EVALUATING TRAFFIC SAFETY IN FORT LAUDERDALE USING A VISION ZERO FRAMEWORK

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
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To my family, friends, and educators who got me where I am today

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ABS	Anti-locking brake system
ERC	Essential recognizability characteristics
ESC	Electronic stability control
FARS	Fatality Analysis Reporting System
FDOT	Florida Department of Transportation
FDR	False discovery rate
GES	General Estimates System
GIS	Geographic Information Systems
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
VIF	Variance inflation factor

Abstract of Thesis Presented to the Graduate School
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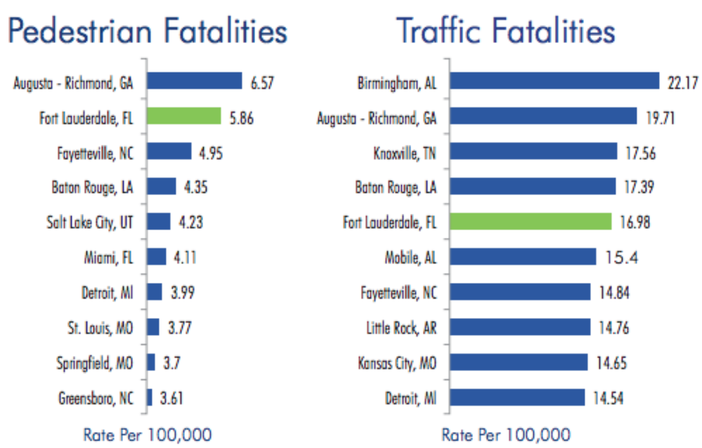
This paper uses geographic information systems and binomial logistic regression to study traffic safety in Fort Lauderdale, Florida. The goal of achieving a society without traffic violence is evaluated through the lens of Vision Zero. Fort Lauderdale suffers from a history of high fatality rates in vehicle crashes and has been identified as one of the most dangerous cities in the nation for pedestrians. In 2015, the city adopted a Vision Zero plan to counteract these trends and follow a model with the ultimate goal of eliminating all serious injuries and deaths on roads. By mapping hot spots of severe crashes, priority areas of concern can be identified. Adding descriptive spatial data about road design near crash points can help explain which factors are significant in impacting injury severity. The research concludes that Vision Zero concepts are reasonable actions to mitigate serious traffic incidents, based on the results of the binomial logistic regression.

CHAPTER 1
INTRODUCTION

An average of 96 Americans die from vehicular collisions each day, and motor vehicle crashes are the leading cause of death for all ages 16 through 24 (NHTSA, 2015). Florida consistently ranks within the top 10 states of highest pedestrian fatalities per 100,000 residents each year (Smart Growth America, 2017). In the past, the general approach to road safety has been to blame road users. This user-oriented framework has been substantiated by facts and data: the World Health Organization’s World Report on Road Traffic Injury Prevention cites human error as the cause for 95% of crashes (2004).

While data may point to human error as a strong contributor to crashes, fatalities should not be treated as an unavoidable byproduct of mobility. A recent paradigm shift toward comprehensive, systems-based thinking introduces the alternative notion that road users share responsibility with the entire transportation system. This system includes, but is not limited to, vehicles, drivers, laws, and engineering. It was this systems-based approach that inspired the Swedish Parliament to pass the Road Traffic Safety Bill in 1997, leading to the creation of a new national program. The philosophy for the program originated as “Nollvisionen”, which translates literally to “The Vision Zero”. It is based on ethical, humanitarian, environmental, and economic beliefs. It relies on the assumption that humans have a basic, inalienable right to safe and healthy transportation. Since its adoption by parliament in 1997, Sweden has decreased annual road fatalities by 38% and is on track to meeting its year 2020 target of cutting traffic deaths by 50% (Trafikverket, 2015).

Cities and countries all over the world have adopted the program, transcending geographic and cultural boundaries. Currently, the United States has over 25 Vision Zero cities (Vision Zero Network, n.d.). One of these cities is Fort Lauderdale. Fort Lauderdale is a mid-sized city of 33 square miles and a population of about 172,000 located along the southeast coast of Florida. Its favorable location near the Atlantic Ocean as well as extensive canal system makes the city popular within the marine industry, attracting yachts, personal boaters, cruise ships, and cargo. Favorable weather has made Fort Lauderdale a popular tourist destination, and increased service to the international airport has yielded increased tourism in recent years. The city entertains, over 14 million visitors in any given year. The Florida community of Fort Lauderdale has adopted its own Vision Zero Plan, citing its ranking within the top 10 pedestrian and traffic fatality rates as a fundamental issue (see Figure 1-1).



CITY OF FORT LAUDERDALE (2009-2014)

	2009	2010	2011	2012	2013	2014	TOTAL
Total Traffic Crashes	4,720	4,910	3,933	6,198	10,133	10,879	40,773
Total Traffic Fatalities	28	20	16	28	18	24	134
Total Pedestrian Fatalities	11	10	4	11	9	12*	57
Total Bicycle Fatalities	4	2	1	3	1	3*	14
Total Pedestrian Injury Crashes	134	119	133	144	189	162	881
Bicycle Injury Crashes	111	95	55	102	110	95	568

*Does not include fatalities that are still under investigation

Figure 1-1. Fort Lauderdale Traffic Fatalities (City of Fort Lauderdale, 2015).

Citizen demand for sidewalks, bikeable streets, and multimodal transportation options are a few factors that have influenced the adoption of its Vision Zero Street Safety Action Plan. The Fort Lauderdale Vision Zero Street Safety Action Plan lists the following main principles:

- Principle 1: There is not an acceptable level of fatality or injury on our streets.
- Principle 2: Traffic deaths and injuries are not accidents, they are preventable crashes.
- Principle 3: The public should expect safe behavior on City streets and actively participate in efforts to make them safer (City of Fort Lauderdale, 2015, p. ii).

The plan separates its action strategies by focusing on the “5 Es”: engineering, education, encouragement, enforcement, and evaluation. By adopting the street safety action plan, Fort Lauderdale hopes to build equity, protect life, increase sustainability, improve the economy, and enhance overall quality of life. In order to materialize these goals, each of the 5 Es has its own implementation and collaboration methods. However, the evaluation and engineering sections could benefit from an investigation of the correlation between current street design features and crash statistics. Currently, there are portions in the engineering section that refer to specific design practices that have been successful in other traffic safety literature. Similarly, the evaluation section refers to generating more hotspot analyses and data granularity (organizing hotspots by mode), but there is currently no evaluation criterion investigating the direct correlation between design and crashes.

The purpose of this study is to evaluate the translation of Vision Zero values and ideals to the City of Fort Lauderdale, focusing on statistically significant crash corridors and correlated road design features. This addresses a perceived gap in the current Fort Lauderdale Vision Zero Street Safety Action Plan that jointly investigates evaluation and engineering criteria (street design features and existing crash data). This thesis paper aims to produce a threefold product: an overview chronicling Vision Zero's development, a statistical analysis of crash trends and built environment within Fort Lauderdale, and finally suggestions for improvement within the community based on Vision Zero best practices and analysis results. The paper relies on geospatial analyses based on data from Signal Four Analytics and Florida Department of Transportation (FDOT) in conjunction with geographic information systems (GIS) and statistics software.

CHAPTER 2
REVIEW OF LITERATURE

Vision Zero Principles and Related Policies

Comparing Traditional and Modern Road Safety Philosophies

Vision Zero emerged as a clear deviation away from prior user-oriented culpability in traffic safety. The user-oriented, utilitarian mentality is referred to as the traditional road design philosophy. By traditional road design logic, road users are the ones accountable for crashes since they are required by law to adapt to road conditions regardless of how unfavorable conditions may be. To further propagate inaccuracy, users and their vehicles were largely treated as one unified body. Early crash analysis practices initiated and concluded road safety evaluation at the accident scene without accounting for granulated crash factors such as injury severity. In comparison, modern definitions stress loss of health as the main indicator of road safety (Johansson, 2009). Road traffic safety currently is defined as "methods and measures for reducing the risk of a person using the road network being killed or seriously injured. The users of a road include pedestrians, cyclists, motorists, their passengers, and passengers of on-road public transport" (Paramjeet, 2014, p. 15). The fundamental differences between traditional and modern inquiry are whether crashes are an unavoidable byproduct of increased mobility in societies and to what extent the level of injury matters in safety analysis. The view on shared responsibility, expectations on road users for safety, and ultimate goals for road safety efforts are amended in today's safe systems and Vision Zero frameworks.

Modern ideals reject the erroneous and oversimplified treatment of accidents as the conclusive safety indicator. Best practices focus on preventing loss of health in crashes despite human fallibility. Aspiring to reduce the frequency of crashes neglects the variable scale of health considerations. Following the logic of modern road safety definitions, if an accident does not yield significant injuries, then there is no loss of health. If there is no loss of health, then it is not considered a safety issue. Vision Zero uses this logic to justify its indifference toward decreasing total collision frequency. Instead, the goal is to eliminate severely injurious collisions.

Traditional philosophy is mainly concerned with perceived costs. Its optimal level of safety would occur where costs of intervention outweigh benefits (i.e. cost of prevented crashes). Although no literature explicitly refers to an optimum level of death/injury, an optimum level is implied within any cost-benefit analysis. This mentality yields “low-hanging fruit” type interventions such as education and enforcement. More expensive solutions like capital improvements are reserved for hotspots. For example, one lower cost intervention that fails to reduce serious harm is intersection signalization. While signals may reduce the frequency of crashes, the injury severity is often significant due to speed and angle (International Transport Forum, 2016). The predominant design strategy for reducing number of vehicular crashes in the traditional sense has been to create space for evasive action and make roads more maneuverable. Roads are designed to be straighter and wider to ease automobile movement. An unintended consequence of this design framework is to facilitate faster driving speeds. Generally, higher travel speeds lead to more intense levels of kinetic energy in collisions. The ultimate product is a scenario in which the number of crashes may decrease, but loss of life increases by a factor of 10 due to augmented crash severity (Johansson, 2009). Again, the traditional methodology reinforces the expendability of human life by prioritizing low-cost solutions, which, although practical, perpetuate the acceptance of fatality in the transportation system. Furthermore, these responses can be criticized as reactive rather than preventive. Reactionary interventions require a baseline number of casualties to create a demand for action, which is a counterintuitive method for preserving human life. In summary, traditional road design philosophy focuses on reducing vehicular collisions whereas modern ideas (e.g. safe systems thinking) focus on minimizing loss of health (Figure 2-1).

	Traditional road safety policy	Safe System
What is the problem?	Try to prevent all crashes	Prevent crashes from resulting in fatal and serious casualties
What is the appropriate goal?	Reduce the number of fatalities and serious injuries	Zero fatalities and serious injuries
What are the major planning approaches?	Reactive to incidents Incremental approach to reduce the problem	Proactively target and treat risk Systematic approach to build a safe road system
What causes the problem?	Non-compliant road users	People make mistakes and people are physically fragile/vulnerable in crashes. Varying quality and design of infrastructure and operating speeds provides inconsistent guidance to users about what is safe use behaviour.
Who is ultimately responsible?	Individual road users	Shared responsibility by individuals with system designers
How does the system work?	Is composed of isolated interventions	Different elements of a Safe System combine to produce a summary effect greater than the sum of the individual treatments- so that if one part of the system fails others parts provide protection.

Figure 2-1. Traditional versus safe system philosophy (International Transport Forum, 2016).

Although systems-based thinking has been applied to other areas of study for many years, it was not necessarily applied to traffic issues until the 1990s. The systems-based approach confronts the dynamic transportation system in its totality, treating the whole as greater than the sum of its parts. Perhaps this delayed onset of a unified, comprehensive strategy can be attributed to the steady decline in crash rates over the past hundred years in most developed nations.

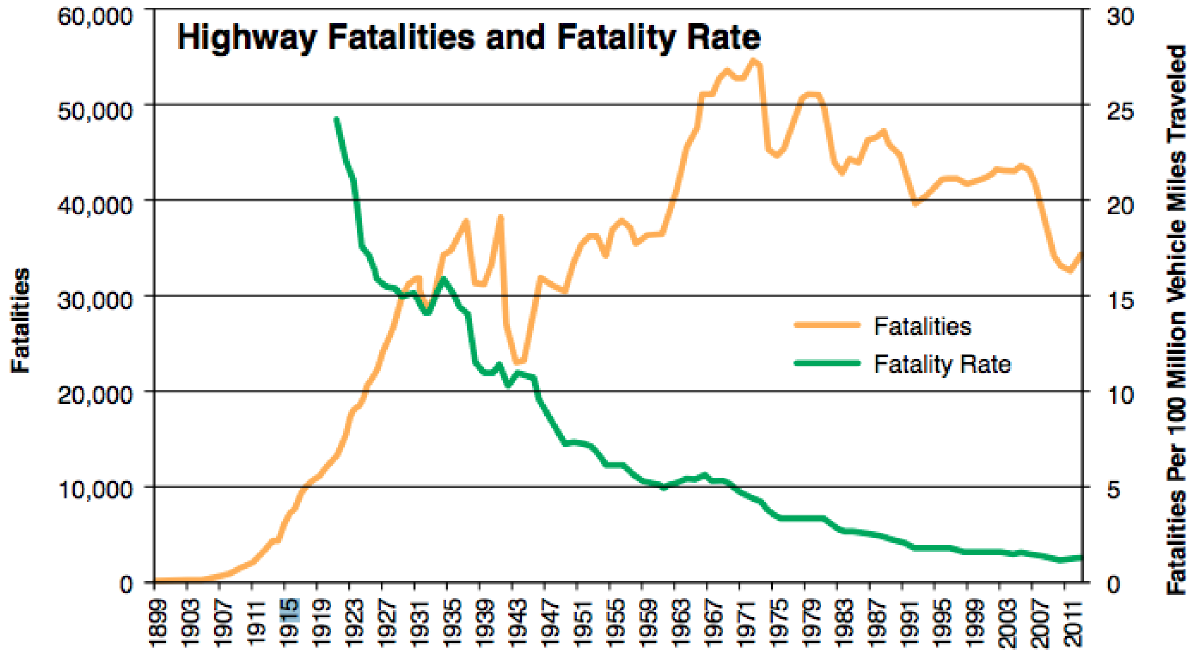


Figure 2-2. Highway fatalities and fatality rate in the United States (Toward Zero Deaths, 2014).

Consumer-based demand for safer vehicles and government-mandated automobile regulations, among other factors, generated safer traffic conditions over time. Since the decrease in crash rates has plateaued in comparison to its lifetime trend (see Figure 2-2), experts are now forced to methodically identify and isolate specific target areas for improvement. The safe systems approach that Vision Zero is based upon surpasses the reactionary, cost-efficiency centric ways of traditional road safety philosophies. The International Transport Forum describes a safe system as:

> …holistic and proactive in essence, managed so the elements of the road transport system combine and interact to guide users to act safely to prevent crashes and, when they occur, ensure that impact forces do not exceed the physical limits of the human body and result in serious injury or death. . .it takes a proactive approach to guide safe behaviour while also assessing the risks inherent in a road network and identifying priority interventions that prevent serious trauma when crashes invariably occur.

> Most of all, a Safe System does not accept trade-offs between human lives and other priorities (2016, n.p.).

It aims to appreciate human behavior, proactively assess infrastructure safety, and treat design flaws prior to crash incidents. Safety is regarded as a prerequisite to an effective transport system.

Vision Zero Principles

Similar to the safe systems approach, Vision Zero's overarching mission statement is that there is no acceptable level of life-altering injury or death in the transport system. The only justifiable number of traffic deaths and serious injuries is zero. On the other hand, minor collisions and injuries must be tolerated. Instead of attempting to get people (who are inherently fallible) to adjust to an unforgiving transport system, the objective is to design a people-friendly road system. It is vital to note that the foundational rationale for the program is ethical. Despite an ethically grounded motivation, the program addresses traffic safety comprehensively and relies on concrete data to produce concrete goals. Each local community may have its own interpretation of Vision Zero, but there are some common fundamental principles for a meaningful commitment. The Vision Zero Network outlines these principles:

1. Traffic deaths and severe injuries are acknowledged to be preventable.
2. Human life and health are prioritized within all aspects of transportation systems.
3. Acknowledgement that human error is inevitable, and transportation systems should be forgiving.
4. Safety work should focus on systems-level changes above influencing individual behavior.
5. Speed is recognized and prioritized as the fundamental factor in crash severity. (2017)

These principles were surprisingly not generated in response to anomalously high crash rates. In fact, at the time of adoption Sweden had some of the lowest traffic death rates per capita in all of Europe (Elvebakk, 2009). The aggressive stance rejecting traffic violence stems from a moral obligation to offer citizens safe mobility. This “zero tolerance” goal is not arbitrary; those who drafted the program researched acceptable levels of fatality in relatable areas such as air and rail travel. Fatality is not considered acceptable in these other modes of transportation; therefore, there is no moral justification to accept road deaths. Traffic deaths have become a habitual event, which is arguably the only reason they are tolerated.

It is important to note that the philosophy does not expect a complete absence of all collisions; there is a certain level of tolerable health loss. This tolerable level is described as non-permanent injury: any injury that will heal over the course of one’s life is tolerable. In stark contrast to traditional road safety, Vision Zero does not aim to eliminate crash occurrences; instead it aims to eliminate serious consequences of accidents. It assumes a fundamental level of human error. However, users are still expected to follow laws and regulations. Preservation of health is the top priority, with the remainder of costs following behind.

It is apparent that humans have certain physical limitations: reaction time, ability to withstand impact, and so forth. Knowing this, it is logical to amend other parts of the traffic system to be more forgiving toward human mortality. The safe systems approach puts human resistance to biomechanical forces at the forefront. Vision Zero strategies utilize data on human tolerance and loss of health to generate concrete design improvements. For example, most of the program’s documents cite the critical difference 20 km/hr can make in a collision. “The probability of a pedestrian being killed rises by a factor of eight as the impact speed of the car increases from 30 km/hr to 50 km/hr” (World Health Organization, 2004, p. 77). Due to the variability in built environment and culture among communities, no universal Vision Zero design guideline exists. However, an abundance of related policy broaches one or more specific topics.

Related Policies

Complete streets

Complete Streets refers to a policy where streets safely accommodate all users of transportation. City planners are increasingly advocating for planning, designing, and building transportation improvements providing appropriate modifications for all travelers (pedestrians, bicyclists, transit users, individual drivers, and persons of all abilities) in order to move in a comprehensive and connected network. This echoes the equity issues addressed by Vision Zero, where all modes are expected to enjoy the same level of safety. Most American cities suffer from an unequal distribution of space and resources to all travelers.

Transportation systems are configured to facilitate efficient movement of individual car users and treat other road users as an afterthought. Complete Streets calls out so-called conventional street design as the culprit for lack of accessibility, safety, and mobility in urban environments. This is proliferated economically, environmentally, and socially in the greater context of society. Byproducts of conventional street design include “traffic congestion, insufficient pedestrian and bicycle safety, decentralized development patterns, air pollution, unnecessarily high vehicles miles traveled, and adverse health outcomes such as disabling injuries and increased rates of cardiovascular disease” (Tacoma-Pierce County Health Department, n.d., p. 1).

Like Vision Zero, Complete Streets realizes that different communities may need different design treatments. The main goal is that safe access will be enabled for all street users. Some general principles include separation of modes, lane dieting, appropriate scales, and minimizing conflict points. Some of examples of these principles may be dedicated bus lanes, curb ramps for the mobility challenged, sufficient lighting, buffered bike lanes, wide sidewalks, and buffered sidewalks. Successful Complete Streets implementation should yield more efficient travel connectivity, less frequent/severe traffic collisions, equitable access to mobility, and boosted economy.

Toward zero deaths

The National Strategy on Highway Safety has launched a framework for the United States to move toward a goal of zero traffic deaths. The document is based directly off Vision Zero, and it establishes the same attitude toward acceptable fatalities and injuries on roads. The goal of the document was to create a unified vision for highway safety stakeholders, despite the many diverse initiatives toward road safety happening at more local levels. In 2011, stakeholders argued that these smaller scale movements must be bolstered by a singular, overarching vision. The 2014 document outlines six key areas for increasing road safety: safer drivers and passengers, safer vulnerable users, safer vehicles, safer infrastructure, enhanced emergency medical services, and improved safety management. The target audience of Toward Zero Deaths is safety organizations and professionals who agree to work aggressively toward intermediate goals specific to their jurisdiction or the safety issue on which they focus. These stakeholders perpetually develop their efforts to improve road safety. Safety organizations and professionals have committed to continue proven best practices as well as introduce new approaches, materials, and technologies to reach safety goals.

One of the distinct strengths of the document is its division of strategic timeframes into short-term (known to be effective and can be implemented in under 5 years), mid-term (may require legislative approval and can be implemented in between five to 15 years), and long-term goals (will have a significant impact on safety, but may take over 15 years to implement). These separate strategic categories are created under the assumption that funding and resources are available; that is, they are divided based solely upon feasibility. Providing proven countermeasures and corresponding timeframes allow stakeholders to consider their individual role in the traffic safety discipline. Furthermore, the six key focus areas are subdivided into even more specified goals, adding to the manageability of tackling road violence.

Road to zero

The National Safety Council has recently adopted another program called the Road to Zero Coalition, which aims to reach zero traffic fatalities. This initiative was created in partnership with the National Highway Safety Administration, Federal Highway Administration, and Federal Motor Carrier Safety Administration. In contrast to most other initiatives, their goal is to reach zero within 30 years. The National Safety Council's main justifications for the attainability of the initiative are:

- "Traffic fatalities and injuries are preventable.
- A future with zero traffic deaths is more certain than ever with the emergence of self-driving cars and the Safe Systems transportation approach.
- A coordinated effort that brings together multiple stakeholders with the same goal can achieve more than individual organizations working independently" (n.d., n.p.).

Contrary to related programs, this national policy does not have an accompanying action plan. Instead it is more of an opportunity for interested parties to join the Road to Zero Coalition and subscribe to the goals the council stands for. Some of the lifesaving strategies the coalition promotes include rumble strips, seatbelt compliance, truck safety, behavioral changes, and data-driven enforcement.

Criticisms

There have been a number of critical reactions to different Vision Zero policies, ranging from being utopian and illusory to populist or dictatorial. Mainly, people express doubts about the value in setting and pursuing a goal that is largely accepted as theoretical versus practical. This boils down to a question of whether the framework is rational. In a purely ethical perspective, the demand for a safe road system--with a complete rejection of injury or death--seems reasonable. Rosencrantz, Edvardsson, and Hansson discuss the rationality of Vision Zero's precision, metrics, approachability, and motivation in their paper "Vision Zero: Is it irrational?"

The precision of terms within Vision Zero principles is sometimes ambiguous. In order for goals to be achievable they must be precisely defined. While Sweden's plan has defined terms for its levels of injury and spatial extent, not every Vision Zero plan discusses its own technical terms for what constitutes a death or serious injury on the road network. For example, does the road network include parking lots and alleyways? In Fort Lauderdale's case, the plan is mostly concerned with roads under city jurisdiction despite numerous fatalities on interstate highways within city limits. This distinction between roads within city limits and city-managed roads could benefit from clarification. Similarly, defining a temporal precision regarding when the goal should be reached would benefit the vision's clarity.

It is important that the goal in question can be evaluated to improve achievement strategies. The ability to assess progress in Vision Zero is complicated by the duality of the goal (decreasing deaths and injuries). There is no reliable weighting for the severities. For example, two years of crash data may be compared where the fatalities have increased, but injuries have decreased. What is the metric to assess the net product? Evaluation is also complicated by the long-term nature of the goal. Assessing chunks of temporal data can be arbitrary when the goal has no defined end date or reasonably estimable solution. Lurking variables within estimations (such as weather and economy) are also difficult to control or account for.

The concept of approachability questions the abstractness and implausibility of reaching zero deaths. Rosencrantz, Edvardsson, and Hansson argue that realistic and unrealistic goals should not be a binary ultimatum, rather there should be a scale that ascertains whether a goal has been reached to a satisfactory degree. Although the goal of zero deaths and injuries is largely intangible, it does not prevent us from pursuing it. It may not be attainable, yet it is possible to increase the degree to which the goal is realized.

Motivation relates to inspiring change agents that further the goal. This might include participation in the goal-setting process, encouragement, and other incentives (Rosencrantz, Edvardsson, and Hansson, 2007). This means that the Vision Zero framework should actively motivate its adopters to achieve the end goal. Since the goal is abstract and not completely precise, it can be argued that it does not inspire motivation. When an aspiration is too great, it may end up being counterproductive since its adopters feel as if it is not possible.

Vision Zero Case Study and Overview of Fort Lauderdale's Plan

Since Vision Zero was initiated in Sweden, its strategies were adapted to the local concerns and environment. Sweden decided to use the following indicators to gauge the effectiveness of its plan: compliance with speed limits (national and municipal road network); sober traffic; use of seat belts; use of helmets (motorcycle, moped, and cyclist); safe passenger cars; safe motorcycles (antilocking brake systems); safe national roads; safe pedestrian, cycle and moped crossings in urban areas; and maintenance of pedestrian and cycle paths (Trafikverket, 2015). The City of Fort Lauderdale organizes its strategies to reach zero traffic fatalities based on the 5 E categories: engineering, education, encouragement, enforcement, and evaluation.

Fort Lauderdale's Vision Zero Street Safety Action Plan

Fort Lauderdale is responding to its citizens' concerns about public safety on city streets. In 2013, Fort Lauderdale adopted its *Fast Forward Fort Lauderdale 2035 Vision Plan* which used a pedestrian priority framework to generate a multimodal transportation network. In subsequent community surveys, citizens have ranked bicycle safety as a top priority for transportation and mobility. Therefore, the focus of capital improvements funding has shifted towards bikeable and walkable streets, greenways, and pathways (City of Fort Lauderdale, 2015).

Vision Zero Fort Lauderdale cites the FARS statistic that the city has the second highest pedestrian fatality rate in the nation at 5.86 per 100,000 (2015). Furthermore, the plan states that the city has the highest fatality rate in the state, averaging approximately 20 traffic deaths each year (2015). The document refers to several macro-scale benefits of pursuing zero traffic deaths: equitable mobility, healthy communities, connectivity, placemaking, and sustainability. The city's core principles in its Vision Zero plan are

1. There is not an acceptable level of fatality on our streets.
2. Traffic deaths and injuries are not accidents; they are preventable crashes.
3. The public should expect safe behavior on City streets and actively participate in efforts to make them safer (City of Fort Lauderdale, p. 2, 2015).

Case Study: Vision Zero Best Practices Matrix

"A Vision for Transportation Safety: *A Framework for Identifying Best Practice Strategies to Advance Vision Zero*" by Fleisher, Weir, and Hunter studies the landscape of strategies employed by 11 domestic cities and three international programs to advance Vision Zero. Despite interest from a growing number of cities in the United States and around the world, established guidance for Vision Zero best practices is minimal. This paper provides a comparison of policy components in the form of a so-called Traffic Safety Best Practice Matrix that aims to address a gap between policy adoption and implementation. The matrix researches safety strategies from San Francisco, San Jose, San Mateo, Los Angeles, Seattle, Portland, Chicago, New York, Washington D.C., Boston, Sweden, the Netherlands, and London. All of these locations can be considered early adopters of Vision Zero and were actively pursuing reduced bicycle, pedestrian, and/or traffic-related injuries and fatalities at the time of the study.

The data in the matrix is twofold: first, it records whether or not a specified safety measure is referenced in the location's safety documents, and second, the efficacy of that safety measure's capacity to reduce injury is ranked. The former indicator is simply a binary "yes" or "no" for existing within the safety plan. The latter falls into one of three categories: proven (proven to be effective based on several evaluations with consistent results), recommended (generally accepted to be effective based on evaluations or other sources), or unknown (lower quality rating; limited evaluation or evidence; experimental outcomes inconsistent and inconclusive between studies) (Fleisher, Wier, and Hunter, 2015). These classifications were quality-controlled by a representative from each city or country that was included in the matrix, usually their own Vision Zero leader or safety expert. One-hundred six safety measures are allocated into nine categories of the matrix which include 1) Supportive Infrastructure/Planning 2) Engineering 3) Education 4) Enforcement 5) Monitoring, Analysis, and Evaluation 6) Policy 7) Large Vehicles 8) Vehicle Technology and 9) Taxi Services/Transportation Network Companies.

The resulting matrix yields an organized visualization of possible levers for cities to use when advancing a safety platform. It also illuminates the contrasting methods among cities to achieve the goal of zero traffic deaths. The engineering segment of the table demonstrates significant clustering of checked values, indicating that these safety measures (like road design) are commonly adopted. Popular engineering methods include lead pedestrian intervals, protected turns, speed limit signage, school zones, lighting, speed bumps, designated bike lanes, and more (Fleisher, Wier, and Hunter, 2015). Education is also a clustered section for the domestic cities. Surprisingly, Sweden does not focus on the educational aspects as much, despite being the Vision Zero pioneer. In contrast, all other locations in the matrix are using mass media and communications for education efforts. Shifts in educational trends could be inspiring a transition from individual driving skills to socio-ecological approaches to education advanced by the field of public health (by policy reform and organizational practices) (Fleisher, Wier, and Hunter, 2015).

The study found that cities are not collaborating among all levels of government despite a general consensus in attitude toward traffic safety initiatives across the federal, state, and local levels. All but one (New York) of the domestic cities included in the study have statewide *Toward Zero Deaths* efforts, yet only a handful of them are engaging with state and federal level organizations to advance their plans. Fleisher, Wier, and Hunter argue that jurisdictional boundaries aside, the shared philosophical goals among the different levels of government should be reason enough to collaborate and overcome challenges for reaching traffic safety goals.

Finally, utilization of the 106 safety methods included in the matrix is low. “Many measures are being implemented by less than 40% of the cities/countries included in the review” (Fleisher, Wier, and Hunter, p. 14, 2015). One of the least frequently applied methods is vehicle technology. Public-private partnerships represent an area of great opportunity in the United States, but only New York and Seattle indicated the intent to partner with industry groups or vehicle manufacturers within their Vision Zero plans. Vehicle technologies like intelligent speed adaptation, lane departure warnings, and alcohol interlocks boast proven safety benefits. The authors allude to vehicle safety standards being federally regulated, therefore leaving local municipalities in a jurisdictional gray space when it comes to technology. They suggest focusing on factors cities control, such as bus fleets, to implement developments in vehicle technology. Alternatively, cities can indirectly involve themselves in technological advancements by collaborating with private companies. For example, New York City partnered with Google to amend their route calculation algorithms to discourage left hand turns (which cause higher crash frequency and severity) (Fleisher, Wier, and Hunter, 2015).

The Traffic Safety Best Practices Matrix is limited by the availability of established Vision Zero programs at the time of the study, as well as comparisons among localities of varying size, geography, and sociopolitical factors. However, it serves a gap in the Vision Zero framework that is a generalized collection of methods to reach zero traffic deaths with accompanying levels of realistic utility. The matrix is best suited for cataloging the range of methods available to advance Vision Zero, engaging in peer exchange, as well as understanding the efficacy of current strategies and their potential for future research. The study provides the following recommendations for advancing Vision Zero implementation in American cities:

1. Develop mechanisms that institutionalize Vision Zero in existing institutions needed for its implementation that extend beyond the transportation sector.

2. Consider approaching education more in line with Sweden where the focus is on creating “respect” for the rules of the road that are being emphasized through system design, e.g. slow speeds. Focus education efforts on how education can support the changes in organizational practices and policy reform that allow for changes in system design.

3. Seek opportunities to engage with state and federal leaders on Vision Zero efforts.

4. Explore technology advances that address the unique safety needs of cities.

5. Pursue automated speed enforcement and other camera technologies that have proven safety benefits.

6. Facilitate accountability by creating web-based, publicly-accessible spatial data systems that monitor, analyze and report fatalities and severe injuries and associated factors, as well as benchmarks on policy progress, to help constituents realize the magnitude and distribution of transportation injuries and create the collective consciousness needed to achieve the policy’s aims (Fleisher, Wier, and Hunter, p. 16, 2015).

Known Characteristics of Automobile Safety

Safety technologies can be described in largely two categories: passive or active. Passive safety systems curb the detrimental effects of a crash that is already occurring (like seat belts and air bags). Active safety systems are geared towards preventing crashes from occurring at all. Active safety systems range from making vehicles more visible to others, to vehicles taking control of themselves in order to avoid collision.

History of Safety Interventions Pre-1920

Surprisingly, automobile safety systems did not exist for decades following the advent of the first cars. The first vehicles were without brakes, headlights, windshields, mirrors, and many other features that we now consider essential components of vehicles. Speeding, reckless driving, and pedestrian fatalities grew in frequency, and by 1910 had become major issues. Naturally, the number of car owners increased gradually until assembly line mass production in the 1920s (White, n.d.). By this time, vehicles became a centerpiece of independence and middle-class America. The first kinds of safety attempts were traditionally oriented social responses controlling driver behavior. These social responses include public awareness campaigns and controlling driver behavior through laws, fines, signals, and drunk driving arrests. Eventually it became evident that automobiles are not foolproof devices that simply reflect the competence of the driver. Rather, there became a widespread acknowledgement that design flaws existed and caused crashes.

1920s-1940s

Manufacturers brought about technological responses in the form of shatter-resistant windshields and all wheel braking. By the 1930s, motorists were educated enough about vehicle safety features that they began demanding vehicles with safety improvements such as hydraulic brakes and steel frames (White, n.d.). This inspired a market-based response to automobile safety. Additionally, the realization that secondary collisions within the vehicle posed just as much danger as the initial exterior impact brought further attention to projectile and impalement risks. Interior hazards like shattering windshields, dashboard knobs, window cranks, and door handles became highly publicized throughout the 1930s by journalists, inventors, and physicians. These efforts inspired nearly immediate safe interior design improvements by brands like Chrysler.

1950s-1970s

Collapsible steering wheels grew in commonality throughout the 1950s, until most manufacturers put vehicles on the market whose steering wheels yielded to drivers upon impact and spared them from impalement (White, n.d.). The scientific community emerged with its own response in the 1950s by conducting crash studies. Crash testing illuminated specific bodily impact-related injuries and their respective causes. In spite of the fact that seatbelts, shock-absorptive steering wheels, and padded dashboards had existed since the 1930s, they were not commonly available features in new vehicles until the response of the scientific community. The results of such crash tests eventually persuaded elected officials to pass seat belt laws in the 1960s.

Around this same time, political activist Ralph Nader made headlines by offering testimony at Senate hearings regarding automobile safety after publishing his popular book called *Unsafe at Any Speed: The Designed-in Dangers of the American Automobile.* He painted American consumers as the victims of corporate neglect and called out the industry's disregard for safety research results and choosing to maintain its hazardous design status quo, meanwhile prioritizing profits over societal wellbeing (White, n.d.). Congress finally authorized the federal government to create safety standards for new vehicles in 1966 under the National Traffic and Motor Vehicle Safety Act, and within two years they had mandated seat belts and padded dashboards among other necessary safety equipment in the manufacture of all new vehicles (White, n.d.)

Unfortunately, the usage rate of seat belts did not reach significant levels until the 1990s, with the help of forced compliance by state law. Although NHTSA had mandated seat belts in 1968, there was never a specific required design. Back in the 1950s, Nils Bohlin at Volvo had created the seat belt we commonly see today: the three-point lap belt. This design proved to be both simple and effective and earned its place as the standard front seat lap belt type (eventually to include the rear seats, too) mandated by NHTSA in 1974 (White, n.d.). The societal opinion towards safety equipment has taken decades to change from apprehension and fear, to acceptability and normality.

1980s-2000s

The 1970s saw further transformational improvements in safety technology as the computer age emerged. Although air bag technology emerged in the 1950s, difficulties regarding technical malfunction, manufacturer doubt, driver hesitation, and inconsistent government policies led to a series of approved and rescinded air bag standards throughout the 1970s and 1980s. Despite several air bag-related fatalities and initial apprehension by drivers, federal law finally mandated dual front air bags in 1988 for good. Anti-lock braking systems (ABS) and electronic stability control (ESC) were also made possible by technological advancements since the 1970s. Between 1984 and 1995, forty-nine states had passed laws requiring occupants to buckle up, meanwhile seat belt compliance increased from under 20% in the 1970s to over 80% in the 1990s (White, n.d.).

Most safety interventions prior to this time are passive safety systems. Air bags, seat belts, anti-shatter windshields, collapsible steering wheels, etc. all focus on minimizing the injuries caused in a secondary collision. Headlights and mirrors are perhaps some of the only active safety systems implemented prior to the computer age.

ESC debuted the ability of the automobile to assert corrective action and involuntarily assist motorists with stabilizing the vehicle in unstable circumstances. It is estimated that ESC alone reduces risk of single vehicle crashes by 40% and reduces the risk of fatal crashes by 56% (Nielsen, 2013). These advancements are just the surface and beginning of active safety system interventions that have come about in recent decades.

Today

Although it is previously mentioned that headlights are one of the few active safety systems implemented prior to the computer age, the advancement of adaptive headlights has heightened their effectiveness. The concept of a headlight is straightforward; vehicles become more visible to others and the road ahead is illuminated. Yet when a vehicle approaches a curve, the headlights only brighten the area immediately in front of the vehicle and not the actual path of the road. The light is lost into the space beyond the curve. This loss of light creates decreased visibility that may lead to a hazardous situation if the driver is not able to identify obstacles in the road. Adaptive headlights address this pitfall by housing the headlight in a rotational assembly that allows the illumination to follow the vehicle's travel path. Coupled with data such as steering wheel angle and speed, the headlight can predict curves in the road ahead. Data indicates that adaptive headlights can provide a 10% reduction in collisions if vehicles are equipped (Nielsen, 2013).

Blind spot information systems are a recent development to combat the areas around the vehicle that are obscured from the driver's view. This spot is commonly located between the rear and side view mirrors in passenger vehicles. A common blind spot incident might involve a driver changing lanes into a nearby vehicle due to the blind spot. The blind spot information system utilizes camera technology on the vehicle’s sides to detect the presence of obscured vehicles and alert the driver (Nielsen, 2013).

Assisted driving technologies are becoming increasingly common and advanced. Previously mentioned interventions demonstrate methods to facilitate safe driving that ultimately require a driver response to avoid danger. Since the Vision Zero theory acknowledges that humans are fallible, situational awareness through active safety systems is still limited to human error. Driver assistance systems aim to alleviate driver responsibility by not only alerting motorists to danger, but also by asserting partial control of the vehicle to avoid impact.

One example of a driver assistance system is collision avoidance (also known as assisted braking). Collision avoidance systems are developed to prevent the common crash scenario of a rear-end collision. Rear-end collisions are often caused by failure of the driver to react in time or to stop quickly enough. Collision avoidance systems depend on radar units mounted to the front of the automobile that detect distance and speed of the car ahead. The vehicle will sound a warning if it detects rapid deceleration in the leading car and will go so far as to apply the brakes for the driver if no action is taken within a certain buffer distance. This assisted brake application is proven to avoid or reduce collision intensity (Nielsen, 2013). It is important to note that the primary benefit of assisted braking is limited to rear-end collision types and other active safety systems are necessary to treat other risks.

Lane departure prevention is another recent safety intervention that utilizes mounted cameras to monitor lane striping on the road ahead of the automobile. This technology combats a less common, but equally dangerous scenario of collisions due to drifting from the vehicle's proper travel lane. A worst-case scenario might result in a head-on collision versus oncoming traffic or versus a stationary object off the roadway. Similarly, departure from the proper travel lane may induce a sideswipe collision type. Lane departure prevention technology can sense the vehicle's location within its proper lane of travel and, if the vehicle begins to drift without a turn signal engaged, will alert the driver via lights, sounds, or vibrations. Lane departure prevention may even go so far as to commandeer the electromechanical steering mechanism to automatically steer the wheel back into the proper lane. It is estimated that over 7,000 crashes could be prevented annually with lane departure warnings alone (Nielsen, 2013).

Although these technological advancements in safety systems continue to grow, inherent limitations present themselves through the unpredictable nature of road systems. For instance, lane departure prevention is contingent upon reliable lane markings. The National Highway Safety Association reports lane departure warning systems may only be effective on 76% of freeways and as little as 36% of non-freeways (Nielsen, 2013). Additionally, the cost of these technologies may preclude many manufacturers and consumers from choosing to implement them. Today's delays in widespread adoption are reminiscent of motorist's historical tendency to doubt or fear the effectiveness of interventions as well as lack of manufacturer proactivity. The development of vehicle-to-vehicle and vehicle-to-infrastructure communication using internet connectivity is quickly emerging. The concept of a ubiquitous vehicle intelligence network could improve safety and fuel economy exponentially. At the same time, data safety concerns (like hacking into a moving vehicle to deliberately alter its course) also pose a real threat. Ultimately, thriving computerized safety systems, increasing affordability of components, and gradually incorporating new technologies will make automated driver aids standard safety features in future vehicles.

Current data trends

The National Highway Safety Traffic Safety Administration (NHTSA) compiles motor vehicle crash data from its Fatality Analysis Reporting System (FARS) and General Estimates System (GES) to provide descriptive crash statistics. FARS was created in 1975 in order to evaluate the most severe type of crash: fatalities. GES, introduced in 1988, utilizes all severity levels from police-reported crashes to create a nationally representative sample. Together, these tools generate a synopsis of the nation's highway safety level, distinguish specific traffic safety issues, propose problem-solving strategies, and offer a quantitative foundation for evaluating the effectiveness of different safety standards or initiatives.

Since their conception, these systems have been able to provide information on general long-term trends. The percent of alcohol-impaired fatalities has decreased since 1988, nonoccupant injury/fatality rates have decreased, and occupant injury/fatality rates have also decreased since the beginning of GES data collection (NHTSA, 2010). Males continue to have over twice the driver involvement rate as females. However, the population-adjusted injury rate for females is higher than males for all ages. Currently, approximately one-third of fatal crashes include alcohol-impaired driving (NHTSA, 2010). 95% of all crashes are involving passenger vehicles or light trucks (NHTSA, 2010). As of 2010, the deadliest driving hours were weekends from midnight to 3 a.m. (NHTSA). In fatal crashes, motorcycles have the highest proportion of collisions with fixed objects, while large trucks have the lowest (NHTSA, 2010). Rural roads with a speed limit of 55 miles per hour have the highest percent of fatal crashes compared to urban roads and other speed limit categories. “The majority of persons killed or injured in traffic crashes were drivers (64%), followed by passengers (27%), motorcycle riders (four percent), pedestrians (three percent), and pedalcyclists (two percent)” (NHTSA, 2010, p. 89).

A recent statement by the National Transportation Safety Board (NTSB) found that speeding has been an underestimated factor in fatal collisions in the recent past. In 2015, speeding contributed to approximately the same number of fatalities as alcohol and failure to use seat belts. The NTSB’s pending study links speeding to 112,580 fatal crashes between the years of 2005 and 2014 (NTSB, 2017). This number is on par with the number of alcohol-involved fatalities during the same period. New information regarding the influence of speeding on fatalities has forced the NTSB to call for more stringent speed control interventions. Seat belts and drunk driving are afforded national campaigns that reach a large audience. Vehicles even have technological indicators reminding to motorists to use their lap belts or not drive under the influence (blood alcohol ignition interlock devices). The NTSB argues that technology could be applied by vehicle manufacturers to alert drivers when they have exceeded the speed limit, especially considering the mortality rates for speeding are on par with the aforementioned factors that receive the same treatment.

Overall, vehicle miles per capita per year traveled in the United States have increased over time; meanwhile total number of fatalities has decreased throughout history. Although fatalities are declining, the Vision Zero standpoint remains that any level of incapacitating injury or death on roads is unacceptable, and every viable crash intervention should be explored in the pursuit of zero.

Risk Factors and Driver Behavior

Prior to making inferences about safe road design or crash statistics in any given area, one must first observe the known underlying causes of crash severity and principles of systematically safe roads.

Swiss Cheese Model

The Swiss cheese model compares accident causation to multiple slices of stacked Swiss cheese. The layers represent defense mechanisms to prevent a hazard from occurring, while the holes represent possible flaws in each defense layer (Figure 2-3). Depending on the seriousness of the flaw, holes can be represented by varying size, frequency, and location. The more layers of defense there are, the less likely it is that an accident will occur. When all of the holes in a series of layers line up, even momentarily, it represents a hazardous incident happening. This failure is referred to as the trajectory of accident opportunity.

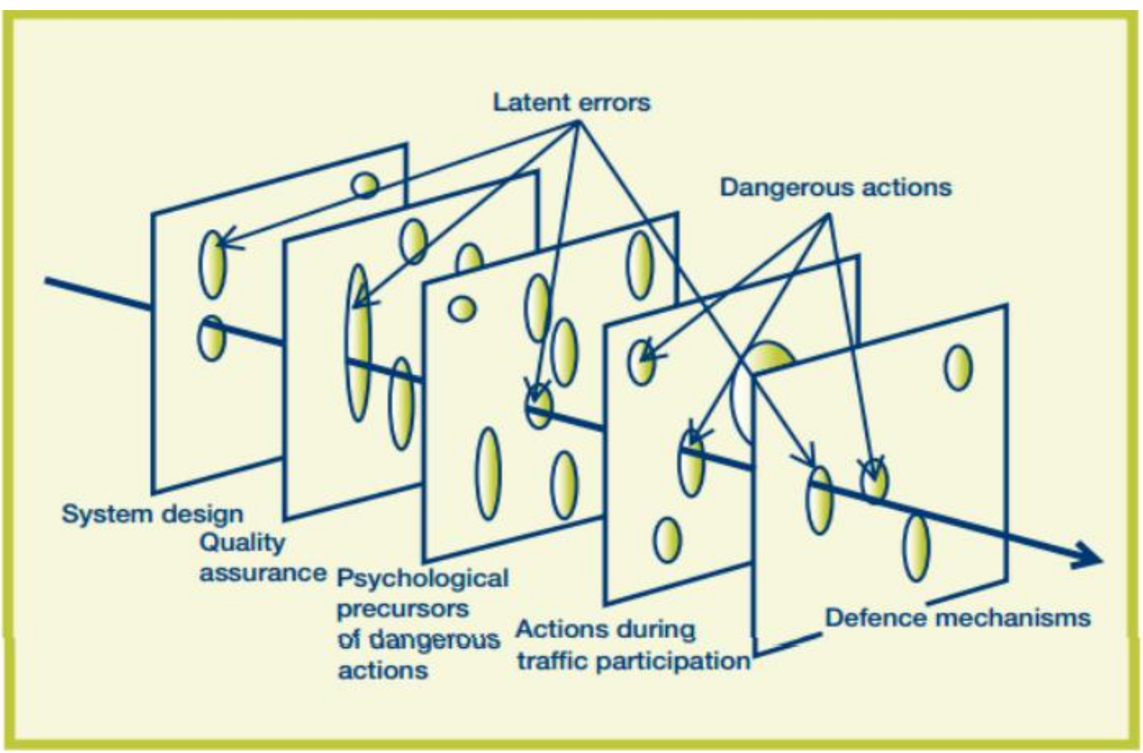


Figure 2-3. Swiss cheese model (SWOV institute for Road Safety Research, 2006).

In relation to traffic accidents, we know that crashes are caused by multiple factors. The cheese slices represent these factors. For example, unfavorable road conditions will often not result in a crash. However, if unfavorable conditions are combined with a sharp curve and driver distraction, the errors might align to cause a system failure. The Swiss cheese model accounts for both active and latent errors. Active errors are the unsafe actions that can be directly linked to a failure, often driver error. Latent errors are factors that are passive and are dormant until all the holes line up. This might include minor design flaws that in a common scenario have no dangerous effect (until combined with multiple other latent and active errors). The idea is that by eliminating these dormant, design flaws or dangerous driving behaviors, the risk of aligning errors in a Swiss cheese model will decrease.

Speed, Risk, and Context

The Risk Compensation Model suggests, “all drivers have a certain tolerance for risk, and they adjust their behavior as the situation demands to keep their risk constant” (Kerksieck, 2016, p. 25). Based on this model, one can deduce that people adjust their behavior to keep the difficulty of driving at homeostasis. When driving, the single largest contributor to risk is speed. People will match their speed to the level of difficulty they experience while driving on a road. For this reason, speed control is top priority in a safe systems approach. Road context is a strong factor in controlling speed and determining reasonable speed limits.

Speed limits should be based on a road’s level and type of conflict (modes, directions, and intersections). Shared space streets that cater to pedestrians should have a speed limit of 10 mph. This includes streets that are unintentionally shared. For example, there are low traffic volumes and no sidewalks. Streets with frequent pedestrian crossings and cyclists mixed with motor traffic should have a 20 mph speed limit. Speeds above 20 mph greatly increase risk for pedestrian injury and create a dangerous speed differential for cyclists who move at 10 mph on average (Kerksieck, 2016). Roads with right angle intersections should have a speed limit of 30 mph. Vehicle safety features will often be successful at preventing harm on 90-degree collisions at this speed. “If two vehicles with roughly equal masses, each traveling 30 mph, collide at 90 degrees, there is roughly a 20% chance of a fatality. As the travel speeds increase to 40 mph, the risk of a fatality approaches 90% for a right-angle collision” (Kerksieck, 2016, p. 29). Figure 2-4 demonstrates the suggested speed limits by roadway context.

Road types combined with allowed road users	Safe speed (km/h)
Roads with possible conflicts between cars and unprotected road users	30
Intersections with possible transverse conflicts between cars	50
Roads with possible frontal conflicts between cars	70
Roads with no possible frontal or transverse conflicts between road users	≥ 100

Figure 2-4. Acceptable speeds for roadway contexts (SWOV Institute for Road Safety Research, 2006).

Five Principles for Systematically Safe Roads

The five principles in brief are homogeneity, predictability and simplicity, functional harmony, forgivingness, and state awareness.

Homogeneity: Speed Control and Separation

Homogeneity refers to the principle that road users with significant differences in mass, speed, and/or direction should remain separated. “The homogeneity principle states that, where vehicles or road users with great differences in mass have to use the same road space, speeds will have to be so low that, should a crash occur, the most vulnerable road users involved should not sustain fatal injuries" (SWOV Institute for Road Safety Research, p. 15, 2006). It is preferable to provide pedestrians, bicyclists, passenger vehicles, and transit operations (e.g. bus or train) their own allocated spaces. Certain circumstances, especially those involving slow operating speeds (such as parking lots and some complete streets) may be appropriate for shared modes of transportation. Pedestrians are the most exposed mode and are thus the first mode to be separated when speed exceeds a reasonable walking pace of about 15 mph (SWOV Institute for Road Safety Research, 2006). A similar pattern follows for separation of bicyclists; as speeds exceed the rate of a typical bicyclist, it is recommended that separate bike facilities be provided. In this way, separation of modes can be considered a tradeoff for increased speed.

The fundamental reasoning behind homogeneity is basic physics. By limiting physical exposure to potential forces of trauma, road users should encounter less risk. Hard materials, rapid deceleration, and large masses are the greatest threats to human biomechanical tolerance. The least protected users are pedestrians, bicyclists, and motorcyclists. The force experienced by crash victims in a collision is proportional to change in their velocities coupled with the relative masses of the vehicles involved upon impact. For this reason, crashes among similarly sized vehicles traveling the same direction are likely to be less severe than among vehicles traveling at different speeds, angles, or masses because the change in velocity is low. A dramatic example of latter scenario might involve a speeding truck and a small personal vehicle, where change in velocity is high and masses are dramatically different. Road design is instrumental in avoiding these hazardous intermodal conflicts.

Road design standards can take up an entire book of their own, but some token concepts for avoiding conflict are as follows. Multilane roads facilitate faster speeds and leave road users like pedestrians and bicyclists more exposed, especially for crossing traffic. Pedestrian crossings at major roadways necessitate added protection, such as a signal and delineated crosswalk. Bicyclists should have a physical separation from vehicles on busy high speed roads. This may be in the forms of dedicated bike lanes or a buffer lane. Two lane roads are therefore preferred, as they encourage vehicles to slow down and be more alert. High speed roads should avoid having driveways because driveways encourage slowing speeds, turning, and crossing traffic. Left turn lanes should be separately designated rather than permitted left turn lanes. Similarly, minor roads that cross multilane, high speed major roads should be avoided, or, if necessary, be signalized to separate the timing of conflicting movement (Kerksieck, 2016). Although not a part of physical design features, reduced speed limits are also a crucial component to minimizing impact severity.

Suggested maximum allowable speeds for different roadway contexts and levels of conflict have been established, but these speeds are based upon a baseline level of responsible road use. Safe speeds depend actively on seat belt use, modern protective design standards on vehicles, and disparate vehicle types (such as motorcycles, whose vulnerability is elevated). The World Health Organization reports that a five percent reduction in traffic speeds can result in a 30% reduction in fatal incidents (2004). However, road design can be more influential in controlling speed than the actual speed limit. A given number of motorists will always exceed the speed limit when the roadway allows for it. Traffic calming, roadway geometry, and signal timing are therefore vital speed controls (Kerksieck, 2016).

Physical barriers are also more effective than simple signage and lane striping to avoid encroachment into the operating space of adjacent users. Vision Zero is famous for its popular preference of roundabout traffic circles in place of traditional signalized intersections. Traditional signalized intersections are reserved for areas where traffic volumes are too high or space is insufficient to install a roundabout. Traditional intersections facilitate head-on and perpendicular angle crashes, sometimes at high rates of speed (some especially fatal circumstances may include running red lights or failing to yield on a left turn), where both speed and angle are unfavorable). Roundabouts funnel traffic into an inherent state of homogeneity: everyone travels in the same direction at approximately the same speed. Additionally, the nature of merging lanes facilitates skewed angles of conflict as opposed to perpendicular or head-on angles, which minimizes collision severity when it occurs.

Predictability and Simplicity

The predictability principle is based on the assumption that road users should be able to perceive and anticipate reasonably expected traffic occurrences from the road system as well as fellow road users. In addition, simplicity is based on the principle that extraneous information should be diminished and the number/variety of decisions to be made by drivers simplified. Road users are constantly presented with changing information and are in a constant state of the decision-making process. Road design should follow a set of reasonable road user expectations, and be consistent, recognizable, and continuous throughout all design components. By making streets simple and predictable, it is reasonable to expect that decisions will be rule or reflex-based rather than reasoning-based, thereby reducing a certain level of human fallibility.

Ideally, uniformity among road categories with similar function and use should elicit a recognizable user response. In contrast, road categories with drastically different functions and uses should elicit a markedly distinct user response to separate user expectations. It is of equal importance that transitions from one road classification to another afford users adequate time and space to adjust their behavior.

Essential recognizability characteristics (ERC) provide a continuous, reliable mechanism for road users to immediately determine reasonable rules and behaviors on a given road class. ERCs address separation of conflicting directions (also known as center line markings) as well as edge line types. Some countries, like the Netherlands, have clearly defined ERC characteristic guidelines (e.g. painted center lines and broken edge lines denote a speed limit of 50 km/h). However, many ERCs are implied rather than explicit. Narrow lane widths suggest slower speed limits and raised medians identify streets where left turns across adjacent traffic lanes are impermissible.

The principle of simplicity aims to avoid the need for high-level reasoning in circumstances of possible conflict on streets. Scenarios involving challenging decisions are ideally simplified to rule-based, subconscious reactions. For example, sudden changes in lane designation (such as a travel lane becoming a turn-only lane) forces unexpected merging. To simplify, turn lanes should always be newly dedicated lanes. Having fewer travel lanes is beneficial for pedestrian crosswalks and left turns since the conflicting flow of traffic is condensed. Similarly, islands or medians for pedestrian crosswalks promote ease of use when gauging gaps in oncoming traffic (the pedestrian can worry about one direction of travel at a time, as opposed to both directions). Unfortunately, though these principles are easy to discuss in theory, the implementation of simplicity is largely missing from road design in the United States. ERCs are generally undefined and tend to be more implied rather than concrete. Road design and intended road function are missing an essential nexus.

Functional Harmony

The principle of functionality stems from functional road classification and traffic flow management. The main distinction between road types is between “flow” roads (designed for movement) and “access” roads (give access to destinations). Roads that connect the major flow and access categories are distributors. Distribution roads direct vehicles between access streets and flow streets (both to and from). Motorized traffic is a burden to access roads and instead should be directed toward flow function roads. These levels of functionality intend to minimize potentially severe conflicts.

Roads that violate the principles of speed control, separation, and recognizability tend to suffer the highest crash rates. Predictability is compromised when roads serve multiple, conflicting purposes. Some street functions are complementary and can coexist without compromising the integrity of the road’s safety and essential purpose. For example, pedestrian priority zones and place functions (also known as activity generators) enhance each other.

Motorways are the prototypical through road in terms of functionality, homogeneity, and predictability. Vehicles are traveling at similar speeds in the same direction. The most vulnerable road users (pedestrians and bicyclists) are excluded completely. Median barriers physically separate oncoming traffic, and crossing traffic is separated by grade (such as elevated overpasses), so there is no direct-contact intersection.

The major functional road classes designated by the FDOT include: freeways, principal arterial, minor arterial, major collector, minor collector, and local roads for both urban and rural contexts (except freeways, which stand alone). For urban roads, the recommended minimum design speeds are 50 mph (freeway), 40 mph (major arterial), 35 mph (minor arterial and major collector), 30 mph (minor collector), and 20 mph (local) (FDOT, 2013). Minimum required lane widths begin at 12 feet for freeways and decrease by one foot for less intense classifications. Figure 2-5 demonstrates the FDOT functional road classifications.

RECOMMENDED MINIMUM DESIGN SPEED (MPH)

TYPE OF ROADWAY	URBAN		RURAL	
	*SPEED RESTRICTIONS		*SPEED RESTRICTIONS	
	WITH	WITHOUT	WITH	WITHOUT
Freeway or Expressway	50	60	***	70
Arterial (Major)	40	55	55	70
Arterial (Minor)	35	50	55	70
Collector (Major)	35	45	50	65
Collector (Minor)	30	40	40	60
Local **	20	30	30	50

* Speed restrictions are features of the design which would effectively limit the operating speed, such as:
  a. Short length of roadway (i.e., dead-end street)
  b. Closely spaced stop signs, traffic signals or other control devices
  c. Locations that would by nature of the surrounding development or land use, indicate to the driver that lower speeds were necessary

** Design speeds lower that 30 mph may be used for local, subdivision type roads and streets. Streets with a design speed less than 30 mph shall be posted with appropriate legal speed limit signs.

Figure 2-5. FDOT speed restrictions by road classification (FDOT, 2013).

FDOT's classifications could be simplified as through roads (highest speeds such as freeways), distributors (moderate speeds such as arterials), and access roads (low speeds such as local streets). By creating more simplified categories, the distinctions among road classes is strengthened and the function of each class because more apparent to road users. This pattern of clearer distinction for road users can be visualized as Figure 2-6.

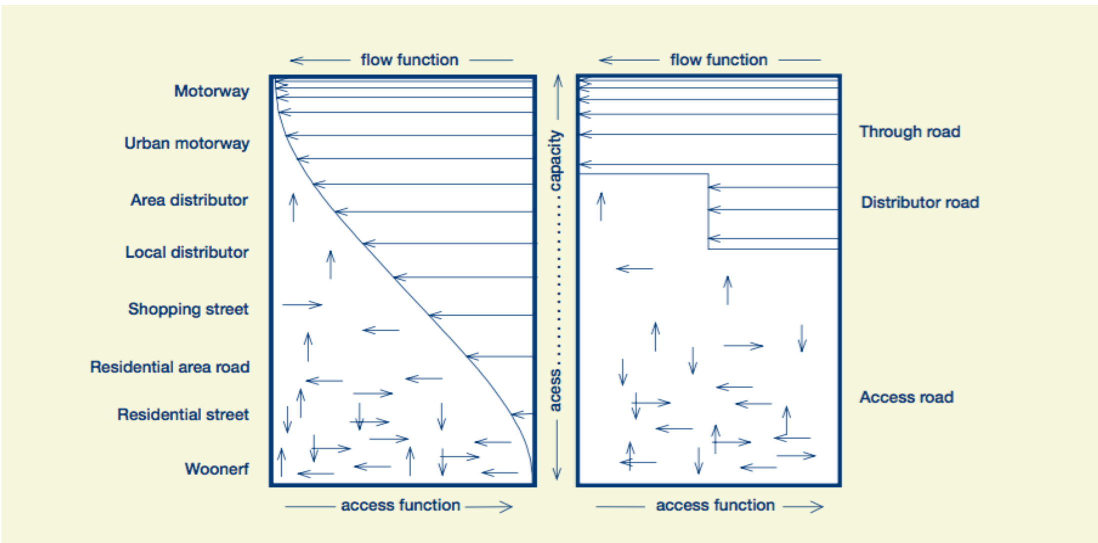


Figure 2-6. Visualizing clear road class distinctions. Left: categorization of roads and streets in flow and access function. Right: categorization of roads according to the tri-partition used in Sustainable Safety (SWOV Institute for Road Safety Research, 2006)

The FDOT design standards use general characterizations of local, collector, and arterial, but they are further subdivided and have multiple different design requirements that muddle the distinctions. These basic classifications are defined as:

- Local- A route providing service which is of relatively low average traffic volume, short average trip length or minimal through-traffic movements, and high land access for abutting property.
- Collector- A route providing service, which is of relatively moderate average traffic volume, moderately average trip length, and moderately average operating speed. These routes also collect and distribute traffic between local roads or arterial roads and serve as a linkage between land access and mobility needs.

- Arterial- A route providing service which is relatively continuous and of relatively high traffic volume, long average trip length, generally higher operating speed, and high mobility importance. In addition, all United States numbered highways shall be arterial roads (FDOT, p. 1-4, 2016).

The reason for investigating and defining the different design criteria and variety of functional road classifications is to point out the fact that two roads of the same functional classification can have very different appearances. This is problematic for the principle of functionality since the nexus of design and innate motorist behavior is lost and predictability based on road function and design is reduced.

Forgivingness

Forgivingness refers to “injury limitation through a forgiving road environment and anticipation of road user behavior” (SWOV Institute for Road Safety Research, 2006). Since Vision Zero is based on the acceptance that humans make mistakes, forgivingness responds to fallibility by supporting a road environment, which absorbs those mistakes. A large component of forgivingness in the built environment is removal of hazardous stationary roadside objects, especially in high-speed areas. Wide median separation, physically divided roadways, and ample shoulder width are some of the design features meant to enhance forgivingness on higher speed stretches. Sweden’s 2+1 alternating passing lane system has become a famous method for combating head-on collisions. This method installs flexible cable barrier systems on the freeway and the striping/barrier for the middle lane alternates every mile or so to allow intermittent passing to occur while the two main travel lanes remain constant. In-vehicle safety interventions like seat belts and air bags are also part of the forgivingness principle.

Urban areas necessitate different treatment to facilitate forgivingness. The methods applied to high speed roads such as wide lanes, gentle curves, and straight lines are often counterproductive in a dense environment, promoting speeding and discouraging more vulnerable modes. Urban areas should rather generate a sense of social forgivingness; more protected users like motorists should be inclined to yield to exposed users like pedestrians and bicyclists. Physical separation may occur in the form of buffer lanes, dedicated bike lanes, on-street parking, raised sidewalks, and landscaping, as opposed to wide medians or cable barriers.

State Awareness

The ability to assess one's own capability to handle the task of driving or participating in traffic is known as state awareness (SWOV Institute for Road Safety Research, 2006). There are many possible reasons for insufficient task capability such as driver inexperience, fatigue, use of drugs/alcohol, and distraction. The following task capability interface model is proposed: road users' task capability is the sum of their own capacities minus the sum of their impairments in their current state. Task capability shall be great enough to meet the requirements of driving (or using the road network) in order to facilitate safe road use. The state awareness principle of systematically safe roads is meant to encourage defensive driving--to recognize and avoid dangerous situations. Achieving state awareness is a function of many previously mentioned strategies: education, technology, and enforcement. The notion of social forgivingness, not unlike the road design principle of forgivingness, is part of state awareness. It urges more experienced and capable drivers to increase maneuvering space for less capable users by anticipatory or defensive behavior.

CHAPTER 3
METHODOLOGY

Study Design

A case study format is used to apply the theories of Vision Zero to a specific geographic context. In order to analyze the current crash trends in Fort Lauderdale, we can carry out spatial statistics and logistic regression. The use of ArcGIS spatial statistics function Optimized Hot Spot Analysis identifies areas with statistically significant incident clustering as opposed to a descriptive heat map surface based on frequency of events. One can choose to look at statistically significant clusters as a method of identifying unusually high crash areas and narrowing down the possible areas for improvement based on that output, rather than generalizing an entire corridor or neighborhood. Furthermore, by organizing crash incidents spatially, one can collect further descriptive details about road design at the crash site. These compounded descriptive attributes can then be added into a logistic regression model in SPSS to fit their odds ratios for a dependent variable (crash severity).

About the Data

The data used for analysis in this study comes from multiple sources. The main sources are Signal Four Analytics and FDOT. A smaller number of features were acquired from Broward County, City of Fort Lauderdale, and the US Census Bureau.

Signal Four Analytics is developed by the Geoplan Center at the University of Florida to support the availability and accessibility to big data for law enforcement transportation planning, and research institutions within the state. The interactive, web-based mapping application fills a niche in the field of crash analysis where data is aggregated from the Florida Department of Highway Safety and Motor Vehicles and

Florida Highway Patrol to provide a mass database of complete, timely, available, and user-friendly analytic capabilities.

The web application allows users to query all records (with the most complete data ranging from 2011 to present) for select geographical and descriptive constraints. The result is a point layer where each feature represents one crash incident, complete with detailed attributes from the associated police report. For this study, the data was queried by geography (within the City of Fort Lauderdale), time (crash occurred between January 1, 2012 and December 31, 2016), and injury severity (all severity levels excluding "no injury" and "property damage only"). These parameters were chosen because of the extent of the study area, five years of historic crash data as a rule of thumb (FHWA, 2011), and because crashes producing no injury are not considered to be a priority by the Vision Zero philosophy. This initial query yielded approximately 10,200 results, with about 900 points in the fatal or incapacitating injury severity level.

Table 3-1 shows the FDOT data that was downloaded and its corresponding description. These features were spatially joined to the Signal Four crash points in order to add more road design information to the crash incident point layer. Remaining data layers include streets (Broward County), city boundary (City of Fort Lauderdale), Connecting the Blocks data (City of Fort Lauderdale), and demographics by census block group (US Census Bureau).

Table 3-1. FDOT data.

Name of File	Metadata Abstract (FDOT, 2017)
Annual Average Daily Traffic	The Annual Average Daily Traffic feature class feature class shows the location of traffic breaks and affiliated annual average daily traffic volumes in the state of Florida as derived from event mapping selected traffic characteristics from the FDOT Traffic Characteristics Inventory.
Traffic Signal Locations	The Traffic Signals feature class shows the location of traffic signals in the state of Florida for on system roadways as derived from event mapping Feature 322, characteristics MAINTAGC, SDESTRET, SIGNALID, SIGNALNC, SIGNALTY, SIGOPDTE, SIGSTRCT and TYPECABL from the FDOT Roadway Characteristics Inventory data.
Functional Classification	The Functional Classification System feature class shows roadway functional classifications as derived from event mapping Feature 121, characteristic FUNCLASS from the FDOT Roadway Characteristics Inventory data.
Maximum Speed Limits	The Maximum Speed Limit feature class shows the posted speed limit as derived from event mapping Feature 311, characteristic MAXSPEED from the FDOT Roadway Characteristics Inventory data.

Table 3-1. Continued.

Name of File	Metadata Abstract (FDOT, 2017)
Median Width	The Median Width feature class shows the median width of a roadway segment as derived from event mapping Feature 215, characteristic MEDWIDTH from the FDOT Roadway Characteristics Inventory data.
Number of Lanes	The Number of Lanes feature class shows the total number of through lanes on a roadway as derived from event mapping Feature 212, characteristic NOLANES from the FDOT Roadway Characteristics Inventory data.
Pavement Conditions	The Pavement Condition feature class shows pavement condition as derived from event mapping Feature 230, characteristic PAVECOND from the FDOT Roadway Characteristics Inventory data.
Sidewalk Barriers	The Sidewalk Barrier feature class shows sidewalk barrier locations along a roadway as derived from event mapping Feature 216, characteristic SDWLKBCD from the FDOT Roadway Characteristics Inventory data. Sidewalk barriers separate motorized vehicle lanes from sidewalks or shared paths. The barrier can be of several types, such as areas for vehicular parking, physical traffic barriers, guardrail, trees, etc.

Table 3-1. Continued.

Name of File	Metadata Abstract (FDOT, 2017)
Bike Slots (overlap bike lanes)	The Bike Slot feature class shows stripe-separated portions of the roadway, not necessarily marked for bicycles, between a through lane and a right turn lane of an intersection, as derived from event mapping Feature 216, characteristic BIKSLTCD from the FDOT Roadway Characteristics Inventory data. This is recorded for all non-limited access highways, including bridge segments.
Outside Shoulder Width	The Outside Shoulder Width feature class shows the width of outside shoulder present along roadway segments as derived from event mapping Feature 214, characteristic(s) SLDWIDTH, SHLDWTH2 and SHLDWTH3 from the FDOT Roadway Characteristics Inventory data.
Inside Shoulder Width	The Inside Shoulder Width feature class shows inside shoulder width information as derived from event mapping Feature 219, characteristic(s) ISLDWDTH, ISLDWTH2 and ISLDWTH3 from the FDOT Roadway Characteristics Inventory data.

Getis Ord Gi* and Optimized Hot Spot Analysis in GIS

Theory

The Getis Ord Gi* statistic identifies significance values for each feature in the dataset to give a resulting set of high or low clustered features. This tool analyzes each feature within the context of its neighbors. To elaborate, although some intersections may have a high frequency of crash incidents, it may not be a statistically significant hot spot. In order to be a statistically significant hot spot, that high frequency area would need to be surrounded by neighboring areas of high frequency. Frequency values are locally summed with the values of their neighbors and then proportionally compared to the sum of all features. A calculation is made within the tool to estimate the expected local sum and compare that to the actual local sum. When the difference is larger than can be reasonably expected as a result of random chance, the z-score indicates statistically significant results (Esri, n.d.). The final output returns a Gi* statistic (essentially a z-score) for each feature in the dataset. Significant positive values indicate hot spots and significant low values indicate cold spots. The output feature class includes z-score, p-value, and confidence level (Gi_Bin).

Additionally, this study uses the optional Apply False Discovery Rate Correction (FDR) parameter. This parameter reduces critical p-value thresholds to account for multiple testing and spatial dependency. FDR estimates the number of false positives given for a certain confidence level and adjusts the critical p-value to reflect them. FDR generates a ranking of significant p-values and removes the weakest (largest) p-values from the statistically significant output based on the estimate of false positives.

The Optimized Hot Spot Analysis tool in ArcGIS uses the same Getis Ord Gi* calculations as the previous tool, however, it derives parameters from the characteristics of your input dataset. For a point layer, the tool would screen your dataset, aggregate incidents into weighted features, and choose an appropriate scale of analysis based on the distribution of the weighted features (Esri, n.d.). While applying FDR correction in the previous tool is optional, FDR in Optimized Hot Spot Analysis is automatically applied.

Hot Spot Methodology

Due to the difference in number of fatal/incapacitating crashes as opposed to non-incapacitating crashes (approximately a 10:1 ratio favoring non-incapacitating crashes), it was worth isolating high severity crashes in their own hot spot analysis. Furthermore, the nature of crashes and high frequency of crashes at Interstate-95 entrance/exit ramps created a clear distortion of significant high crash clusters centered along Interstate-95. For this reason, separate maps were created for crashes on interstate highways, versus all other roads. The resulting map series has four Optimized Hot Spot Analysis maps: Fatal/incapacitating injuries excluding highways, fatal/incapacitating injuries on all roads, all crash severities on all roads, and all crash severities excluding highways.

The detailed process for generating the Getis Ord Gi* Hot Spot maps in this paper is as follows. In order to define specific segments of the road network that are statistically significant, crash incident point features were snapped to the road network in order to generate a crash frequency number for each segment of the roadway. The distances of the road segments were calculated using “calculate field”. Another field was then added to divide the number of incidents snapped to a segment by the respective distance of the road segment to normalize the frequencies. The Getis Ord Gi* Hot Spot Analysis tool was then run using the normalized frequency field as the input and an inverse distance band with a quarter-mile boundary. The resulting map series includes all crashes and fatal/incapacitating crashes.

Logistic Regression

Logistic Regression Theory

Logistic regression is used to generate an odds ratio in a model with multiple explanatory/independent variables for a dichotomous dependent variable. In simple logistic regression, the response/dependent variable is binary (dummy coded either 0 or 1). This model was chosen since it supports the testing of multiple continuous or categorical variables and applies to a broad range of research situations. There are also no assumptions for the distribution of the data.

The result of the model shows the impact of each independent variable on the odds ratio of the observed event, in this case if a crash incident was fatal/incapacitating (1) or not (0). The greatest advantage to logistic regression is the avoidance of confounding effects, which stem from analyzing the association of all variables together (Sperandei, 2014). Logistic regression is like linear regression; in fact, it is a nonlinear transformation of the model (see Figure 3-1). The logit model takes the natural logarithm of the odds ratio probability that an event occurs (dependent variable), which results in a logit distribution with estimated probabilities constrained between 0 and 1.

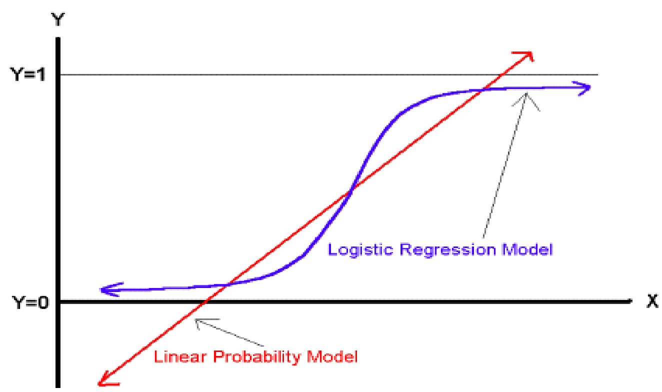


Figure 3-1. Comparing Linear and Logit Regression (Whitehead, n.d.)

The dataset in this study has categorical variables with multiple levels. When a dataset has multiple level categorical variables they must be dummy coded into n-1 binary variables, where n represents the number of levels in the variable. The dummy variable assumes the value of 1 if a category is met and 0 if it is not met. For multiple levels, one of the categories will be assigned as the reference category. The reference category is not enumerated in the model and is represented when all other categories are labeled 0 (by process of elimination, one can deduce that the reference variable is 1). Luckily, SPSS statistical software package conducts this process automatically.

It should be noted that using a saturated model with many variables, as well as multilevel categorical variables using many degrees of freedom, could lessen the statistical power of the model. The sample size used in this study (~10,000) is large enough that it should counteract the saturation of the model and its multilevel categorical variables. There is always a possibility that results are spurious.

Logistic Regression Steps

Checking assumptions

In theory, the first step is to check the assumptions of the logistic regression. However, since the selection of significant variables to use in the final model was an iterative process, the assumptions were checked last. Assumptions 1, 2 and 3 are filled by the nature of the data. Assumption 4 (linearity between continuous predictor variables and the dependent variable) can be tested using the Box-Tidwell test. Box-Tidwell includes the model interactions between continuous predictors and their logs in the regression (Wuensch, 2016). If the interaction is significant, then the assumption of linear relationship between independent variables and the dependent variable has been violated. In SPSS, the natural log of the continuous independent variable (speed) was calculated. Then, the natural log of the predictor is added to the model as an interaction term with its original value. The assumption is met (Figure 3-3).

Checking multicollinearity

Although not explicitly listed as an assumption of the binomial logistic regression model, checking for multicollinearity in the model is recommended. Multicollinearity occurs when two or more of the predictor variables in a model are highly correlated and the result is a difficulty in determining their distinct effect on the model. This can be tested by running the model's predictor and dependent variables in SPSS linear regression function and asking for the collinearity diagnostics (this is a current workaround to retrieve collinearity diagnostics which are not built-in as an option of the binomial logistic regression procedure). This returns the variance inflation factor (VIF) values. VIF can indicate when multicollinearity exists by indicating how inflated the standard error of the coefficient is compared to what the standard error would be if it was not correlated with any other predictor variables. Different literature refers to different cutoff points for an acceptable VIF, the range is anywhere from 2.5 to 10 (Midi, Sarkar, & Rana, 2010). Figure 3-4 indicates the results of the collinearity diagnostics.

It is possible that the Front to Rear crash type is experiencing some collinearity, but using the rule of thumb for spatial statistics as a VIF of 7.5 the VIF of 6.9 is not overly problematic (Xuan, 2016).

Model fit

The outputs from the binomial logistic regression give odds ratios comparing the different probabilities that independent variables have relative to crash severity. The final model includes 16 independent variables. To begin with, the Omnibus Tests of Model Coefficients table includes the Chi-Square goodness of fit test. It has the null hypothesis that intercepts and all coefficients are zero, in other words the added variables make no difference to the model. Since the significance value is 0.000, or below the 95% confidence p-value of 0.05, we can reject the null hypothesis. The Chi-Square goodness of fit test suggests that adding the 16 independent variables to the model does significantly increase the ability to predict a difference in crash severity.

The Model Summary provides the Cox & Snell R squared (measured on a scale that never reaches 1) and Nagelkerke R squared statistics (measured on a scale from 0 to 1), which are the logistic regression equivalent of R squared (also referred to as pseudo R squared). Based on the Nagelkerke R squared, the explained variation in the dependent variable based on the model is around 13.6%. Subjectively, this pseudo R squared value leaves much to be desired. However, it is the best value out of all the models run. The Hosmer & Lemeshow test also measures goodness of fit. It does so by dividing the data into 10 ordered groups based on probability estimates (low to high). Each of the 10 ordered groups is then split in two based on the data's actual frequency of successes and failures. Expected frequencies are compared to the model frequencies to generate a p-value. The null hypothesis for Hosmer & Lemeshow is that there is no difference between the observed values and model-predicted values. For this test, you want to accept the null hypothesis to imply that the model fits the data. The model returns a Hosmer & Lemeshow significance value of 0.635, which is greater than the 95% confidence p-value of 0.05. This indicates that the fit of the model is not statistically different from the fit of the observed data and is therefore a good fit. The model correctly classifies 91.7% of the data cases, based on the Classification Table (Figure 3-5).

Logistic regression workflow

Other statistical analysis methods were researched, but ultimately the binomial logistic regression was chosen. It should be noted that the dichotomous dependent variable in this study is derived from a set of ordinal data: crash severities ranging from no injury, possible injury, non-incapacitating injury, incapacitating injury, to fatality. These severities have no quantifiable difference in value; therefore it would be inappropriate to reclassify the categories into a numerical value in order to gain a higher level of measurement or to pass assumptions for other statistical tests. I acknowledge that there is a loss of information that occurs when the ordinal data is transformed into binary categories. Furthermore, the number of fatalities is less than one percent of the overall dataset, so the sample representing fatalities would have been small if not merged with incapacitating injuries. Collapsing these two severity levels into one binary variable is aligned with the Vision Zero framework, which concerns itself with fatal and incapacitating injuries. The resulting two categories were derived from the dataset: fatal/incapacitating injury (represented numerically as 1), or not (represented numerically as 0).

In order to prepare the data for input into statistical software package SPSS, the data needed to be spatially organized and compiled into a spreadsheet using ArcGIS. Figure 3-2 demonstrates the flow of information from multiple different files into one singular shapefile. All of the design features from Table 3-1 as well as census data were spatially joined to the target layer of crash incidents from Signal Four Analytics. The settings for the spatial join tool were to transfer the attributes from the closest feature within 100 feet (250 feet for traffic signals). These distances were chosen based on the author’s own practical crash mapping experience.

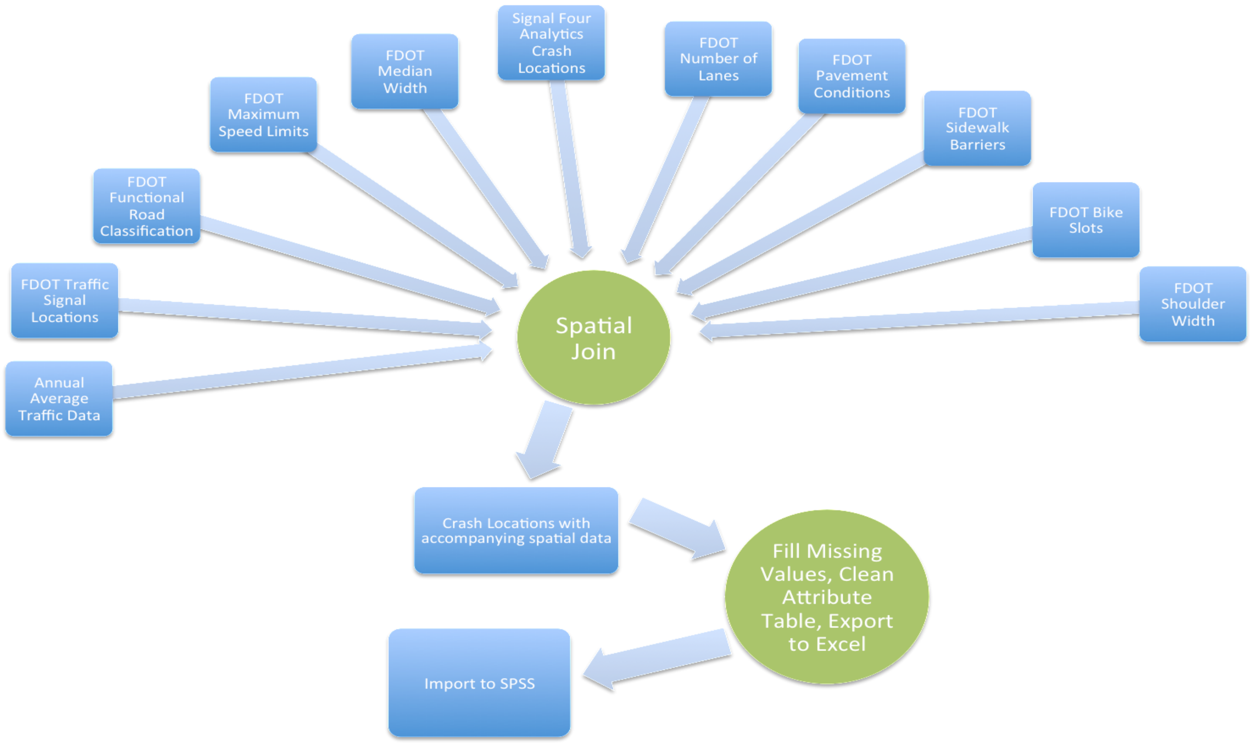


Figure 3-2. Flow of data from ArcMap to SPSS

Unfortunately, not all features were within the defined distances to receive joined attributes. In order to control for a number of these missing (null) values, the ArcPro tool “Fill Missing Values” was used. The computation method chosen was average of K nearest neighbors, defined with 15 neighbors. The tool preserves all existing values and replaces null values based on the neighborhood average to minimize the impact of those null values on subsequent analysis. If the average calculated by the “Fill Missing Values” tool is not statistically significant, then the value is not calculated and is left blank. This is important to note since values that do not meet the tool’s defined confidence level will not be estimated. The tool is more sophisticated than a simple average calculation. Logistic regression does not use records with any missing data cells, so to preserve the sample size, reasonable effort was made to fill null cells. Some missing values were filled manually, especially those occurring on Interstate-95. Missing values for Interstate-95 were manually filled using a select by attribute query, “select from [layer] s4crashes where [attribute] street_name is LIKE ‘%95%’”. Despite best efforts, a number of descriptive fields were left with hundreds of null values and was left out of the regression. The compromise would have been to estimate the null fields unreliably, or to keep them in the regression knowing that it would decrease the sample size by over 10%. 9,998 records were included in the final regression. Once the maximum reasonable number of cells was filled, the table was re-coded and collapsed for the constraints of logistic regression. All categorical variables were dummy coded.

Binomial logistic regression has the following assumptions:

- Assumption #1: Your dependent variable should be measured on a dichotomous scale.
- Assumption #2: You have one or more independent variables, which can be either continuous or categorical.
- Assumption #3: You should have independence of observations and the dependent variable should have mutually exclusive and exhaustive categories.
- Assumption #4: There needs to be a linear relationship between any continuous independent variables and the logit transformation of the dependent variable (Laerd, n.d.).

All of the assumptions were tested and met. The output of the tests is in the results section.

The binomial logistic regression procedure in SPSS offers multiple variable selection methods. One of these methods is called Forward Wald. In order to gauge the initial significance of a saturated model, the Forward Wald method of variable entry was run. This is a stepwise process that iterates a regression model by adding one variable at a time and calculating whether the model was improved by each added variable or not. This process is repeated until the remaining variables are all significant (it excludes variables that are not significant). Forward Wald uses a “stepwise selection method based on the significance of the score statistic, and removal testing based on the probability of the Wald statistic" (IBM Support, 2017). The variables in the equation table are measured by the Wald test, which uses the null hypothesis that the beta value for each variable is 0. This process is not recommended for producing final results, so the results of the stepwise process are not included in this paper. However, it is a helpful process to begin filtering out the dependent variables and moving from a saturated model to one with less predictors.

Once all of the above steps were taken, the repetitive process of adding and removing significant and insignificant predictor variables to an Enter method regression began. The Enter method adds all the predictors into one single block and runs their statistics all at once. After many trials, the final variables were chosen and assumptions were checked on the final variables. Note that the initial saturated model had over 60 predictor variables and the final model has 16.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	Drug_Relat(1)	.730	.301	5.884	1	.015	2.076	1.150	3.744
	First_HE_WithinJunction(1)	.465	.158	8.675	1	.003	1.591	1.168	2.168
	SPEED	.257	.141	3.322	1	.068	1.293	.981	1.704
	signalVALUE1(1)	-.452	.086	27.641	1	.000	.636	.537	.753
	Other_Crash_Type(1)	1.580	.600	6.928	1	.008	4.854	1.497	15.738
	Bicycle_Crash_Type(1)	.679	.157	18.618	1	.000	1.973	1.449	2.686
	Ped_Crash_Type(1)	1.107	.113	95.809	1	.000	3.026	2.425	3.778
	RearEnd_Crash_Type(1)	-1.017	.177	32.917	1	.000	.362	.256	.512
	_angle_Manner_of_collision(1)	.459	.163	7.930	1	.005	1.582	1.150	2.177
	FronttoRear_Manner_of_Collision(1)	.879	.214	16.828	1	.000	2.408	1.582	3.663
	Other_Manner_of_Collision(1)	.847	.159	28.385	1	.000	2.332	1.708	3.185
	ThruRoad_First_HE_ReltoIntersection(1)	.748	.179	17.552	1	.000	2.113	1.489	2.999
	Daylit_Light_Cond(1)	-.587	.078	56.971	1	.000	.556	.477	.647
	UrbanPrincipalArterial_funclass(1)	.208	.096	4.760	1	.029	1.232	1.021	1.485
	ShouderType_Paved(1)	-.517	.098	27.794	1	.000	.596	.492	.722
	MotorcycleYN(1)	1.623	.132	151.924	1	.000	5.068	3.915	6.560
	LNspeed by SPEED	-.047	.029	2.616	1	.106	.954	.900	1.010
	Constant	-5.729	1.283	19.954	1	.000	.003		

a. Variable(s) entered on step 1: Drug_Relat, First_HE_WithinJunction, SPEED, signalVALUE1, Other_Crash_Type, Bicycle_Crash_Type, Ped_Crash_Type, RearEnd_Crash_Type, _angle_Manner_of_collision, FronttoRear_Manner_of_Collision, Other_Manner_of_Collision, ThruRoad_First_HE_ReltoIntersection, Daylit_Light_Cond, UrbanPrincipalArterial_funclass, ShouderType_Paved, MotorcycleYN, LNspeed * SPEED .

Figure 3-3. Box-Tidwell test results

Coefficients[a]

Model		Collinearity Statistics Tolerance	VIF
1	Drug_Relat	.986	1.014
	First_HE_WithinJunction	.988	1.012
	SPEED	.701	1.426
	signalVALUE1	.915	1.093
	Angle_Crash_Type	.812	1.231
	Bicycle_Crash_Type	.918	1.089
	Ped_Crash_Type	.840	1.190
	RearEnd_Crash_Type	.197	5.065
	_angle_Manner_of_collision	.333	3.003
	FronttoRear_Manner_of_Collision	.145	6.902
	Other_Manner_of_Collision	.360	2.781
	ThruRoad_First_HE_ReltoIntersection	.790	1.265
	Daylit_Light_Cond	.955	1.047
	UrbanPrincipalArterial_funclass	.880	1.136
	ShouderType_Paved	.785	1.273
	MotorcycleYN	.983	1.017

a. Dependent Variable: BinarySeverity

Figure 3-4. Multicollinearity diagnostics

Classification Table[a]

	Observed		Predicted BinarySeverity 0	Predicted BinarySeverity 1	Predicted Percentage Correct
Step 1	BinarySeverity	0	9155	13	99.9
		1	815	15	1.8
	Overall Percentage				91.7

a. The cut value is .500

Figure 3-5. Goodness of fit test

CHAPTER 4
RESULTS

Synthesized Results of Literature Review and Fort Lauderdale Vision Zero Plan

The City of Fort Lauderdale relies on the 5 Es of engineering, education, encouragement, enforcement, and evaluation as the centerpiece of its Vision Zero action plan. Engineering strategies are meant to create safe and convenient spaces to travel through, with inspiration from Complete Streets Policy and related programs. These engineering strategies largely represent physical road design amendments like crosswalks and bike lanes. Educational strategies are intuitive. They include teaching residents about safe and proper methods for participating in traffic (all modes). This includes supporting related programs like Safe Routes to School and BikeSafe. Encouragement strategies attempt to stimulate behavioral change by means of public participation, outreach, and community events. Some special events the city has been hosting to distribute safety gear and build a sense of responsible road user behavior include Open Streets (reclaiming the road from motor vehicles) and Family Fun Ride (bicycling). Targeting high-crash corridors and speeding zones with law enforcement officers is one of the prerogatives of the enforcement strategy. The main goal of enforcement is for road users to obey traffic law. Evaluation strategies are concerned with documentation, data collection, and efficacy analysis. Lastly, action strategies are carried out by a steering committee composed of state, county, local, and neighborhood organizations. The steering committee is meant to catalyze a holistic paradigm shift in citizens' safety philosophy.

Based on preliminary comparisons to other case studies as well as a comprehensive summary of traffic safety, Fort Lauderdale's plan has a strong basis for success. However, the perceived area of improvement in policy that this paper strives to satisfy is included within the evaluation category. This category alludes to data collection, crash analysis, and evaluation of infrastructure. However, it does not unify these actions in the way that this paper has done by considering all mentioned topics simultaneously. The methodology for evaluating traffic safety, road design, crash characteristics, and Vision Zero policy used in this study offers a unified approach to what is now treated as multiple separate action items. Evaluation may be strengthened by administering multiple action items at once through advanced analysis techniques such as spatial statistics, regression modeling, and collection of big data.

Regression Results

The logistic regression model was performed to gauge the effects of drugs, harmful event locations, speed, proximity to FDOT signals, crash types, manner of collision, light condition, functional road classification, shoulder type, and motorcycle involvement. Table 4-1 lists all the explanatory variables in the model and their full-length name. All independent variables are statistically significant. The multilevel categorical variables are tested against a reference category.

The reference category for each set of categorical variables was set to the lowest nominal value (0). This means that the interpretation for each categorical variable is an odds ratio between the listed category and the reference category (yes versus no). Exp(B) indicates the corresponding change per unit for each continuous independent variable against the dependent variable, which may also be expressed as a percentage. If the Exp(B) is greater than 1, then the odds increase and vice versa. For example, the reference category for lighting conditions is “Daylit_Light Cond(0)” or “daylight - no.

Table 4-1. Explanatory Variables.

Variable Label	Description
Drug_Relat	Driver Drug related (yes)
SPEED	Maximum speed limit on the roadway
Other_Crash_Type	Crash type defined as “other/unknown”
Bicycle_Crash_Type	Crash type defined as “bicycle”
Ped_Crash_Type	Crash type defined as “pedestrian”
RearEnd_Crash_Type	Crash type defined as “rear end”
_angle_Manner_of_Collision	Manner of collision defined as “angle”
FronttoRear_Manner_of_Collision	Manner of collision defined as “front to rear”
Other_Manner_of_Collision	Manner of collision defined as “other/unknown”
ThruRoad_First_HE_ReltoIntersection1	First harmful event location in relation to intersection: through road
First_HE_WithinJunction1	First harmful event within interchange
Daylit_Light_Cond	Light conditions: daylight
UrbanPrincipalArterial_funclass	Functional road class: urban principal arterial
ShoulderType_Paved	Shoulder type: paved
signalVALUE1	FDOT traffic signal within 250 feet
MotorcycleYN	Motorcycle involved

Daylit_Light_Cond(1) is the code for “daylight - yes”. Therefore, the likelihood of a severe crash occurring in daylight conditions is 55.6% as likely (or about half as likely) as in non-daylight conditions, holding all else equal (derived from Exp(B) value 0.556). Similarly, a one mile per hour increase in max speed limits yields a statistically significant three percent higher likelihood that a crash will be severe. The SPSS output from the regression is in Figure 4-1.

Drug-related driving is more than twice as likely to result in a severe crash than non-drug-related driving. If the first harmful event is within an intersection it is 57.2% more likely to be severe than if it were not. Being within 250 feet of an FDOT traffic signal has smaller odds of severity than not at a traffic signal. An “other/unknown” crash type is over four times as likely to be severe than a different crash type. A bicycle crash type is almost twice as likely to result in a severe injury than a non-bicyclist accident.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	Drug_Relat(1)	.759	.301	6.372	1	.012	2.135	1.185	3.848
	First_HE_WithinJunction(1)	.452	.157	8.245	1	.004	1.572	1.154	2.140
	SPEED	.029	.004	43.522	1	.000	1.030	1.021	1.038
	signalVALUE1(1)	-.420	.084	25.049	1	.000	.657	.557	.774
	Other_Crash_Type(1)	1.511	.599	6.363	1	.012	4.533	1.401	14.666
	Bicycle_Crash_Type(1)	.683	.157	18.830	1	.000	1.980	1.454	2.695
	Ped_Crash_Type(1)	1.114	.113	97.206	1	.000	3.046	2.441	3.802
	RearEnd_Crash_Type(1)	-1.014	.177	32.819	1	.000	.363	.256	.513
	_angle_Manner_of_collision(1)	.458	.163	7.916	1	.005	1.581	1.149	2.176
	FronttoRear_Manner_of_Collision(1)	.872	.214	16.587	1	.000	2.391	1.572	3.636
	Other_Manner_of_Collision(1)	.839	.159	27.911	1	.000	2.315	1.695	3.161
	ThruRoad_First_HE_ReltoIntersection(1)	.690	.174	15.665	1	.000	1.994	1.417	2.806
	Daylit_Light_Cond(1)	-.587	.078	56.944	1	.000	.556	.477	.648
	UrbanPrincipalArterial_funclass(1)	.268	.089	9.114	1	.003	1.307	1.098	1.555
	ShouderType_Paved(1)	-.550	.097	32.167	1	.000	.577	.477	.698
	MotorcycleYN(1)	1.625	.132	152.405	1	.000	5.078	3.923	6.573
	Constant	-3.694	.232	252.812	1	.000	.025		

a. Variable(s) entered on step 1: Drug_Relat, First_HE_WithinJunction, SPEED, signalVALUE1, Other_Crash_Type, Bicycle_Crash_Type, Ped_Crash_Type, RearEnd_Crash_Type, _angle_Manner_of_collision, FronttoRear_Manner_of_Collision, Other_Manner_of_Collision, ThruRoad_First_HE_ReltoIntersection, Daylit_Light_Cond, UrbanPrincipalArterial_funclass, ShouderType_Paved, MotorcycleYN.

Figure 4-1. Final SPSS results

Pedestrian crash type is more than three times as likely to result in a severe injury than a non-pedestrian crash type. Rear end crash types are less probability to result in severe injuries than other types. If the manner of collision is at an angle, you are 58.1% more likely to die or be incapacitated than non-angle crashes. Front-to-rear and other/unknown collision types are over twice as likely to be severe than not. When the first harmful event occurs on a through road, odds are nearly double that it will be fatal or incapacitating compared to non-through roads. Daylight conditions are half as likely to yield severe crashes compared to non-daylight conditions. The urban principal arterial functional class is 30.7% more likely to result in a severe injury than other roads. When the shoulder is paved, the odds of severe injury are about half compared to roads without paved shoulders. Motorcycle-involved incidents are over five times as likely to result in a fatality or incapacitating injury than crashes without motorcycle involvement. Recall that each of these resulting statements is contingent upon all else in the model remaining equal.

Hot Spot Results

All Optimized Hot Spot maps show significant hot spots along Sunrise Boulevard east of Interstate-95. They also share a hot spot at the intersection of NW 31st Avenue and NW 19th Street (near Royal Palms Park). Figures 4-2, 4-3, 4-4, and 4-5 demonstrate the results of the analysis.

The Getis Ord Gi* Hot Spot maps look very different from the optimized maps (Figures 4-6 and 4-7). This is likely because the length of the road segments is not standardized. Also, due to the sheer number of different road segments in the layer, it is possible that many segments received no weight value in the incident field. Therefore, the Getis Ord Gi* statistic would be less adept at locating hotspots since most of the dataset has a 0 value. However, there are still a few road segments that came up as significant on Figure 4-6. By visual comparison, it appears the significant road segments line up with the significant hexagon bins from the former map series.

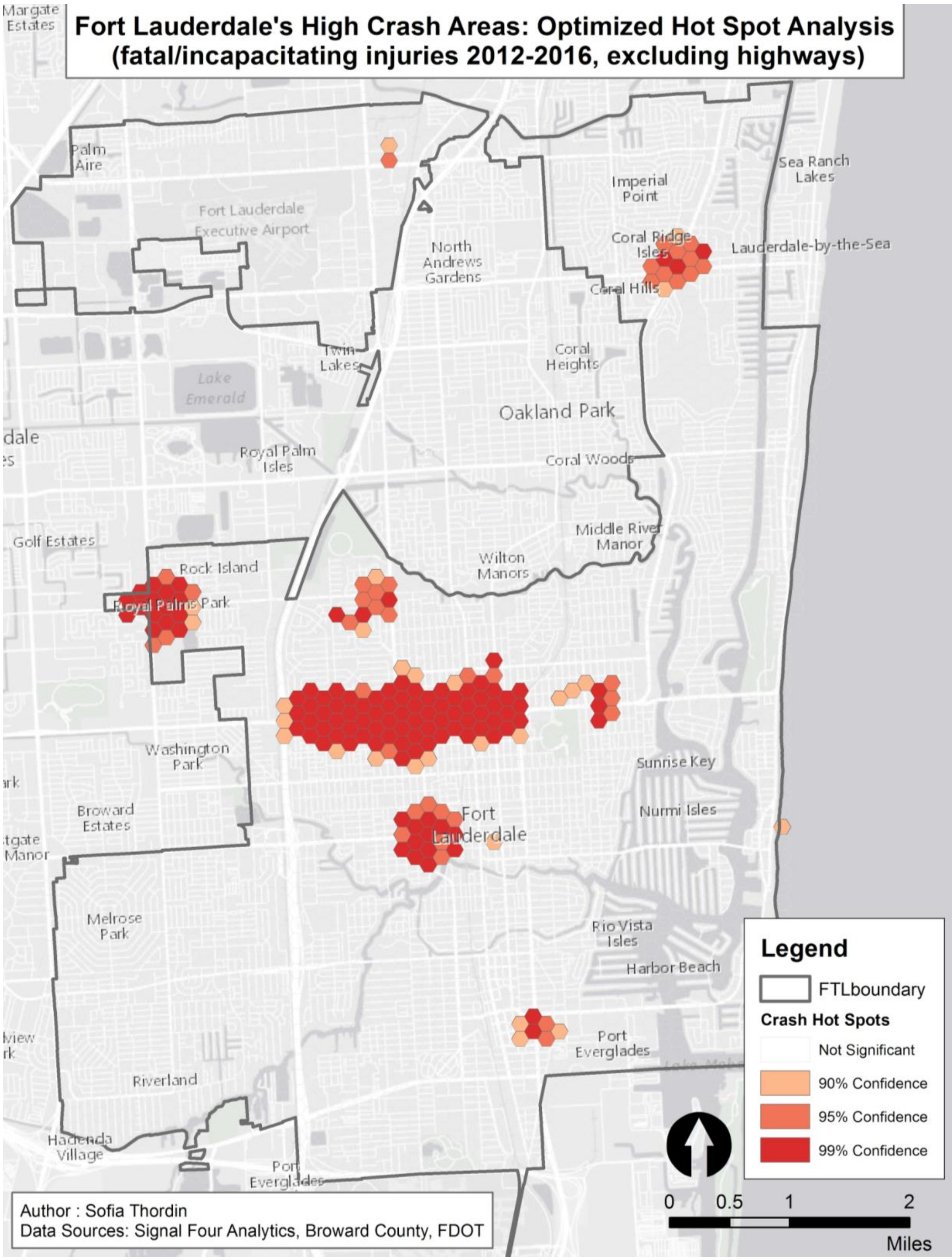


Figure 4-2. Optimized Hot Spot Fatal/Incapacitating Injuries Excluding Highways

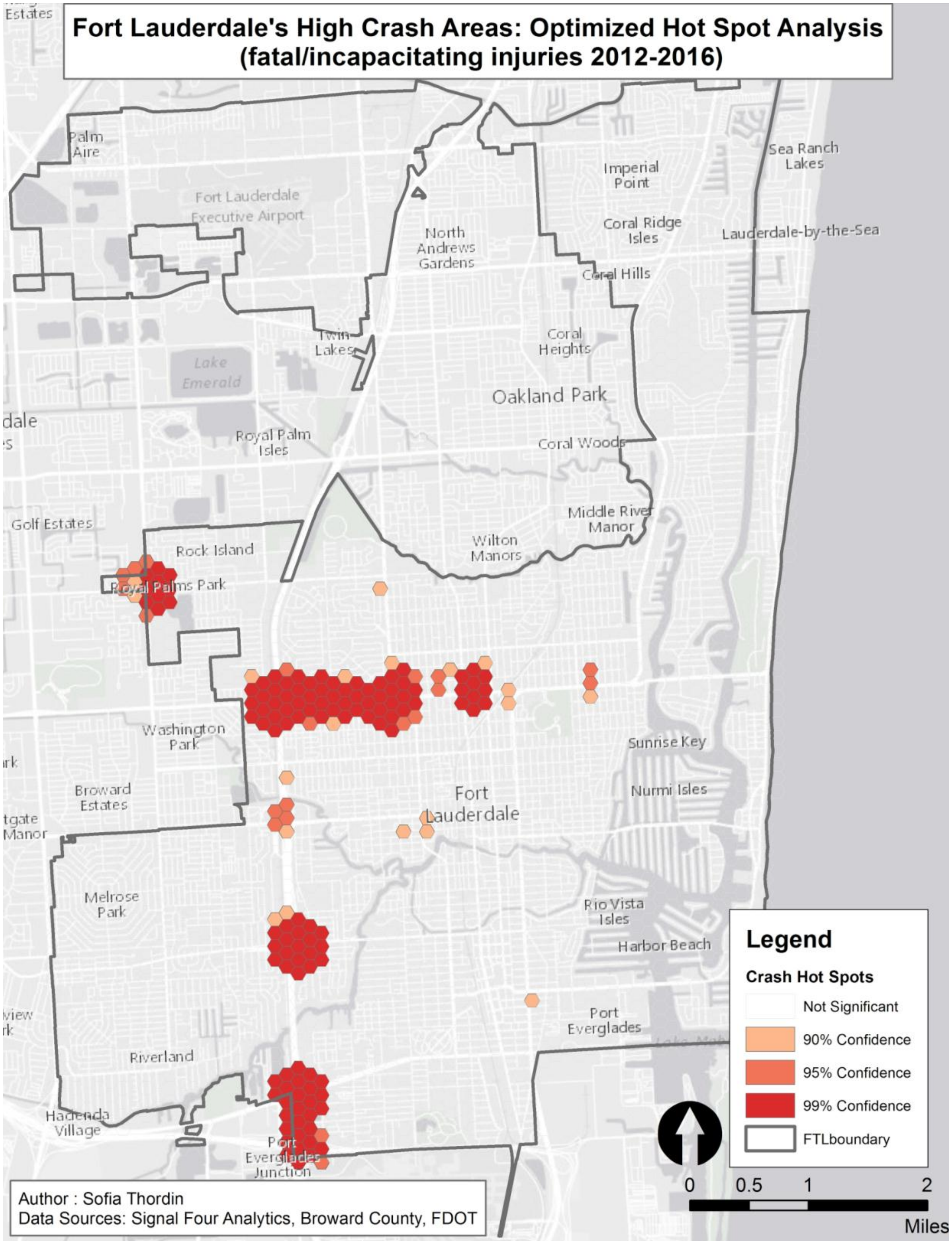


Figure 4-3. Optimized Hot Spot Fatal/Incapacitating Injury

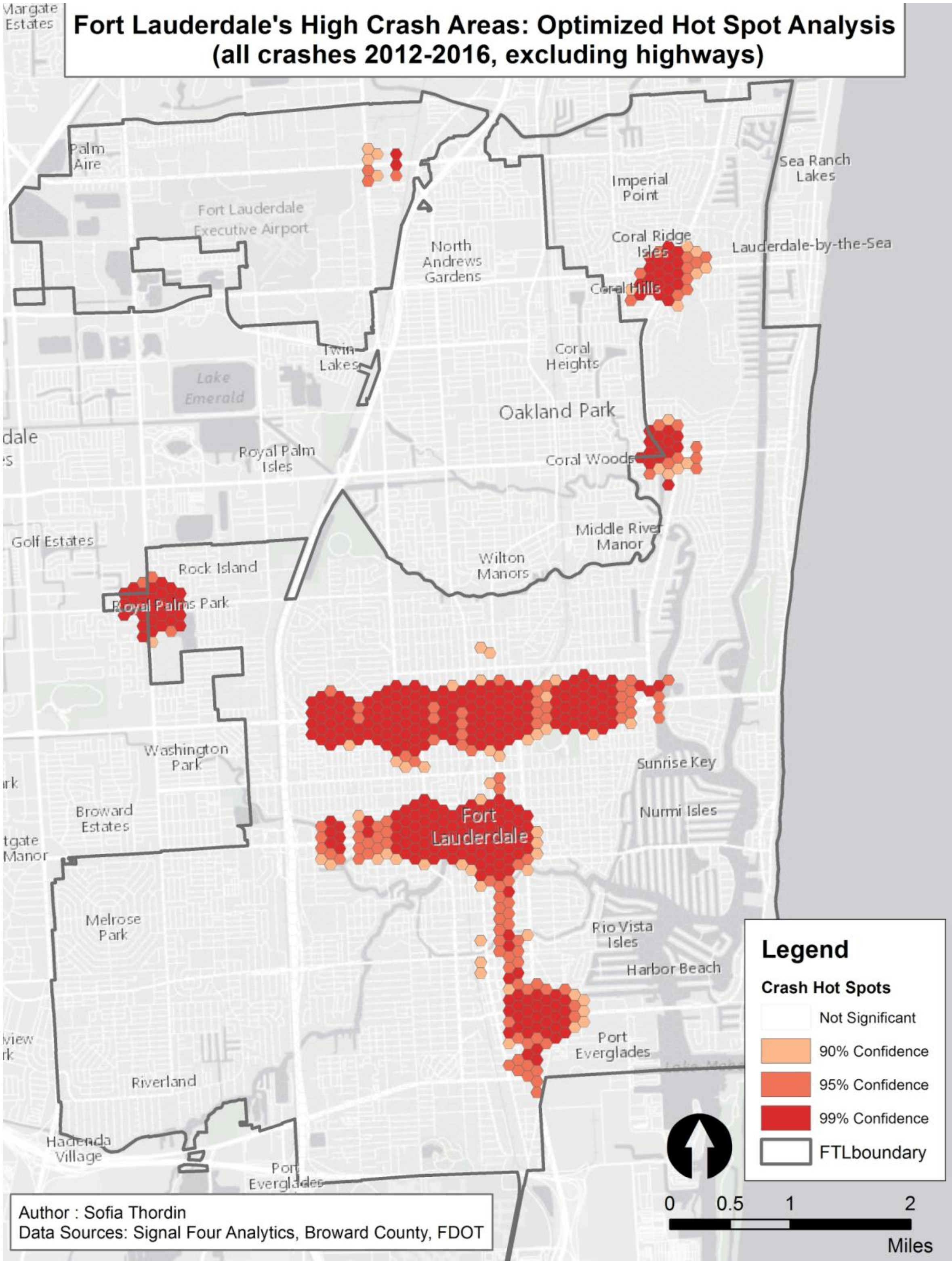


Figure 4-4. Optimized Hot Spot All Crashes Excluding Highways

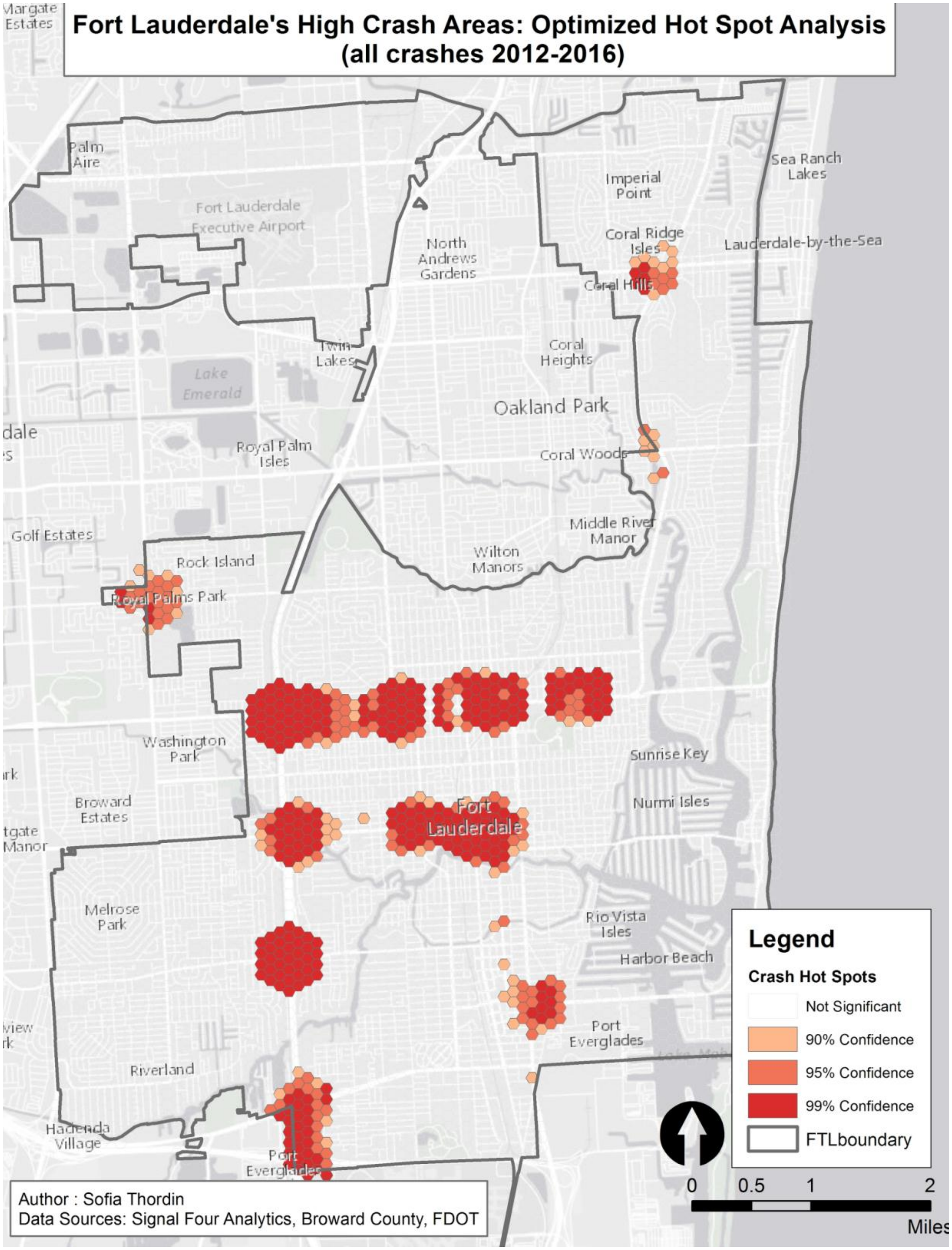


Figure 4-5. Optimized Hot Spot All Crashes

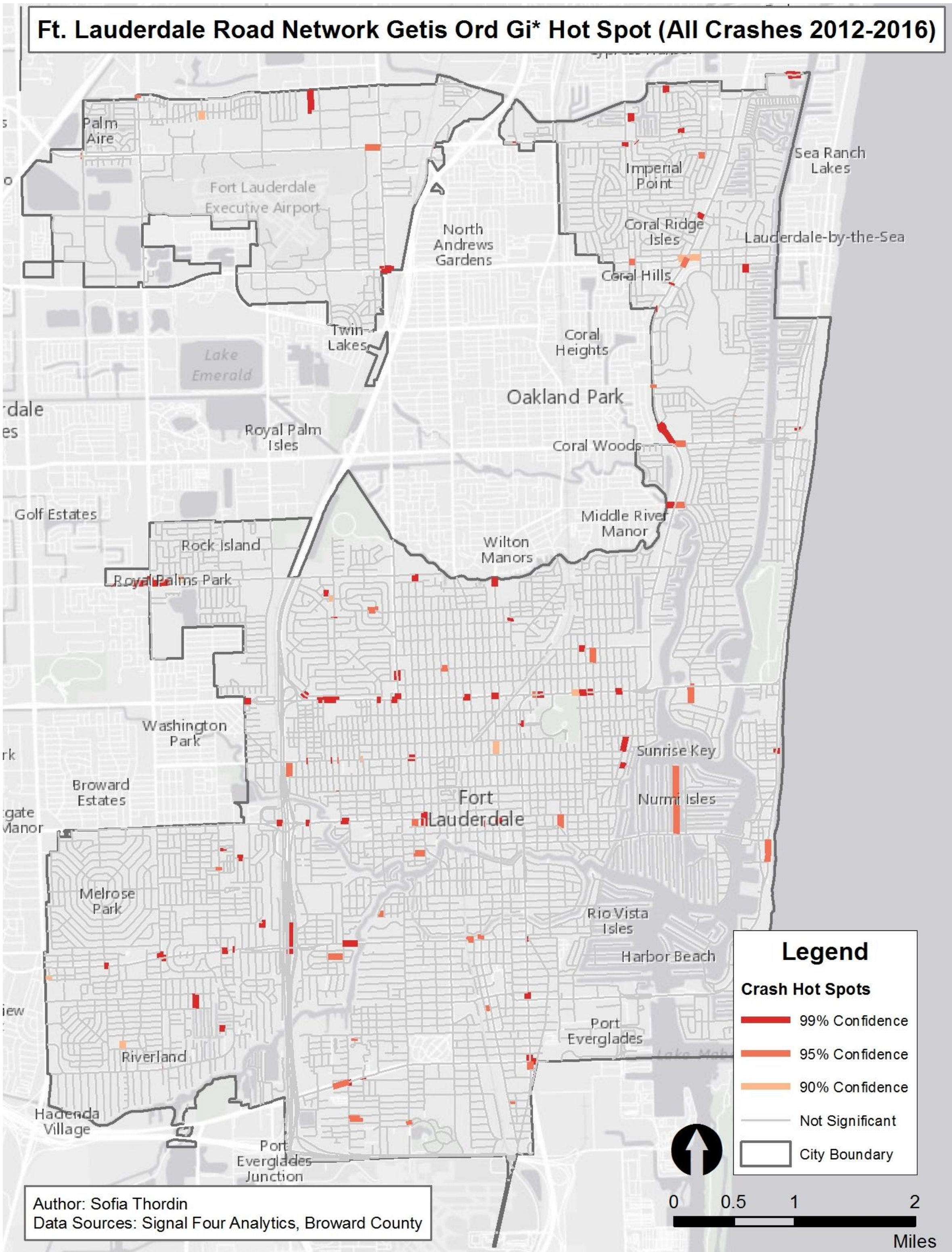


Figure 4-6. Getis Ord Gi* Hot Spot All Crashes

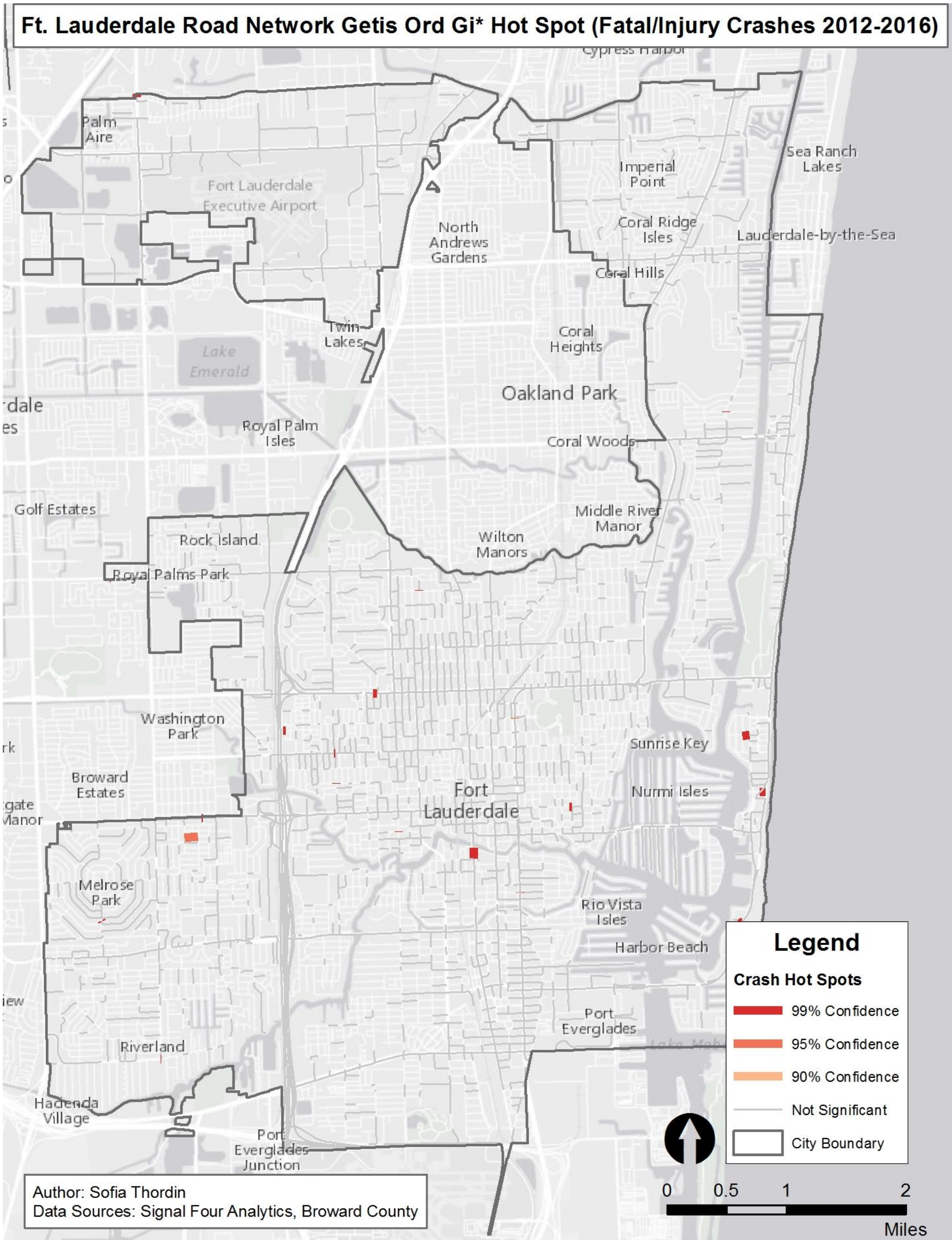


Figure 4-7. Getis Ord Gi* Hot Spot Fatal/Severe Injury

CHAPTER 5
CONCLUSION

Discussion

Interpretation of Results

Unfortunately, while running the many test models and stepwise regressions to filter out insignificant explanatory variables, most of the design feature attributes were cast away and determined not statistically significant. Because one of the goals of the study was to evaluate the effect of road design features on likelihood of severe injury, it is disappointing that the data was not usable. Furthermore, census data proved to be insignificant too. There was some speculation of whether the demographics in a census block group might reflect injury levels or have some correlation to the overall urban environment. However, the statistics were inconclusive.

The variables that remained in the model seem to have logical final odds ratios. If anything, the fact that a crash type “rear end” and manner of collision “front to rear” have opposing odds is confusing. One would assume that because a rear-end crash type is making a front to rear motion that they would follow suit. This raises discussions about the definitions and consistency in crash reporting. Also, the fact that driver distraction and alcohol-related driving were statistically insignificant (although close to 90% confident in some test models), seems odd. It is quite possible that distracted and impaired driving is underreported.

A number of the resulting ratios are aligned with currently existing Vision Zero guidelines. Therefore, one might claim that the results of the logistic regression support the continuation of pursuing zero. The higher injury risk for vulnerable road users, such as bicyclists, pedestrians, and motorcyclists, is supported in the literature and known. In this case, the suggestion might be to continue separating exposed modes of travel from motorized modes of travel. When considering speed is a significant factor, the clear deduction would be to support decreasing speed limits where conflicts may occur.

The ambiguity of the other/unknown categories leaves some lingering questions. Other/unknown crash types have a high odds ratio and a strong statistical significance level. Unfortunately, these categories are lumped together as miscellaneous circumstances and do not actually contribute much interpretable information because of their mysteriousness. Interestingly, both through roads and intersection crashes are more likely to be severe.

Signalization overall seems to be a solid traffic control method and should perhaps be considered in some of the map's hot spot areas. The hot spot maps would also support the results of the regression. For example, the urban principal arterial functional classification is represented by numerous hot spots on the maps (especially Sunrise Boulevard). It would be interesting to further review the statistics on motorcycle crashes to check for attributes like helmet use. The odds ratio of motorcycle crashes to severe injury is high and significant. Vision Zero cannot advise people against free will to choose whichever mode they prefer, but it can support driver education and enforcement for things like helmet use.

Overall, the results of the hot spot maps and regression seem aligned. Urban principal arterial road types with higher speeds and curb/unpaved shoulders have a higher risk of injury. These road classifications are visible in the hot spot maps. The results support Vision Zero theories and point to the suggestion that if the City of Fort Lauderdale sticks to its goals in its plan; it will eventually begin to see results.

Limitations of Research

The research is clearly limited by several things: data availability/quality, reliability of crash forms, and loss of information when transforming from ordinal data to scale data. Nearly all of the road design attributes came from the FDOT. This means that the most accurate dataset for design methods stemmed from non-local roads. The discrepancy in jurisdiction among road types creates a lapse in data contiguity and availability. Furthermore, this lack of complete data forced the filling of null cells with estimation methods, which is not ideal (although it is a functional mathematical tool with statistical validity). While the FDOT shapefiles are updated as of this year, using data over a five-year period poses the risk of inaccurately treating some incidents that have had design interventions in the recent past.

One of the main human factors in the data collection process is the law enforcement officer who completes the crash form. The nature of the work is inherently subjective and different officers will have different methods for completing the forms. Furthermore, the frequency that “other” and “unknown” fields are used is high.

Lastly, the statistical methods used for the study were not technically the best fit for the data type on hand. An ordinal logistic regression would have kept a higher level of measurement in crash severity. There are also other generalized linear models or negative binomial regression that may have been able to fit the dataset. The results of the model are only as strong as the data put into it.

Suggestions for Future Research

In future research, I would suggest using data with a continuous dependent variable in order to open up the possibilities for other mathematical procedures. A continuous dependent variable would also allow for spatial regression within ArcGIS.

The possibility of calculating a cost to society would be a viable solution to this setback. Future research should seek more granular data from other sources aside from FDOT. FDOT's dataset for design features is incomplete for smaller local roads. If pursuing another regression-type analysis, I would probable separate interstate highways from other roads and run regressions side-by-side. This is because many of the road design features that exist on city streets do not exist on highways. Therefore, there were thousands of null values for things like sidewalks, which might have otherwise had a significant impact on the model.

It may be beneficial to isolate an even smaller study area, perhaps one of the identified hot spots (like Sunrise Boulevard) and survey the area manually. This would ensure that a critical high crash corridor is being studied and that the results are timely and accurate. A manual survey may include citizen responses or suggestions about safety issues in the corridor.

Summary and Conclusion

The final takeaway from the study can be summarized as, "keep studying." Based on the hot spots identified in the map analysis and the results of the regression, the road types and design interventions that may be considered problematic are the same ones that are referenced in all of the Vision Zero literature. Separating modes, educating drivers about safe behavior, minimizing conflict on roads, adding signalization where it is necessary, and lowering speed limits to forgiving levels are just a few of the methods that can be supported in this paper's findings. Further research focused on smaller areas, like high crash corridors, would be a worthwhile endeavor. Similarly, gathering more granular spatial data from local sources and running the regression over again on a continuous dependent variable would be great improvements to this effort.

LIST OF REFERENCES

Buckley, A. (2017). Dealing with incomplete data for mapping and spatial analysis. Retrieved from https://www.slideshare.net/aileenbuckley/dealing-with-incomplete-data-for-mapping-and-spatial-analysis

Fleisher, A., Wier, M., & and Hunter, M. (2015). A vision for transportation safety: A framework for identifying best practice strategies to advance vision zero. *Journal of the Transportation Research Board,* (TRB 95th Annual Meeting Compendium of Papers) doi:10.3141/2582-09

Florida Department of Transportation. (2013). *URBAN BOUNDARY and FUNCTIONAL CLASSIFICATION HANDBOOK*. Tallahassee: Florida Department of Transportation.

Florida Department of Transportation. (2016). *MANUAL OF UNIFORM MINIMUM STANDARDS FOR DESIGN, CONSTRUCTION AND MAINTENANCE FOR STREETS AND HIGHWAYS (commonly known as the "Florida Greenbook")*. Tallahassee: Florida Department of Transportation.

IBM Support. (2014). Multicollinearity diagnostics for LOGISTIC REGRESSION, NOMREG, or PLUM. Retrieved from http://www-01.ibm.com/support/docview.wss?uid=swg21476696

IBM Support. (2017). Logistic regression variable selection methods. Retrieved from https://www.ibm.com/support/knowledgecenter/en/SSLVMB_24.0.0/spss/regression/logistic_regression_methods.html

International Transport Forum. (2016). *Zero road deaths and serious injuries leading a paradigm shift to a safe system: Leading a paradigm shift to a safe system*. Paris: OECD Publishing.

Johansson, R. (2009). Vision zero – implementing a policy for traffic safety. *Safety Science, 47*, 826. doi:10.1016/j.ssci.2008.10.023

Jurewicz, C. (2009). In Hall K. (Ed.), *Speed limit setting principles in the safe system context* Australasian Road Safety, Policing and Education Conference.

Kolacz, H. (2012). Lab 4 instructions multiple linear regression. Retrieved from http://www.stat.ualberta.ca/statslabs/stat252/files/ins4.pdf

Laerd. (n.d.). Binomial logistic regression using SPSS statistics. Retrieved from https://statistics.laerd.com/spss-tutorials/binomial-logistic-regression-using-spss-statistics.php

Larsson, Peter, Dekker, Sidney W.A.,Tingvall, Claes,. (2010). The need for a systems theory approach to road safety. *SAFETY Safety Science, 48*(9), 1167-1174.

Midi, H., Sarkar, S., & Rana, S. (2010). Collinearity diagnostics of binary logistic regression model. *Journal of Interdisciplinary Mathematics, 13*(3), 253. doi:10.1080/09720502.2010.10700699

National Highway Traffic Safety Administration. (2010). *Traffic safety facts 2010 A compilation of motor vehicle crash data from the fatality analysis reporting system and the general estimates system.* (No. DOT HS 811 659). Washington DC: National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration. (2016). *The road ahead: National traffic highway safety administration strategic plan 2016-2020*

National Highway Traffic Safety Administration. (2017). *Quick facts 2015.* (No. 812 348).US Department of Transportation.

National Transportation Safety Board. (2017). *NTSB aims to reduce speeding-related crashes*. Washington, DC: National Transportation Safety Board.

Nielsen, D. (2013). Automotive active safety systems. *Illumin, XV*

Paramjeet, A. (2014). Study of causes of accidents due to high vehicle density and road conditions and their remedial actions. *International Journal for Research in Applied Science and Engineering Technology, 2*(VII), 14.

Rosencrantz, H., Edvardsson, K., & Hansson, S. O. (2007). *Vision zero – is it irrational?* doi:https://doi.org/10.1016/j.tra.2006.11.002

Smart Growth America. (2017). *Dangerous by design 2016*. Smart Growth America.

Sperandei, S. (2014). Understanding logistic regression analysis. *Biochemia Medica, 24*(1), 12. doi:10.11613/BM.2014.003

Toward Zero Deaths. (2014). *Toward zero deaths: A national strategy on highway safety.*

Trafikverket. (2012). *Vision zero on the move.* (No. 100506). Borlange: Swedish Transport Administration.

Trafikverket. (2015). *Analysis of road safety trends 2014. management by objectives for road safety work towards the 2020 interim targets.* (No. 2015:103). Borlange: Swedish Transport Administration.

Vision Zero Network. (2017). Vision zero cities map. Retrieved from https://visionzeronetwork.org/resources/vision-zero-cities/

Wegman, F., Aarts, L., & Bax, C. (2008). *Advancing sustainable safety: National road safety outlook for the netherlands for 2005–2020* doi:https://doi.org/10.1016/j.ssci.2007.06.013

White, R. (n.d.). Auto safety history. Retrieved from http://amhistory.si.edu/onthemove/themes/story_86_3.html

Whitehead, J. (n.d.). An introduction to logistic regression. Retrieved from http://www.appstate.edu/~whiteheadjc/service/logit/intro.htm

World Health Organization, Peden, M. (2004). *World report on road traffic injury prevention*. Geneva: World Health Organization.

Wuensch, K. (2016). Binary logistic regression with SPSS. Retrieved from http://core.ecu.edu/psyc/wuenschk/MV/MultReg/Logistic-SPSS.pdf

Xuan, Z. (2016). Multiple regression. *GIS for environmental applications: A practical approach* (pp. 219). New York: Routledge.

BIOGRAPHICAL SKETCH

Sofia Thordin was born in Fort Lauderdale, Florida in 1995. In 2016, she earned her Bachelor of Science in Sustainability and the Built Environment and Bachelor of Arts in geography from the University of Florida (UF). She enrolled in the Master of Urban and Regional Planning combined degree program at UF in 2015 and graduated from the program fall 2017. As an aspiring generalist planner, Sofia has worked on alternative fuels, historic preservation, web mapping/GIS, development review, and traffic safety projects during her internships. She aspires to support social and ecological sustainability through urban planning.