		●		●	
5. Improve Pedestrian Access and Mobility	●	●		●		●	
6. Encourage Walking by Improving Aesthetics	●	●		●			●
7. Improve Compliance With Traffic Laws			●	●			●
8. Eliminate Behaviors That Lead to Crashes			●	●		●	●

Figure A-22 Pedestrian Performance Objective Matrix

Objective	Shared Roadway	On-Road Bike Facilities	Intersection Treatments	Maintenance	Traffic Calming	Trails/Shared-Use Paths	Markings, Signs, Signals	Education and Enforcement	Support Facilities and Programs
1. Provide safe on-street facilities/space for bicyclists.	●	●		●	●		●	●	●
2. Provide off-road paths or trails for bicyclists.				●		●	●	●	●
3. Provide and maintain quality surfaces for bicyclists.	●			●			●	●	
4. Provide safe intersections for bicyclists.	●		●		●	●	●	●	
5. Improve motorist behavior/ compliance with traffic laws.	●		●	●	●		●	●	●
6. Improve bicyclist behavior/ compliance with traffic laws.	●	●	●	●	●	●	●	●	●
7. Encourage and promote bicycling.	●	●		●		●	●	●	●

Figure A-23 Bicyclist Performance Objective Matrix

Crash Group	Pedestrian Facility Design	Roadway Design	Intersection Design	Traffic Calming	Traffic Management	Signals and Signs	Other Measures
1. Dart/Dash	•	•		•	•	•	•
2. Multiple Threat/Trapped	•	•	•	•		•	•
3. Unique Midblock	•	•		•		•	•
4. Through Vehicle at Unsignalized Location	•	•	•	•	•	•	•
5. Bus-Related	•	•		•		•	•
6. Turning Vehicle	•	•	•	•	•	•	•
7. Through Vehicle at Signalized Location	•	•	•	•	•	•	•
8. Walking Along Roadway	•	•				•	•
9. Working or Playing in Roadway	•	•		•	•	•	•
10. Non-Roadway	•	•		•		•	•
11. Backing Vehicle	•	•		•			•
12. Crossing an Expressway	•					•	•

(Countermeasures)

Figure A-24 Pedestrian Crash-typing Matrix

Crash Group	Shared Roadway	On-Road Bike Facilities	Intersection Treatments	Maintenance	Traffic Calming	Trails/Shared-Use Paths	Markings, Signs, Signals	Education and Enforcement
1. Motorist failed to yield – signalized intersection	•		•		•	•	•	•
2. Motorist failed to yield – non-signalized intersection	•		•		•	•	•	•
3. Bicyclist failed to yield – signalized intersection	•		•		•	•	•	•
4. Bicyclist failed to yield – non-signalized intersection	•		•		•	•	•	•
5. Motorist drove out – midblock	•					•	•	•
6. Bicyclist rode out – midblock	•				•	•	•	•
7. Motorist turned or merged left into path of bicyclist	•	•	•		•	•	•	•
8. Motorist turned or merged right into path of bicyclist	•	•	•		•	•	•	•
9. Bicyclist turned or merged left into path of motorist	•		•	•	•	•	•	•
10. Bicyclist turned or merged right into path of motorist	•	•	•	•	•	•	•	•
11. Motorist overtaking bicyclist	•	•		•	•	•	•	•
12. Bicyclist overtaking motorist	•	•		•		•	•	•
13. Non-motor vehicle crashes	•			•		•	•	•

(Countermeasure Group)

Figure A-25 Bicyclist Crash-typing Matrix