Utilizing multiple data sources in the preparation of a Vision Zero Plan for the City of Alexandria

Image source: VisitAlexandria

SUBMITTED BY:

SHUBHA PUNASE

Guided by:
Dr. Ralph Buehler
Mr. Steven Chozick
Dr. Elizabeth Morton

SPIA, Virginia Tech – National Capital Region
Alexandria, Virginia MURP

VirginiaTech
National Capital Region

SPIA Virginia Tech School of Public and International Affairs

UTILIZING MULTIPLE DATA SOURCES IN THE PREPARATION OF A VISION ZERO PLAN FOR THE CITY OF ALEXANDRIA

INVESTIGATING THE RELATIONSHIP BETWEEN TRANSPORTATION INFRASTRUCTURE, SOCIO-ECONOMIC CHARACTERISTICS, AND CRASH OUTCOMES IN THE CITY

December 2016

Submitted by Shubha Punase
shubhap@vt.edu

For the partial fulfillment
of Masters in Urban and Regional Planning (MURPL)
School of Public and International Affairs, Virginia Tech - National Capital Region, Alexandria Center, 1021 Prince Street, Alexandria, VA 22314

Guided by
Dr. Ralph Buehler, Associate Professor in Urban Affairs and Planning, School of Public and International Affairs, Virginia Tech- National Capital Region, Alexandria Center, 1021 Prince Street, Suite 200, Alexandria, VA 22314
ralphbu@vt.edu

Mr. Steven Chozick, Visiting Professor in Urban Affairs and Planning, School of Public and International Affairs, Virginia Tech - National Capital Region, Alexandria Center, 1021 Prince Street, Alexandria, VA 22314
Division Chief, Emerging Technologies & Advanced Analytics, City of Alexandria, 123 N Pitt St., Alexandria, VA 22314
schozick@vt.edu; steven.chozick@alexandriava.gov

Dr. Elizabeth Morton, Associate Director for Urban Design Initiatives, School of Public and International Affairs, Professor of Practice, Urban Affairs and Planning, Virginia Tech - National Capital Region, Alexandria Center, 1021 Prince Street, Suite 200, Alexandria, VA 22314
ElizabethMorton@vt.edu

Dedicated to my parents Sukla & Amalendu Bikas Parial and sister Swati Parial, who are the pillars of strength in my life, and inspire me to work consistently towards achieving greater heights. I also dedicate this to my husband Rahul and my son Shourya, who have been supportive throughout my master's program.

Acknowledgements

I sincerely thank my capstone committee, Dr, Ralph Buehler, Mr. Steven Chozick, and Dr. Elizabeth Morton, for guiding me through the capstone project. I especially thank Mr. Steven Chozick, GIS Division Chief, City of Alexandria, for allowing me to use the data and resources at City's GIS Division for this project. I am grateful to Ms. Hillary Orr, Complete Streets Manager, City of Alexandria, for providing me the opportunity to work on this project and for helping me get the crucial crash data for the analysis. I also thank Ms. Heather Reynolds, Mr. Philip Antonucci, Mr. Tim Kyburz, and Ms. Erica L. Bennett, at the Alexandria Police Department (APD), who graciously provided the individual crash reports for the analysis. Special thanks to my friend, Ranjana Guha, for her help with this complex project. Lastly, I thank my colleagues Ms. Corinna Nowak, Mr. Michael Smith, and Mr. Jimmy Bryant, at City's GIS Division, for their help.

Abstract

"Vision Zero," first adopted by Sweden in 1997, is a road safety policy that aims to achieve a transportation system having zero fatalities or serious injuries for all modes of transportation. It takes a proactive approach to road safety system by identifying risk and taking steps to prevent injuries. Historically, traffic related crashes have disproportionately impacted vulnerable communities and system users including people of color, low income individuals, seniors, children, and pedestrians, bicyclists, and transit users (who typically walk to and from public transport). These inequities are addressed in the Vision Zero framework by prioritizing interventions in areas that need safety improvements the most.

In 2016, the Alexandria City Council voted unanimously to develop a "Vision Zero" policy and program as a part of its updated transportation master plan. It required an initial equity analysis to assess the impact of traffic crashes on the traditionally underserved communities / groups (groups from atleast one of these categories: low-income; minority; elderly; children; limited English proficiency; persons with disabilities; and/or pedestrians/ bicyclists/ transit users). This study combines three different methods to investigate the equity issues regarding traffic safety: 1) descriptive analysis of the spatial pattern of crashes and their relationship with the demographic profiles of neighborhoods at census block group level (for 2010-2014 period); 2) descriptive analysis of the crash trends in Alexandria; and 3) exploratory regression analyses for two different units of analysis (an aggregate regression analysis of crashes at census block group, and a disaggregate regression analysis of the individual level crash reports of traffic crashes). The analysis found that the elderly, school aged children, rail/subway users, and pedestrians had a higher risk of fatalities and severe injuries in traffic crashes. Higher job densities, alcohol impairment, and speeding were significantly related to higher KSI, whereas, smaller block sizes (higher number of street segments per sq. mile area of census block group), higher housing density, and use of safety equipment were related to lower KSI.

TABLE OF CONTENTS

LIST OF MAPS (MAIN REPORT)

LIST OF CHARTS (MAIN REPORT)

LIST OF TABLES (MAIN REPORT)

Utilizing Multiple Data Sources In The Preparation Of A Vision Zero Plan For The City Of Alexandria: Investigating The Relationship Between Transportation Infrastructure, Socio-Economic Characteristics, And Crash Outcomes In The City

I. Introduction

In 2016, City of Alexandria passed a bill to move forward with the "Vision Zero Plan." "Vision Zero," first adopted by Sweden in 1997, is a road safety policy that aims to achieve a transportation system having zero fatalities or serious injuries for all modes of transportation (Fleisher, 2015). It takes a proactive approach to road safety system by identifying risk and taking steps to prevent injuries (Vision Zero Network, 2016; Fleisher, 2015). There are two major guiding factors in the Vision Zero framework: 1) People will make mistakes no matter how well-educated and compliant they are in obeying traffic laws. Although, the traditional approach to safety immediately places the responsibility of safety on the road users (bad drivers, careless bicyclists, distracted pedestrians), the vision zero framework focuses on the road safety analysis and planning to eliminate the risks that can cause severe injuries and fatalities due to crashes; 2) It is known that the chances of survival or recovery from an injury diminishes after a critical point. Thus, the vision zero framework focuses on decreasing the likelihood of fatal crashes or severe injuries by designing the transportation system in a way that prevents high impact crashes (Fleisher, 2015).

Historically, traffic related crashes have disproportionately impacted vulnerable communities and system users. (Vision Zero Network, 2016). These inequities are addressed in the Vision Zero framework by prioritizing interventions in areas that need safety improvements the most. Thus, the Alexandria Vision Zero Plan required an initial equity analysis to assess the impact of traffic crashes on the traditionally underserved communities / groups (groups from atleast one of these categories: low-income; minority;

elderly; children; limited English proficiency; persons with disabilities; and/or pedestrians/ bicyclists/ transit users). This paper aims to investigate the factors that are influencing killings (fatalities) and severe injuries (KSI) in Alexandria, and identify the vulnerable communities (demographics)/system users (bus/rail/subway users, bicyclist, and pedestrians) that are disproportionately impacted by them.

II. Framework for identifying "Social Inequity"

"Social equity" entails elimination of any form of disproportionate impact on communities and/or system users identified as vulnerable. Historically, low income individuals, people of color, seniors, children, and/or pedestrians/ bicyclists/ transit users have been identified as the vulnerable groups disproportionately impacted by traffic related crashes (Vision Zero Network, 2016). To identify equity issues in Alexandria, this paper first examines the historical pattern of crashes and injuries in the city to identify the intersection of high frequency of killings (fatalities) and severe injuries (KSI), and vulnerable communities/groups. Then, it uses an exploratory regression analysis of crash data to reveal the magnitude of impact on each group in terms of KSI occurrence. However, these vulnerable

Equity in transportation is well-defined and elaborated by Sandt et al. (2016):

> "Equity in transportation seeks fairness in mobility and accessibility to meet the needs of all community members. A central goal of transportation equity is to facilitate social and economic opportunities through equitable levels of access to affordable and reliable transportation options based on the needs of the populations being served, particularly populations that are traditionally underserved. Traditionally underserved groups include individuals in at least one of the following categories: Low Income, Minority, Elderly, Limited English Proficiency, or Persons with Disabilities. An equitable transportation plan considers the unique circumstances impacting various community members' mobility and connectivity needs and uses this information to determine appropriate amount of resources to allocate to different people and places so that the transportation network more effectively serves all members."

communities/groups are not completely exclusive of each other. For example, income, race, and transportation mode choice of a person could be highly correlated. Moreover, the geographic location of a person could depend on all these aspects, as well. Individuals within each group also have different levels of vulnerabilities that could impact them more or less in an event of traffic related injuries. For example, when exposed to the same amount of risk, a low-income pedestrian may face a higher impact of KSI as opposed to a high-income pedestrian -- as the economic and social costs in the event of severe injury or death may be much more difficult to overcome for a low-income individual. This paper carefully examines these correlations, and considers them for the equity analysis of traffic crashes in Alexandria.

III. Previous research

Previous studies in safety analysis have investigated the relationships between crashes and various factors influencing them. These findings provide the background for this research and analysis.

A. Previous research methods

Previous studies in traffic safety have utilized a variety of methods for analysis. For spatial units, most of the conventional studies grouped crashes in spatial units that range from the individual intersection or road section level, to the zip code or county level (e.g. Amoros et al., 2003; Miaou et al., 2003; Noland and Oh, 2004; Noland and Quddus, 2004; MacNab, 2004). Crash outcomes for assessing the road safety also varied: injuries; injury severity; and crashes (collisions and/or falls) (Reynolds, 2009). Crash modeling deferred too – some considering them as disaggregate point events (e.g. Levine et al., 1995; Jones et al., 1996) while others aggregated them at different levels ranging from road sections to local census tracts or counties (e.g. Shankar et al., 1995; Amoros et al., 2003; Miaou et al., 2003; Noland and Oh, 2004; MacNab, 2004). However, the major limitation of these studies is the use of proxy variables for traffic flow estimation and the lack of spatial correlation analysis.

Individual crash level approach

The individual crash level approach in traffic safety analysis is helpful in identifying the actual impact of a crash outcome on the individuals involved in a crash incident with respect to their demographic characteristics. This approach involves considering each crash as a unit of analysis (Golob et al., 2004a). Numerous researchers have already applied this approach by associating crash injury severity with driver and roadway characteristics (Abdel-Aty, 2003; Abdel-Aty & Abdelwahab, 2000; Duncan, Khattak, & Council, 1998; Abdel-Aty & Pande, 2007).

B. Previous research on equity in traffic crashes

i. Crash frequency

a. Demographic factors

Very few previous studies have specifically conducted an "equity analysis" to investigate the relationship between crash related injuries and vulnerable communities. However, many road safety studies do provide evidence that the demographic characteristics of the communities and injured person have been important predictors of crash injuries and severities (Eluru & Bhat, 2007; Shariat-Mohaymany et al., 2015; Schneider, et al., 2010; Romano, et al., 2012; Davison et al., 2013). For crash location based studies, regions that were more impoverished (Aguero-Valverde and Jovanis, 2006) and low-income (Huang et al., 2010) showed a higher number of traffic related crashes. Also, regions with a higher ratio of elderly population (aged 75 years or older) showed a lower number of traffic crashes (Karim et al., 2013; Huang et al., 2010; Noland and Quddus, 2004; Aguero-Valverde and Jovanis, 2006).

The characteristics and behavior of individuals involved in a crash incident have also shown relationship with crash incidence and frequencies in many older and recent studies. Gender and age of individuals were found significant in large number of studies (Karim et al., 2013; Bose et al., 2011; Huang et al., 2010; Quddus, 2008; Noland and Quddus, 2004; LaScala et al., 2004; Aguero-Valverde and Jovanis, 2006). Higher Vehicular Miles Traveled (VMT) by an individual, which is also reflective of driving as the primary mode of commuting, was found to increase the risk of crash occurrences in individuals (Aguero-Valverde & Jovanis, 2006; Qin et al., 2013).

b. Non-demographic factors

Previous traffic safety studies highlight various spatial characteristics of the built environment and crash circumstances significant in predicting crash frequencies. The spatial attributes -- built form, street pattern, and transportation infrastructure (signal density, presence of sidewalks, buffers between the road and the sidewalk, shoulder width, pavement conditions, street lighting, number of travel lanes, presence of medians, traffic controls at intersections, and posted speed limits) -- were found significant in many previous studies (Eluru & Bhat, 2007; Shariat-Mohaymany et al., 2015; Schneider, et al., 2010; Ouyang & Bejleri, 2014; Marshall & Garrick, 2011; Hanson, et al., 2013; Rodríguez et al., 2015; Qin, et al., 2013). Land use (Ouyang & Bejleri, 2014), intersection characteristics (Eluru & Bhat, 2007; Rifaat, et al., 2011), and vehicle characteristics (Eluru & Bhat, 2007; Rifaat, et al., 2011) were also important factors. Variables that reflect exposure, e.g., annual average daily travel (Venkataraman et al., 2013) and vehicle-miles traveled (VMT) (de Guevara et al., 2004; Aguero-Valverde and Jovanis, 2006; Hadayeghi et al., 2003; Karlaftis and Tarko, 1998; Quddus, 2008), were positively associated with traffic crash frequency. Crash occurrence increased with road length (Levine et al., 1995; de Guevara et al.,2004; Aguero-Valverde and Jovanis, 2006; Hadayeghi et al., 2003; Karlaftis and Tarko, 1998; Quddus, 2008; Venkataraman et al., 2014b), whereas, crash frequency increased in areas with higher population density (de Guevara et al., 2004; Levine et al., 1995; Hadayeghi et al., 2003) and greater pedestrian exposure (Lam et al., 2013; Rhee et al., 2016). Moreover, higher traffic signal density and annual average daily traffic (AADT) occupancy ratios of trucks showed an increase in number of crashes (Huang et al., 2010; Siddiqui et al., 2012; Rhee et al., 2016), as well. Street pattern characteristics that were significant in previous studies included grid-iron and mixed patterns (Rifaat, et al., 2011). Crash characteristics (Hasselberg, et al., 2005) and weather/environmental conditions (Rifaat, et al., 2011; Aguero-Valverde & Jovanis, 2006; Romano, et al., 2012) were also significant in predicting crash occurrence.

ii. Crash outcomes - fatal and severe injuries

Previous studies indicate that various factors found significant in predicting increased severe injuries and fatalities in traffic related crashes bear a different relationship from their prediction of crash frequencies. Different units of analysis, like intersections, census block group, etc., were used to find the relationship between them. Since, a traffic collision involving pedestrians results in higher injury severity, the variables found significant in predicting pedestrian crashes are also included in this section.

a. Demographic factors

Demographic characteristics that were significant in predicting crash outcomes in previous studies include: population density; age; income; and employment rate. Contrary to the crash frequency, densely populated regions reduce the proportion of severe injury involving crashes (Noland and Quddus, 2004). However, another study contradicts this, where, increase in population density showed an increase in fatal crashes at census block group level (Ouyang & Bejleri, 2014). CBGs with a higher ratio of population aged 75 years or older showed an increase in the number of fatalities associated with crashes, as opposed to the lower crash frequencies associated with this demographic characteristic at a census block group level (Karim et al., 2013; Huang et al., 2010; Aguero-Valverde and Jovanis, 2006; Noland and Quddus, 2004). Studies indicate that crash frequency involving pedestrians are lower in areas with high income levels and high unemployment rates (Noland and Quddus, 2004; Quddus, 2008; LaScala et al., 2004), and higher in areas with lower income level (Loukaitou-Sideris et al., 2007). Also, they were more frequent in areas with higher density of young adult population and at intersections within ¼ mile of areas with higher percentage of residents below 18 years (Schneider et al., 2010).

b. Non-demographic factors

Various non-demographic factors that showed relationship with severe and fatal injuries include land use, traffic exposure, transportation infrastructure and facilities, intersection characteristics and individual's behavior. In CBGs, crashes occurring closer to commercial sites increased severe and fatal injuries, whereas, higher housing and job density reduced it (Ouyang & Bejleri, 2014). However, the CBGs with higher job density also showed an increase in pedestrian crashes that usually leads to severe or fatal injuries in a crash incident (Ouyang & Bejleri, 2014). CBGs with higher land use mix increased the severe and fatal injury outcomes of crash incidents. For intersection studies, pedestrian crash frequency was higher at intersections within 0.1 mile of commercial properties (Schneider et al., 2010), and with higher number of residential driveways within 50 feet of the intersections (Schneider et al., 2010).

Traffic congestion was found to be associated with reduced crash severity in previous studies. Both higher degree of urbanization (Noland and Quddus, 2004), and higher traffic volume to capacity ratio of streets reduced crash severity (Hadayeghi et al., 2003).

Transportation infrastructure and facilities, street pattern, and intersection characteristics also show strong relationships with injury severities caused by traffic crashes. In CBGs, crashes closer to bus stops increased all types of crash injuries, whereas, increase in number of intersections reduced them (Ouyang & Bejleri, 2014). In addition, CBGs with higher number of road segments and bus stops show increased pedestrian and fatal crash frequencies (Ouyang & Bejleri, 2014). Improving road geometrics is recommended in many studies for reducing fatalities (Noland, 2003; Noland and Quddus, 2004; Noland and Oh, 2004; Venkataraman et al., 2011). Intersection characteristics of more right turn lanes increased pedestrian crashes, whereas, raised medians on both intersecting streets reduced them (Schneider et al., 2010).

Individuals' risk-taking behavior of speeding (Møller & Haustein, 2014; Fernandes, R. et al., 2010), driving under alcohol influence (Fergusson et al., 2003; Turner & McClure 2010; Fernandes, R. et al., 2010), and not using the safety equipment (Fernandes, R. et al., 2010) also related to higher crash injury severities.

Finally, traffic safety studies provide crash occurrences as well as outcomes either as crash rates (total crashes per vehicle miles travelled) or total number of crashes occurring in a spatial unit of aggregation. This should be carefully considered while interpreting the relationships presented in these studies.

Table 1 provides a summary of the previous literature for the factors influencing crash severity.

Table 1. Literature review summary of variables influencing crash severity in traffic crashes

Variables	Effect	Variables	Effect
<u>Demographic / Socio-economic</u>		<u>Physical</u>	
Density		*Land use*	
• Population density	↓	• Crashes closer to commercial sites (at census block group level)	↑
Age		• Increase in proportion of land use mix (at census block group)	↑
▪ Higher ratio of population aged 75 years or older	↑	• More residential driveways within 50 feet (of intersections)	↑
▪ Higher young adult population density	↑	• Increase in housing density (at census block group level)	↓
▪ Greater percentage of residents younger than age 18 yrs within 0.25 mile (near intersections)	↑	• Increase in job density (at census block group level)	↓ ↑
Income		• More commercial properties within 0.1 mile (of intersections)	↑
▪ Regions with higher income levels	↓	*Traffic congestion*	
▪ Regions with lower income levels	↓	• Higher degree of urbanization	↓
		• Higher street volume to capacity ratio	↓
<u>Physical</u>		<u>Individual's behavior</u>	
Transportation infrastructure & facilities		*Risk taking*	
• Increase in the number of road segments (at census block group)	↑	• Speeding	↑
• Road geometrics	↓	• Alcohol use	↑
• Pedestrian exposure	↑	• Not using safety equipment (seat belt, helmet, etc.)	↑
• Higher number of bus stops (at census block group)	↑		
• Crash occurring closer to bus stops (at census block group)	↓		
• Increase in number of intersections (at census block group)	↓		
		Increase in injury severity	↑
		Reduction in injury severity	↓

Table 2. Summary of variables influencing crash severity in traffic crashes from previous studies

FACTORS	CRASH SEVERITY	RELATIONSHIP	REFERENCE
DEMOGRAPHIC/ SOCIO-ECONOMIC			
DENSITY	Low population density	Higher ratio of crashes with severe injuries; lower fatal and pedestrian crashes.	Noland and Quddus, 2004; Ouyang & Bejleri, 2014
AGE	Higher ratio of population aged 75 years or older	Increase in casualties	Karim et al., 2013; Huang et al., 2010; Noland and Quddus, 2004; Aguero-Valverde and Jovanis, 2006
	Young adult population density	Higher frequency of pedestrian crashes	Noland and Quddus, 2004; Quddus, 2008; LaScala et al., 2004
INCOME	Regions with high income levels	Lower frequency of pedestrian crashes	Noland and Quddus, 2004; Quddus, 2008; LaScala et al., 2004
	Regions with lower income levels	Lower risk of pedestrian crashes	Loukaitou-Sideris et al., 2007
PHYSICAL			
LAND USE			
	Increase in proportion of land use mix (at census block group)	Increases all types of crashes and pedestrian crashes	Ouyang & Bejleri, 2014
	Increase in housing density	Reduces severe, fatal, and pedestrian crashes	Ouyang & Bejleri, 2014
	Increase in job density	Reduces severe and fatal crashes, and increases pedestrian crashes	Ouyang & Bejleri, 2014
TRAFFIC CONGESTION	Higher degree of urbanization	Reduces crash severity	Noland and Quddus, 2004
	Higher street volume to capacity ratio	Reduces crash severity	Hadayeghi et al., 2003
TRANSPORTATION INFRASTRUCTURE & FACILITIES	Increase in the number of road segments (at census block group)	Increases all types of crashes	Ouyang & Bejleri, 2014
	Pedestrian exposure	Higher crash frequency in dense urban areas	Lam et al., 2013
	Higher number of bus stops at a census block group	Increases all types of crashes	Ouyang & Bejleri, 2014
	Crashes that were closer to bus stops (at census block group level)	Decreased all types of crash injuries	Ouyang & Bejleri, 2014
	Increase in number of intersections at census block group	Decreased all types of crashes	Ouyang & Bejleri, 2014
INDIVIDUAL'S CHARACTERISTICS			
INDIVIDUAL'S BEHAVIOUR	Speeding	Increases crash severity	Møller & Haustein, 2014; Fernandes, R. et al., 2010
	Alcohol use	Increases crash severity	Fergusson et al., 2003; Turner & McClure 2010; Fernandes, R. et al., 2010
	Not using safety equipment (seat belt, helmet, etc.)	Increases crash severity	Fernandes, R. et al., 2010

C. Previous research guiding Alexandria's equity analysis

This study adopts various research methods and the significant variables associated with crash outcomes (fatality and severe injury) in previous research for the equity analysis of Alexandria's traffic crashes. Previous studies on road safety have used variables related to neighborhood demographic characteristics (for example, percentage of high-income groups, percent of elderly, etc.) to understand the relationship between these characteristics and the crash outcomes. Similar demographic representation of the vulnerable groups (percent of minorities, percent of elderly, percent of pedestrians, and percent of low income groups) is used in this analysis to understand the relationship between a specific community and the impact of crash outcomes. Here, the higher number of killed and severely injured (KSI) in a neighborhood is the measure of higher risk. Whereas, the intersection of high-risk / high-risk neighborhood locations and vulnerable individual / higher concentrations of vulnerable communities would represent "inequities."

For the scale, a community level unit of analysis (census block group) is used in this study. Performing the analysis at a community level can help inform decisions of planning, design, and development in jurisdictions, as most of the densities, urban design, and land-use mix are relevant at this scale for planning purposes. Moreover, this scale is also mostly aligned with the planned unit developments or urban redevelopment or station area land use planning initiatives (Ouyang & Bejleri, 2014). Most spot or regional level traffic safety analyses lead to primary safety interventions directed to either spot-level engineering improvements, or regional level education and law enforcement campaigns (Dumbaugh et al., 2011). This scale of analysis often fails to address the importance of community scale designs in improving safety (Marshall et al., 2011). The US Census Bureau 2014 American Community Survey (ACS) data (5-year estimates) is used for this analysis which provides the most current data for the demographic makeup of cities, and with the least margins of errors among other ACS estimates.

In addition to community level analysis, previous studies also show that the individual crash level or disaggregate analysis (Porter, 2011) of crash data provide insights to the relationship between crash injury severity and individuals involved in a crash. This form of analysis utilizes an individual's information, for example – place of origin (home address); gender; age; education; income; and race – to investigate relationships between individuals' characteristics, and the outcomes of crashes they were involved in. Results might differ from the community/neighborhood level results that are derived from an aggregate analysis, which draws conclusions from the aggregated data of crashes at census block groups. For example, in an aggregate analysis of crashes, higher concentrations of low-income neighborhoods might show a disproportionately higher impact of crashes due to higher injuries and fatalities. This might not be the case in disaggregate analysis as most injuries might be sustained by individuals travelling from outside the city limits. Hence, using a disaggregate analysis would help to identify the actual disproportionate impact of traffic injuries on the traditionally underserved communities of concern.

IV. Research design

This study integrates a variety of tools and various scales of analysis to identify the relationships between KSI and vulnerable communities/groups in Alexandria. It initially looks at the spatial pattern of KSI at census block groups and the traffic crash trends in the city. This section uses descriptive analysis to identify the potential inequities for the traditional communities of concern, like low-income groups, minorities, elderly, and pedestrian/bicyclist/transit users in the city. The descriptive analysis of the spatial pattern of crashes uses ArcGIS to visualize spatial relationships, and the crash trend analysis utilizes data visualization with pivot charts to guide its descriptive analysis. This is followed by two different regression analyses to measure the risk of KSI for vulnerable communities/groups at two different scales – at the census block group (aggregate analysis) and the individual crash incidents (disaggregate analysis) -- using ArcGIS and the statistical software tool, Stata.

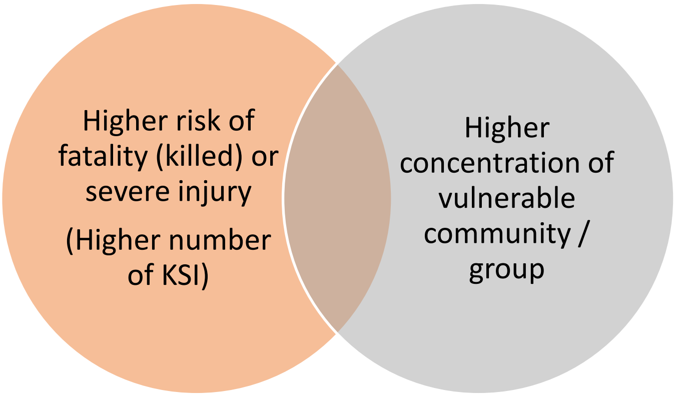


Figure 1. Intersection of higher risk of fatality (killed) or severe injury (KSI) in a traffic crash and higher concentration of vulnerable communities would identify inequities in this study.

V. Data

A. Source

Crash data for this analysis was provided by the Alexandria Police Department (APD) and City's Transportation and Environmental Services (T&ES), in September 2016. This includes crash reports with the details of individuals involved in a crash for the span of 2010–2014. This data was utilized for both the aggregate and disaggregate analyses. For the details of traditionally underserved communities/groups, the 2014 Census American Community Survey (ACS) profiles (5-year estimates from 2010-2014) for City's the 106 census block groups was provided by the GIS division (Table 3). Data for other control variables were also provided by the GIS division which included -- streets, signalized intersections, metro stations, bus stops, bus route, and premises.

Table 3. Details of original data used for analysis

DATA	TYPE/FORMAT	DATE	SOURCE	TOTAL OBSERVATIONS	UNIT OF ANALYSIS
CRASH REPORTS					
Crash report	Crash reports with details of all individuals involved	2010-2014	Alexandria Police Department (APD)		Census block group level; individual level
AMERICAN COMMUNITY SURVEY (ACS) PROFILES					
Population/ age	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
Race	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
Sex	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
Income	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
Means of transportation to work	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
Poverty	GIS layer	2014	GIS Division, City of Alexandria	106	Census block group level
SPATIAL					
Streets	GIS layer	N/A	GIS Division, City of Alexandria	N/A	Census block group level

DATA	TYPE/FORMAT	DATE	SOURCE	TOTAL OBSERVATIONS	UNIT OF ANALYSIS
Address locator	Locator	N/A	GIS Division, City of Alexandria	N/A	N/A
Bus stop	GIS layer	N/A	GIS Division, City of Alexandria	N/A	Census block group level
Bus route	GIS layer	N/A	GIS Division, City of Alexandria	N/A	Census block group level
Metro station	GIS layer	N/A	GIS Division, City of Alexandria	N/A	Census block group level
Premises (addresses)	GIS layer	N/A	GIS Division, City of Alexandria	N/A	Census block group level

B. Data cleanup, manipulation, and interpretation

The crash data reports (23,112 entries) for the five-year span (2010-2014) (which contained details of all individuals involved in a crash incident) was the foundation of this research. This data was carefully cleaned to remove errors in crash locations, and by making street and intersection addresses consistent throughout. The individual level crash data was then manipulated using the computer software Stata to create separate variables for each factor found significant in injury severity or fatality from previous studies. A detailed summary of these factors with their respective fields, interpretation, and recoding is provided in Appendix – Section C Table 2 of this report. This data was then used for the descriptive analysis (DA) of crash trends, and the individual level disaggregate regression analysis (DRA).

To get the crash level data, each of these individual level entries (23,112) were aggregated to their crash (incident) level using Stata for the descriptive analysis (DA) of crash trends. These individual crashes (8,062 incidents) were then geocoded in ArcGIS to locate them on the Alexandria map for the descriptive analysis (DA) of spatial pattern of crash data (as point densities). These crashes were further aggregated at the census block group level (in Stata) for the descriptive analysis (DA) of spatial pattern of crash data at census block group (CBG) level and aggregate regression analysis (ARA) at the CBG level. (Figure 2)

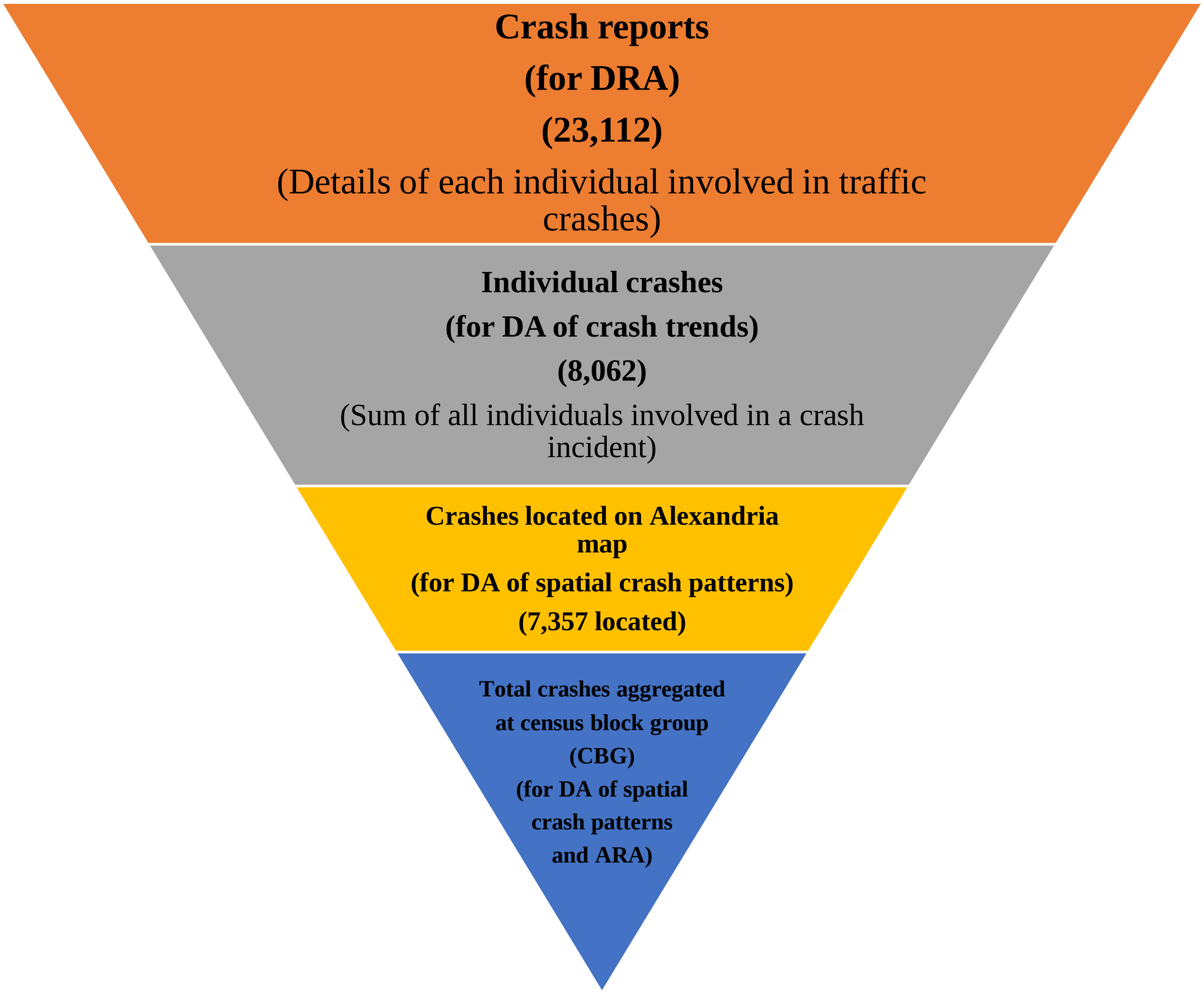
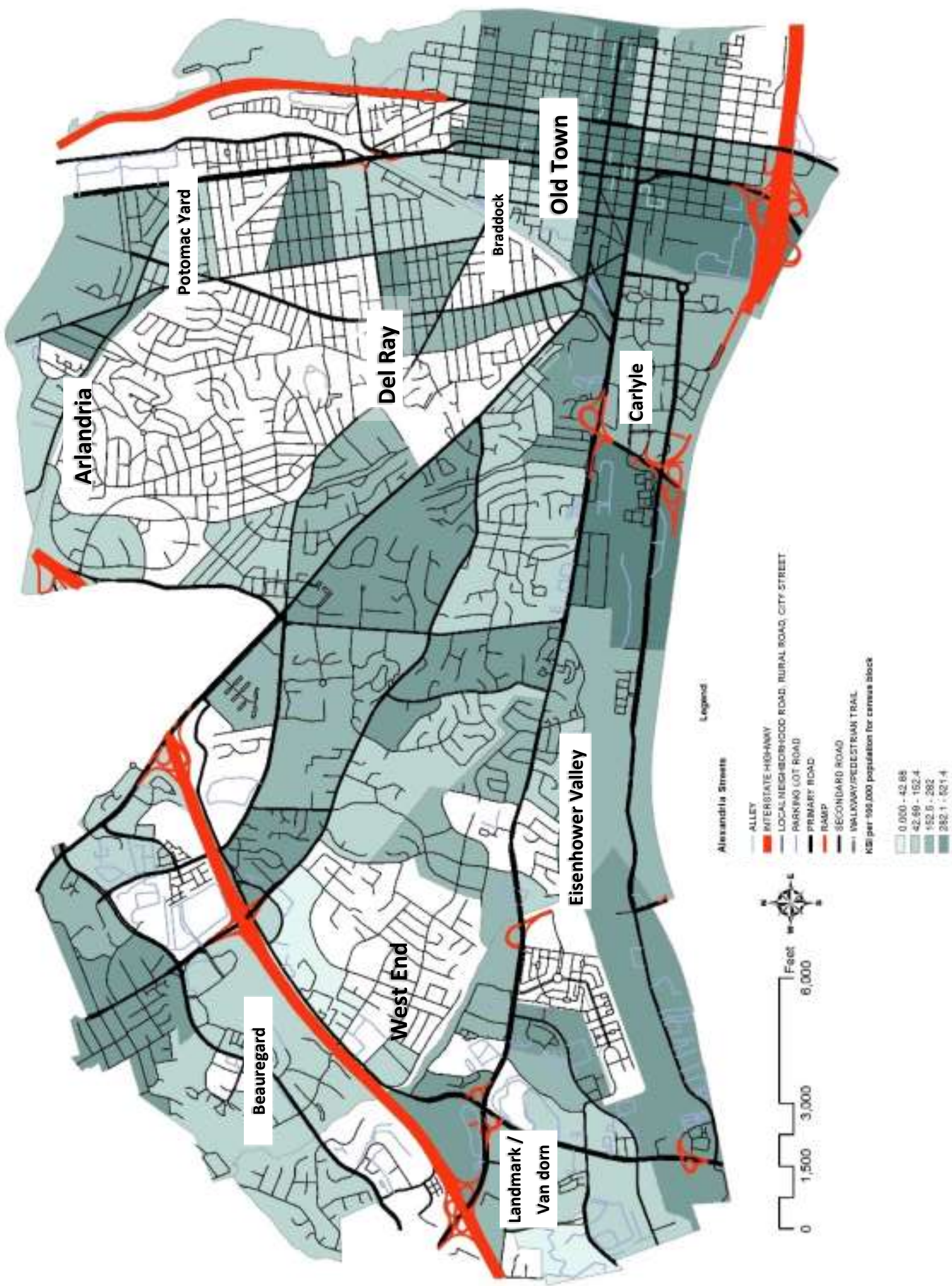


Figure 2. Steps involved in the manipulation of crash data for descriptive analysis (DA), aggregate regression analysis (ARA) and disaggregate regression analysis (DRA)



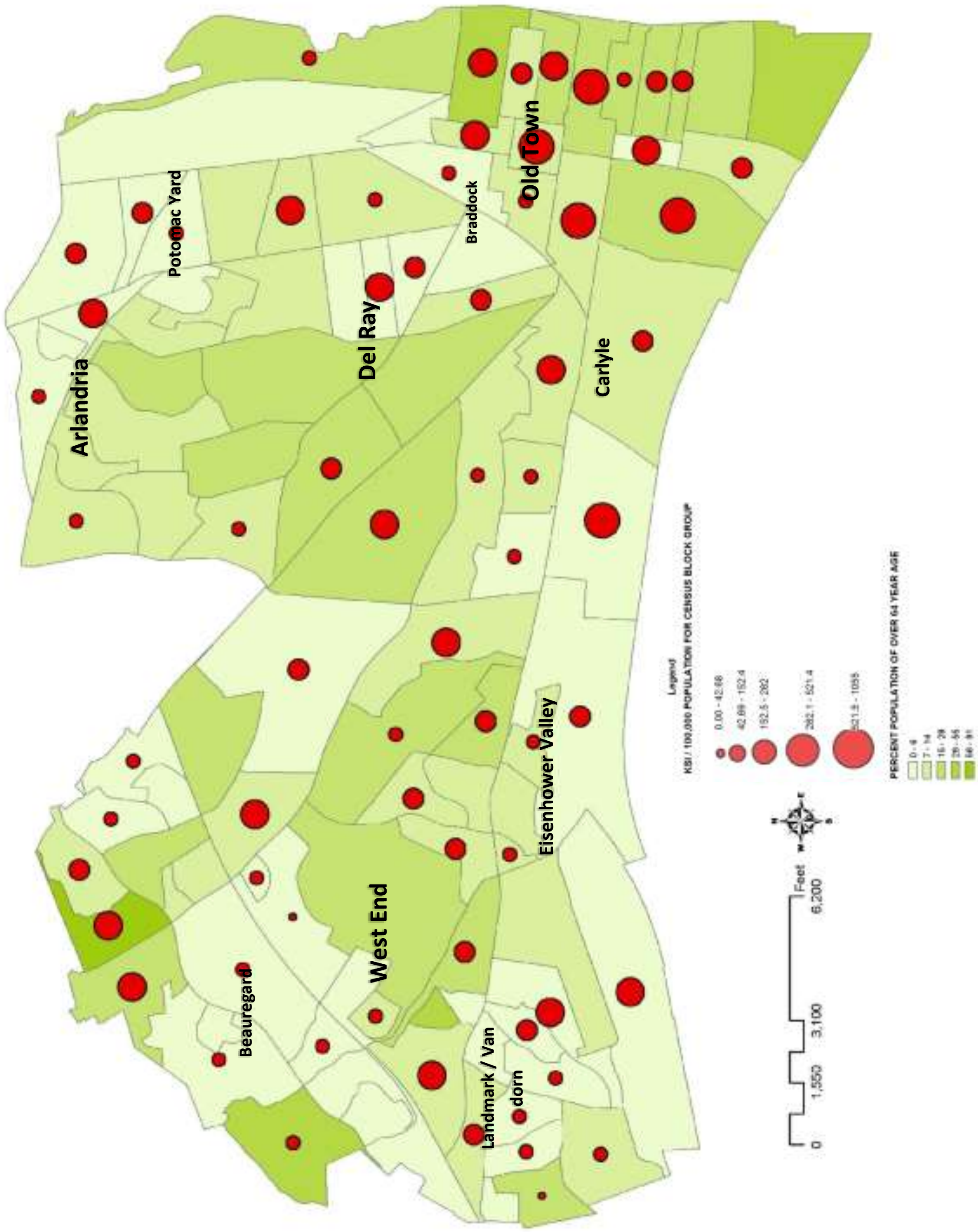
Map 1. KSI involving crashes per 100,000 population aggregated at each census block group level (2010-2014) (Source: APD, City of Alexandria, Virginia). The darker colors represent higher number of KSI involving crashes per 100,000 population (for each census block groups) for the five-year period of 2010-2014.

VI. Methodology

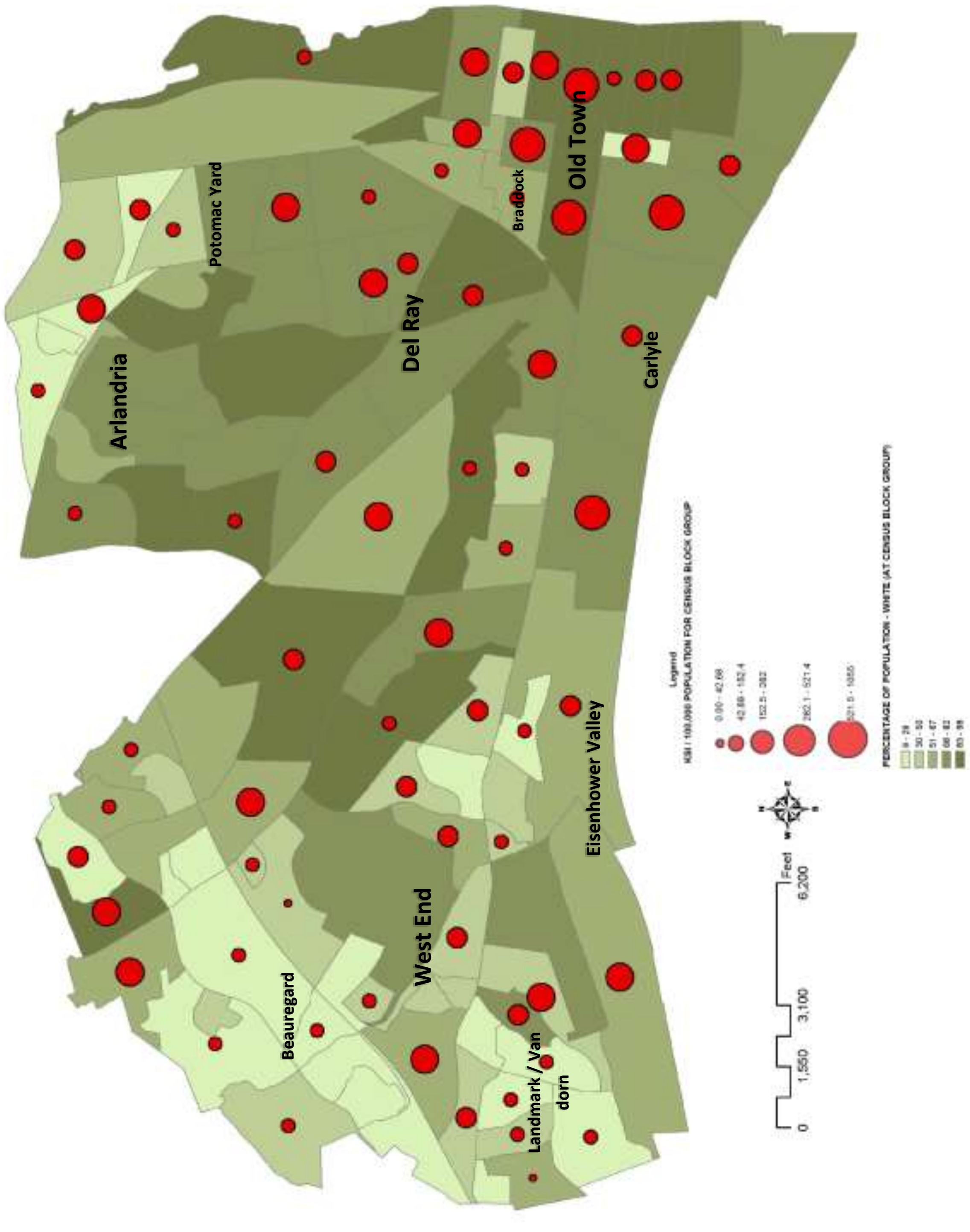
*A. **Descriptive analysis (DA) of the spatial distribution of crash incidents involving KSI***

Analyzing the spatial relationship of high number of KSI involving crash occurrence with respect to the city's demographic profile helps to visually identify the vulnerable communities/neighborhoods that might be disproportionately impacted by these crash outcomes. This paper utilizes two different spatial units of aggregation -- KSI involving crashes aggregated at census block group; and KSI involving crashes aggregated at the crash location using point density (point density provides a more granular visualization of the KSI involving crash locations).

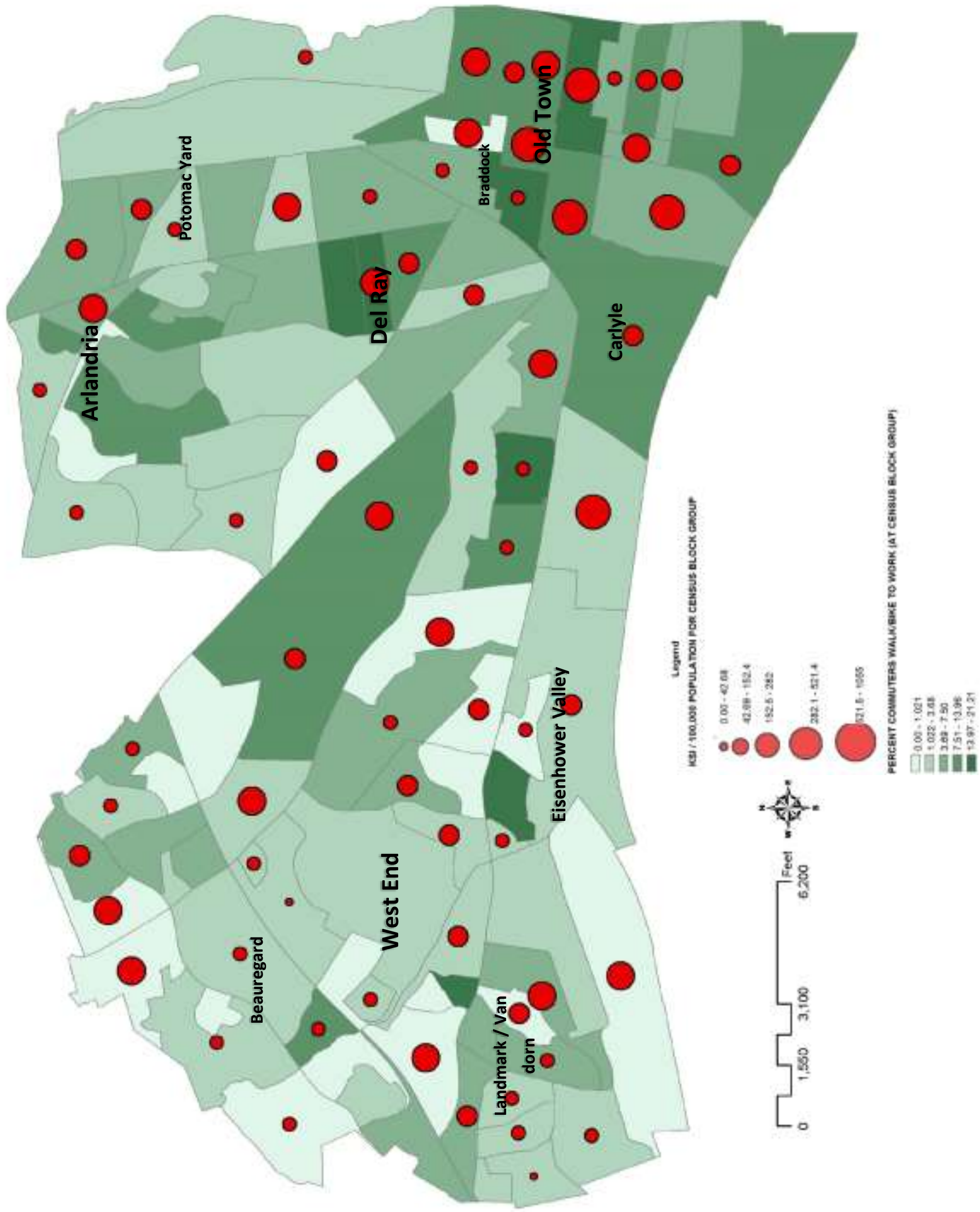
The 2010-2014 individual crashes were first geocoded using ArcMap to locate them on the Alexandria map. Among the 8062 individual crashes, 7357 crashes were successfully matched using city's GIS address locator. Most of the crashes that failed to locate had either missing or incorrect addresses. Due to time constraint, only some of them were located manually, and the rest of the data was eliminated from the analysis. The KSI involving crashes were then identified using a spatial selection of attributes from the total crashes located earlier on the map. These crashes were then spatially joined to each census block groups using ArcMap. The graduated color symbology was utilized for the visualization of patterns for total number of crashes with KSIs (Killings or Severe Injuries) at the block group level. The total crash occurrence was then normalized by total population (Map 1). The point density estimation tool of ArcMap was utilized to create the density map of KSI involving crashes. This method weighed the fatalities (weighed 10) twice the weight of severe injuries weight (weighed 5) to emphasize the fatalities more than severe injuries. The total weight generated by the number of fatalities and severe injuries in a crash provides the severity weight of the crash that was used to create the point density.



Map 2. KSI involving crashes per 100,000 population for each census block group (CBG) level (2010-2014) with respect to the percentage senior population (over 64 years) for CBG (Source: APD, City of Alexandria, Virginia, Census ACS profile 2014). Higher KSI involving crashes show correlation with the higher percentage of seniors over the age of 64 years in the census block groups.



Map 3. KSI involving crashes per 100,000 population for each census block group level (2010-2014) with respect to the percentage white population for census block groups (Source: APD, City of Alexandria, Virginia, Census ACS profile 2014). High KSI involving crashes do not show correlation with the higher percentage whites in census block groups.



Map 4. KSI involving crashes per 100,000 population for each census block group level (2010-2014) with respect to the percentage population commuting by walking/biking. High KSI involving crashes do not show correlation with the higher percentage of population commuting through walking/biking to work in census block groups.

For KSI involving crashes at the census block group level, a higher number of KSI involving crashes was found in areas with a higher percentage of seniors over the age of 64 years (Map 2). This bears similarity to the findings from previous studies where a higher percentage of population over 75 years was found to be associated with a higher number of fatalities at the census block group level. A higher number of KSI involving crashes was also seen in areas with higher concentration of males (A. Map 2, Appendix). On the other hand, KSI involving crashes are low in most of the high-income areas (A. Map 3, Appendix), which also aligns with the previous research findings. KSI does not show a clear relationship with areas of higher percentage of population walking /biking to work (Map 4). In addition, it also does not show a correlation with race/ethnicity (Map 3), as higher number of KSI involving crashes occurred in both low as well as high percent white areas at CBG level.

Findings from the descriptive analysis of spatial distribution of crash incidents involving KSI

1. Higher number of KSI involving crashes were found in areas with:

- Higher percentage of seniors over the age of 64 years (Map 2)
- Higher concentration of males (A. Map 2, Appendix)

2. Does not show a correlation with:

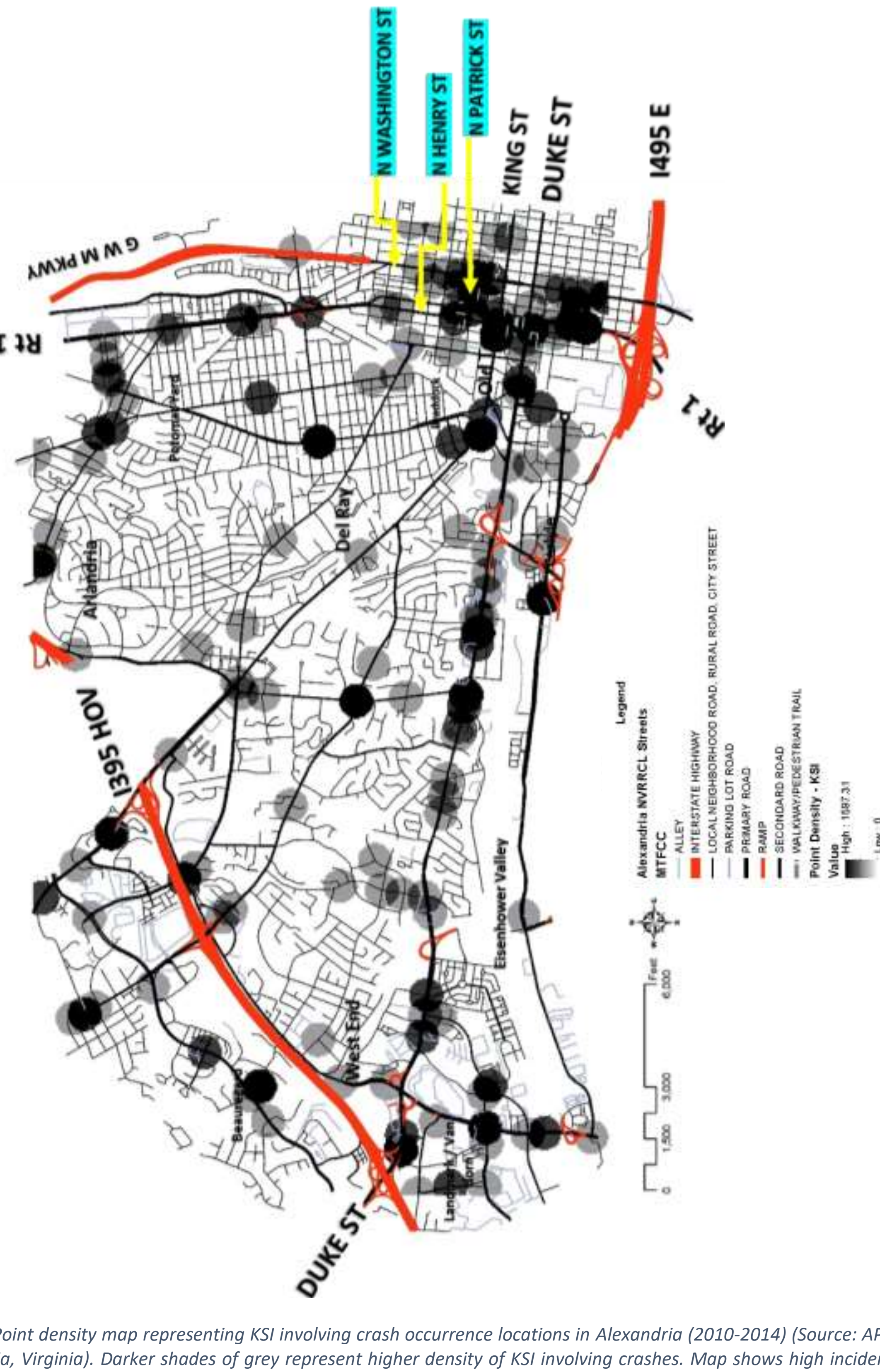
- Race/ethnicity (Map 3)
- Percentage of population walking /biking to work (Map 4)

3. Low number of KSI involving crashes was found in:

- Most of the high-income areas (A. Map 3, Appendix)

4. Point density KSI involving crashes (Map 5) show:

- High incidence along the arterials and their intersections (high traffic volumes)
- Highest at the intersections of Old Town
- The streets (arterials) that have most crashes as well as the most KSI involving crashes are –
  - Duke St
  - Jefferson Davis Highway (RT 1)
  - Washington St
  - Patrick St and Henry St



Map 5. Point density map representing KSI involving crash occurrence locations in Alexandria (2010-2014) (Source: APD, City of Alexandria, Virginia). Darker shades of grey represent higher density of KSI involving crashes. Map shows high incidence of KSI crashes along the arterials and their intersections.

Point density KSI involving crashes (Map 5) show high incidence along the arterials and their intersection. This also aligns with the high traffic volumes and is seen highest at the intersections of Old Town. Arterials that have the most crashes as well as the most KSI involving crashes are -- Duke St, Jefferson Davis Highway, Washington St, Patrick St and Henry St – located on the eastern and southern sides of Alexandria.

B. *Descriptive analysis (DA) of the traffic crash trends for the five-year period of 2010-2014*

i. Crash occurrence and injury severity trends

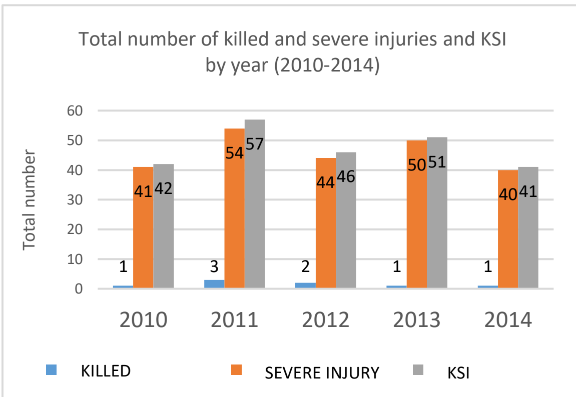


Table 4. Total number of killed, severely injuries, and KSI by year (2010-2014) (Source: APD, City of Alexandria, Virginia)

In Alexandria, the highest numbers of crashes were reported in the year 2012 (for the five-year period of 2010-2014) (Chart 1, Appendix). There was an approximately nine-percent rise in the reported crashes in 2012 from the 2010 level. The number of crash incidents reduced sharply in 2013 from the 2012 level, it stayed almost the same in the following year. However, the year 2015 saw a significant drop in crashes. This drop might also be credited to city's “Complete Streets[1]” Policy that was reenacted by City Council in April 2014.

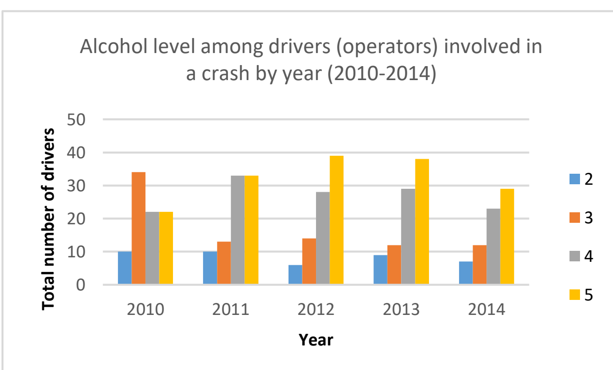


Figure 4. Alcohol impairment level (2=low, 5=high) among drivers (operators) involved in a crash by year (2010-2014) (Source: APD, City of Alexandria, Virginia)

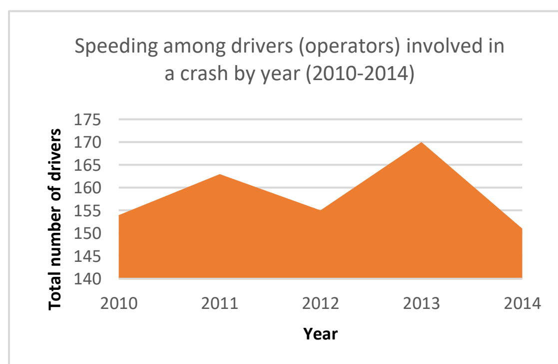
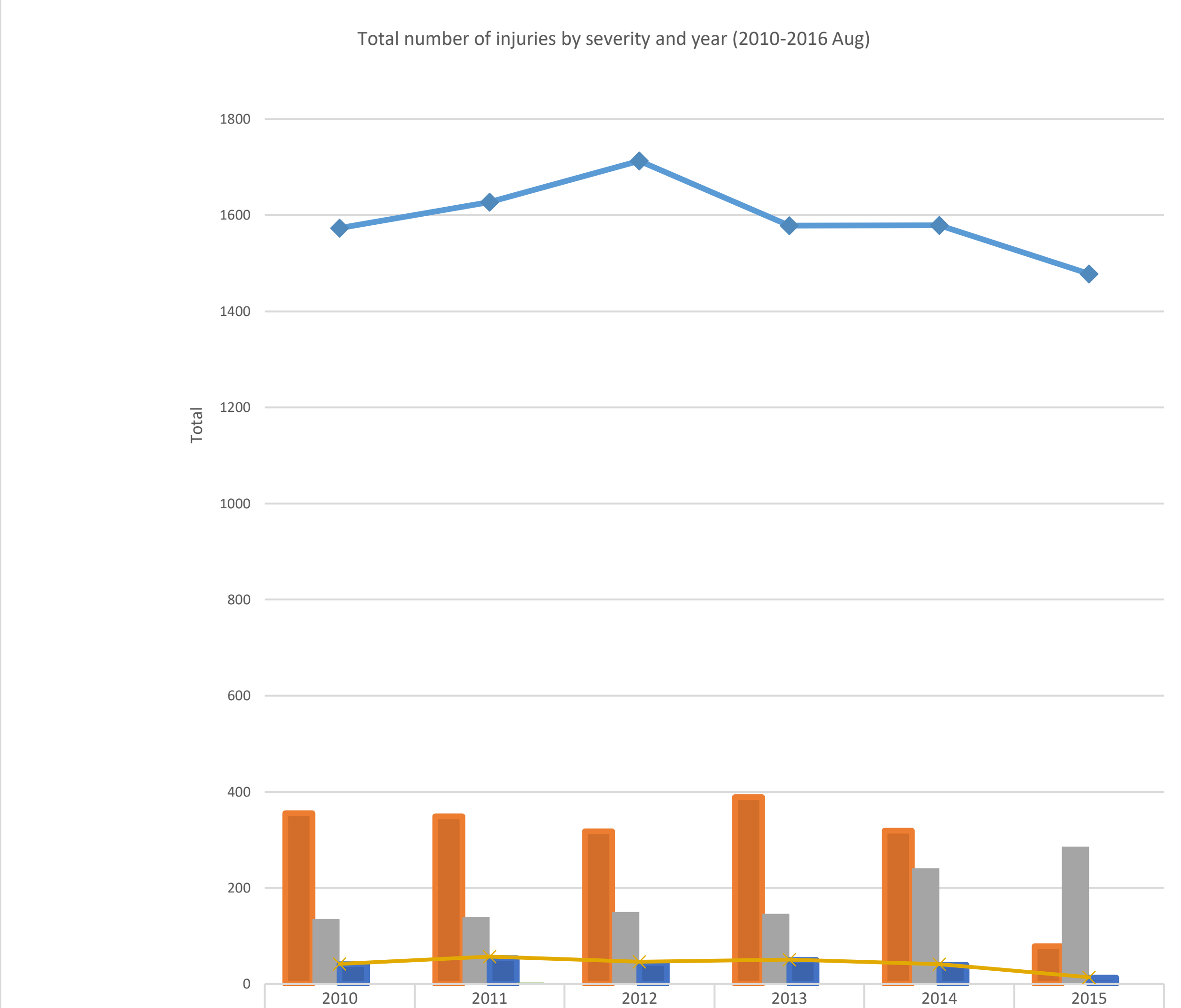


Figure 3. Speeding trend among drivers (operators) involved in a crash by year (2010-2014) (Source: APD, City of Alexandria, Virginia)

[1] “Co… egrat… design that allows for “safe and convenient travel along and across streets for all users, including pedestrians, bicyclists, riders and drivers of public transportation, as well as drivers of other motor-vehicles” (City of Alexandria, May 11, 2015, p 1). City's initial Complete Streets Policy (adopted in 2011) was directed to the transportation planners, engineers, and developers to “routinely design and operate the entire right of way to enable safe access for all users [--] regardless of age, ability, or mode of transportation” (City of Alexandria, May 11, 2015, p 1). In 2014, the reenactment recognized the pedestrians, bicyclists, and the riders and drivers of public transportation also as the transportation system users -- in addition to the motor vehicle drivers (City of Alexandria, Complete Streets; City of Alexandria, May 11, 2015).



	2010	2011	2012	2013	2014	2015
MINOR INJURIES	355	349	318	389	319	79
MODERATE INJURIES	135	140	150	146	241	286
SEVERE INJURIES	41	54	44	50	40	13
KILLED	1	3	2	1	1	1
CRASH INCIDENTS	1573	1627	1713	1578	1579	1478
KSI	42	57	46	51	41	14

Figure 5. Total number of injuries by severity and year (2010-2015) (Source: APD, City of Alexandria, Virginia)

Highest number of crashes were reported in 2012 (Chart 1, Appendix), and highest number of KSI, fatalities, and severe injuries occurred in 2011. On the other hand, KSI and severe injuries were lowest in 2014. (Figure 5)

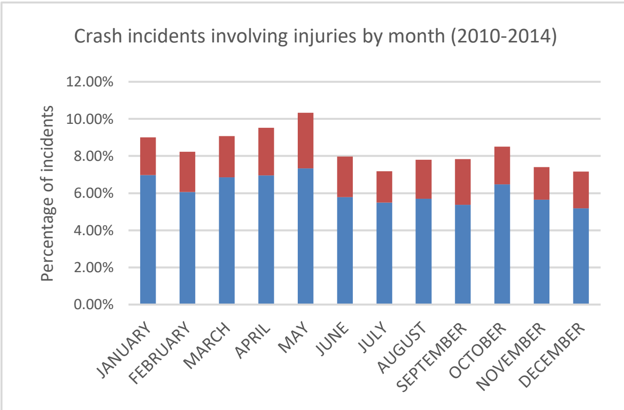


Figure 6. Percentage of crash incidents and incidents involving injuries (red color = crash incidents involving injuries; blue color = crash incident with no injuries) by month (2010-2014) (Source: APD, City of Alexandria, Virginia)

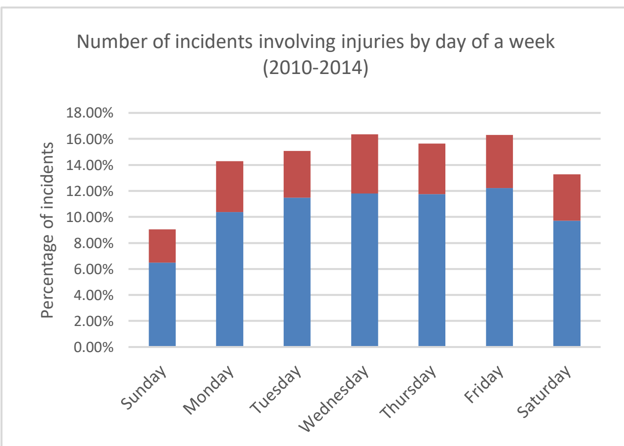


Figure 7. Number of crash incidents and incidents involving injuries (red color = crash incidents involving injuries; blue color = crash incident with no injuries) by day of week (Source: APD, City of Alexandria, Virginia)

Injury involving crashes were highest in the month of May (Spring) and lowest in the month of July (Summer) (Figure 6). The rise in crash occurrence at the onset of Spring might be due to increased outdoor activity, leading to increased pedestrian exposure which is associated with increase in crash frequencies in urban areas (Lam et al. 2013). Whereas, the low crash numbers in Summer could be indicative of the decreased traffic volumes on the streets (Federal Highway Administration, Jan 2012), as with no schools, teachers and students are away from the roads, reducing the traffic volumes during the summer break (Gordon, Aug 2015) (Figure 6).

Crash involving injuries were high all through the weekdays (Figure 7). The incidence of injuries

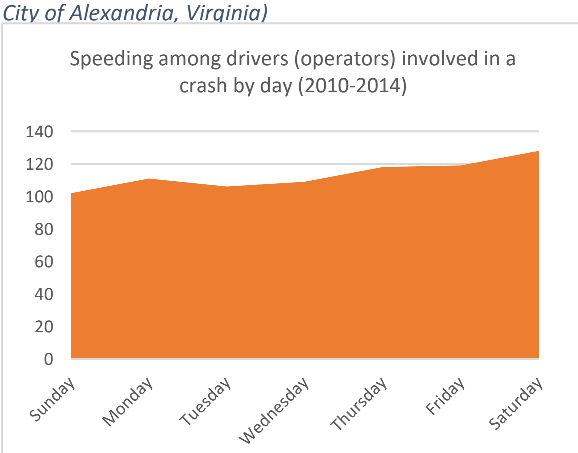


Figure 9. Total number of drivers (operators) reported speeding before a crash incident (by day of week) (2010-2014) (Source: APD, City of Alexandria, Virginia)

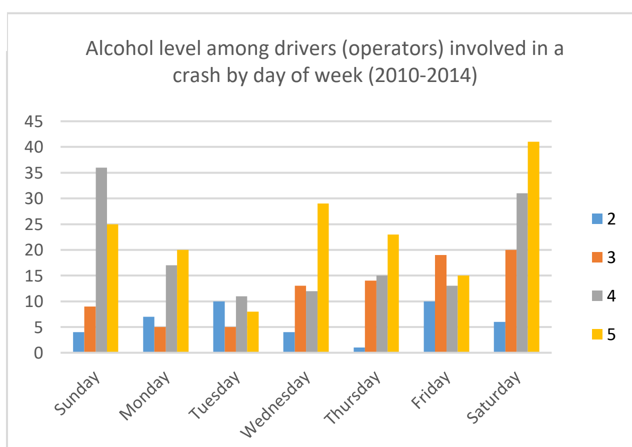


Figure 8. Total number of drivers (operators) involved in a crash incident for different level of alcohol influence (2=low, 5=high) (2010-2014) (Source: APD, City of Alexandria, Virginia)

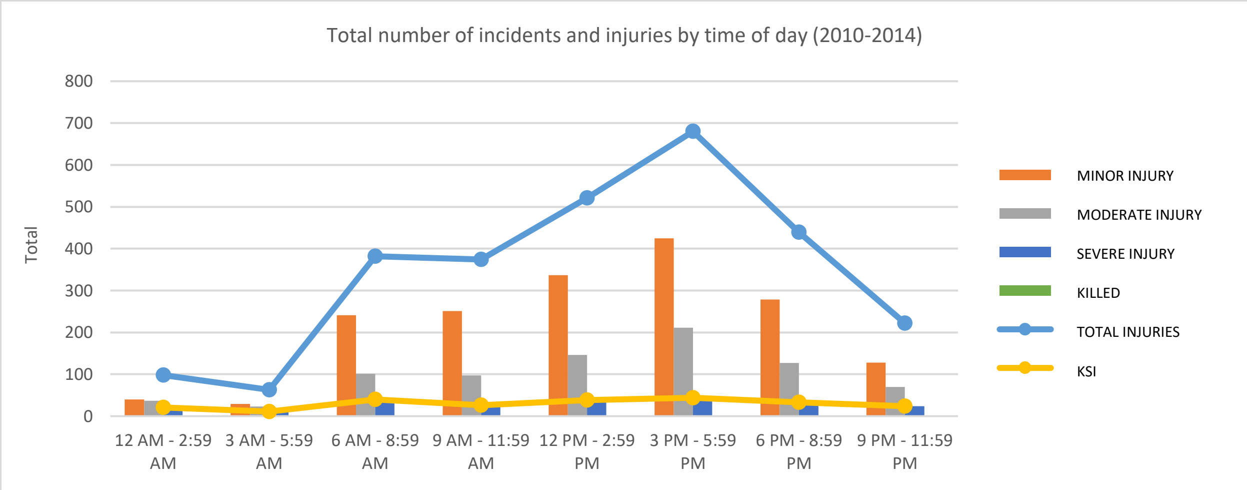


Figure 11. Number of incidents and injuries by time of day (2010-2014) (Source: APD, City of Alexandria, Virginia)

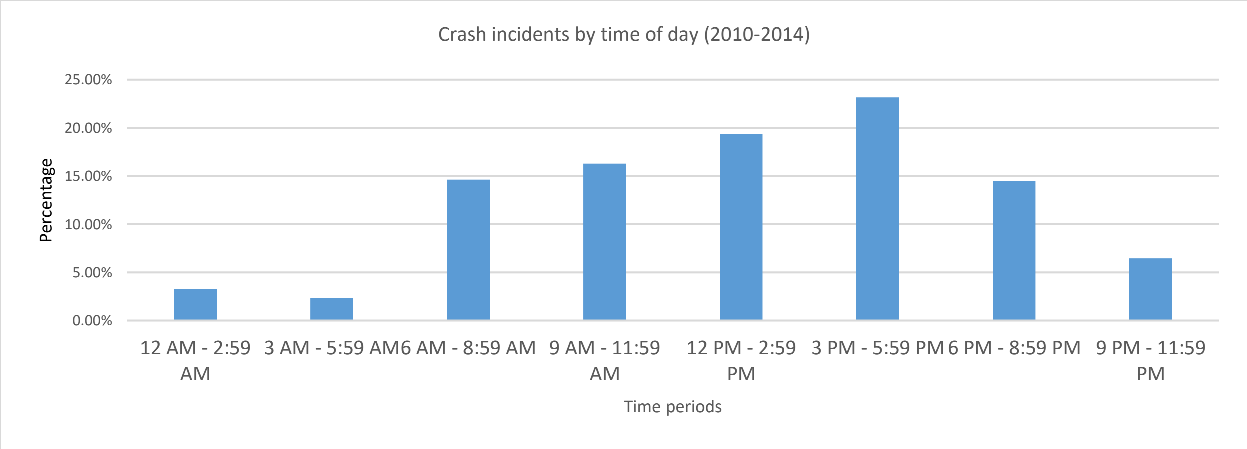


Figure 10. Percentage of crash incidents by time of day (2010-2014) (Source: APD, City of Alexandria, Virginia)

peaked in mid-week, whereas, severe and fatal injuries and KSI were highest in the beginning and end of the week. Weekends show lower crash occurrence, which might be due to reduced traffic volumes. However, a significant percentage of crashes involving injury is still seen on weekends (Figure 10). Since, the number of crashes involving speeding and driving under alcohol influence was also significantly higher during weekends (Figure 8 & 9), this might also be the cause of the rise in injury involving crashes on weekends.

Risk of injuries in a crash incident was highest during the “day time” (Chart 4, Appendix). The highest number of KSI occurred during evening peak traffic hours (3pm–6pm) of the onset of week, whereas, fatalities were highest during the morning (6am–9am) and evening peak hours (3pm–6pm) of travel as well as in the midday hours. This suggests that higher traffic volumes (during daytime and evening peak hours) and higher crash occurrence might be correlated. KSI have lowest frequencies on Sunday, and during the early morning hours 3am–6am. (Figure 11)

Crash trends suggest that the vulnerable roadway users are at higher risk of injuries -- with almost all

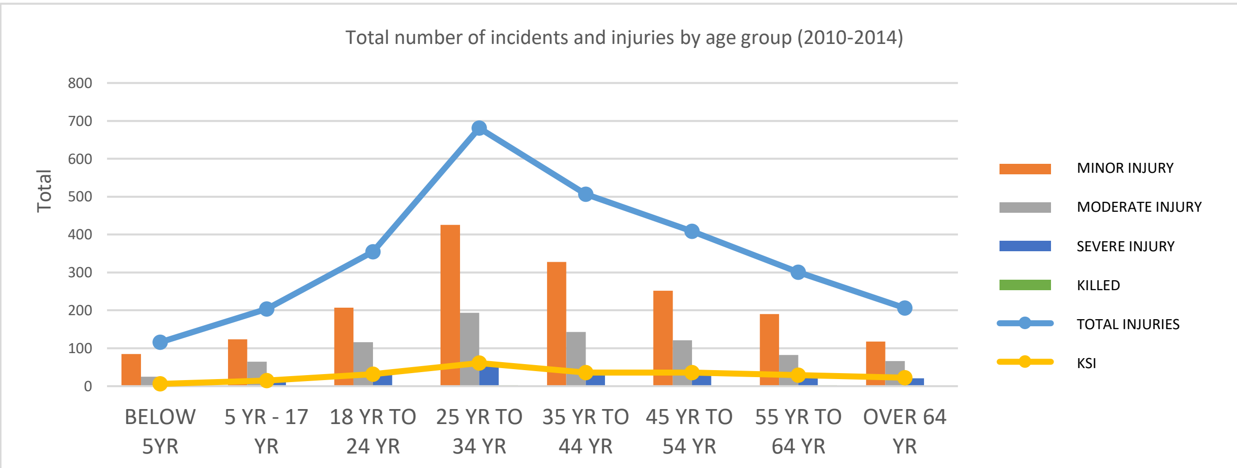


Figure 12. Number of incidents and injuries by age group (2010-2014) (Source: APD, City of Alexandria, Virginia)

pedestrian, motorcyclist, and bicyclist crashes resulted in injuries (Chart 3, Appendix). Highest percentage of injury related crashes (over 12 percent) occurred at "signalized intersections." This might mean that the signalized intersections are correlated with higher crash frequencies, aligned with the findings from previous studies (Huang et al., 2010; Siddiqui et al., 2012; Rhee et al., 2016).

ii. Crash severity and individuals' characteristics

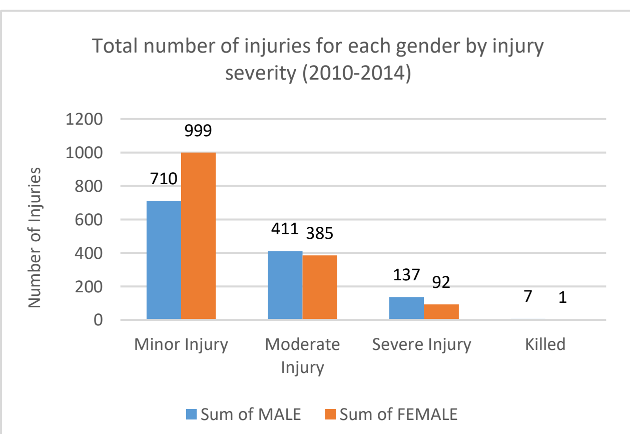


Figure 13. Injury severity across gender (2010-2014) (Source: APD, City of Alexandria, Virginia)

KSI was highest among young adults (the 25yr-35yr old age group), lowest among under school aged children (the below 5yr-old age group), and shows a drop with increase in age (Figure 12). This might be both due to the presence of similar proportion of individuals from these age groups in crashes and on streets in Alexandria.

However, for seniors, 10.68 percent of all injuries were either a fatality or severe injury (KSI) -- highest among all the age groups.

Although, females were more prone to sustain an injury during a crash incident, males had a much higher chance of sustaining severe injury or getting killed in a crash. For 2010-2014 crash data, males sustained

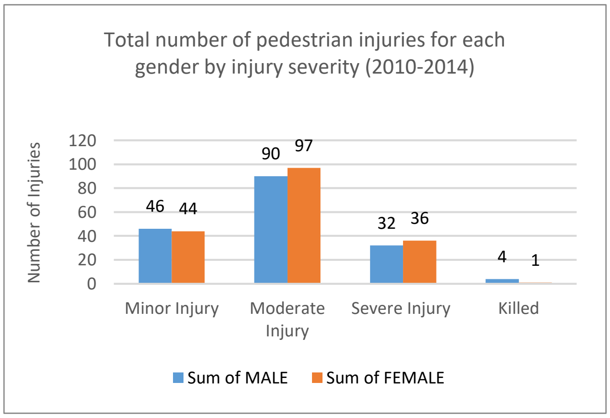


Figure 14. Injury severity of pedestrians across gender (2010-2014) (Source: APD, City of Alexandria, Virginia)

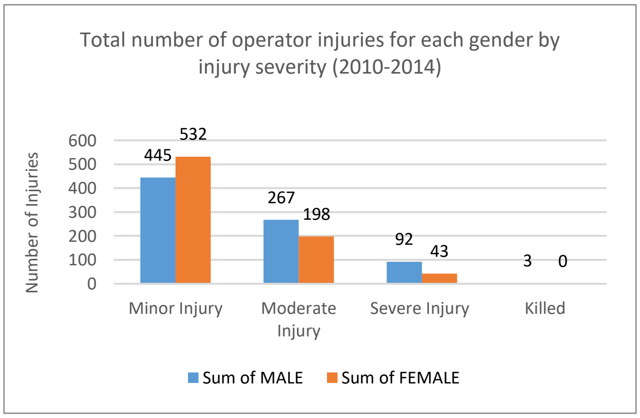


Figure 15. Injury severity of operators across gender (2010-2014) (Source: APD, City of Alexandria, Virginia)

14.23 percent fewer injuries than females. Contrarily, males had seven-times the number of fatalities and a 54.84 percent higher KSI than their female counterparts. However, looking just at pedestrian injuries, there is a higher proportion of females with severe and moderate injuries. Fatality among pedestrians involved in crashes still has a higher proportion of males (Figure 14). Pedestrian KSI was highest for pedestrian action "crossing a signalized intersection". This suggests that higher pedestrian KSI might be associated with presence of traffic signal at intersection (Chart 14, Appendix).

Males showed less precautionary and higher risk-taking behavior than females. Male drivers involved in a crash were twice more likely to be under alcohol influence than a female driver. This was true at all levels of alcohol impairment reported in crash reports. This might also be due to the higher number of males choosing to drive after alcohol consumption, and many females might be choosing to either not drive or carpool, instead. Alcohol consumption showed increases in 2012 and 2013 but came down in 2014. Alcohol impairment as well as total crashes involving drivers under alcohol influence was significantly higher during weekends compared to weekdays. Male drivers also show higher numbers in crashes while speeding, than female drivers. However, in 2013 and 2014, there has been an increase in the number of female drivers, involved in crashes, while driving higher than posted speeds. Safety equipment usage among drivers also shows higher number of males choosing not to use one. Naturally, sustaining a more severe injury in a crash occurrence is seen high among drivers who did not use any safety equipment.

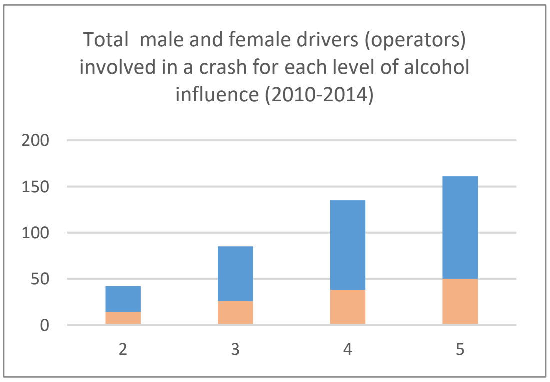


Figure 17. Proportion of male and female drivers (blue color = male; pink color = females) (operators)involved in a crash incident for each level of alcohol impairment (2=low, 5=high) (2010-2014) (Source: APD, City of Alexandria, Virginia)

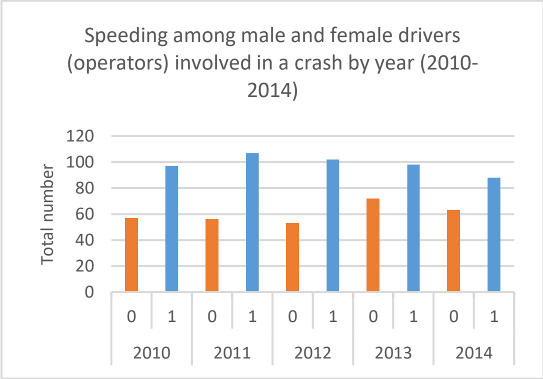


Figure 16. Speeding among males (represented by 1) and females (represented by 0) drivers (operators) involved in a crash by year (2010-2014) (Source: APD, City of Alexandria, Virginia)

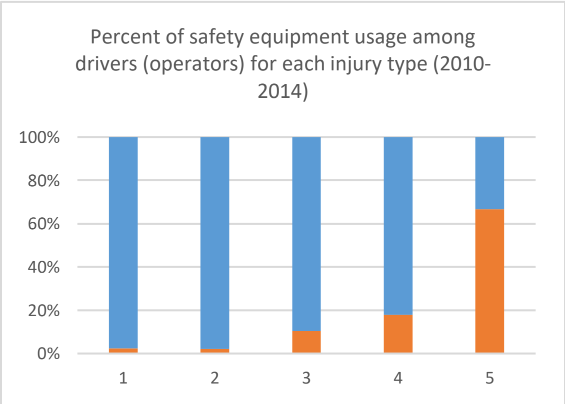


Figure 18. Safety equipment usage (color blue = safety equipment used; color orange = safety equipment not used) among drivers (operators) during a crash occurrence by type of injury (1 = no injury, 2 = minor injury, 3 = moderate injury, 4 = severe injury, 5 = killed) (2010-2014) (Source: APD, City of Alexandria, Virginia)

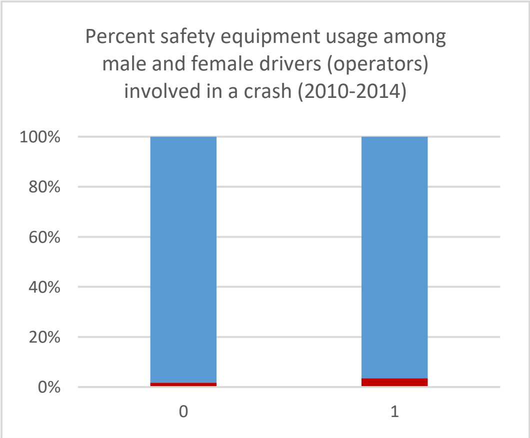


Figure 19. Percentage safety equipment usage (color blue = safety equipment used; color red = safety equipment not used) among male (represented by 1) and female (represented by 0) drivers (operators) during a crash occurrence (2010-2014) (Source: APD, City of Alexandria, Virginia)

C. Equity analysis using regression

i. Investigating the risk of KSI among non-whites, low-income population, and alternate transportation users in Alexandria.

This section uses an aggregate regression analysis (ARA) to investigate the KSI risk associated with the vulnerable communities/groups in Alexandria at census block group level, and incorporates a Negative Binomial Regression (NBR) (incident rate ratio) method for this purpose. Here, the demographic characteristics of the neighborhood – race (Percentage population – White, Percentage population – African American, and Percentage population – Hispanic), income (Percentage of households with income–under 50K, Percentage of households with income – over 150K, and Percentage of poor households – poor family with child), and transportation mode choice of commuting (Percentage of commuters – drive to work, Percentage of commuters – use bus to work, Percentage of commuters – use light rail to work, and Percentage of commuters – walk/bike to work) -- are the predictor variables (independent variables), and the total number of killed or severely injured (KSI) in the neighborhoods are the response variables (dependent variable). The unit of analysis is the census block group (CBG). The model also uses other statistically significant variables influencing KSI from previous research as control variables.

This method helps to identify the relationship between the demographic characteristics of neighborhoods (race/income/transportation mode choice of commuting) and the risk of KSI at census block group level, when rest of the factors (variables) remain constant. A statistical significance shown by these demographic groups (variables) in predicting KSI represents an existing relationship between the two at the census block group level in Alexandria. In addition, the type of relationship (positive or negative) between the predictor and response variables show if neighborhood locations of higher concentration of a community demographics increases (positive relationship) the KSI risk or decreases it (negative relationship). If higher concentration of a vulnerable group (non-white/low-income/pedestrians, bicyclist, and transit users) shows a positive relationship with higher KSI occurrence at the census block group level, it indicates possible inequity. Moreover, the magnitude of variance in KSI predicted by them represents the magnitude of risk of KSI associated with each group at the census block group level. (Details of this analysis are provided in the appendix section of this report.)

During the analysis, some variables showed collinearity with other variables. Thus, those variables were eliminated from the model, and/or replaced by other indicator variables to represent the same. For instance, the percentage of households with income–under 50K (PER_HH_U50K) and percentage of households with income – over 150K (PER_HH_O150K) variables that showed high collinearity, were replaced by the percent poor households of famililies with children (PER_FAMCHILD_POV) as the indicator of neighborhood demographics of low-income group, instead. Similarly, the variables representing the percent of commuters who drive to work (PER_DRIVE) and the percent-white population (PER_P_WHITE) also showed high collinearity, and hence removed from the final model.

Results

Both indicators of the minority population -- percent-Hispanic (PER_P_HISP) and percent-AfricanAmerican (PER_P_BLACK) -- and low-income/poor groups (PER_FAMCHILD_POV) did not show a relationship with KSI at the neighborhood / census block group level. However, the increase in percentage of subway/rail users for commute to work (PER_RAIL) shows increased risk of KSI at the census block group level in Alexandria, when rest of the factors (variables) remain constant.

In addition, the KSI risk also tends to increase in areas with higher percentage of elderly population (PER_P_O64), when rest of the factors (variables) remain constant -- similar to the relationship found in previous studies. Increase in job density increases KSI risk, whereas, increase in residential density tends to reduce it. This finding also aligns with the results from previous studies. Smaller block sizes or higher number of street segments per sq mile area of census blocks reduces the KSI risk at the census block group level -- which is different from previous research findings. However, there was a correlation found between the “street segment density” and the “street intersection density” variables during the analysis (Table 7. Appendix). Hence, the results for “street segment density” might be reflecting the relationship between “street intersection density” variable and KSI occurrence (previous studies show reduction in KSI with the increase in street intersections) (Table 1).

ii. Investigating the impact of KSI on males and elderly in Alexandria

This section uses a disaggregate regression analysis (DRA) to investigate the risk of KSI on the individuals (of the vulnerable groups – males and seniors) involved in a crash incident. It uses a Binomial Logistic Regression (BLR) (odds ratio) method to achieve this. Killed or severely injury (KSI) is the dependent or response variable for this model. The gender and elderly age group are independent or predictor variables for the analysis. The unit of analysis is the individual involved in a crash incident. It also uses other statistically significant variables influencing KSI from previous research as control variables in this model. This method helps to identify the relationship between the gender and age group of the individuals involved in a crash incident and the risk of KSI, when rest of the factors (variables) remain constant. Any significance shown by the gender/age group of individuals in predicting KSI represents a relationship between the two. In addition, the type of relationship (positive or negative) between the predictor and response variables represents an increase (positive relationship) or reduction (negative relationship) in KSI risk. Moreover, the magnitude of variance in KSI predicted by them represent the magnitude of KSI risk associated with each group. Thus, if the KSI risk on a vulnerable gender (females) or age group (children, elderly) is higher than other groups, it may indicate inequity. (Details of this analysis are provided in the appendix section of this report.)

Results

Results did not show a statistically significant relationship between the gender of an individual (involved in a crash incident) and the KSI risk. Risky behaviour of speeding, alcohol usage level, and pedestrian violation of traffic rules, more prominent in males, are associated with increasing risk of a KSI during a crash incident. Also, the vehicular action of running off the road, turning left, and going straight are significantly associated with incresing the KSI occurrence.

The elderly age group shows a statistically significant relationship with the KSI risk. Elderly shows the second highest magnitude of risk among all age groups, with the 5to17year-old-age-group at the top. This shows the two most vulnerable age groups (elderly and school aged children) are at highest risks of KSI in Alexandria.

Other control variables also show a statistically significant relationship with the KSI risk. Greater KSI risk is associated with with deteriorating lighting conditions. This may mean that a street faclility like presence of street lights could play an important role in reducing the KSI occurrence. On the other hand, KSI risk decreased on streets with no traffic controls with respect to the reference group of traffic controls around the crash incident. The KSI risk increased for pedestrians at intersections (signalized and non-signalized) and on streets without sidewalks with respect to the reference group of pedestrian actions variable. This reflects a higher risk of KSI for pedestrians on street in an event of collision. The KSI risk also increased for individuals going straight on streets with respect to the reference group of vehicular maneuver variable.

Individual’s risk taking behaviour show statistically significant relationship with the KSI risk as well. Increase in alcohol level, and speeding during a crash incident increases the KSI risk. On the other hand, using a safety equipment in a crash decreases the KSI risk.

VII. Discussion & Recommendations

The equity analysis suggests a higher risk of KSI on the elderly and school aged children in Alexandria. Higher percentage of elderly (over-64year-age-group) showed correlation with the increase in KSI involving crash occurrence in the census block groups in the city (Map 2). The aggregate regression analysis results also show that for two similar neighborhoods, higher percentage of elderly population is associated with a higher risk of KSI. Moreover, the crash trends show that 10.68 percent of the injuries sustained by elderly are KSI in Alexandria crashes. The disaggregate regression analysis supports this, showing them with the second highest odds of sustaining KSI in a crash incident from the other age groups, when the crash circumstances are similar. This shows the elderly age group is at the highest risk of KSI, both at the community and individual level. Since, there is a high number of this group within low-income and disability, keeping these groups in mind while drafting policies for road safety may help to serve this group equitably. The disaggregate regression analysis also highlighted that while keeping all other crash circumstances constant, the school aged children (5to17year-age-group) have the highest odds of sustaining KSI as a crash outcome (among all age groups). Since this age group (5to17year-age-group) is a highly vulnerable group, drafting policies oriented towards safe streets for children could be helpful in achieving equity in traffic safety in Alexandria.

For gender, the analysis does not provide any relationship between KSI and an individual's gender. Although, females registered a higher number in injuries and pedestrians impacted in a crash incident (Figure 13 & 14), the regression analysis did not show a statistically significant relationship of female gender with KSI occurrence for individuals involved in crashes in Alexandria. However, as female pedestrians are more prone to severe injuries in Alexandria (Figure 14), and many families having single female with children are in poverty (Census ACS 2014 profile for Alexandria), they should be kept in mind while looking at the high-risk areas at census block group level. On the other hand, males showed significantly higher numbers in the crash related KSI. Males sustained a 54.84 percent higher KSI, and seven-times the number of fatalities of their female counterparts (Figure 13 & 14). But, the results from regression analysis did not show a significant relationship between the male gender and KSI occurrence for individuals involved in a crash incident. Males also show higher risk-taking behavior, like, driving under alcohol influence, speeding, and not using safety equipment (Figure 16-19). The results of disaggregate regression analysis shows that these risky behaviors are significant in increasing the odds of sustaining a KSI in a crash incident. This might also mean that the male gender is also at high risk of KSI, due to their risk-taking behavior. Therefore, road safety policies may consider both the genders for an equitable traffic safety in Alexandria.

Also, the CBGs with higher percentage of poor families with children did not show a relationship with higher KSI. But, data shows that Alexandria has a high number of households of single female parent with children that are under poverty (Census ACS 2014 profile for Alexandria). Moreover, there is a probability that an elderly is also among the low-income/disabled/without medical insurance status. Further analysis of the demographics of the impacted individuals would reveal if elderly, females, and children belong to one of the traditionally vulnerable groups. Thus, keeping them in mind while drafting policies for road safety may help to serve them equitably.

The racial measure of higher density of Hispanics and African Americans did not show increased risk of KSI in the neighborhoods. Since, the neighborhoods with higher percent of Hispanics/African Americans might also have a higher percent of seniors/elderly, poor, and/or disabilities, a detailed investigation of these communities is recommended. This would reveal the magnitude of impact on the other vulnerable groups as well.

CBGs with higher concentrations of commuters taking rail/subway to work shows a statistical relationship with higher KSI. Since many rail users usually choose to live close to rail/stations and access the rail/subway stations by walking, this may pose a disproportionately higher risk on them as well. In addition, individuals from other vulnerable groups (minorities, poor, low-income, children, elderly, females, and disabled) might be in these areas. Considering the demographics of the areas with higher percentage of rail commuters may provide more information about each group that is impacted. Creating road safety policies oriented towards rail/subway users could provide an equitable traffic safety in the city.

Since pedestrian and bicyclists are at highest risk of fatality and severe injury, this group should be kept in mind while analyzing the other vulnerable communities in the city (Chart 3, Appendix; Figure 14). Pedestrians were the most vulnerable system users identified in both the aggregate and disaggregate regression analysis. In the disaggregate analysis, the odds of KSI increased in pedestrian who were crossing on intersections and were walking on streets with no sidewalks. Some communities like high-income and high percent white might seem unlikely to be at risk. However, there might be significantly higher shares of pedestrians and bicyclists who are at risk of fatality or severe injury. This might change the measures of identifying equity issues in the neighborhoods. Commuters taking rail/subway to work also show higher risk of KSI at community level. Many rail/subway users may live close to rail/stations and bike/walk to access the rail/subway stations. Moreover, other vulnerable groups (minorities, poor, low-income, children, elderly, females, and disabled) might also be located within these areas. Further analysis of the demographics of the areas with high percentage rail/subway commuters could reveal if other vulnerable groups are also impacted within these areas. Drafting policies oriented towards pedestrian safety could be also helpful in achieving equity in traffic safety in Alexandria.

The street infrastructure, pattern, and land use also showed relationship with increase in KSI risk at census block group level. The smaller block sizes (increase in number of street segments per sq. mile) and higher housing density reduced KSI, whereas, increase in job density (offices per sq. mile) increased it. This suggests the street pattern could play an important role in reducing KSI occurrence, and safety improvements around offices might reduce the risk. The decrease in lighting increased KSI in individuals. This could mean that the street infrastructure quality and mainteinance (both street and its facilities like street lights) could play an important role in reducing KSI occurrence.

Due to time constraints, this analysis did not include other equity measures suggested in literature review and other sources for the census block group – like, percentage of population with disability; percentage of renters; percentage of single women households with children; and percentage of limited English language proficiency. Further analysis of these measures would reveal more in depth information about the traffic crash related equity issues and their individual measures in the City.

In addition, a location based analysis (at census block group level) with the equity measures can only provide the information about the risk that individuals might be facing in these neighborhoods. Contrarily, individuals impacted in a crash incident might be completely different from the neighborhood profile. Most of the drivers might be commuting from outside the city whereas most of the pedestrian/bicyclists and transit users might be the residents. Thus, to understand the real dynamics in play within the neighborhoods and to understand who is actually impacted in each of the neighborhoods -- where the disproportionately higher impact of crashes are seen -- it is important to look into the demographics of the individuals involved in the crash incidents. This could involve a regression analysis of the individual crashes, similar to the one carried out in this study. Additional details of the individuals required for this analysis includes -- individuals' address, income, education level, race, disability, limited English language proficiency, and primary mode of transportation to work. This data could either be provided by the Alexandria Police Department (APD) or could be gathered from the hospital or driving records of the individuals. In addition to that, by having a more accurate data entry system, the APD could be resourceful in helping with future crash data for this analysis.

Table 5 Comparison of previous research findings and analysis results in Alexandria

Factor	Previous research	Analysis Results	Factor	Previous research	Analysis Results
Demographic / Socio-economic			Physical		
Density			*Land use*		
• Population density	↓	N/A*	• Crashes closer to commercial sites (at census block group level)	↑	N/A*
Age			• Increase in proportion of land use mix (at census block group)	↑	N/A*
• Higher ratio of population aged 75 years or older (at census block group level)	↑	↑	• More residential driveways within 50 feet (of intersections)	↓	N/A
• Higher young adult population density (at census block group level)	↑	↑	• Increase in housing density (at census block group level)	↓ ↑	↓
• Greater percentage of residents younger than age 18 yrs within 0.25 mile (near intersections)	↑	N/A	• Increase in job density (at census block group level)	↑	↑
Income			• More commercial properties within 0.1 mile (of intersections)	↑	N/A
• Regions with higher income levels	↓	N/A*	*Traffic congestion*		
• Regions with lower income levels	↓	✖	• Higher degree of urbanization	↓	N/A*
			• Higher street volume to capacity ratio	↓	N/A
Physical			Individual's behavior		
Transportation infrastructure & facilities			*Risk taking*		
• Increase in the number of road segments (at census block group)	↑	↓ **	• Speeding	↑	↑
• Road geometrics	↓	N/A	• Alcohol use	↑	↑
• Pedestrian exposure	↑	N/A	• Not using safety equipment (seat belt, helmet, etc.)	↑	↑
• Higher number of bus stops (at census block group)	↑	✖			
• Crash occurring closer to bus stops (at census block group)	↓	✖			
• Increase in number of intersections (at census block group)	↓	N/A*			
			Increase in injury severity	↑	
			Reduction in injury severity	↓	
			No significance	✖	

* Removed from the model due to high collinearity with other variables in the regression analysis
** Found collinear with "number of intersections" variable – results might be reflecting the relationship of that variable

VIII. Limitations and future research

This research was conducted within the time constraints of a semester, and thus, could not cover all aspects of the equity measures for the city. The current analysis only provides the gender and age factors for the equity analysis to understand the impact of crash injuries on an individual with respect to their demographics. Thus, it only provides the gender and age measures of equity for the individuals. A detailed equity analysis could be done using crash data including the details of individuals' address, income, education level, race, and primary mode of transportation to work. This analysis also could not include other equity measures suggested in literature review for the census block group – like, vehicle ownership; percentage of population with disability; percentage of renters; percentage of single women households with children; and percentage population with limited English language proficiency. Further analysis of these measures would reveal more in depth information about the crash related equity issues and their individual measures in the City.

The point density estimation of KSI involving crashes was used for identifying the neighborhood corridor areas of high concentration of KSIs in this study. Although outside the scope of this paper, this method may provide other insights about the disproportionate distribution of transportation infrastructure and facilities (in quantity, quality, and availability) that are crucial in improving the road safety. Moreover, modeling them with performance measures may also help in predicting the policy impact of the investments and for prioritizing improvements -- for instance, utilizing a scenario based model on ArcGIS for proposed transportation improvements (by applying a safety and an equity index), and measuring its performance using the same model with the gathered crash data after improvements. Crash data collected by APD could be highly resourceful for these assessments and similar road safety studies.

Traffic crash reports provided by the APD for this analysis is totally dependent upon the reporting officer's understanding of the circumstances and their interpretation of the crash incident on the report.

Hence, the analysis comes with the limitations put forth by the available data. Also, the inaccurate and partially filled crash reports usually make it difficult to use them for these studies. Promoting accurate, and complete data collection of traffic crashes could be highly resourceful for future road safety studies.

Due to data unavailability, the regression analysis uses population density as a proxy for the exposure component in the analysis. Future studies may replace it with the accurate measures of exposure in the analysis. Moreover, KSI being rare event in Alexandria crash data, the data had a very high proportion of zeroes in the dataset. A different method of regression analysis that could address this issue is the Zero-Inflated regression analysis.

IX. References

Abdel-Aty, M. & Pande, A. (2007). Crash data analysis: Collective vs. individual crash level approach. Journal of Safety Research - ECON proceedings 38, pp. 581–587.

Alver, Y. et al. (2014). Interaction between socio-demographic characteristics: Traffic rule violations and traffic crash history for young drivers. Accident Analysis and Prevention 72, pp. 95–104.

Arzemanian, S. et al. (1993). Geographic Distribution of Fatal Motorcycle Crashes, by Design Type, in Los Angeles, Orange, and San Diego Counties from 1983-1995. Journal of Safety Research Vol. 24, Pp. 87-95.

Aguero-Valverde, J. & Jovanis, P.P. (2006). Spatial analysis of fatal and injury crashes in Pennsylvania. Accident Analysis and Prevention 38, pp. 618–625.

Bates, L. J. et al. (2014). Factors Contributing to Crashes among Young Drivers, Sultan Qaboos Univ Med J. 2014 Aug; 14(3): e297–e305. Published online 2014 Jul 24. PMCID: PMC4117653

Bener, A. & Crundall, D. (2008). Role of gender and driver behaviour in road traffic crashes. International Journal of Crashworthiness. Volume 13, 2008 - Issue 3. Pages 331-336. http://dx.doi.org/10.1080/13588260801942684

Bliss, L. (Sept 2016). Vision Zero's Troubling Blind Spot. CityLab http://www.citylab.com/commute/2016/09/black-lives-matter-and-vision-zero/497495/

Chen, F. et al. (2014). Refined-scale panel data crash rate analysis using random-effects tobit Model. Accident Analysis and Prevention 73, pp. 323–332.

Chen, L. et al. (2013). Safety countermeasures and crash reduction in New York City—Experience and lessons learned. Accident Analysis and Prevention 50, pp. 312– 322.

Chimba, D. et al. (2010). Effect of bus size and operation to crash occurrences. Accident Analysis and Prevention 42, pp. 2063–2067.

City of Alexandria (May 11, 2015). Complete Streets Update. Memorandum. https://www.alexandriava.gov/uploadedFiles/tes/info/2015-05-11%20Agenda%20Item%206-%20Complete%20Streets%20Update.pdf

City of Alexandria - Complete Streets https://www.alexandriava.gov/CompleteStreets

City of Portland - Vision Zero Action Plan. (2016). http://www.portlandoregon.gov/transportation/71730

de Guevara, F. L. et al. (2004). Forecasting crashes at the planninglevel: simultaneous negative binomial crash model applied in Tucson, Arizona.In: Transportation Research Record, Journal of the Transportation ResearchBoard, No. 1897. Transportation Research Board of the National Academies,Washington, D.C, pp. 191–199.

DC Vision Zero Action Plan – updated (2015). A Plan of Action http://www.dcvisionzero.com/assets/updated-dc-vision-zero-action-plan.pdf

Dong, N. et al. (2014). Evaluating Spatial-Proximity Structures in Crash Prediction Models at the Level of Traffic Analysis Zones. Journal of the Transportation Research Board, No. 2432, pp. 46–52. DOI: 10.3141/2432-06

Dumbaugh, E. & Rae, R. (2009). Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety, Journal of the American Planning Association, 75:3, 309-329, DOI: 10.1080/01944360902950349.

Dumbaugh, E. et al. (2011). Using GIS to develop a performance-based framework for evaluating urban design and crash incidence. URBAN DESIGN International Vol. 16, 1, 63–71.

Dumbaugh, E. et al. (2013). The built environment and the incidence of pedestrian and cyclist crashes. URBAN DESIGN International Vol. 18, 3, 217–228.

Dumbaugh, E. & Zhang, Y. (2013). The Relationship between Community Design and Crashes Involving Older Drivers and Pedestrians. Journal of Planning Education and Research 33(1) 83–95.

Eluru, N. & Bhat, C. R. (2007). A joint econometric analysis of seat belt use and crash-related injury severity. Accident Analysis and Prevention 39, pp. 1037–1049.

Federal Highway Administration (Jan 2012). Traffic volume trends January 2012. US Department of Transportation https://www.fhwa.dot.gov/policyinformation/travel_monitoring/12jantvt/12jantvt.pdf

Fergusson D. et al. (2003). Risky driving behaviour in young people: prevalence, personal characteristics and traffic accidents. Aust N Z J Public Health. 2003; 27(3):337-42. https://www.ncbi.nlm.nih.gov/pubmed/14705290

Fernandes, R. et al. (2010). A systematic investigation of the differential predictors for speeding, drink-driving, driving while fatigued, and not wearing a seat belt, among young drivers. Transportation Research Part F: Traffic Psychology and Behaviour, Volume 13, Issue 3, May 2010, Pages 179–196

Fleisher, A. (2015). A Vision for Transportation Safety: A Framework for Identifying Best Practice Strategies to Advance Vision Zero. Transportation Research Board. http://docs.trb.org/prp/16-3828.pdf

Gordon, H. (Aug 2015) Commuters are getting a lesson in the joys of summer vacation. The Buffalo News. August 5, 2015 http://buffalonews.com/2015/08/05/commuters-are-getting-a-lesson-in-the-joys-of-summer-vacation/

Hadayeghi, A. et al. (2003). Macrolevel Accident Prediction Models for Evaluating Safety of Urban Transportation Systems. In Transportation Research Record: Journal of the Transportation Research Board, No. 1840, pp. 87–95.

Hanson, C.S. et al. (2013). The severity of pedestrian crashes: an analysis using Google Street View Imagery. Journal of Transport Geography 33, pp. 42–53.

Hu, P.S. et al. (1998). Crash Risks of Older Drivers: A Panel Data Analysis. Accident Analysis and Prevention, Vol. 30, No. 5, pp. 569–581.

Huang, H. et al. (2011). Indexing crash worthiness and crash aggressivity by vehicle type. Accident Analysis and Prevention 43, pp. 1364–1370.

Ivan, J. N. (2000). Explaining Two-Lane Highway Crash Rates Using Land Use and Hourly Exposure. Accident Analysis and Prevention, Vol. 32, No. 6, pp. 787–795.

Keller, J. et al. (2006). Type of Collision and Crash Data Evaluation at Signalized Intersections. Institute of Transportation Engineers. ITE Journal; Feb 2006; 76, 2; ProQuest pg. 30.

Kim, K. et al. (2006). Influence of Land Use, Population, Employment, and Economic Activity on Accidents. In Transportation Research Record: Journal of the Transportation Research Board, No. 1953, pp. 56–64.

Lenguerrand, E. et al. (2006). Modelling the hierarchical structure of road crash data—Application to severity analysis. Accident Analysis and Prevention 38, pp. 43–53.

Levine, N. et al. (1995). Spatial analysis of Honolulu motor vehiclecrashes. II. Zonal generators. Accid. Anal. Prev. 27 (5), 675–685.

Litman, T. (2002). Evaluating Transportation Equity. Guidance For Incorporating Distributional Impacts in Transportation Planning. Victoria Transport Policy Institute. http://www.vtpi.org/equity.pdf (Original publication: World Transport Policy & Practice http://ecoplan.org/wtpp/wt_index.htm , Volume 8, No. 2, Summer, pp. 50-65.)

Logistic regression (ND). IDRE research technology group. UCLA. http://www.ats.ucla.edu/stat/stata/dae/logit.htm

Loo, B. P. Y. (2006). Validating crash locations for quantitative spatial analysis: A GIS-based approach. Accident Analysis and Prevention 38, pp. 879–886.

Lord, D. & Mannering, F. (2010). The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives. Transportation Research Part A 44, pp. 291–305.

Lord, D. (2005). Poisson, Poisson–Gamma and Zero-Inflated Regression Models of Motor Vehicle Crashes: Balancing Statistical Fit and Theory. Accident Analysis and Prevention, Vol. 37, No. 1, pp. 35–46.

Marshall, W.E. & Garrick, N.W. (2011). Does street network design affect traffic safety? Accident Analysis and Prevention 43, pp. 769–781.

Meng, Q. & Weng, J. (2011). Evaluation of rear-end crash risk at work zone using work zone traffic data. Accident Analysis and Prevention 43, pp. 1291–1300.

Miaou, S. P. (1994). The Relationship Between Truck Accidents and Geometric Design of Road Sections—Poisson Versus Negative Binomial Regressions. Accident Analysis and Prevention, Vol. 26, No. 4, pp. 471–482.

Møller, M. & Haustein, S. (2014). Peer influence on speeding behaviour among male drivers aged 18 and 28. Accid Anal Prev. 2014 Mar;64:92-9. doi: 10.1016/j.aap.2013.11.009. Epub 2013 Dec 1.

Morency, P. et al. (2012). Neighborhood Social Inequalities in Road Traffic Injuries: The Influence of Traffic Volume and Road Design. American Journal of Public Health: June 2012, Vol. 102, No. 6, pp. 1112-1119.doi:10.2105/AJPH.2011.300528. http://ajph.aphapublications.org/doi/abs/10.2105/AJPH.2011.300528

Negative binomial regression (ND). IDRE research technology group. UCLA. http://www.ats.ucla.edu/stat/stata/dae/nbreg.htm

Noland, R.B. & Oh, L. (2004). The effect of infrastructure and demographic change on traffic-related fatalities and crashes: a case study of Illinois county-level data. Accident Analysis and Prevention 36, pp. 525–532.

Ouyang, Y. & Bejleri, I. (2014). Geographic Information System–Based Community-Level Method to Evaluate the Influence of Built Environment on Traffic Crashes. Journal of the Transportation Research Board, No. 2432, pp. 124–132. DOI: 10.3141/2432-15.

Pande, A. & Abdel-Aty, M. (2009). Market basket analysis of crash data from large jurisdictions and its potential as a decision support tool. Safety Science 47, pp. 145–154.

Park, B.-J. et al. (2010). Bias properties of Bayesian statistics in finite mixture of negative binomial regression models in crash data analysis. Accident Analysis and Prevention 42, pp. 741–749.

Van Petegem, J.W.H.(J.H.) & Wegman, F. (2014). Analyzing road design risk factors for run-off-road crashes in the Netherlands with crash prediction models. Journal of Safety Research 49, pp. 121–127.

Petritsch, T. A. et al. (2006). Sidepath Safety Model Bicycle Sidepath Design Factors Affecting Crash Rates. Journal of the Transportation Research Board, No. 1982, pp. 194–201.

Plug, C. et al. (2011). Spatial and temporal visualisation techniques for crash analysis. Accident Analysis and Prevention 43, pp. 1937– 1946.

Porter, B. E. (2011). Handbook of Traffic Psychology. Academic Press, Jun 22, 2011 - Psychology

Qin, X. et al. (2013). Developing Truck Corridor Crash Severity Index. Journal of the Transportation Research Board, No. 2386, pp. 103–111. DOI: 10.3141/2386-12.

Qin, X. & Reyes, P. E. (2011). Conditional Quantile Analysis for Crash Count Data. Journal of Transportation Engineering, 2011, 137(9): 601-607.

Quddus, M.A. (2008). Modelling area-wide count outcomes with spatial correlation and heterogeneity: An analysis of London crash data. Accident Analysis and Prevention 40, pp. 1486–1497.

Retting, R. A. et al. (2003). A Review of Evidence-Based Traffic Engineering Measures Designed to Reduce Pedestrian–Motor Vehicle Crashes. Peer Reviewed. American Journal of Public Health, September 2003, Vol 93, No. 9.

Reynolds, C.CO. (2009). The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. Environmental Health 2009, 8:47 doi:10.1186/1476-069X-8-47.

Rhee, K.-A. et al. (2016). Spatial regression analysis of traffic crashes in Seoul. Accident Analysis and Prevention 91, pp. 190–199.

Rifaat, S.M. et al. (2011). Effect of street pattern on the severity of crashes involving vulnerable road users. Accident Analysis and Prevention 43, pp. 276–283.

Romano, E. O. et al. (2012). Traffic environment and demographic factors affecting impaired driving and crashes. Journal of Safety Research 43, pp. 75–82.

Sanchez, T. W. et al. (2003). MOVING TO EQUITY: Addressing Inequitable Effects of Transportation Policies on Minorities. http://www.racialequitytools.org/resourcefiles/sanchez-moving-to-equity-transportation-policies.pdf

Sandt, L. et al. (2016). Pursuing Equity in Pedestrian and Bicycle Planning. FDOT http://www.fhwa.dot.gov/environment/bicycle_pedestrian/resources/equity_paper/

Schneider, R. J. et al. (2010). Association Between Roadway Intersection Characteristics and Pedestrian Crash Risk in Alameda County, California. Journal of the Transportation Research Board, No. 2198, pp. 41–51. DOI: 10.3141/2198-06.

Shariat-Mohaymany, A. et al. (2015). Exploring Spatial Non-Stationarity and Varying Relationships between Crash Data and Related Factors Using Geographically Weighted Poisson Regression. Transactions in GIS, 19(2): 321–337.

Siddiqui, C. et al. (2012). Macroscopic spatial analysis of pedestrian and bicycle crashes. Accident Analysis and Prevention 45, pp. 382– 391.

Sulaiman, S. (Aug 2016). Vision Zero: LADOT, Focus Group Have Same Goals, Different Ideas About How to Reach Them. StreetsBlog LA http://la.streetsblog.org/category/special-features/vision-zero/

Teoh, E. R. & Campbell, M. (2010). Role of motorcycle type in fatal motorcycle crashes. Journal of Safety Research 41 (2010) 507–512.

Teschke, K. et al. (2014). Bicycling crash circumstances vary by route type: a cross-sectional analysis. BMC Public Health 14:1205.

Turner, C. & McClure, R. (2010). Age and gender differences in risk-taking behaviour as an explanation for high incidence of motor vehicle crashes as a driver in young males. Journal Injury Control and Safety Promotion, Volume 10, 2003 - Issue 3. Pages 123-130 http://www.tandfonline.com/doi/abs/10.1076/icsp.10.3.123.14560

Ukkusuri, S. et al. (2012). The role of built environment on pedestrian crash frequency. Safety Science 50, pp. 1141–1151.

Untaroiu, C. D. et al. (2009). Crash reconstruction of pedestrian accidents using optimization techniques. International Journal of Impact Engineering 36, pp. 210–219.

Vision Zero Action Plan – City of New York (2014). http://www.nyc.gov/html/visionzero/pdf/nyc-vision-zero-action-plan.pdf

Vision Zero Boston. Action Plan (2015). CITY OF BOSTON TRANSPORTATION DEPARTMENT http://chicagocompletestreets.org/wp-content/uploads/2016/02/Boston_ActionPlan.pdf

Vision Zero. Los Angeles 2015-2025 (2015). Eliminating traffic deaths in Los Angeles by 2025. http://visionzero.lacity.org/wp-content/uploads/2015/09/VisionZeroLosAngeles.pdf

Vision Zero Network (2016). Case Study 1 - What makes Vision Zero different? http://visionzeronetwork.org/wp-content/uploads/2016/03/VZN-Case-Study-1-What-makes-VZ-different.pdf

Vision Zero San Francisco 2024 http://visionzerosf.org/equity/

Vision Zero San José (2015). Current Status and Actions. https://www.sanjoseca.gov/DocumentCenter/View/42849

Wang, X. & Abdel-Aty, M. (2008). Analysis of left-turn crash injury severity by conflicting pattern using partial proportional odds models. Accident Analysis and Prevention 40, pp. 1674–1682.

Wu, H. et al. (2014). Analysis of Crash Data Using Quantile Regression for Counts. Journal of Transportation Engineering, 2014, 140(4): 04013025.

Image

Cover page image source: Visitalexandriava.com