INVESTIGATING HOW LAND USE PATTERNS AFFECT TRAFFIC ACCIDENT RATES NEAR FRONTAGE ROAD CROSS-SECTIONS: A CASE STUDY ON INTERSTATE 610 IN HOUSTON, TEXAS

By

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Abstract:

Frontage roads, acting as a transition between high-speed free-flowing traffic on highways and low-speed congestion traffic on local streets, have been used as the "primary design solution" to alleviate traffic congestion on highways in Texas since the late 1940's (Kockelman et al. 2001, 1). Frontage roads in Houston and the rest of Texas were designed to provide easy access to a variety of land use types located near a frontage road cross-section. However, today some land use areas near frontage road cross-sections have become heavily commercialized, which produces more vehicle traffic congestion and accidents (Kockelman et al. 2001).

In this study, I propose to take a geographical approach to examining the traffic accident patterns near frontage road cross-sections. Various socioeconomic and land use variables are identified through a multiple linear regression analysis to explain why some frontage road cross-sectional locations have high clusters of accidents. The results show that a higher percentage of commercial and industrial land use, a higher mean household income, and a lower percentage of undevelopable land use have a significant influence in increasing an individual's risk of getting into a vehicle traffic accident near frontage road cross-sections.

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CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Frontage roads are very common in Texas. Acting as a transitional road between high-speed free-flowing traffic on highways and low-speed congestion traffic on local streets, frontage roads have been used as the "primary design solution" to alleviate traffic congestion (Kockelman et al. 2001, 1). When construction on frontage roads began in the late 1940's, government officials believed frontage roads were the best method for dealing with traffic growth and reducing overall construction costs (Slotboom 2003). However, within the past ten years, the Texas Department of Transportation (TxDOT) has begun to criticize frontage roads (Wright 2002). The perception towards frontage roads changed when numerous reports such as the ones conducted by Kockelman et al. (2000; 2001; 2003; 2004; 2005) and Fitzpatrick et al. (1996; 2010) linked frontage roads to increased traffic congestion, traffic accidents, design flaws, and construction costs. Though researchers have started investigating the above issues, accidents continue to be problematic in Texas.

In this thesis, I will investigate what types of land use and socioeconomic variables influence vehicle traffic accidents located near frontage road cross-sections in Houston, Texas. Understanding what types of land use influence vehicle traffic accidents will help the TxDOT either design safer frontage roads or not construct frontage roads altogether.

In 1995, the American Association of State Highway Officials (AASHTO) Green Book (528) labeled frontage roads as “the ultimate in access control”. By adopting frontage roads as the major method for alleviating traffic congestion, Texas has invested a significant amount of money, time, and resources towards constructing frontage roads (Slotboom 2003). However, Kockelman et al. (2001) have shown that the financial cost of constructing frontage roads is higher than constructing roadways without frontage roads. Moreover, higher costs do not guarantee a safer travel condition (Kockelman et al. 2001). On the contrary, frontage roads are linked to traffic congestion and traffic accidents because of weaving patterns and short inter-ramp spacing, which “can create serious merging and diverging issues” (Kockelman et al. 2001, 7). When a vehicle traffic accident does occur near a frontage road cross-section, this directly correlates to unnecessary time, costs, environmental hazards, and risk to personal welfare, which imposes a burden on other individuals (Hanson 1995; Bilbao-Ubillos 2008). This unnecessary burden severely affects an individual’s daily activities (e.g. shopping, work, sporting event) and can hinder a city’s economy while putting a strain on emergency personnel (Hanson 1995; Muller 1995).

Over the years, TxDOT policymakers, planners, and engineers began to change their opinions toward frontage roads and started to “criticize frontage roads for their expense, their contribution to traffic congestion, and environmental and safety risks” (Wright 2002, 12). This perception regarding frontage roads led the TxDOT to reconsider its half-century old notion about the benefits of frontage roads and form a new policy in roadway construction (Wright 2002). The new policy change, however, was vehemently opposed by the public and business organizations, which forced the “TxDOT to withdraw its proposal to limit construction of frontage roads” (Wright 2002, 13).

While a higher concentration of vehicle traffic accidents has been documented to exist near the intersection of a highway and frontage road cross-section, this is not the case at every location (Fitzpatrick et al. 1996). Some locations benefit from frontage roads because they provide easy access to an activity site without the increase in construction costs, traffic congestion, and traffic accidents (Slotboom 2003). The ability to identify which land use and socioeconomic variables influence vehicle traffic accidents near frontage road cross-sections is extremely crucial to the transportation, economy, and construction of frontage roads in Texas. When vehicle traffic accidents hinder the movement of people, goods, and information, it is difficult for a society to grow economically (Traynor 2008).

1.2 Objectives

Civil engineers have accomplished the majority of frontage road research by analyzing how the design of frontage roads contributes to vehicle traffic accidents. For example, researchers such as Hunter and Machemehl (1997), Kockelman et al. (2001), and Fitzpatrick et al. (2010) have found that distance between entrance and exit ramps, ramp length, sign placement, lighting, ramp grade, and speed limit influence vehicle traffic accidents. However, the results that civil engineers have found do not provide a complete understanding of why vehicle traffic accidents happen near frontage road cross-sections. Another alternative is to understand frontage road traffic accidents geographically. Since frontage road cross-sections are used to provide easy access to a variety of land use types in a diverse socioeconomic environment, a geographical perspective is logical to examine the interaction between land use patterns and vehicle traffic accidents in the area.

This research presents a case study on Interstate 610 (I-610) in Houston, Texas. The goal is to provide a geographical perspective on vehicle traffic accidents that occur near frontage road cross-sections. I will use quantitative methods to investigate which land use and socioeconomic variables influences vehicle traffic accidents and employ geographical information systems (GIS) methods to reveal cluster patterns not easily noticeable to the public, government officials, and emergency management. The results will help traffic engineers and city planners make better decisions towards reducing vehicle traffic accidents and improve the safety of the transportation network (Wang et al. 2009).

1.3 Area of Study

The focus area of this study is on I-610 (Figure 1), a 37.972 mile loop within the city of Houston, which is located in Harris County, Texas (TxDOT 2012b). The city has a population of 2,099,451 with a population density of 3,501 per square mile (U.S. Census 2010). The greater Houston metropolitan area has a population of 4,092,459 making Houston the fourth-most populated metropolis in the nation (City of Houston 2012). I chose Houston to study vehicle traffic accidents because it has is a large population and a wide range of socioeconomic values which corresponds to an “individual's risk of being involved in an accident” (Anderson 2010, 2196). In addition, the limited public transportation system in Houston makes traveling in vehicles easier to get to an activity (Slotboom 2003).

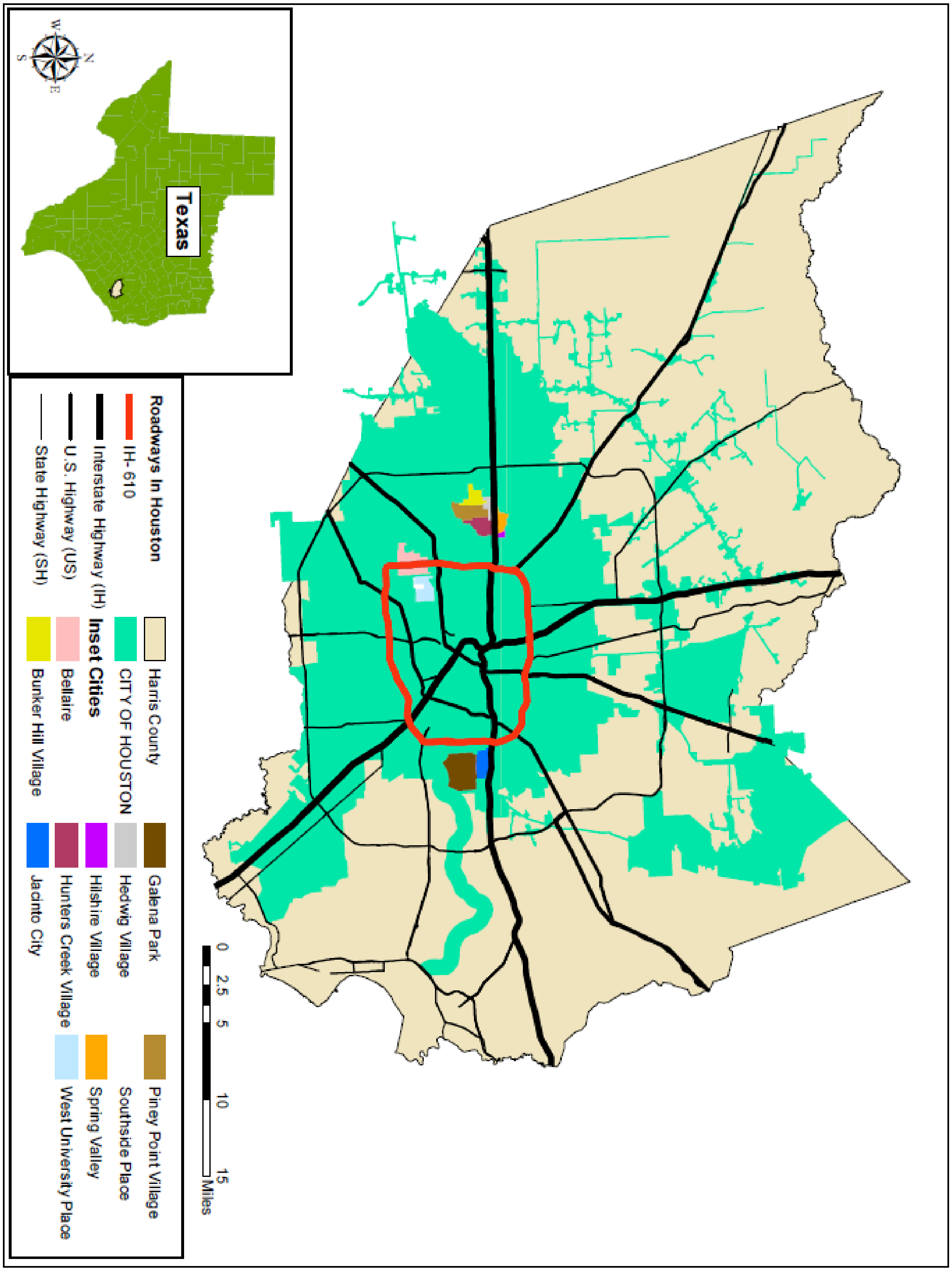

Figure 1 – Thesis Study Area

1.3.1 Kernel Density - Accident Map of I-610

Kernel density is helpful to identify where a concentration of vehicle traffic accidents is located, because kernel density analysis reveals “hot spots” or clusters (frequency) (Larsen 2010). When kernel density is used within GIS, it provides a powerful visualization tool to reveal useful information from the dataset. This method is beneficial because it presents data as a smooth surface where the density of every traffic accident location reflects a similar intensity of other nearby vehicle traffic accidents (Hashimoto 2005). As shown in Figure 2, the kernel density helps identify the vehicle accident “hot spots” along the I-610 loop. The red and orange colors show the highest concentrations of vehicle traffic accidents, while the green shows where the lowest concentrations of vehicle traffic accidents occur.

From Figure 2, we can learn that traffic accidents along I-610 do not present an even distribution pattern in space. Higher concentrations of vehicle traffic accidents occur mainly on the western side of I-610. Sporadic higher concentrations of vehicle traffic accidents also show up in places labeled as C, W, and U. The cause for these higher concentrations of vehicle traffic accidents to occur in these locations is largely from the surrounding land use being highly commercialized; however, there might be other factors that influence higher concentrations of vehicle traffic accidents (Kockelman et al. 2001). In this study, I look specifically at land use and socioeconomic variables to examine the causes of vehicle traffic accidents.

Though kernel density is a great visualization tool for locating a concentration of vehicle traffic accidents, it does not accurately portray the likelihood of being involved in an accident, because it does not factor in average annual daily traffic (AADT). AADT is beneficial and is presented in the statistical analysis section because it helps standardize vehicle traffic accidents between two different locations.

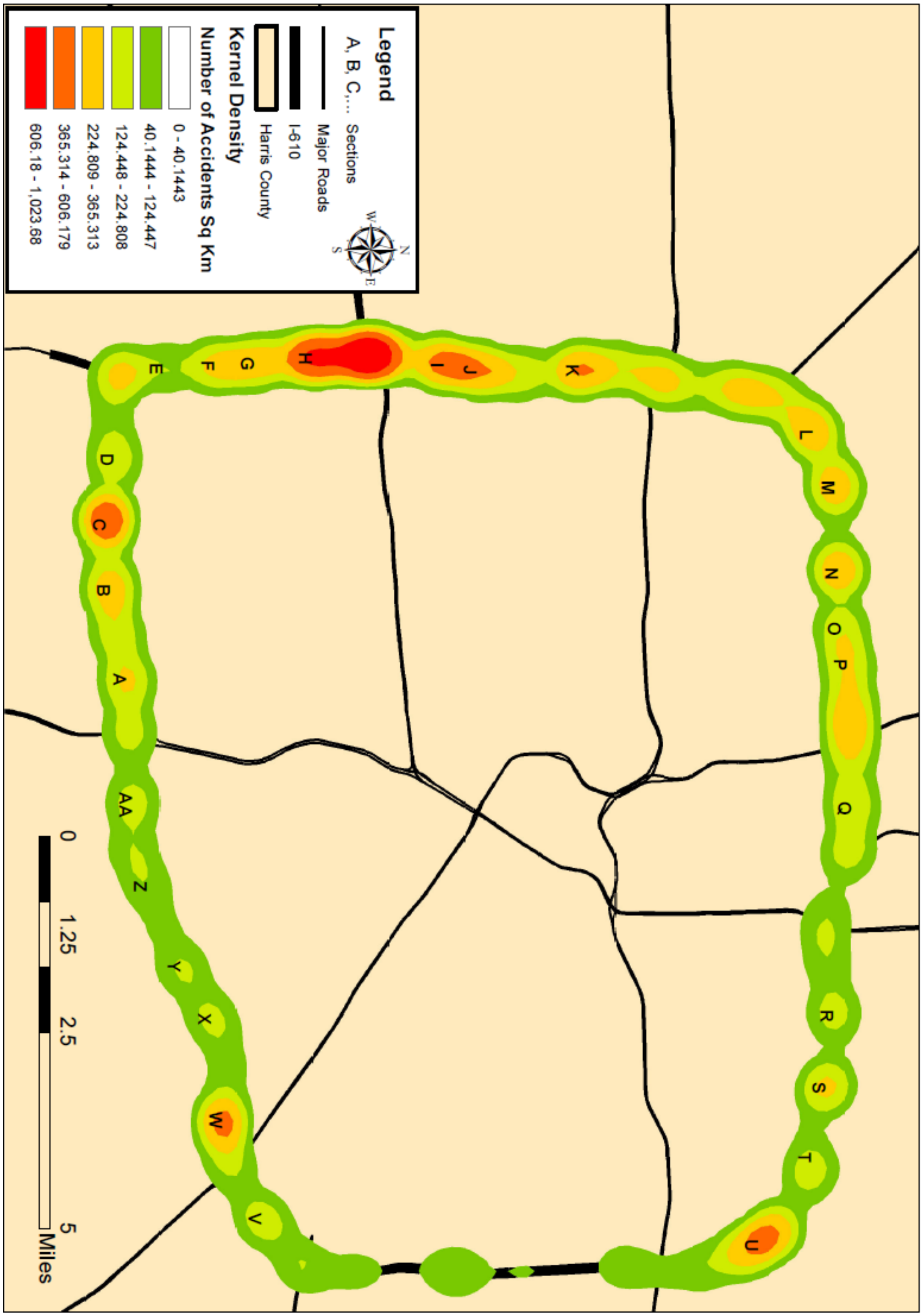

Figure 2 – Kernel Density Map

1.4 Research Questions

In this study, I am going to address two questions based on the premise that certain types of land use and socioeconomic variables located near frontage road cross-sections influence vehicle traffic accidents.

Question 1: What socioeconomic and land use variables correlate to a higher traffic accident rate near frontage road cross-sections?

Question 2: How can we use these socioeconomic and land use variables to discern different types of frontage road cross-sections that are experiencing vehicle traffic accident problems?

I will use these two questions to guide my examination at the connections between frontage road cross-sections and traffic accident rates on I-610 in Houston. Quantitative methods, such as statistical analysis, will be used to help me tackle the above questions. By answering these two questions, this study is expected to provide a better understanding to transportation planners on what specific land use and socioeconomic variables influence vehicle traffic accidents at frontage road cross-sections. Even though this study focuses only on I-610 in Houston, the methods can be adapted to examine similar scenarios in other cities with frontage roads as well and the results can offer insight on fully understanding the role of frontage roads in the transportation system in a city.

CHAPTER II

REVIEW OF LITERATURE

2.1 Background - How Automobiles Shape Our Roads

The automobile first came into public view at the beginning of the twentieth century as a "pleasure vehicle" that only the most affluent individuals could afford (Weiner 2008, 7). What the automobile (used interchangeably with vehicles) offered compared to other modes of transportation was the ability to travel longer distances in a shorter amount of time (Hanson 1995). When new manufacturing techniques were developed, this helped increase automobile production and reduced costs, making it more affordable to the middle class (Hanson 1995; Easterling 1999). The combination of public demand and automobile's timesaving ability made owning an automobile essential to completing multiple daily activities. With few roadways built, the existing road network system became overwhelmed, creating a new dilemma for cities: traffic congestion (Whitton 1962; Grava 2003; Weiner 2008). It was not until 1956 that construction of the National System of Interstate and Defense Highways (National Highway System) began. This development provided a vast timesaving improvement for transporting people, goods, and information across the country as well as within urban areas (Lomax and Levinson 1997; Grava 2003; Weiner 2008). Today the National Highway System still has a significant impact on travel in America, but the transportation planning process for urban areas has changed over the years. The planning process has gone from constructing highways to a more strategic planning process that improves the highway (Weiner 2008).

2.2 Introduction - Improving Highway Efficiency

Automobiles dominate the highway landscape and provide society with virtually unlimited amounts of mobility, but "threaten to choke" cities with traffic congestion (Grava 2003, 127). To understand how vital transportation is to urban areas, an analogy can be made by describing the city as the heart, the highways as the arteries, and the economy as the lifeblood flowing throughout the network. Automobiles and road networks serve the purpose of advancing the economy by transporting "people, goods, and information within the local metropolitan area" as efficiently as possible (Muller 1995, 26). If the economy is hindered by traffic congestion, serious problems exist for a city, which can affect "income, employment, production, resource consumption, pollution generation, and tax revenues" (Weiner 2008, 158).

There are numerous interpretations that describe vehicle traffic congestion, but Lomax and Levinson define congestion as a "travel time or delay in excess of that normally incurred under light or free-flow travel conditions" (1997, 550). Principally, what classifies as vehicle traffic congestion is personal preference, however; vehicle traffic congestion can be split into two different categories, reoccurring and random (Downs 2004, 37). Reoccurring vehicle traffic congestion occurs around the same time every day and causes high volumes of traffic, but theoretically is avoidable (e.g. rush hour) (Downs 2004). Random traffic congestion involves incidents, which are characterized as "any nonrecurring event that causes a reduction of roadway capacity or an abnormal increase in demand" (Farradyne 2000, 1-2). Incidents are considered unavoidable and contribute to nearly 60 percent of all traffic congestion (Ullman and Ogden 1996, 221; Downs 2004). Vehicle traffic accidents are a subclass of incidents and contribute around 10 to 15 percent of all incidents, but causes the greatest amount of lost time to congestion delays (Flak 1997b, 375; Downs 2004). If vehicles were involved in fewer accidents, this would significantly reduce traffic congestion, travel time, and energy use (Downs 2004).

One of the problems confronting many urban areas across the U.S., such as Houston, is that cities try to solve traffic-related problems in their own unique way. For example, some cities such as Los Angeles, Minneapolis-St. Paul, and Denver use high occupancy vehicle (HOV) or high occupancy toll (HOT) lanes to increase traffic flow (Konishi and Mun 2010). Some major cities in California also use stoplights at entrance ramps to highways as a way to control traffic flow (CalTrans 2007). Houston uses two prominent kinds of traffic-solving techniques: toll roads and frontage roads. Toll roads help reduced travel time and decrease vehicle traffic congestion because only certain individuals are prepared to pay for these services (Hensher and Goodwin 2004). Transportation planners also see toll roads as a way to help pay for the construction of new roads without burdening taxpayers (Hensher and Goodwin 2004). While toll roads are useful to a city, they do not pose any major hazards to individuals. However, frontage roads today are increasingly acting as the major arterial roadway instead of the highway, which does pose a major hazard to individuals by contributing to more traffic congestion and traffic accidents (Kockelman et al. 2001).

What makes the transportation infrastructure in Houston, Texas unique compared to other urban areas is the extensive use of frontage roads (also called service roads, collector roads, or feeder roads) (Slotboom 2003). The extreme practice of constructing frontage roads as part of Texas' highway network design plan is publicized by the fact that 81 percent of Houston's highways (including toll roads) have frontage roads (Slotboom 2003, 95). The purpose of frontage roads is to "distribute and collect traffic between local streets and interchanges", but the practicality of frontage roads helps reduce local traffic from entering the highway just to go a short distance (Lord and Bonneson 2007, 20). This helps reduce the number of vehicles on the highway (Kockelman et al. 2001; Slotboom 2003). In the event of an emergency, emergency vehicles can quickly enter the highway at the closest frontage road ramp while traffic on the highway can be diverted onto frontage roads (Slotboom 2003). This assures that the flow of traffic is continuously moving. Frontage roads have their advantages on Houston's road network. However, in 2000, the Texas Transportation Commission revealed that frontage roads may have inadvertently "added to congestion in urban areas" because frontage roads increase the number of access points (Kockelman et al. 2001, 5).

Many different transportation research topics focus on traffic congestion problems related to: economic impacts (Kopits and Cropper 2005; Traynor 2008), social impacts (Barber 1995), and environmental impacts (Hanson 1995; Stutz 1995). These issues, however, are the outcomes to traffic congestion. In this literature review, I identify vehicle traffic accidents as the main topic of focus because solving traffic accident problems will help reduce traffic congestion and travel time as well as alleviate economic, social, and environmental impacts simultaneously. First, I convey the negative impacts vehicle traffic accidents have on congestion. Second, I discuss in-depth how frontage roads became a widespread method by the TxDOT in order to reduce construction costs and alleviate traffic congestion. I also include the benefits and detriments of frontage road assessments from researchers, government officials, and the public. Third, I show how transportation and land use data are important to solving vehicle traffic accidents. Finally, I present the benefits of GIS to visual identify areas of concentrated highway accidents.

2.3 Vehicle Traffic Accidents - Understanding the Impacts

Transportation research began in the early 1920s as a rudimentary way to forecast and identify what the maximum volume of vehicles a roadway could manage; this eventually evolved to include vehicle traffic accidents (Weiner 2008). Vehicle traffic accidents are difficult to comprehend at first glance, because they can appear to be either human error, mechanical failure, or the result of a weather event. In addition, the main responsibility of first responders to a crash site is to transport anyone injured and quickly clear the vehicle from the road while determining whether any traffic laws were violated (Flak 1997a). This process makes it easy for law enforcement and the public to overlook spatial patterns attributed to vehicle crashes. Until Moellering wrote *The Journey to Death: A Spatial Analysis of Fatal Traffic Crashes* (1974), which describes the spatial characteristics of vehicle traffic accidents, geographers were rarely involved in transportation research (Whitelegg 1987).

Today, traffic accidents in urban areas are heavily associated with congestion delays, which results in the loss of millions of dollars a year (Flak 1997b; Downs 2004). As vehicle traffic accidents continue to get worse for American cities, travel time and travel costs for daily commuters increase (Cambridge Systematic 2004). For example, in the

2011 Urban Mobility Report, a Houston commuter experiences an average of 57 hours of delays and uses 28 gallons of extra fuel a year, which results in an annual additional cost of $1,171 per driver (Schrank et al. 2011, 20). Businesses are also affected by time stuck in traffic because it increases the amount of wasted gas, employee pay, and delivery time (Flak 1997b). In return, traffic congestion forces businesses to cover the added costs by increasing the price of consumer goods (Banister 2011). Since the impacts from vehicle traffic accidents represent a "key portion" of the traffic congestion, these statistics demonstrate that reducing traffic accidents will help increase the economy of a city by improving traffic congestion (Flak 1997b, 376).

Not only do vehicle traffic accidents affect the economy, they also increase air and water pollution, energy consumption, and noise pollution (Hanson 1995; Bilbao-Ubillos 2008). Vehicle traffic accidents have become a serious problem for urban areas such as Houston, which is attempting to solve traffic-related problems by providing a more efficient transportation network system that is capable of relieving traffic congestion. In Texas, the majority of the public and businesses believe the solution to this problem is frontage roads.

2.4 Improving Daily Movement - Understanding Frontage Roads

The "primary design solution" to traffic congestion in the State of Texas is frontage roads, which provide access to highways in both urban and rural areas (Eisele et al. 2010, 1). Also known as service roads, frontage roads are streets that run parallel to a highway corridor and are designed to keep local traffic off the highway that would otherwise use the highway to travel only a short distance (Slotboom 2003; Kockelman et al. 2004). With around 6,761 miles of frontage roads, no other state or country has put as much time, effort, and money into building frontage roads than Texas (Kockelman et al. 2004; Persad et al. 2012, 72). Because few regions contain frontage roads, few researchers have examined traffic accidents on frontage roads even though findings reveal that frontage roads contribute to the hazards of a road network (Kockelman et al. 2001). The earliest known research examining vehicle traffic accidents on frontage roads was done by Woods and Chang (1983) and reported in *Accident Analysis of the Conversion from Two-Way Frontage Road Operation*. Since this report, few changes have been made to frontage roads to make them safer.

The first highway (Gulf Freeway) in Texas was built in 1948, and ever since Texas has used frontage roads in every highway design project (Slotboom 2003). Dewitt Greer, chief engineer of the State Highway Department (TxDOT's precursor), was the architect behind the first frontage road design (Wright 2002; Persad et al. 2012). Greer eventually became known as the father of the modern Texas highway system for his persistent effort and belief that all Texas highways should be able to serve local, interregional, and bypass through-traffic (Slotboom 2003; Persad et al. 2012). The only possible highway design capable of serving all three criteria is frontage roads. Another reason Greer pursed frontage roads was because he saw them as a cost-effective measure to an expensive highway system (Wright 2002). When the construction of highways began, the state was required to compensate property owners for their land because highways are a limited access road (Kockelman et al. 2001; Wright 2002). By building a highway with frontage roads, the TxDOT could obtain land rights without compensating property owners because frontage roads contain multiple access points (Kockelman et al. 2001). The idea of using frontage roads for unrestricted land rights was brilliant, but unknowing to Greer, his method helped commercialize frontage roads (Beaumont et al. 2006).

Frontage roads, especially in urban areas, have become the ideal location for businesses because businesses along frontage roads provide easy access and can lure consumers who would instead have to travel onto side streets (Kockelman et al. 2001; Slotboom 2003). This made frontage roads “more than just transportation corridors; they form the city’s principal commercial strips and business centers” (Slotboom 2003, 93). Along with becoming “commercial strips”, frontage roads are used to help relieve traffic congestion, provide vehicles with easy access to the highway, and reduce emergency response time (Eisele et al. 2010). The function of frontage roads is to limit vehicle access onto major arterial highways by separating the faster highway traffic from slower local traffic (Kockelman et al. 2001). Today frontage roads are functioning as the major arterial roadway instead of the highway (Kockelman et al. 2001). This has created a higher volume of vehicles on ramps, intersections, and local networks, which also tends to cause more vehicle traffic accidents. Because of these problems the TxDOT “criticized frontage roads for their expense, their contribution to traffic congestion and environmental and safety risks” (Retting et al. 2001; Wright 2002, 1; Kockelman et al. 2004). This means frontage roads are creating more congestion problems instead of solving them. It “may also be one of the reasons other states have avoided frontage road construction” (Kockelman et al. 2001, 5).

On June 28, 2001, the TxDOT approved a new policy limiting new construction of frontage roads, but quickly had to reverse the decision to only “special cases” because of the public’s outcry (Wright 2002; Kockelman et al. 2004, 1). While the TxDOT cannot eliminate current frontage roads, researchers have studied numerous methods to curtail the volume of traffic in and around frontage roads to help eliminate vehicle traffic accidents. For example, researchers found that the design of a short merge lane when entering and exiting a frontage road or highway (Figure 2) creates a weave maneuvering pattern that increases vehicle traffic accidents (Bonneson and Zimmerman 2007; Fitzpatrick et al. 2010).

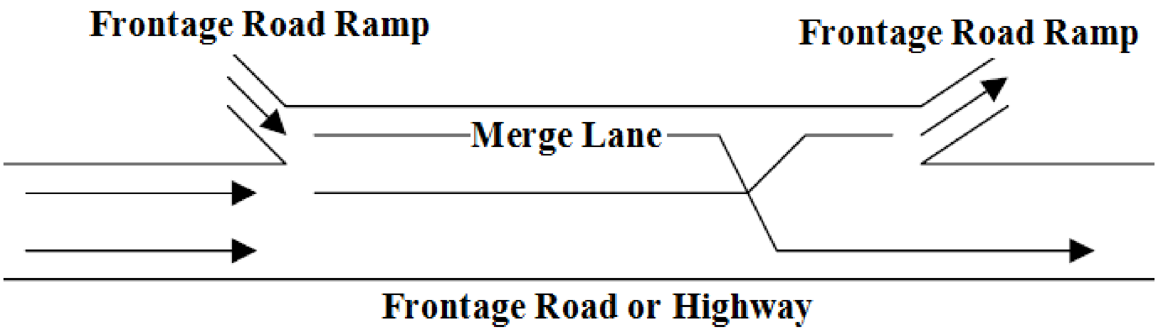

Figure 3 – Weave Maneuvering Pattern (Kockelman et al. 2000, 13)

Frontage roads have become the norm in Texas that few wish to relinquish. Understanding geographical aspects such as land use can help explain why certain locations have a higher concentration of vehicle traffic accidents near frontage road cross-sections. As Slotboom (2003, 93) explains, “The frontage road heavily influences development patterns, and the resulting land use form is perhaps the most freeway-focused in the world.” Researchers such as Kockelman et al. (2001) suggest that land use surrounding frontage roads be analyzed along with socioeconomic variables to identify high volumes of traffic. Since high volumes of traffic correlate to an increase in traffic accidents, recognizing land use is imperative for any transportation research project.

2.5 Understanding the Relationship between Transportation and Land Use Patterns

Transportation is an important influence in how cities are shaped, while land use affects the volume of traffic based on the number of trips generated by vehicles; as land use changes, so do traffic flow patterns and vice versa (Gakenheimer and Wheaton 1976; Whitelegg 1987). Understanding the research behind the strong interdependent relationship between transportation and land use patterns in urban areas is vital towards preventing and reducing vehicle traffic accidents (Wedagama et al. 2006).

One of the earliest studies identifying transportation and land use was by J.H. von Thünen, who in 1826 published *The Isolated State.* In *The Isolated State*, von Thünen first proposed the idea of opportunity cost, which described that land near a central market place will be smaller in size and more expensive because of higher demand and shorter travel distance (Wheeler et al. 1998). With the advent of new technology such as the locomotive followed by the automobile, the demand for a shorter travel distance changed to a demand for faster mobility (Weiner 2008). While von Thünen's research predicted that availability and distance influence the location of land use, this is not true today. With faster mobility, accessibility and attractiveness now influence the location of land use, which correlates to the amount of vehicle traffic flow within a region; as more vehicles travel to a location, the more likely vehicle traffic accidents occur (Giuliano 1995). Land use is an integral part to solving vehicle traffic accidents because land use affects where vehicle traffic accidents occur (Ng et al. 2002). The difficulty, however, is identifying what specific variables contribute the most to vehicle traffic accidents, which can be accomplished through regression analysis.

The main objective of any regression analysis model is to obtain, interpolate, predict, and compare relationships between the dependent variable and the independent variables (Hashimoto 2005). Regression analysis helps estimate the statistical significance of independent variables to the dependent variable of the data model (Hashimoto 2005). If an independent variable shows a statistically significant correlation with the dependent variable, this indicates that the independent variable has some influence toward the dependent variable as well as the remaining independent variables (Burt et al. 2009). For research studies involving vehicle traffic accidents, regression analysis helps understand the relationship between the number of vehicle accidents to the potential independent variables that might cause the accident (Ng et al. 2002).

This makes applying regression analysis to a transportation research study an important component to understanding what variables influence vehicle traffic accidents. For example, when land use is applied to a transportation research problem, Barber (1995) and Ng et al. (2002) discovered that certain types of land use generate higher volumes of traffic at specific times of the day. This indicates that various parts of a city can experience different volumes of traffic throughout the day (Barber 1995; Wedagama et al. 2006). Barber (1995) uses this information to classify land use types based on the origin or destination of an activity. This is a substantial result, because Barber (1995) helps explain why a concentration of vehicle traffic accidents occurs at a specific location at a certain time of the day. While land use is an important of transportation research, another way transportation and land use patterns can help explain vehicle traffic accidents is through visualization (Wang et al. 2009).

2.6 Applying GIS to Spatial Research

Visualization is one of the most important tools a researcher can use to present their findings; for geographers this is a map. Maps come in various forms such as the use of a computer-based mapping system, also known as GIS, which has the ability to process large amounts of data (Wang et al. 2009). GIS is used for the multiple purpose of “capturing, storing, analyzing, and displaying geographical information” in such a way that is capable of presenting a powerful statement (Nyerges 1995, 240). Transportation researchers can use GIS to greatly improve the “relationships between travel, land use, and other factors” through analysis of visualizing traffic accidents (Weiner 2008, 20; Wang et al. 2009). For example, Ng et al. (2002) collected traffic accident and land use data in Hong Kong, and applied a regression analysis model to their research. The researchers use GIS to “visually comprehend spatial analytical results” and claim that GIS is the “best” tool for comparing, visualizing, and analyzing traffic accident data (Ng et al. 2002, 388).

When transportation data are collected from multiple sources and disciplines, at first glance the data seem too impractical to employ in research. Geographers, however, use GIS to arrange the data effectively and combine the information together to visually show an outcome never before perceived (Nyerges 1995). For example, some transportation researchers use GIS to analyze traffic accident data such as hot spot analysis. Hot spot analysis are a useful quantitative method that is beneficial to a transportation research study because hot spots help identify concentrations of similar events within a geographical space (Songchitruksa et al. 2009; Gundogdu 2010). This provides a powerful statement when trying to emphasize a particular hazard, generate public awareness, or explain why certain variables frequently cause traffic accidents at certain locations (Songchitruksa et al. 2009).

Traffic accidents are considered unpredictable, but the use of hot spots as a quantitative method can help “predict reliable estimates of expected accidents” (Gundogdu 2010, 764). For example, Gundogdu (2010) uses hot spots to assist researchers and planners in discovering that certain spatial-temporal variables produce more accidents than other spatial-temporal variables. Larsen (2010, 26) uses hot spots to uncover different patterns and variables about vehicle traffic accidents, indicating that the location of vehicle traffic accidents are “more clustered than would be expected by chance alone.” While there are numerous types of methods and variables a researcher can use to analyze traffic accident data, no matter the outcome, hot spots can be applied to many “similar road networks especially using different accident parameters” (Gundogdu 2010, 768).

The importance of GIS to transportation research is through a visual representation such as hot spots, which are able to locate a concentration of vehicle traffic accident. While most transportation researchers do not emphasize their research geographically, Kockelman et al. (2001, 50) stress that if a researcher is able to use GIS he or she “may be able to draw more statistically and practically significant conclusions.”

2.7 Conclusion

Since the invention of the automobile, traffic-related problems have caused significant economic, environmental, and congestion problems that are further increased by traffic accidents (Downs 2004; Weiner 2008). All urban road network systems are in constant flux to improve transporting people, goods, and information throughout the city as a way to enhance the economy while also trying to keep traffic free-flowing (Lomax and Levinson 1997). In Texas, construction of frontage roads was originally thought to be the best method for reducing highway construction costs and traffic congestion (Kockelman et al. 2001). Researchers and TxDOT officials, however, claim that businesses along frontage roads are the cause of many traffic-related headaches such as traffic accidents (Retting et al. 2001; Kockelman et al. 2004). In 2001, the TxDOT sought to eliminate the construction of frontage roads but was profoundly overruled by business owners and by the public, which enjoy the easy access to businesses without having to divert onto side streets (Wright 2002; Kockelman et al. 2004).

The goal of this thesis research project is to analyze and determine what kinds of land use and socioeconomic indicators help create vehicle traffic accidents in Houston. Vehicle traffic accidents have been labeled as "complex events that rarely result from a single cause" (Retting et al. 2001, 723). Understanding what contributes the greatest to vehicle traffic accidents can help determine the best preventive measures while alleviating half of all urban related traffic congestion problems (Garrison and Ward 2000, 44). A significant amount of research from Kockelman et al. (2001) and Fitzpatrick et al. (2010) have determined that the commercialization and the weaving pattern produced by frontage roads increases vehicle traffic accidents. However, this increase is only experienced at certain locations. While many researchers such as Levine et al. (1995) and Ng et al. (2002) have included different kinds of land use to explain vehicle traffic accidents, no one to my knowledge has analyzed what effects certain kinds of land use have on vehicle traffic accidents near frontage roads. As Kockelman et al. (2001, 50) state, "More research is needed to determine if there is a causal link between frontage-road corridors, demographics, employment densities, and land uses".

CHAPTER III

METHODOLOGY

3.1 Choosing the Study Area

This case study focuses on the frontage road cross-sections located on I-610 in Houston, Texas. There are three main reasons why Houston is selected for this study. The first reason is Houston has an ample number of vehicle traffic accidents as well as an extensive array of different land use types. These features make Houston a useful area for studying the relationship between vehicle traffic accidents and adjacent land use types. The second reason is Houston has regional disparities of population density, workplace density, and income levels that can help emphasize which regions are more accident-prone. The third reason is Houston has the worst traffic delays per auto commuter of all cities in Texas (Schrank et al. 2011, 20). By conducting a case study on a city with the worst traffic delays, I hope the results will provide insight on solving similar traffic congestion problems in other Texas cities such as Dallas/Fort Worth, San Antonio, and Austin.

While there are many highways to choose from within the Houston metropolitan area, I specifically chose the frontage road cross-sections located on I-610 only for this study due to the following three reasons. First, the problem size will be manageable given the time limit for this study. Second, the I-610 loop serves as a good representation for Houston traffic conditions because the overall average annual daily traffic (AADT) flow on I-610 is the largest, suggesting a greater chance for traffic accidents to occur (Gharaibeh et al. 1997; TxDOT 2011, 5 & 8). Third, there is a wide diversity of land use types adjacent to or near the highway, which when combined with socioeconomic data; helps examine what impact a vehicle traffic accident has to a frontage road cross-section.

3.2 Data Collection

3.2.1 Accident Data

The vehicle traffic accident data used in this study were obtained from the TxDOT Traffic Operations Department. As this department only releases data up to five years to the public, the accidents analyzed in this study are between January 1, 2007 and December 31, 2011. Under Texas Transportation Code, Section 550.065, Subsection (f)(1)(F), the law states, "*the department may not release the date of any accident, other than the year*"; implying I cannot analyze whether a particular month or season contributes to an increase in accidents.

The vehicle traffic accident data were supplied by a Texas Peace Officer's Crash Report attending the scene of:

> *Any crash involving a motor vehicle in transport that occurs or originates on a traffic way, results in injury to or death of any person, or damage to the property of any one person to the apparent extent of $1,000.* (TxDOT 2012a)

Texas Peace Officers record a wide variety of data, but the most relevant information used for this study was the total number of vehicles involved in an accident and the coordinate location of those accidents. The five years of data obtained from the TxDOT

Traffic Operations Department provided the largest number of vehicle traffic accidents available for research. It includes 12,029 vehicle traffic accidents but only 10,221 are used for analysis because 1,808 did not have coordinates. TxDOT first produced the data in spreadsheet format, which I converted over to a point shapefile format using the geocoding function in ESRI's ArcGIS software.

The locations of vehicle traffic accidents are all geocoded as points onto the centerline of I-610 even though some vehicle traffic accidents occurred on entrance/exit ramps, connectors, or frontage roads. This implies that the points may not represent the exact location where the accident actually occurred but within 200 feet I determined an accident is no more than 200 feet from the given coordinate locations because the total width of an eight-lane Texas highway including frontage roads is around 400 feet (Kockelman et al. 2001, 54).

Table 1 shows the total number of accidents separated by year and whether the accident has a locational reference. Between 2009 and 2010 there is a significant increase in the number of accidents, which is attributed to a new input data procedure by the TxDOT. This should not affect my results because I will not be comparing different years.

Vehicle Traffic Accident Totals	**2007**	**2008**	**2009**	**2010**	**2011**	**Totals**
With Locational Reference	1600	1687	1514	2794	2626	10221
Without Locational Reference	192	350	545	332	389	1808
Total	1792	2037	2059	3126	3015	12029

Table 1 - Number of Vehicle Traffic Accidents per Year

3.2.2 Roadway Data

The Houston road network shapefile was retrieved from the U.S. Census Bureau's TIGER Line data for 2011. All major roadway sections have two parallel links representing different directions of roadways. From the Houston road network shapefile I was able to distinguish which roads were interstate roads, US highways, state highways, entrance and exit ramps, frontage roads, and local roads. From the road network shapefile, I determined what would describe a frontage road cross-section the best from these three criteria. First, there must be an entrance and exit ramp on both sides of I-610. Second, the entrance and exit ramps must connect between the highway and frontage road. Third, the frontage road segment must start before the first entrance or exit ramp and extend past second entrance or exit ramp (See Figure 4).

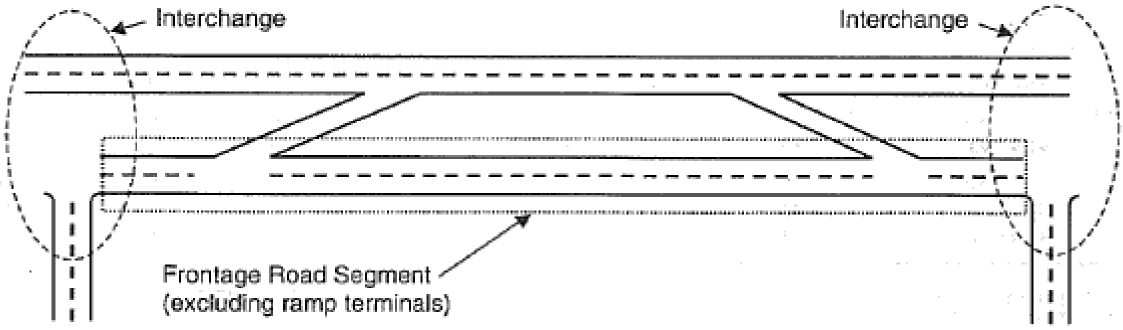

Figure 4 – Frontage Road Segment (Lord and Bonneson 2007, 21)

3.2.3 Census Data

The 2010 Census tracts surrounding I-610 are used as spatial units instead of Traffic Analysis Zones (TAZ) because the 2010 TAZ shapefile and socioeconomic data have not been updated. TAZs are described as “special areas delineated by state and/or local transportation officials for tabulating traffic-related data” (U.S. Census 2011). Though TAZs are ideal for transportation related projects, transportation researchers such as Kockelman et al. (2001) have used Census tracts instead of TAZs.

In order to examine the socioeconomic characteristics of the nearby area, I employed a one-mile buffer radius from a frontage road cross-section. There are several reasons for the choice of one-mile buffer radius. First, Fitzpatrick et al. (2010, 6) argue that the ideal distance between an entrance and exit ramp should be between 4,300 feet and 5,300 feet; a one-mile buffer radius adequately covers this distance. Second, the highway network system in the city of Houston is built so that most individuals do not have to travel more than a mile off highways to get to an activity site. Last, this distance covers the growth and development created by frontage road corridors that leads to traffic congestion (Kockelman et al. 2001).

There are a total of 27 frontage road cross-sections identified along I-610 in this study (see Figure 5). Figure 6 shows the one-mile buffer zones defined around these cross-sections and the 110 Census tracts which intersect with the buffer zones.

3.2.4 Traffic Volume Data

The TxDOT (2011) provided the AADT for 21 stations located around the I-610 loop, as measured in 2010. In Figure 6, the highest values for AADT are located on the west side of the I-610 loop. This area also contains the highest concentration of commercial land use and worker population. The lowest AADT values are located on the east side of the loop, which contains the highest concentration of manufacturing land use and lowest population numbers. The AADT values are used in this research as a traffic volume parameter that helps standardize vehicle traffic accidents into traffic accident rates, which is a more accurate depiction of vehicle traffic accidents (Lord et al. 2005).

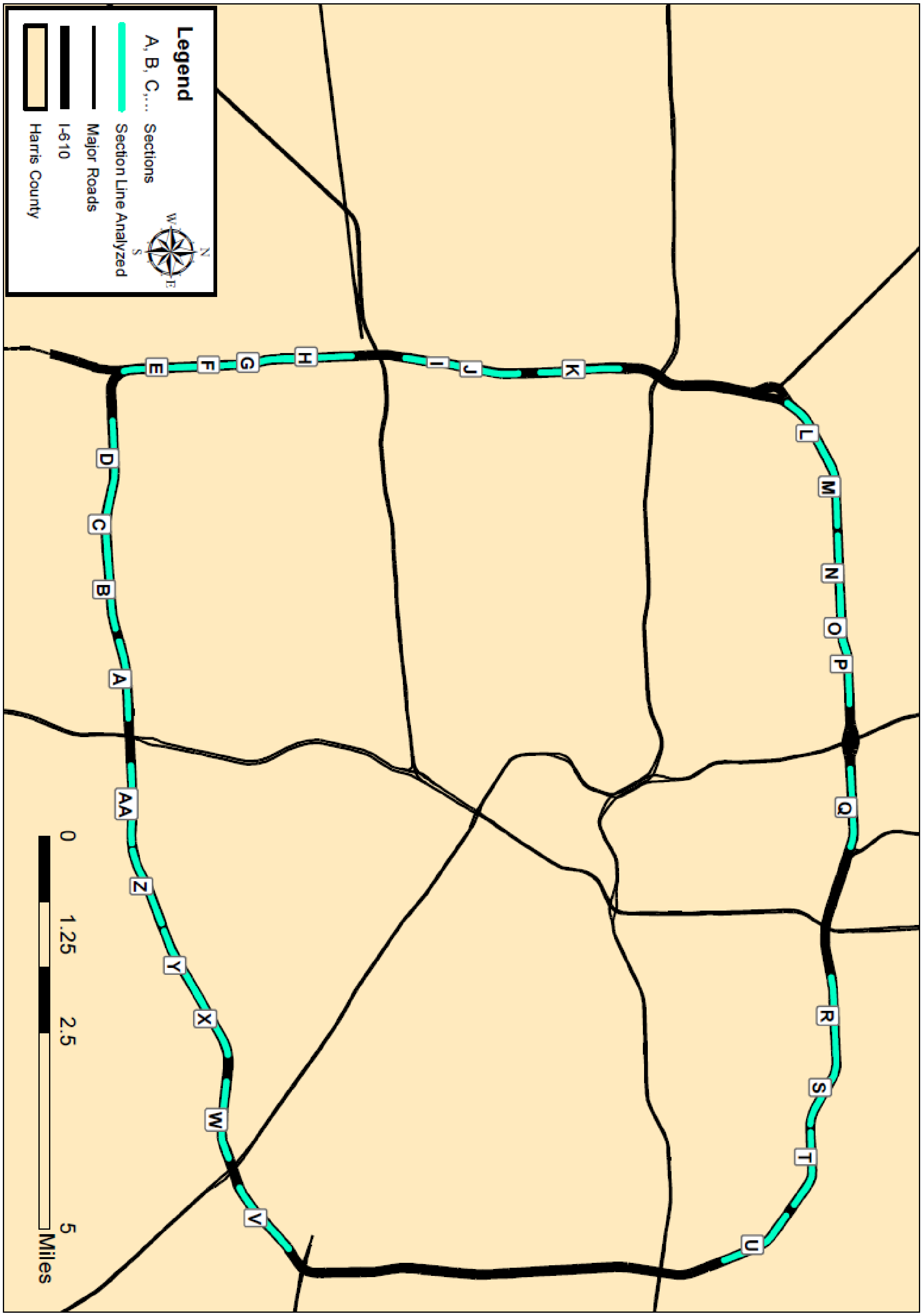

Figure 5 – Frontage Road Cross-Sectional Locations

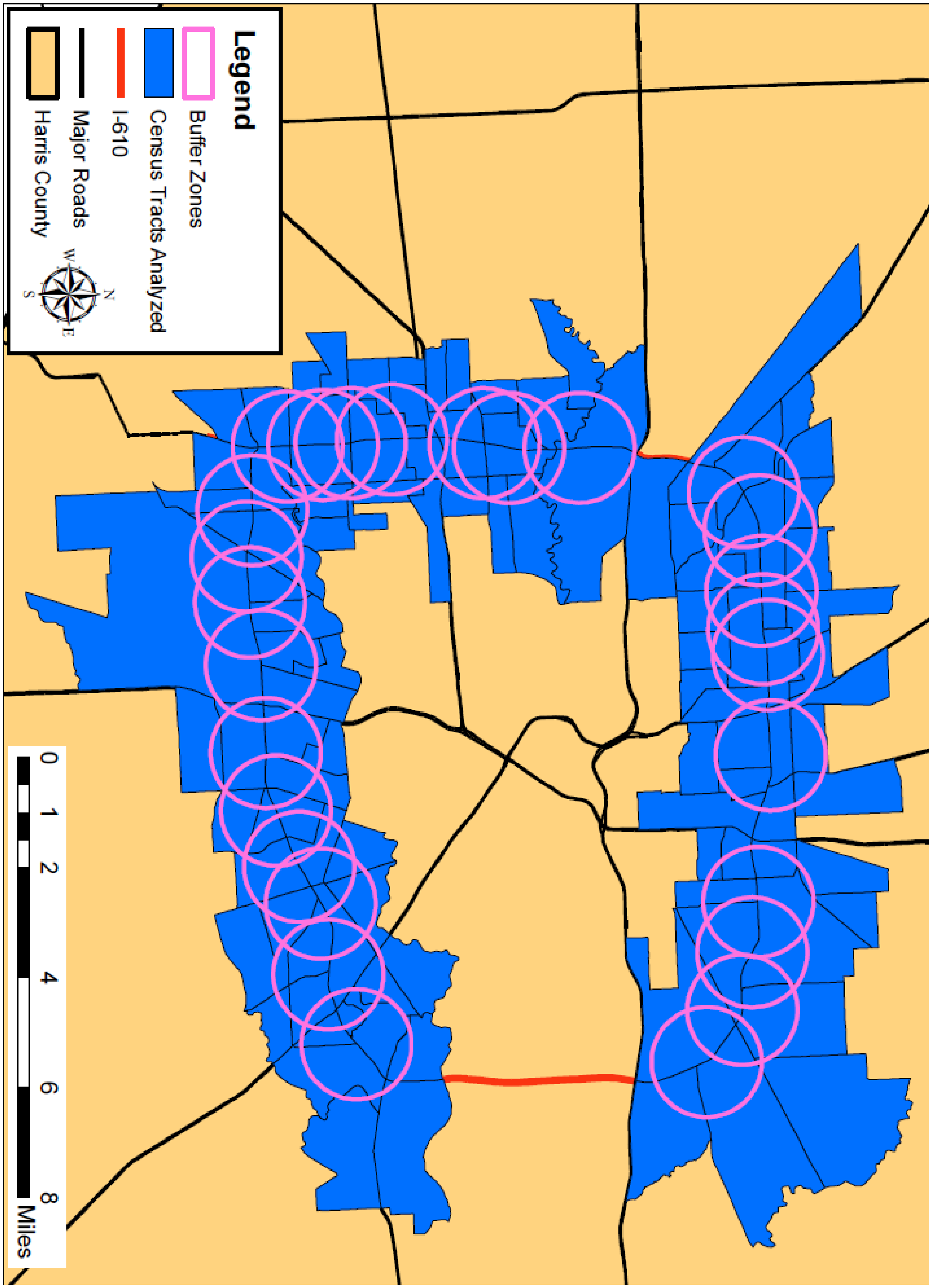

Figure 6 – Census Tracts Analyzed

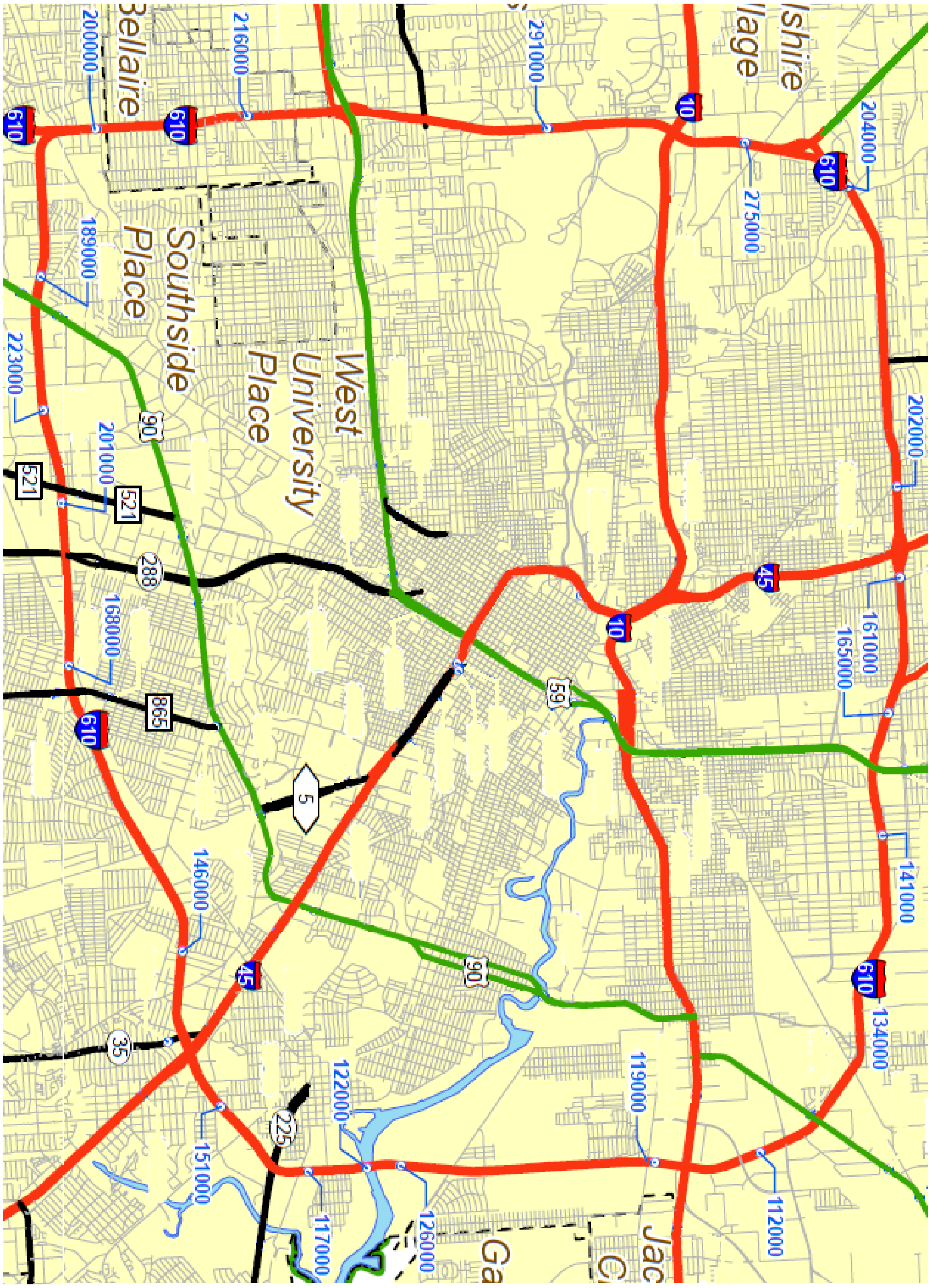

Figure 7 – Location of AADT Stations (TxDOT 2011)

3.2.5 Land Use Data

The Houston-Galveston Area Council (H-GAC) provided the 2010 Land Use Land Cover parcel shapefiles and I converted them into a geodatabase format file. The dataset contains ten different land use categories: Commercial, Residential, Industrial, Farm/Ranch, Other, Parks, Water, Roads, Undevelopable, and Undetermined. I decided to combine the land use categories Undetermined and Water with the Undevelopable category because all three categories represent a similar type of land use group. The eight land use categories are used in this study as independent variables because as Ng et al. (2002, 401) describe, “land use…factors can affect the accident occurrences”. A map of the land use data for Houston, TX is shown in Figure 8.

3.3 Data Processing

3.3.1 Software Used

The GIS software used in this research is ESRI’s ArcGIS 10, which is used for visualizing, comparing, and analyzing datasets such as vehicle traffic accidents, census tracts, and traffic volume along I-610. Another software program, SPSS Statistics, is used for statistical analysis.

3.3.2 Defining Relevant Factors for Analyzing Vehicle Traffic Accidents near Frontage Road Cross-sections

I identified 27 frontage road cross-sectional locations along the I-610 road network based on the criteria that the frontage road cross-section has both an on and off ramp connecting highway and frontage road in both directions. To derive the total number of vehicle accidents that occurred around a frontage road cross-section, I used a half-mile linear buffer window to define the search range for nearby accidents. A linear buffer window starts from the center of a frontage road cross-section and extends in both directions along the highway. By forcing all 27 sections to have the same buffer length, this eliminates having to convert different buffer lengths, which reduces conversion errors.

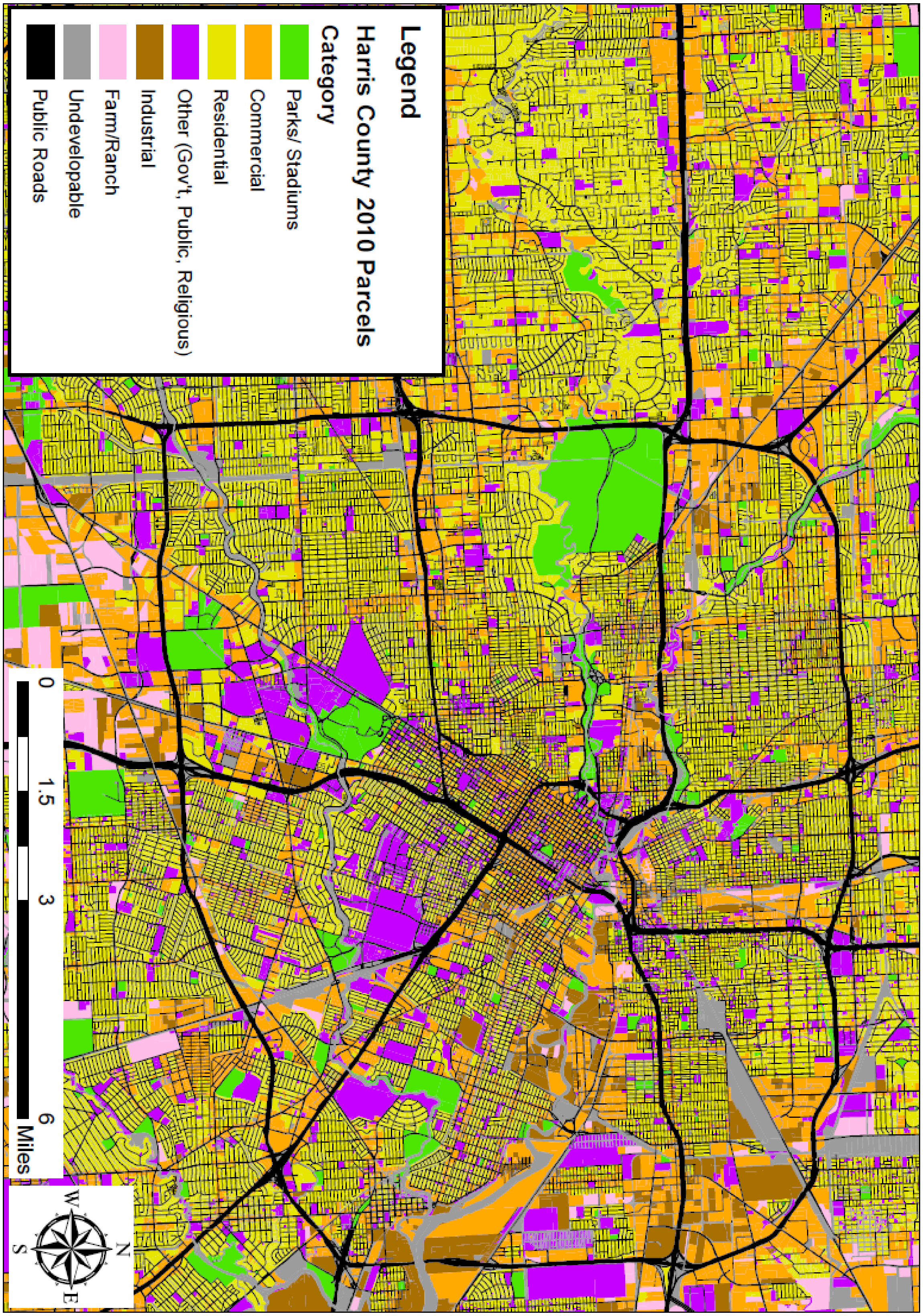

Figure 8 - Land Use Map for the City of Houston

As mentioned earlier, a one-mile radius buffer from the center of a frontage road cross-section is used to define the neighborhood area of the cross-section. In GIS I utilize both the frontage road buffer zones and land use patterns which are divided into eight categories (outlined in Section 3.5.2). By intersecting the frontage road buffer zones and land use data, I can calculate the percentage of each land use category based on the total area of the frontage road buffer zone. For example, Figure 9 shows a typical frontage road cross-section with a one-mile buffer zone, half-mile linear buffer window, traffic accident locations, and different land use types.

The socioeconomic factors associated to each frontage road cross-section will be derived from census data. However, as the boundary lines of the cross-section buffer zones and the census tracts do not overlap, extra steps are required to estimate the socioeconomic factors for the cross-sections.

To derive the total population living within each one-mile buffer of a frontage road cross-section, I first locate all the census tracts that intersect a cross-section buffer zone, established in Figure 5. The percentage of each census tract's area that falls within the buffer zone is then calculated. Assuming that the population is evenly distributed within a census tract, I derive the number of people living within the cross-section buffer zone by multiplying the total population of each census tract by the percentage of each census tract's area within the buffer. Once this has been accomplished, I sum up the adjusted values for all involving census tracts to get the total population living within the neighborhood of a frontage road cross-section.

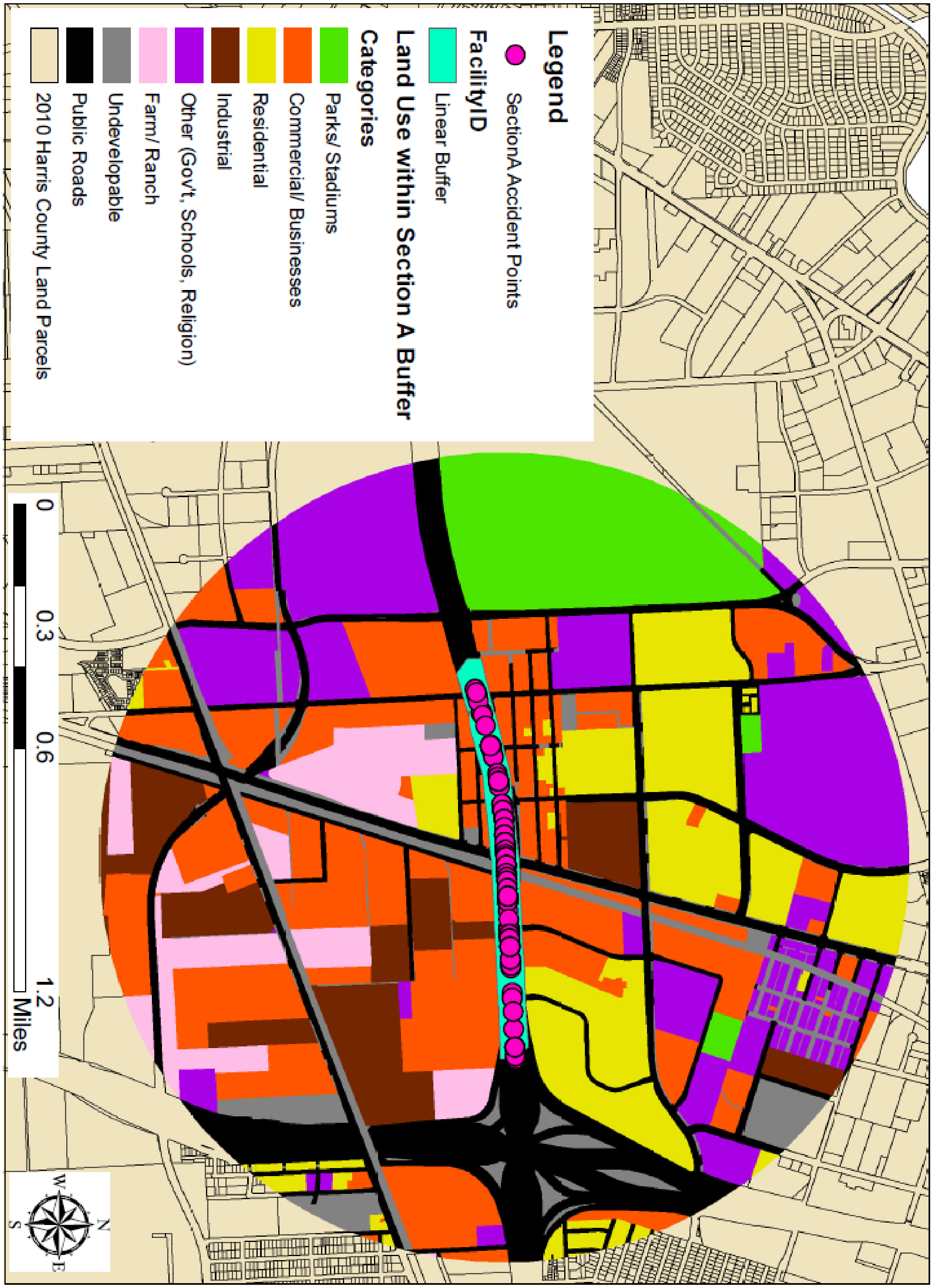

Figure 9 - Typical Frontage Road Cross-Section

A similar method is used to calculate the total worker population in each buffer zone. I locate all the census tracts that fall within the one-mile buffer radius of a frontage road cross-section. I then find the worker population of each census tract from the Census' OnTheMap website, and multiple it by the percentage of each census tract's area that falls within the one-mile buffer radius. Once this has been accomplished, all the census tracts are summed together to get the total worker population within the neighborhood of a frontage road cross-section.

To derive population of service worker, I locate all the census tracts that fall within the one-mile buffer radius of a frontage road cross-section. I then find the population of service worker of each census tract from Census' OnTheMap website and multiple it by the percentage area of each census tract that falls within the one-mile buffer radius. Once this has been accomplished, all the census tracts are summed together to get the frontage road cross-section's population of service worker.

To calculate mean household income, I locate all the census tracts that fall within the one-mile buffer radius of a frontage road cross-section. I first find the mean household income of each census tract from Census and multiply it by the number of households in the census tract and by the percentage area of each census tract that falls within the one-mile buffer radius. This gives me the new adjusted mean household income for each census tract that falls within the one-mile buffer radius of the frontage road cross-section. Once this has been accomplished, the new adjusted mean household incomes for each census tract are summed and then divided by the total adjusted number of households that fall within the buffer to get the frontage road cross-section's mean household income. Using the above methods, socioeconomic factors (including total population, total worker population, total service worker population, and mean household income) are calculated for each frontage road cross-section identified in this study.

3.4 Hot Spots - Kernel Density

The methods used to choose an appropriate search radius are crucial to providing a meaningful kernel density result. However, there are no hard rules to determine an appropriate search radius in a kernel density analysis for identifying the accident "hot spots" along the highways. Holcombe (1995) found that nearly all vehicle traffic accidents occurred within 2,200 feet from a ramp junction to a cross-street, while only two outlier accidents occurred after 3,000 feet. Meanwhile, according to Fitzpatrick et al. (2010) the length between two cross-sections should be at least 4,300 to 5,300 feet long (Figure 10). Based on these findings, I use a one-mile search radius for the Kernel Density analysis in this study.

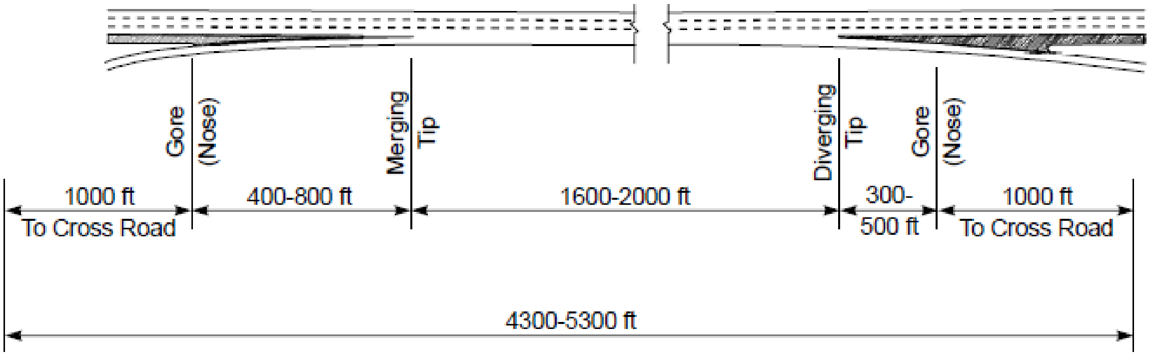

Figure 10 – Ideal Length Between Two Cross-Sections (Fitzpatrick et al. 2010, 6)

3.5 Statistical Analysis

Quantitative methods are a mathematical approach to solving an analytical problem such as vehicle traffic accidents. A mathematical model is a popular type of quantitative method that is able to "predict the occurrence of certain events" such as the frequency of vehicle traffic accidents (Campbell 2004, 55). There are many kinds of mathematical models such as the generalized linear model, the Bernoulli random variables model, and the log-linear model that help identify what variables cause vehicle traffic accidents. The most common type of mathematical model, however, is the regression model, which estimates the "statistical significance of multiple variables in one model" (Hashimoto 2005, 15).

Regression analysis model can be carried out via two major models: multiple linear regression and Poisson regression. Many researchers analyzing vehicle traffic accidents use the Poisson regression model because vehicle traffic accidents are "discrete, often sporadic and more likely random events" (Chin and Quddus 2003, 90). However, when traffic accident counts are converted to traffic accident rates, it is more appropriate to use a multiple linear regression model, because the Poisson regression equation is used only for a vehicle accident count (SPSS 2010).

3.5.1 Multiple Linear Regression Model

The multiple linear regression model is used to answer the first research question, which is an extension of the linear regression model based on the expression:

$$Y_i = \alpha + \beta X_i + u_i \qquad \text{Eq.1}$$

Where

Y = Dependent variable

α = y intercept

β = Slope of the line

X = Independent variable

u = Error term. It represents all other factors that may influence the independent variable but are not used in the problem (Kahane 2008).

A multiple linear regression model contains two or more independent variables and is based on the expression:

$$Y_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + u_i \qquad \text{Eq.2}$$

The purpose of adding multiple independent variables $\beta_i X_i$ to the linear regression model is to understand the influence of multiple factors on the outcome of the dependent variable Y_i.

3.5.2 Variables

In this study, 13 variables are selected for multiple linear regression analysis. The land use variables are provided by the Houston-Galveston Area Council, which originally contained ten land use types. However, as mentioned earlier, I combined Undevelopable land use with Undetermined and Water land use. Therefore, the following eight types of land use variables are used in the analysis: commercial; industrial; residential; other; parks; farm ranch; roads; undeveloped

The remaining independent variables I chose are socioeconomic related, which is used to understand an individual's travel patterns to an activity site within a frontage road cross-section. These include: total population; total workplace population; total population of service workers; mean household income

I use total population because it provides an initial amount of potential travel movements within the buffer zone. Workplace population illustrates how many potential workers travel to a frontage road cross-section to get to work. Population of service worker represents the combination of vehicle travel of individuals going to work, but also of customers traveling to the business location because of services offered. Mean household income is included, because the larger the household income, the more vehicles the household owns (Kahn 1998). More vehicles indicate there could be more trips made to events or activities.

The dependent variable for this model is vehicle traffic accident rate (VAR_MVM_Y), which comprises of weighted average annual daily traffic (WAADT). WAADT is the conversion of AADT for each study's frontage road cross-section. Even though AADT is provided throughout different locations along I-610, AADT is not located at every frontage road cross-section. The conversion from AADT to WAADT is calculated based on the gravitational distance between two AADT locations on either side of the frontage road cross-section. As a result, VAR_MVM_Y equation becomes standardized.

$$VAR\_MVM\_Y = (Accidents * 1{,}000{,}000) / (WAADT * 365 * Year) \qquad \text{Eq.3}$$

Where:

One million – Used as a constant to describe the number of vehicle miles traveled.

Accidents – Describes the total number of vehicles involved in an accident.

Year – Number of years the data spanned.

The above variables will be used in the multiple linear regression model to determine how significant the variables are to producing vehicle traffic accidents. While regression analysis examines the relationship between variables, it does not identify which frontage road cross-sections are hazardous to travelers. This task is more suited for cluster analysis, which groups frontage road cross-sections into homogeneous groups based on variables inputted into the cluster analysis.

3.6 Cluster Analysis

To answer the second question of this study, cluster analysis is used as a statistical method because it classifies homogeneous observations into two or more groups based on a combination of variables (Rogerson 2006). Cluster analysis is ideal for this study because it will classify frontage road cross-sections into similar groups. This is based on the variables determined in the multiple linear regression method as significant. By implementing the significant variables into the cluster analysis, the cluster analysis assigns each frontage road cross-section into a group with similar homogeneous properties (Rogerson 2006).

There are two main types of cluster analysis methods that can be used, nonhierarchical and hierarchical methods. While a nonhierarchical method begins with a known number of groups *K* and each observation is assigned to one of the *K* groups according to the significant variables, a hierarchical cluster analysis starts by assuming a single group and then divides the group into a specified number of subgroups (Gatignon, 2010). Because I will not predetermine the number of groups before the analysis, the hierarchical approach is chosen for this study. The outcome of a hierarchical cluster analysis will then be used to distinguish several groups of frontage road cross-sections that are associated with different traffic accident rate, land use pattern, and socioeconomic characteristics in the neighborhood.

For this study, I use SPSS to perform a hierarchical cluster analysis and use the significant independent variables from the multiple linear regression model – stepwise method as well as the dependent variable. In SPSS, I label cases by frontage road cross-sections, which will then be divided into different groups. In the statistics category of

SPSS, I use the agglomeration schedule because it shows how the hierarchical cluster analysis gradually clusters frontage road cross-sections together. In the methods category of SPSS, I cluster frontage road cross-sections based on Ward's method for two reasons. First, Ward's method uses analysis of variance approach, which estimates the distances between frontage road cross-sectional clusters (Burns and Burns 2008). Second, the Ward's method is also the most commonly used method (Rogerson 2006). Since variables with large values will contribute more on the distance between frontage road cross-sections than smaller values, there needs to be a transformation to standardize the values. In SPSS's methods category, the transformation is set to z-scores and the z-score standardizes values with a mean of 0 and a standard deviation of 1 (SPSS 2010). To compute distances between frontage road cross-sections, I use squared Euclidean for two reasons. First, it places more weight on objects that are further apart and second it is the most commonly used distance measured (Burns and Burns 2008).

Based on the hierarchical analysis outcome using the Ward's method and squared Euclidean distance, I can determine an appropriate number of clusters that should be used for this study. Since the purpose of the cluster analysis is to reduce the number of observations by grouping frontage road cross-sections based on similar characteristics, this study can reveal the highest and lowest frontage road cross-sections that produce vehicle traffic accidents.

3.7 Conclusion

In this chapter, I have described the methods that will help investigate what might cause a concentration of vehicle traffic accidents to occur near frontage road cross-sections. The benefits of using GIS, statistical analysis, and cluster analysis to help explain vehicle accident rates are to uncover hidden patterns through a larger representation (Gundogdu 2010). By definition, accidents are considered “random and unpredictable” (Gundogdu 2010, 764), but when studied using probability methods in a statistical framework, models can predict similar aggregate accidents.

CHAPTER IV

RESULTS AND ANALYSIS

4.1 Introduction

The goal of this chapter is to provide the results and determine how different land use and socioeconomic variables influence traffic accident rates by answering the questions previously outlined in the Objective and Research Question section. In the first section, I explain why I chose the specific socioeconomic variables as well as provide an overview of all the variables' statistical properties. I also discuss the results of the final multiple linear regression model, which will provide awareness into why certain land use and socioeconomic variables increase traffic accident rates near frontage road cross-sections. In the second section, I explain the results of the cluster analysis, which determines what frontage road cross-sections are likely to contain a higher traffic accident rate. The final section concludes by identifying why some frontage road cross-sections increase the risk for individuals to be involved in a traffic accident while other frontage road cross-sections help alleviate traffic accidents. By answering these two research questions, I will be able to explain why certain land use types and socioeconomic variables make the design of the frontage roads increase traffic accident rates.

4.2 Statistical Properties of Variables

The statistical properties of every variable in Table 2 provide an initial understanding of the dataset

Variables	**Mean**	**Standard Deviation**	**Min**	**Max**
Vehicle Accident Rate Per Million Vehicle Miles Per Year (Traffic Accident Rate)	1.7995	0.9179	0.9308	4.6658
Total Population	13163	4283	3182	22346
Workplace Population	13501	20107	1798	89063
Population of Service Workers	6684	10543	295	47899
Mean Household Income	$81,776	$54,744	$32,923	$210,650
Commercial Land Use	19.97%	9.00%	7.14%	42.72%
Industrial Land Use	3.04%	4.90%	0.00%	21.49%
Residential Land Use	35.08%	12.35%	10.55%	52.45%
Other Land Use	7.13%	3.31%	1.74%	16.70%
Parks Land Use	4.02%	8.11%	0.04%	40.42%
Farm/Ranch Land Use	1.90%	2.76%	0.00%	10.17%
Roads Land Use	22.45%	5.39%	11.55%	30.21%
Undevelopable Land Use	6.40%	4.45%	1.56%	21.37%

Table 2 – Variable Statistical Properties

4.2.1 Pearson's Correlation

While Table 2 provides a glimpse of the dataset, to enhance our understanding of how the independent variables relate to the dependent variable, I use Pearson's correlation as a way to help explain what variables are independently significant to other variables. In Appendix 1, the variables with the highest positive correlation to the dependent variable *traffic accident rate* are *commercial* land use (.510) and *industrial* land use (.395). This is noteworthy because other researchers such as Kockelman et al. (2001) and Cooner et al. (2007) also found that the commercialization along frontage roads increases traffic accidents. Comparing other significant correlation variables, there is a moderately negative correlation between the variable *total population* and *industrial* (-.543) and *total* *population* and *undevelopable* land use (-.562). This is consistent with few people living near manufacturing plants or undevelopable land. *Total population* does have a moderately positive correlation to *residential* and *road* land use, which is understandable because people have to travel using roadways to get to residential areas. Two variables that have an extremely high positive correlation (.993) are *workplace population* and *population of service workers*. This is logical because the population of service workers is part of the *workplace population*, but problematic for regression analysis due to multicellular issues.

While all the variables initially chosen for this research are helpful to understanding vehicle traffic accidents, not all the variables are the best indicators to explain the variations in traffic accident rates. The use of a stepwise linear regression model is beneficial to this research because it automatically eliminates the weakest variables based on the *t*-statistics of the estimated coefficients as well as ameliorating multicollinearity (University of Leeds-School of Geography 2012).

4.3 Results of the Multiple Linear Regression Model - Stepwise Method

Before the stepwise regression model computed the results in SPSS, I changed the probability of the F Entry from 0.05 to 0.10. By increasing the significance level for variables to be included in this research, I lower the confidence level from 95% to 90%. In social sciences, having a 90% or greater confidence level of rejecting the null hypothesis is considered an acceptable prediction of the dependent variable (Kahane 2008).

The independent variables that I believe explain vehicle traffic accident rates the best based on the statistical analysis results are *commercial* land use, *industrial* land use, *mean* *household income*, and *undevelopable* land use shown in Table 3. While Pearson's correlation indicated that *commercial* (.510) and *industrial* (.395) land use were significant to the dependent variable, it did not indicate *mean household income* (.156) and *undevelopable* land use (-.174).

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.761	0.383		1.988	0.06
	Commercial	5.201	1.753	0.51	2.966	0.01
2	(Constant)	0.08	0.496		0.161	0.87
	Commercial	6.261	1.738	0.614	3.603	0
	Mean household income	0.006	0.003	0.342	2.009	0.06
3	(Constant)	0.049	0.476		0.103	0.92
	Commercial	5.266	1.762	0.517	2.988	0.01
	Mean household income	0.006	0.003	0.386	2.334	0.03
	Industrial	5.574	3.187	0.297	1.749	0.09
4	(Constant)	0.635	0.528		1.205	0.24
	Commercial	4.517	1.687	0.443	2.677	0.01
	Mean household income	0.006	0.003	0.333	2.122	0.05
	Industrial	9.136	3.441	0.487	2.655	0.01
	Undevelopable	-7.38	3.562	-0.358	-2.07	0.05

Table 3 – The Best Independent Variables
a. Dependent Variable: *Traffic Accident Rate*

It took the Stepwise linear regression model four steps to determine what independent variables to include. The Stepwise procedure operates by choosing to retain the smallest significance value out of the remaining variables until the threshold of the F Entry significance value becomes greater than 0.10 for all variables. Originally, the F Entry was 0.05, but this only generated the significance variable *commercial*. I discuss in more detail the fourth model because this is the final threshold for independent variables that passed below the significance value of 0.10.

Under the Unstandardized Coefficients column *B* in Table 3 the "constant" term or *α* value is 0.635. The independent values for the β coefficient are also shown in column *B*. The β coefficient values represent the how much *Y* changes if the independent value changes by one unit (Kahane 2008). Together, the α and β values found in column *B* can be inserted into Equation 2 for predicting vehicle *traffic accident rates*. Thus, the multiple linear regression equation is

$$Y_i = 0.635 + 4.517X_1 + .006X_2 + 9.135X_3 - 7.383X_4 \qquad \text{Eq.4a}$$

By replacing the Y and X's with variable names, the equation becomes

$$\textit{Traffic Accident Rate} = 0.636 + 4.517(\textit{Commercial}) + .006(\textit{Mean Household Income}) + 9.136(\textit{Industrial}) - 7.383(\textit{Undevelopable}) \qquad \text{Eq.4b}$$

From this equation, the β coefficient of these four variables is the best at predicting *traffic accident rates*. The negative sign by *undevelopable* land use is accurate, because individuals are unlikely to travel to an *undevelopable* area. A smaller percentage of undevelopable land in a cross-sectional area will increase traffic accident rates. The next step is to identify the probability significance that these variables have toward increasing *traffic accident rates*.

In the fourth model, the significance (*Sig.*) column in Table 3, shows that all the chosen independent variables have a significance level of .05 or less. This implies that these four variables have a greater than 95% confidence level of rejecting the null hypothesis. By rejecting the null hypothesis, I am confident that the independent values are a reliable indicator in explaining the dependent variable.

The strongest predictor of *traffic accident rates* can be found under the Standardized Coefficients column Beta, which allows us to compare the effect of variables measured on different scales (Kahane 2008). In table 3, *commercial* land use has a Beta predictor of 0.443, *mean household income* has a Beta predictor of 0.333, *industrial* land use has a Beta predictor of 0.487, and *undevelopable* land use has a Beta predictor of -0.358 for *traffic accident rates*. All the variables have a similar moderate effect on *traffic accident rates*, but originally, Pearson's correlation indicated that *commercial* land use was the most influential and *industrial* land use was the second most influential predictors of *traffic accident rates*. Instead, based on the multiple linear regression model, *industrial* land use is the most influential followed by *commercial*, *undevelopable*, and *mean household income*. While the Beta determines what variable shows the strongest influence, it does not show how well the combined influence of significant variables predicts *traffic accident rates*.

An important part of determining how well the selected variables represent the dependent variable is by examining R Square. The R Square indicates what proportion of the dependent variable is explained by the independent variables. The results from the Stepwise Regression model produced an R Squared of 0.532 as shown in Table 4. This means that together, the four best predictors of the independent variables chosen in this thesis explain nearly 53.2% of the variance in *traffic accident rates*. Though a higher percentage is ideal, 53.2% is considered acceptable (Kahane 2008).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	Sig. F Change
1	0.51	0.26	0.231	0.8051116	0.26	8.798	0.007
2	0.606	0.367	0.314	0.7602864	0.106	4.035	0.056
3	0.664	0.441	0.368	0.7296501	0.074	3.058	0.094
4	0.73	0.532	0.447	0.6823868	0.091	4.296	0.05

Table 4 – R Square

Based on Pearson's correlation, the frontage road cross-section that contains the highest percentage of *commercial* land use should also contain the highest traffic accident rate, but this is not true. Using statistical analysis, the multiple linear regression model stepwise method determined that the best optimal combination for predicting *traffic accident rates* is *commercial*, *mean household income*, *industrial*, and *undevelopable* land use.

Although initially, *commercial* land use was the strongest influence at predicting traffic accident rates through Pearson's correlation, the multiple linear regression – stepwise method indicated that variables *industrial* land use, *undevelopable* land use, and *mean household income* were also influential. More surprising is the Standardized Coefficients indicate that *industrial* land use is slightly more influential than *commercial* land use in causing vehicle traffic accidents, while *undevelopable* land use and *mean household income* have less of an influence. While the multiple linear regression model answered what variables are influential to the dependent variable. However, to determine which frontage road cross-sections are most hazardous for vehicle traffic accidents, I need to use the cluster analysis method. This method will group frontage road cross-sections based on similar characteristics found by the four significant variables plus the dependent variable.

4.4 Cluster Analysis Results

The results of the cluster analysis are shown by the dendrogram in Figure 11. The dendrogram summarizes the hierarchical agglomeration process by linking frontage road cross-sections based on similar characteristics. Objects that are grouped together early have more similar characteristics based on the variables used in the cluster analysis (Burns and Burns 2008). One big problem when conducting a cluster analysis is determining the optimal number of clusters to use, which is largely subjective but can be decided based on the agglomeration schedule shown in Table 5 (Burns and Burns 2008). In the coefficients column, looking from the bottom to the top, the changes in numbers becomes smaller. However, there is a clear separation point between stage 21 and stage 22 as well as in the dendogram. Since this is the fifth stage from the bottom, the optimal number of clusters I use is five. Based on the five clusters in Figure 11, the circles surrounding the frontage road cross-sections show how I group the clusters.

As a way to decipher the results of the five groups, each group has its own color. In Appendix 2, I also group all the frontage road cross-sectional data analyzed for this research into different color categories similar to Figure 11. By looking at all the variables used in this study, I can explain why certain frontage road cross-sections are clustered together. I will first analyze each color group, based on the average value result for each variable by explaining how the significant variables predict the group's traffic accident rates. Finally, I compare different groups and explain any anomalies in the results.

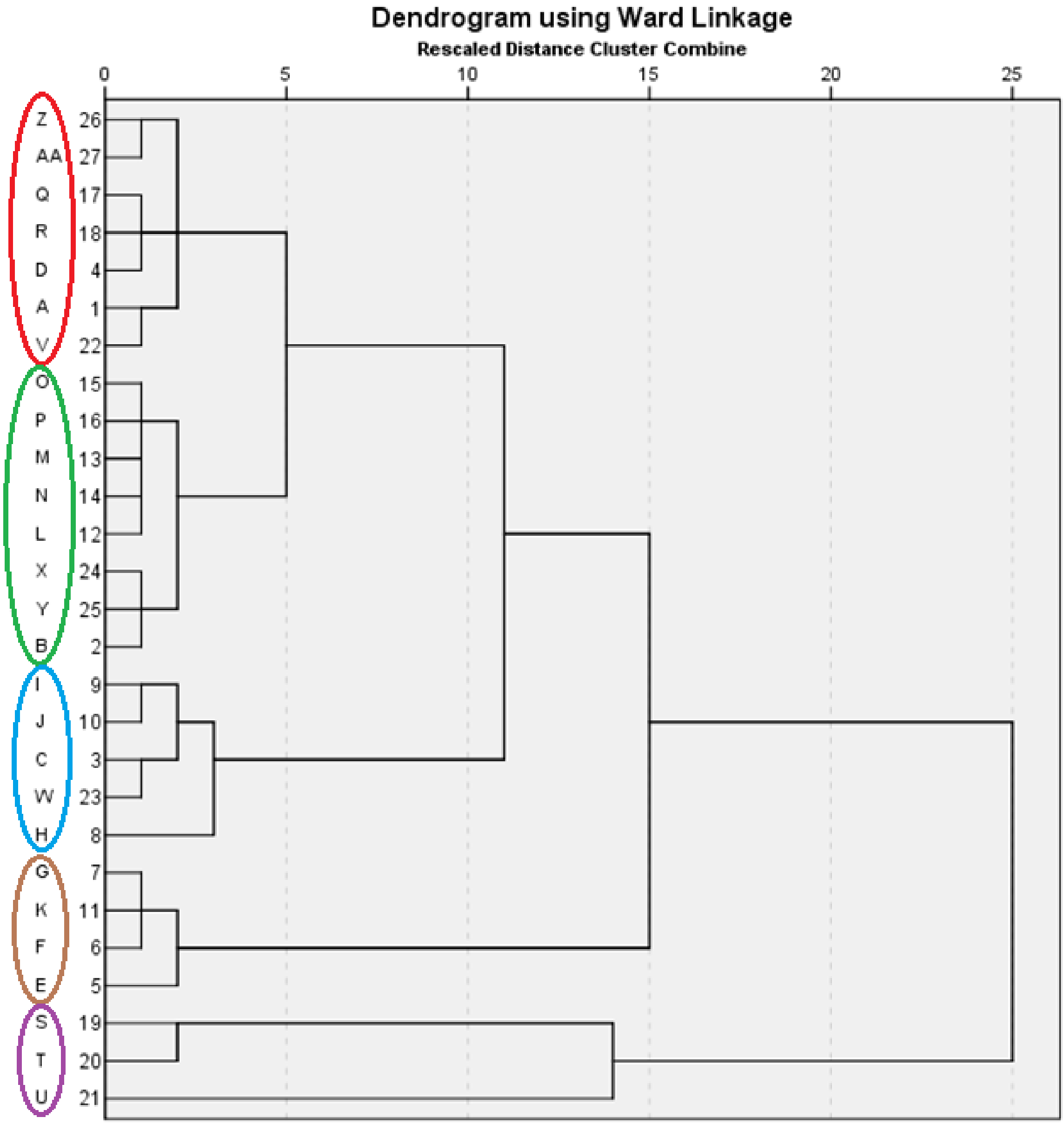

Figure 11 – Results of the Cluster Analysis

Agglomeration Schedule

Stage	Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	Cluster 1	Cluster 2		Cluster 1	Cluster 2	
1	26	27	.081	0	0	17
2	15	16	.163	0	0	13
3	13	14	.256	0	0	8
4	7	11	.488	0	0	9
5	9	10	.764	0	0	20
6	24	25	1.054	0	0	14
7	17	18	1.345	0	0	12
8	12	13	1.640	0	3	13
9	6	7	1.975	0	4	15
10	3	23	2.455	0	0	20
11	1	22	3.263	0	0	19
12	4	17	4.373	0	7	17
13	12	15	5.557	8	2	18
14	2	24	7.134	0	6	18
15	5	6	8.776	0	9	25
16	19	20	10.454	0	0	24
17	4	26	12.415	12	1	19
18	2	12	15.278	14	13	22
19	1	4	18.273	11	17	22
20	3	9	21.320	10	5	21
21	3	8	24.863	20	0	23
22	1	2	31.378	19	18	23
23	1	3	48.379	22	21	25
24	19	21	69.597	16	0	26
25	1	5	91.327	23	15	26
26	1	19	130.000	25	24	0

Table 5 - Agglomeration Schedule

4.4.1 Cluster Analysis - Red Group

The Red group contains seven frontage road cross-sections, averages the lowest *traffic accident rate*, and has a *traffic accident rate* range between all frontage road cross-sections of 0.506. The percentage of *commercial* land use as well as *mean household income* is well below the mean average shown in Table 2. Land use for *industrial* and *undevelopable* is near the overall average. Other significant information about the Red group is that the *total population* and *residential* land use is slightly above average, while the *worker population* is significantly smaller; indicating only local residents are likely to travel within this area. These results show that the Red group is indeed indicative of a low *traffic accident rate*.

4.4.2 Cluster Analysis - Green Group

The Green group contains eight frontage road cross-sections and averages the second lowest *traffic accident rate*. The range for the *traffic accident rate* in the Green group is 1.011. What is interesting about the Green group is that the percentage of *industrial* land use is the lowest out of all the groups, but for the other three significant variables, they are near normal. From looking at the data, the Green group should not have the second lowest *traffic accident rate*. However, since the percentage of *industrial* land use for the Green group is very small and the *industrial* land use Beta value is large, *industrial* land use plays a slightly more important role in vehicle traffic accidents.

4.4.3 Cluster Analysis - Blue Group

The Blue group contains five frontage road cross-sections and averages the highest *traffic accident rate* with a range of 1.592. This range is larger only because the frontage road cross-section H is an outlier. Within the Blue group, three out of the four variables (*commercial* land use, *undevelopable* land use, and *mean household income*) predicted by the stepwise multiple linear regression is significant to the high *traffic accident rate*. Out of the five groups, the Blue group's *commercial* land use and *mean household income* are both the second highest average while *undevelopable* land use is the lowest average. The lower the percentage of *undevelopable* land, the higher the *traffic accident rate* will be because of the negative coefficient from the stepwise linear regression results. Other findings display the *total population*, *worker population*, and *service worker population* are the highest within the Blue group, which could signify there are wealthy locals and outside individuals that travel to and from these frontage road cross-sections. Even though *industrial* land use is not influential to the Blue group, the other three variables that are significant to this research are characteristic to the high *traffic accident rate*.

4.4.4 Cluster Analysis - Brown Group

The Brown group contains four frontage road cross-sections and is the midpoint between the higher and lower *traffic accident rates* with a range of 1.08. The Brown group contains the highest *mean household income* average, but also comprises the lowest average percentage of *commercial* land use. The high *mean household income* does correlate to the high percentage of *residential* and *park* land use because wealthier individuals tend to use more space and separate themselves from commercialized areas (Glaeser et al. 2008). The offset between the high *mean household income* and low *commercial* land use does represent a *traffic accident rate* that is the closest to the statistical properties' mean value.

4.4.5 Cluster Analysis - Purple Group

The Purple group contains three frontage road cross-sections and has the second highest *traffic accident rate* average with a range of 3.266. This is the largest range out of all the groups because the frontage road cross-section U is an outlier. What makes frontage road cross-section U an outlier is because it has the highest *traffic accident rate* out of all the frontage road cross-sections and should be placed with the highest *traffic accident rate* group. It seems that the only reason frontage road cross-section U is with T and S is because of the squared Euclidean method used to establish a proximity. The Purple group has the highest average percentage of both *commercial* and *industrial* land use; however, the Purple group has the highest average percentage of *undevelopable* land and the lowest *mean household income* average.

The Purple group is the only group where two of the best predictor variables are not representative to the *traffic accident rate*. There are two key explanations why the traffic accident rate is high even though the variables *undevelopable* land and *mean household income* should help reduce *traffic accident rates*. The first reason is that the Standard Coefficient Beta, shown in Table 3, places more emphasis on *commercial* and *industrial* land use than on *mean household income* and *undevelopable* land use. The second reason is the high percentage of *industrial* land use indicates a high potential for truck traffic (Carr 1998). The majority of trucks traveling to these frontage road cross-sections will not be familiar with the area because it is not a normal traveled destination (Hedlund and Blower 2006).

4.4.6 Cluster Analysis - Conclusion

By grouping frontage road cross-sections together, this study is able to identify cross-sectional groups that are most hazardous (i.e., with high vehicle traffic accident rates) on I-610 from their corresponding geographical setting through land use types and socioeconomic characteristics. The objective of the cluster analysis is to group similar frontage road cross-sections based on the significant variables selected from the multiple linear regression. With four significant variables indicated by the multiple linear regression method, I added the dependent variable (*traffic accident rate*) to the cluster analysis as a way to "group observations based on similar data structure" (Golob et al. 2004).

The results of the cluster analysis determined that there are five different groups of frontage road cross-sections, where each of these five groups signifies a level of hazard intensity for vehicles traveling on I-610. Most frontage road cross-sections are grouped together based on similar *traffic accident rates*. However, a couple frontage road cross-sections resemble outliers in their groups. In the Blue group, frontage road cross-section H has a slightly higher *traffic accident rate* compared to other frontage road cross-sections. Similarly, frontage road cross-section U in the Purple group has quite a different *traffic accident rate* from the rest of the frontage road cross-sections in the group. The reason that these two unique cases are placed within their respective groups is because of how the distance is defined between two cases for cluster analysis in this study. Besides the vehicle *traffic accident rate*, four other factors are included in calculating the distance between cases for the cluster analysis. Although the two cases have quite a different *traffic accident rate* in comparison to other frontage road cross-sections within their respective groups, they are similar to their groups when other factors are considered. Overall, the derived groups from the cluster analysis present an effective way to capture the major frontage road cross-section type with different traffic accident rates and surrounding environment settings along I-610.

In summary, cluster analysis is a great method to group frontage road cross-sections into different hazardous categories. Since the Blue and Purple group are the two most hazardous groups, I know which frontage road cross-sections are also hazardous. I also know what type of land use pattern and socioeconomic characteristics affect the neighborhood around the frontage road cross-sections. This type of information is particularly beneficial to transportation planners for gaining a better understanding of the potential problems around a frontage road cross-section and developing safer road designs around the frontage road cross-section.

CHAPTER V

CONCLUSION

5.1 The Importance of Traffic Accident Research

The American transportation system has an elaborate system of road networks that has allowed vehicles to travel with greater accessibility and mobility in a quicker amount of time to a destination (Slotboom 2003). In urban areas, such as Houston, the continuous flow of vehicles throughout the road network is critical to the sustainability of a city (Muller 1995). When the flow of traffic is hindered by an event such as a vehicle traffic accident, individuals lose a significant amount of time due to traffic congestion on the road network. To resolve congestion issues, every state devises its own methods of solving this problem. The state of Texas has designed a unique policy for its highway road network system that includes having frontage roads constructed parallel to highways. In the early years of highway construction frontage roads were believed to be beneficial for alleviating construction costs and traffic congestion. Kockelman et al. (2001), however, has found that frontage roads actually increase congestion near land use areas that are heavily commercialized.

This study confirms the results of Kockelman et al. (2001) that a higher percentage of commercial land use increases the risk of an individual becoming involved in an accident, especially near a frontage road cross-section. By using statistical analysis, the study also found that a higher percentage of industrial land use, a lower percentage of undevelopable land use, and a higher mean household income all contribute to higher vehicle traffic accident rates near frontage road cross-sections. While the multiple linear regression model outlines what variables most influence vehicle traffic accidents, cluster analysis groups frontage road cross-sections into categories with similar traits. To visualize the most hazardous frontage road cross-sections, this study used GIS to map out the possible locations. By identifying what combination of frontage road cross-sections and land use types is correlated to higher amount of vehicle traffic accidents, transportation planners and emergency response units can plan accordingly.

The benefits of this study are to help identify frontage road cross-sections that pose the most risk to individuals traveling on I-610. From Question 1, this study found that commercial land use, industrial land use, undevelopable land use, and weighted mean household income are a significant contributor to vehicle traffic accidents; the most striking question is why some variables do not influence vehicle traffic accidents. The reason why some potentially influential variables such as total population, workplace population, and percentage of residential land use are not significant contributors to vehicle traffic accidents is that individuals have prior knowledge of their travel destination. The purpose of commercial land use near frontage road cross-sections is to attract as many customers as possible to a location; therefore, many customers are unfamiliar with the surrounding land use area. Similarly, industrial land use has heavy truck traffic where individuals are also unfamiliar with the surrounding land use area. Individuals who live and work near a frontage road cross-section have prior experience and knowledge of any potential hazards that might affect the area and know how to maneuver around those problems. This is the reason why frontage road cross-sections may not be suitable in areas where the primary goal of land use is to attract as many individuals to a location that do not have prior knowledge of the land use area.

When government officials and transportation planners prepare plans to construct frontage roads, they should have prior knowledge on what kinds of land use will occur in the area. If the surrounding land will be used for commercial or industrial development, government officials and transportation planners should be cautious to use frontage roads or choose an alternative method.

5.2 Limitations

The most significant limitations to this study is the accurate count for the number of vehicles involved in an accident before 2010, because the TxDOT changed how it input vehicle traffic accident data. While I do not think this has affected the results, there is always a slight possibility. In addition, vehicle traffic accidents that did not have coordinate locations were not used in this research, so the traffic accident density could be marginally inaccurate. The next limitation I am concerned with is the locations of where vehicle traffic accidents occurred because I am relying on the coordinate accuracy of a third party. The final limitation is the accuracy of AADT. While the TxDOT

provided the data for 22 locations, I estimated the AADT for each frontage road cross-section based on weighted distance so there is a slight error in the accuracy.
Despite these minor limitations, I have a sound understanding of results from this research study of vehicle traffic accidents on I-610 in Houston, Texas.

5.3 Advancing the Research

Future research should examine frontage road cross-sections for other highways in Texas to verify whether the same variables applied in this research provide similar results in other areas. For example, if other areas have similar results as this study, government officials and transportation planners can devise a plan to reduce vehicle traffic accidents. If the results are not similar to other areas in Texas, this indicates the variables that contribute to vehicle traffic accidents are a local issue that the City of Houston needs to resolve.

Another direction to advance this research is to consider the variation of traffic accident rates to different times of the day. While this study uncovered that frontage road cross-sections C, H, I, J, U, and W contain the highest traffic accident rates based on daily travel, a more accurate approach is analyzing how traffic accident rates are affected during different times of the day since individuals access different types of land use during different times of the day.

REFERENCES

AASHTO. 1995. *A policy on geometric design of highways and streets, 1994*. American Association of State Highway and Transportation Officials. Washington D.C.

Anderson, T.K. 2010. Using geodemographics to measure and explain social and environment differences in road traffic accident risk. *Environment and Planning A* 42(9): 2186-2200.

ArcGIS. Version 10.0. Redlands, CA: ESRI, Inc.

Banister, D. 2011. The trilogy of distance, speed, and time. *Journal of Transportation Geography* 19(4): 950-959.

Barber, G. 1995. Aggregate characteristics of urban travel in context. In *The geography of urban transportation*, 2nd ed., ed. S. Hanson, 81-99. New York, NY: The Guildford Press.

Beaumont, P., Brinkmann, R., Ellis, D., Pourteau, C. and Webb, B.V. 2006. *Anywhere to everywhere: The development of the interstate highway system in Texas*. Texas Transportation Institute, with partial support from the Southwest Region University Transportation Center. Available at http://tti.tamu.edu/documents/TTI-2006-8.pdf. (last accessed 24 March 2012).

Bilbao-Ubillos, J. 2008.The costs of urban congestion: Estimation of welfare losses arising from congestion on cross-town link roads. *Transportation Research Part A* 42(8): 1098-1108.

Bonneson, J. and Zimmerman, K. 2007. Procedure for using accident modification factors in the highway design process. Texas Transportation Institute at The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-4703-P5.pdf (last accessed 26 December 2012).

Burns, R. and Burns, R. 2008. *Business research methods and statistics using SPSS*. London, UK: Sage Publications Ltd.

Burt, J.E., Barber, G.M., Rigby, D.L. 2009. *Elementary statistics for geographers*, 3rd ed. New York, NY: Guilford Press.

CalTrans. 2007. District 7 projects: Interstate 210 ramp metering. Available at http://www.dot.ca.gov/dist07/travel/projects/details.php?id=2 (last accessed 30 April 2012).

Cambridge Systematic. 2004. *Traffic congestion and reliability: Linking solutions to problems congestion*. Cambridge, MA: Cambridge Systematics. Available at http://ops.fhwa.dot.gov/congestion_report_04/congestion_report.pdf (last accessed 26 December 2012).

Campbell, M.L. 2004. Determining the safety of urban arterial roads. Master's thesis, Department of Civil Engineering, Worcester Polytechnic Institute, Worcester, MA.

Carr, A.J.P. 1998. Choctaw Eco-Industrial Park: an ecological approach to industrial land-use planning and design. *Landscape and Urban Planning* 42(2-4): 239-257.

Chin, H.C. and Quddus, M.A. 2003. Modeling count data with excess zeroes: An empirical application to traffic accidents. *Sociological Methods Research* 32(1): 90-116.

City of Houston. 2012. About Houston: Business overview. Available at www.houstontx.gov/abouthouston/business.html. (last accessed 30 April 2012).

Cooner, S.A., Venglar, S., Rathod, Y., Pultorak, E.J., Williams, J.C., Vo, P., and Mattingly, S.P. 2007. Ramp reversal projects: Guidelines for successful implementation. Texas Transportation Institute at The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-5105-1.pdf (last accessed 26 December 2012).

Downs, A. 2004. *Still stuck in traffic: Coping with peak-hour traffic congestion*. Washington, DC: Brookings Institution Press.

Easterling, K. 1999. *Organization space: Landscapes, highways, and houses in America*. Cambridge, MA: The MIT Press.

Eisele, W.L., Frawley, W.E., Yager, C.E. Park, E.S. 2010. Converting frontage roads from two-way to one-way operation: Preliminary findings of safety impacts. Presented at the ITE 2010 Annual Meeting & Exhibit. Vancouver, Canada. Available at http://www.ite.org/annualmeeting/compendium10/pdf/AB10H2802.pdf (last accessed 26 December 2012).

Farradyne, P.B. 2000. *Traffic incident management handbook*, prepared for the Office of Traffic Management, Federal Highway Administration, Department of Transportation. Available at http://ntl.bts.gov/lib/jpodocs/rept_mis/13286.pdf (last accessed 26 December 2012).

Fitzpatrick, K., Nowlin, R.L., and Parham, A.H. 1996. Procedures to determine frontage road level of service and ramp spacing. Texas Transportation Institute at The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/ tti.tamu.edu/ documents/ 1393-4F.pdf (last accessed 26 December 2012).

Fitzpatrick, K., Porter, R.J., Pesti, G., Chu, C-L, Park, E.S., and Le, T. 2010. Guidelines for spacing between freeway ramps. Texas Transportation Institute at The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/ tti.tamu.edu/ documents/0-5860-1.pdf (last accessed 26 December 2012).

Flak, M.A. 1997a. Incident management needs along work zones. In *Traffic congestion and traffic safety in the 21st century: Challenges, innovations, and opportunities*, ed. R.F. Benekohal, 250-256. New York, NY: American Society of Civil Engineers.

Flak, M.A. 1997b. Reducing accident impacts under congestion. In *Traffic congestion and traffic safety in the 21st century: Challenges, innovations, and opportunities*, ed. R.F. Benekohal, 375-381. New York, NY: American Society of Civil Engineers.

Gakenheimer, R. and Wheaton, W.1976. Research priorities in urban transportation planning. *Transportation Journal* 5(1): 23-41.

Garrison, W.L. and Ward, J.D. 2000. *Tomorrow's transportation: Changing cities, economies and lives*. Norwood, MA: Artech House, Inc.

Gatignon, H. 2010. *Statistical analysis of management data*. New York, NY: Springer.

Gharaibeh, N.G., Hicks, J.E., and Hall, J.P. 1997. Analysis of accidents, traffic, and pavement data. In *Traffic congestion and traffic safety in the 21st century: Challenges, innovations, and opportunities*, ed. R.F. Benekohal, 396-402. New York, NY: American Society of Civil Engineers.

Giuliano, G. 1995. Land use impacts of transportation investments: Highway and transit. In *The geography of urban transportation*, 2nd ed., ed. S. Hanson, 305-341. New York, NY: The Guildford Press.

Glaeser, E.L., Kahn, M.E., and Rappaport, J. 2008. Why do the poor live in cities? The role of public transportation. *Journal of Urban Economics* 63(1): 1-24.

Golob, T.F., Recker, W.W., and Alvarez, V.M. 2004. Freeway safety as a function of traffic flow. *Accident Analysis and Prevention* 36(6): 933-946.

Grava, S. 2003. *Urban transportation systems: Choices for communities*. New York, NY: McGraw-Hill.

Gundogdu, I.B. 2010. Applying linear analysis methods to GIS-supported procedures for preventing traffic accidents: Case study of Koyna. *Safety Science* 48(6): 763-769.

Hanson, S. 1995. Getting there: Urban transportation in context. In *The geography of urban transportation,* 2nd ed., ed. S. Hanson, 3-25. New York, NY: The Guildford Press.

Hashimoto, T. 2005. Spatial analysis of pedestrian accidents. Department of Environmental Science and Policy. Master's thesis, University of South Florida, Tampa, FL.

Hedlund, J. and Blower, D. 2006. Large truck crash causation study (LTCCS) analysis series: Using LTCCS Data for statistical analysis of crash risk. U.S. Dept. of Transportation – Federal Motor Carrier Safety Association. Publication #: FMCSA-RI-05-037. Available at http://www.fmcsa.dot.gov/facts-research/research-technology/ analysis/ltccs.htm (last accessed 9 December 2012).

Hensher, D.A. and Goodwin, P. 2004. Using values of travel time savings for toll roads: Avoiding some common errors. *Transport Policy* 11(2): 171-181.

Holcombe, S.L. 1995. Modeling accidents at ramp junctions of diamond interchange and frontage roads. Master thesis, Department of Civil Engineering, The University of Texas at Arlington.

Hunter, M. and Machemehl, R. 1997. Reevaluation of ramp design speed criteria: Review of practice and data collection plan. Center for Transportation Research, The University of Texas at Austin. Available at www.cc.utexas.edu/research/ctr/ pdf_reports/1732_2.pdf (last accessed 26 December 2012).

Kahane, L.H. 2008. *Regression basics*, 2nd ed. Los Angeles, CA: Sage Publications, Inc.

Kahn, M.E. 1998. A household level environmental Kuznets curve. *Economics Letters* 59(2): 269–273.

Kockelman, K., Machemehl, R., Overman, A.W., Madi, M., Sesker, J., Peterman, J., and Handy, S. 2000. Frontage roads in Texas: Legal issues, operational issues, and land use distinctions. Center for Transportation Research at The University of Texas at Austin. Available at ftp://ftp.dot.state.tx.us/pub/txdot-info/rti/psr/1873-s.pdf (last accessed 26 December 2012).

Kockelman, K., Machemehl, R., Overman, A.W., Madi, M., Sesker, J., Peterman, J., and Handy, S. 2001. Frontage roads in Texas: A comprehensive assessment. Center for Transportation Research at The University of Texas at Austin. Available at http://www.utexas.edu/research/ctr/pdf_reports/1873_2.pdf (last accessed 26 December 2012).

Kockelman, K., Machemehl, R., Overman, A.W., Sesker, J., Madi, M., Peterman, J., and Handy, S. 2003. Frontage roads: An assessment of legal issues, design decisions, costs, operations, and land-development differences. *Journal of Transportation Engineering*. 129(3): 242-252.

Kockelman, K., Bouldin, W.C., Hakimi, S., and Machemehl, R.B. 2004. Freeway design decisions for revised frontage road policy. Center for Transportation Research at The University of Texas at Austin. Available at http://www.utexas.edu/research/ctr/pdf_reports/5_1873_01_1.pdf (last accessed 26 December 2012).

Kockelman, K., Waller, T., Gulipalli, P., Kalmanje, S., Karoonsoontawong, A., and Ukkusuri, S. 2005. Application of credit-based congestion pricing in Texas: Operational considerations and impacts. Center for Transportation Research at The University of Texas at Austin. Available at http://www.utexas.edu/research/ctr/pdf_reports/0_4634_1.pdf (last accessed 26 December 2012).

Konishi, H. and Mun, S-I. 2010. Carpooling and congestion pricing: HOV and HOT lanes. *Regional Science and Urban Economics* 40(4): 173–186.

Kopits, E. and Cropper, M. 2005. Traffic fatalities and economic growth. *Accident Analysis and Prevention* 37(1): 169–178.

Larsen, M.A. 2010. Philadelphia traffic accident cluster analysis using GIS and SANET Masters of Urban Spatial Analytics Capstone Project, Department of Urban Spatial Analytics, Penn Institute for Urban Research, University of Pennsylvania, Philadelphia. Available at http://penniur.upenn.edu/uploads/media_items/larsen-capstone-musa.original.pdf (last accessed 30 March 2012).

Levine, N., Kim, K. E., and Nitz, L. H. 1995. Spatial analysis of Honolulu motor vehicle crashes: Part I. Spatial patterns. *Accident Analysis Prevention* 27(5): 625-631.

Lomax, T.J. and Levinson, H.S. 1997. Overview of congestion measurement principles. In *Traffic congestion and traffic safety in the 21st century: Challenges, innovations, and opportunities*, ed. R.F. Benekohal, 549-555. New York, NY: American Society of Civil Engineers.

Lord, D., Manar, A., and Vizioli, A. 2005. Modeling crash-flow-density and crash-flow-V/C ratio relationships for rural and urban freeway segments. *Accident Analysis and Prevention* 37: 185-199.

Lord, D. and Bonneson, J.A. 2007. Development of accident modification factors for rural frontage road segments in Texas. *Journal of the Transportation Research Board* 2023: 20-27.

Moellering, H. 1974. The journey to death: A spatial analysis of fatal traffic crashes in Michigan, 1969, Department of Geography. University of Michigan, Ann Arbor. Geography Publication No 13.

Muller, P.O. 1995. Transportation and urban form: Stages in the spatial evolution of the American metropolis. In *The geography of urban transportation,* 2nd ed., ed. S. Hanson, 26-52. New York, NY: The Guildford Press.

Ng, K-s., Hung, W-t., Wong, W-g. 2002. An algorithm for assessing the risk of traffic accident. *Journal of Safety Research* 33(3): 387- 410.

Nyerges, T. 1995. GIS support for urban and regional transportation analysis. In *The geography of urban transportation,* 2nd ed., ed. S. Hanson, 240-265. New York, NY: The Guildford Press.

Persad, K.R., Machemehl, R., Weatherby, C., Stockton, W., Nash, P., Cleveland, T. 2012. Seven TxDOT strategic research briefs for FY 2011. Center for Transportation Research, The University of Texas at Austin. Available at http://www.utexas.edu/research/ ctr/ pdf_reports/0_6661_rb.pdf (last accessed 26 December 2012).

Retting, R.A., Weinstein, H.B., Williams, A.F., and Preusser, D.F. 2001. A simple method for identifying and correcting crash problems on urban arterial streets. *Accident Analysis and Prevention* 33(6): 723-734.

Rogerson, P.A. 2006. *Statistical methods for geography: A student guide,* 2nd ed. London, UK: Sage Publications.

Schrank, D., Lomax, T, and Eisele, B. 2011. TTI's 2011 urban mobility report. Texas Transportation Institute, The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2011.pdf (last accessed 26 December 2012).

Slotboom, O.F. 2003. Houston freeways: A historical and visual journey. Available at www.HoustonFreeways.com/ebook.aspx (last accessed 26 December 2012).

Songchitruksa, P., Balke, K., Zeng, X., Chu, C-L, Zhang, Y., and Pesti, G. 2009. Evaluating and improving incident management using historical incident data: Case studies at Texas transportation management centers. Texas Transportation Institute at The Texas A&M University System. Available at http://d2dtl5nnlpfr0r.cloudfront.net/ tti.tamu.edu/documents/0-5485-1.pdf (last accessed 26 December 2012)

SPSS. 2010. PASW advanced statistics 18, Chicago, IL: SPSS Inc. Available at http://www.unt.edu/rss/class/Jon/SPSS_SC/Manuals/v18/PASW%20Advanced%20Statistics%2018.pdf (last accessed 28 December 2012).

Stutz, F.P. 1995. Environmental impacts. In *The geography of urban transportation,* 2nd ed., ed. S. Hanson, 376-406. New York, NY: The Guildford Press.

Texas Transportation Code, Section 550.065, Subsection (f)(1)(F). 2007. Available at http://www.statutes.legis.state.tx.us/Docs/TN/htm/TN.550.htm (last accessed 25 August 2013).

Traynor, T.L. 2008. Regional economic conditions and crash fatality rates – A cross-county analysis. *Journal of Safety Research* 39: 33-39.

TxDOT. 2011. Houston base sheets. Transportation Planning and Programming Division. Available at http://ftp.dot.state.tx.us/pub/txdot-info/tpp/traffic_counts/2010/hou_base.pdf (last accessed 8 May 2012).

TxDOT. 2012a. Annual motor vehicle crash data report definitions. Available at http://ftp.dot.state.tx.us/pub/txdot-info/trf/crash_statistics/2012/definitions.pdf (last accessed 25 August 2013).

TxDOT. 2012b. Highway designation file. Transportation Planning and Programming Division. Available at http://www.txdot.state.tx.us/tpp/hwy/ih/ih0610.htm (last accessed 25 August 2013).

Ullman, G. L. and Ogden, M. A. 1996. Analysis of major freeway incidents in Houston, Texas, In *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington, D.C., 1554: 221-227.

University of Leeds-School of Geography. 2012. Stepwise linear regression. Available at http://www.geog.leeds.ac.uk/courses/other/statistics/spss/stepwise/ (Last accessed 2 December 2012).

U.S. Census. 2010. QuickFacts. Available at http://quickfacts.census.gov/qfd/states/48000.html (last accessed 30 April 2012).

U.S. Census. 2011. 2010 Census traffic analysis Zone program MAF/TIGER partnership software participant guidelines. Available at http://ctpp.transportation.org/Documents/TAZ_MTPS_Participant_Guidelines_Final.pdf (last accessed 2 January 2013).

Wang, J., Shen, Y and Khattak, A. 2009.Visualization of traffic accidents. *MODSIM World Conference & Expo 2009*, Virginia Beach, VA: 317-321.

Wedagama, D.M.P., Bird, R.N., and Metcalfe, A.V. 2006. The influence of urban land-use on non-motorized transport casualties. *Accident Analysis and Prevention* 38(6): 1049–1057.

Weiner, E. 2008. *Urban transportation planning in the United States: History, policy, and practice,* 3rd ed. New York, NY: Springer Science + Business Media, LLC.

Wheeler, J.O., Muller, P.O., Thrall, G.I., Fik, T.J., and Hodler, T.W. 1998. *Economic geography*, 3rd ed. New York, NY: John Wiley & Sons, Inc.

Whitelegg, J. 1987. A geography of road traffic accidents. *Transactions of the Institute of British Geographers* 12(2): 161-176.

Whitton, R.M. 1962. Profiles of the future: The interstate highway system. *Business Horizons* 5(4): 5-26.

Woods, D.L. and Chang, M-S. 1983. Accident analysis of the conversion from two-way to one-way frontage road operation. In *Freeway Ramp and Frontage Road Operation Research Study 2-8-80-288*. Available at http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/288-3.pdf (last accessed 26 December 2012).

Wright, B. 2002. Backing out of frontage roads? *Fiscal Notes*, June: 12-13.

APPENDICES

Pearson's Correlation

		VAR_MVM_Y	WT_Pop	W_Workers	Commercial	Farm-Ranch	Industrial	Other	Parks	Residential	Roads	Undevelopable	WHMI	All_Services
VAR_MVM_Y	Pearson Correlation	1	-.111	.294	.510**	.085	.395*	-.279	-.091	-.250	-.230	-.174	.156	.259
	Sig. (2-tailed)		.582	.137	.007	.674	.042	.158	.652	.209	.248	.386	.437	.193
WT_Pop	Pearson Correlation	-.111	1	.231	-.333	-.465*	-.543**	-.113	-.176	.577**	.762**	-.562**	.159	.249
	Sig. (2-tailed)	.582		.246	.090	.014	.003	.575	.380	.002	.000	.002	.428	.210
W_Workers	Pearson Correlation	.294	.231	1	.336	-.223	-.189	-.292	.073	-.003	-.046	-.185	.396*	.993**
	Sig. (2-tailed)	.137	.246		.086	.264	.344	.139	.718	.988	.820	.355	.041	.000
Commercial	Pearson Correlation	.510**	-.333	.336	1	.452*	.373	.070	-.044	-.729**	-.578**	.038	-.304	.328
	Sig. (2-tailed)	.007	.090	.086		.018	.055	.730	.828	.000	.002	.850	.124	.095
Farm-Ranch	Pearson Correlation	.085	-.465*	-.223	.452*	1	.365	.424*	.105	-.718**	-.612**	.292	-.382*	-.173
	Sig. (2-tailed)	.674	.014	.264	.018		.061	.027	.604	.000	.001	.140	.049	.389
Industrial	Pearson Correlation	.395*	-.543**	-.189	.373	.365	1	.015	-.190	-.592**	-.490**	.491**	-.247	-.206
	Sig. (2-tailed)	.042	.003	.344	.055	.061		.942	.344	.001	.009	.009	.214	.302
Other	Pearson Correlation	-.279	-.113	-.292	.070	.424*	.015	1	-.097	-.373	-.175	.260	-.479*	-.242
	Sig. (2-tailed)	.158	.575	.139	.730	.027	.942		.632	.055	.382	.190	.011	.223
Parks	Pearson Correlation	-.091	-.176	.073	-.044	.105	-.190	-.097	1	-.279	-.422*	-.232	.294	.072
	Sig. (2-tailed)	.652	.380	.718	.828	.604	.344	.632		.159	.028	.244	.137	.720
Residential	Pearson Correlation	-.250	.577**	-.003	-.729**	-.718**	-.592**	-.373	-.279	1	.792**	-.379	.412*	-.010
	Sig. (2-tailed)	.209	.002	.988	.000	.000	.001	.055	.159		.000	.051	.033	.959
Roads	Pearson Correlation	-.230	.762**	-.046	-.578**	-.612**	-.490**	-.175	-.422*	.792**	1	-.426*	.018	-.039
	Sig. (2-tailed)	.248	.000	.820	.002	.001	.009	.382	.028	.000		.027	.930	.846
Undevelopable	Pearson Correlation	-.174	-.562**	-.185	.038	.292	.491**	.260	-.232	-.379	-.426*	1	-.218	-.204
	Sig. (2-tailed)	.386	.002	.355	.850	.140	.009	.190	.244	.051	.027		.275	.307
WHMI	Pearson Correlation	.156	.159	.396*	-.304	-.382*	-.247	-.479*	.294	.412*	.018	-.218	1	.392*
	Sig. (2-tailed)	.437	.428	.041	.124	.049	.214	.011	.137	.033	.930	.275		.043
All_Services	Pearson Correlation	.259	.249	.993**	.328	-.173	-.206	-.242	.072	-.010	-.039	-.204	.392*	1
	Sig. (2-tailed)	.193	.210	.000	.095	.389	.302	.223	.720	.959	.846	.307	.043	

**. Correlation is significant at the 0.01 level (2-tailed).*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 1 – Pearson’s Correlation

Sections	VAR_MVM_Y	Commercial	Industrial	Undevelopable	WHMI	WT_Pop	W_Workers	Farm-Ranch	Other	Parks	Residential	Roads	All_Services
Z	0.938	11.21%	0.26%	2.41%	$36,394	16428	2674	1.19%	6.78%	1.11%	49.69%	27.36%	870
D	0.948	13.25%	4.05%	9.97%	$84,278	15111	5026	2.85%	8.62%	0.97%	38.61%	21.69%	3547
AA	0.986	11.29%	1.42%	3.81%	$32,923	12852	3979	1.61%	7.29%	2.46%	41.90%	30.21%	1478
R	1.211	12.25%	1.28%	8.91%	$35,573	8022	1798	0.06%	13.58%	1.34%	42.84%	19.76%	295
V	1.248	12.78%	7.42%	4.22%	$42,837	22346	4836	0.36%	7.70%	2.49%	36.42%	28.61%	2014
A	1.377	23.23%	7.38%	6.40%	$47,948	11897	12664	5.81%	16.70%	8.18%	12.67%	19.63%	9222
Q	1.444	10.21%	0.00%	6.19%	$43,869	16192	3900	2.51%	5.21%	0.32%	45.22%	30.12%	2435
Avg	1.165	13.46%	3.12%	5.99%	$46,260	14693	4982	2.06%	9.41%	2.41%	38.19%	25.34%	2837
Y	0.931	22.83%	1.40%	6.94%	$39,976	14166	4663	0.77%	7.08%	0.44%	36.91%	23.63%	1189
X	0.980	29.14%	0.48%	7.92%	$41,986	14762	6742	1.46%	8.74%	4.62%	26.66%	20.97%	2442
M	1.484	22.27%	1.41%	5.91%	$84,354	12017	15395	0.00%	6.32%	3.34%	38.49%	22.26%	6994
B	1.486	35.05%	0.25%	3.05%	$50,077	10485	10843	7.14%	11.95%	17.15%	11.74%	13.68%	7416
N	1.539	24.45%	0.49%	4.61%	$81,495	12506	10857	0.11%	4.86%	0.38%	40.20%	24.90%	5319
O	1.643	16.37%	0.57%	4.43%	$70,806	12991	7073	0.11%	5.40%	0.52%	44.40%	28.21%	3336
L	1.851	24.93%	2.49%	6.69%	$68,101	13471	18484	0.00%	6.85%	3.69%	32.66%	22.69%	6790
P	1.942	15.84%	0.57%	3.99%	$59,286	14162	5443	0.11%	4.74%	0.41%	45.20%	29.17%	2545
Avg	1.482	23.86%	0.96%	5.44%	$62,010	13070	9937	1.21%	6.99%	3.82%	34.53%	23.19%	4504
I	2.433	31.70%	1.05%	4.56%	$124,200	17101	89063	0.18%	4.35%	0.23%	34.22%	23.70%	47899
J	2.510	28.02%	0.04%	4.79%	$155,842	14995	71025	0.28%	3.16%	6.40%	37.87%	19.43%	34922
C	2.632	28.93%	0.40%	2.42%	$67,067	12845	7473	10.17%	7.97%	5.88%	27.04%	17.19%	5012
W	2.960	21.62%	0.10%	1.56%	$47,166	19949	7810	0.00%	7.50%	3.14%	38.80%	27.28%	4040
H	4.025	18.87%	3.63%	6.49%	$126,389	16681	24065	0.00%	7.91%	0.54%	36.92%	25.64%	10280
Avg	2.912	25.83%	1.04%	3.96%	$104,133	16314	39887	2.13%	6.18%	3.24%	34.97%	22.65%	20431
E	1.030	7.14%	3.65%	8.21%	$164,121	14392	4576	0.41%	5.12%	0.80%	49.65%	25.03%	3658
K	1.519	8.86%	0.00%	3.43%	$185,494	9253	17375	0.28%	1.74%	40.42%	30.48%	14.79%	7597
F	1.672	10.43%	2.07%	5.34%	$210,650	13721	7119	0.00%	4.76%	1.21%	51.78%	24.41%	4016
G	2.106	10.24%	0.11%	4.11%	$189,920	15471	11843	0.00%	6.47%	1.31%	52.45%	25.31%	5782
Avg	1.582	9.17%	1.46%	5.27%	$187,546	13209	10228	0.17%	4.52%	10.93%	46.09%	22.38%	5263
T	1.398	21.98%	14.27%	21.37%	$35,755	4554	3010	6.03%	6.82%	0.72%	14.89%	13.92%	372
S	1.632	23.46%	5.91%	18.75%	$35,338	5839	2255	5.39%	11.93%	0.50%	18.93%	15.13%	348
U	4.666	42.72%	21.49%	6.25%	$46,106	3182	4526	4.54%	2.86%	0.04%	10.55%	11.55%	652
Avg	2.565	29.39%	13.89%	15.46%	$39,066	4525	3264	5.32%	7.20%	0.42%	14.79%	13.53%	457

Appendix 2 – Cluster Analysis Division

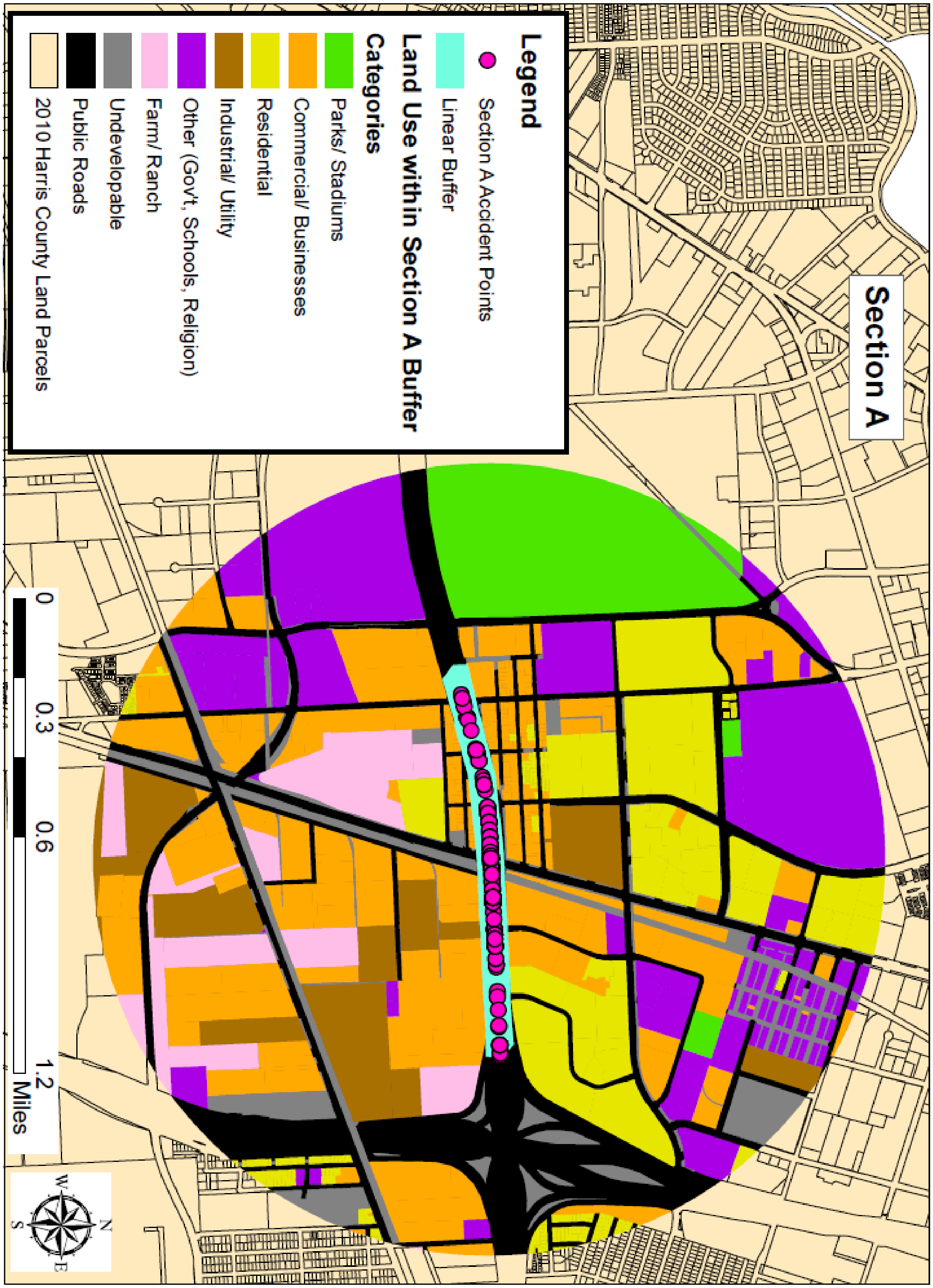

Figure 12 – Section A Frontage Road Cross-Section

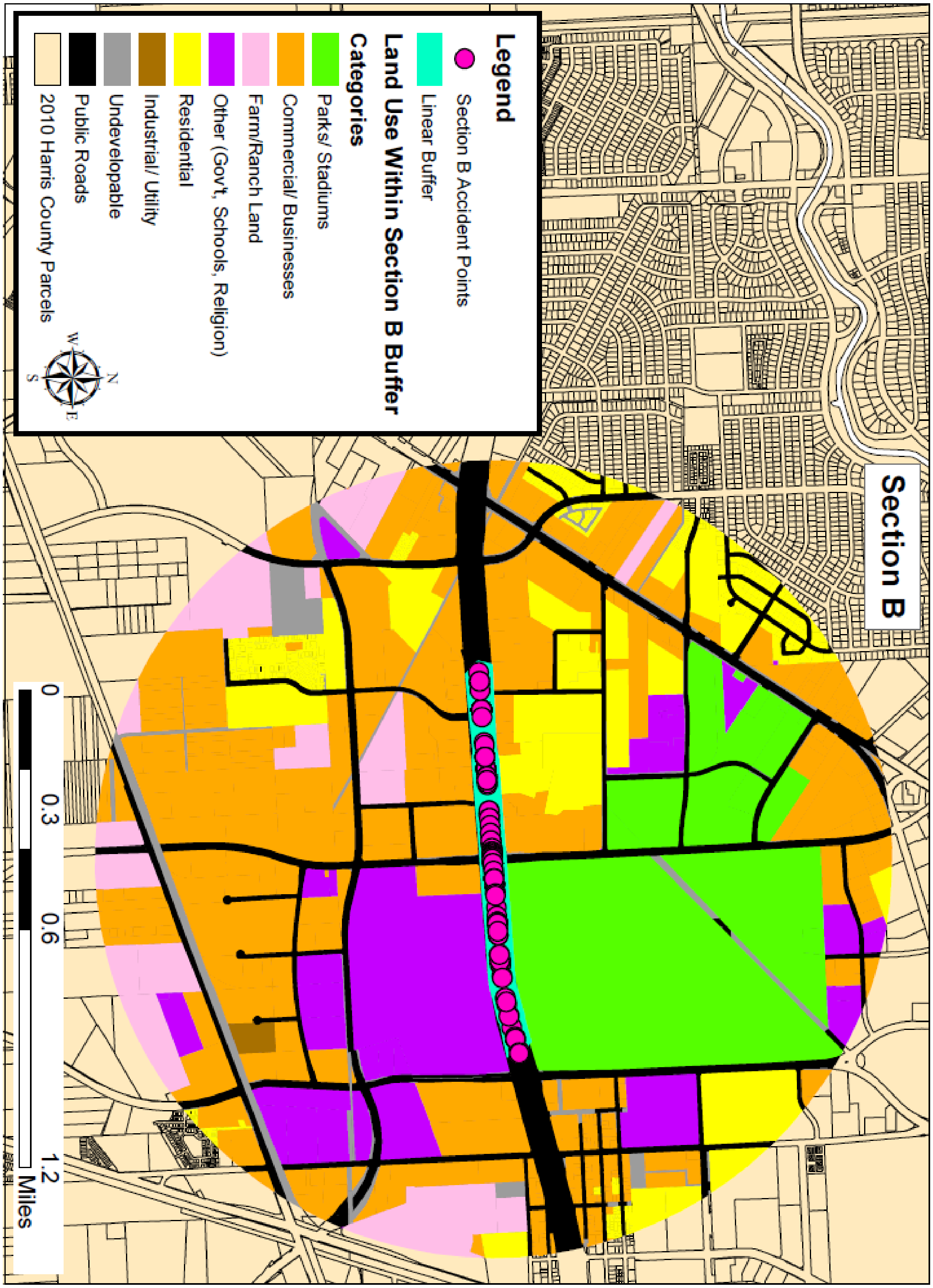

Figure 13 – Section B Frontage Road Cross-Section

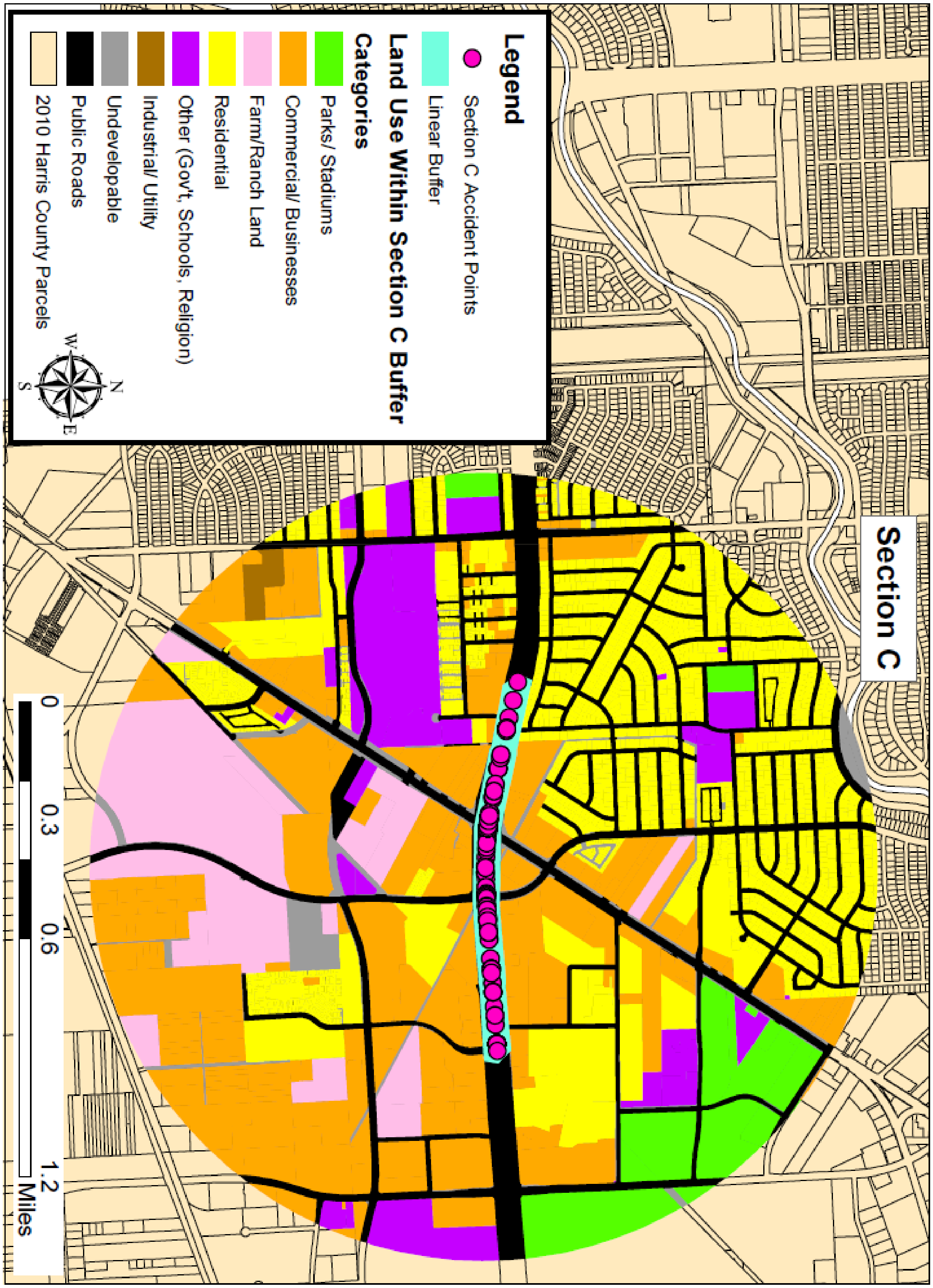

Figure 14 – Section C Frontage Road Cross-Section

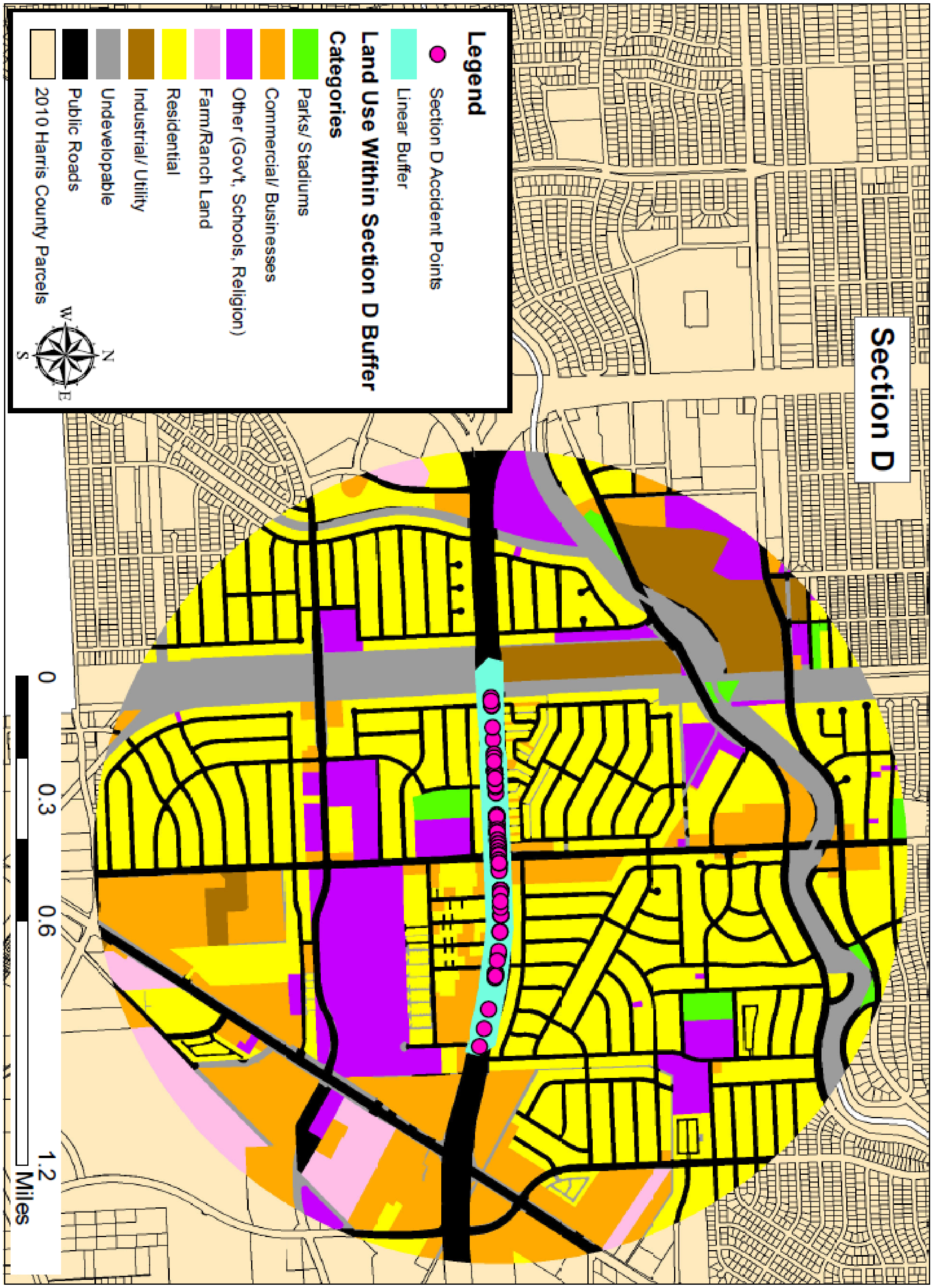

Figure 15 – Section D Frontage Road Cross-Section

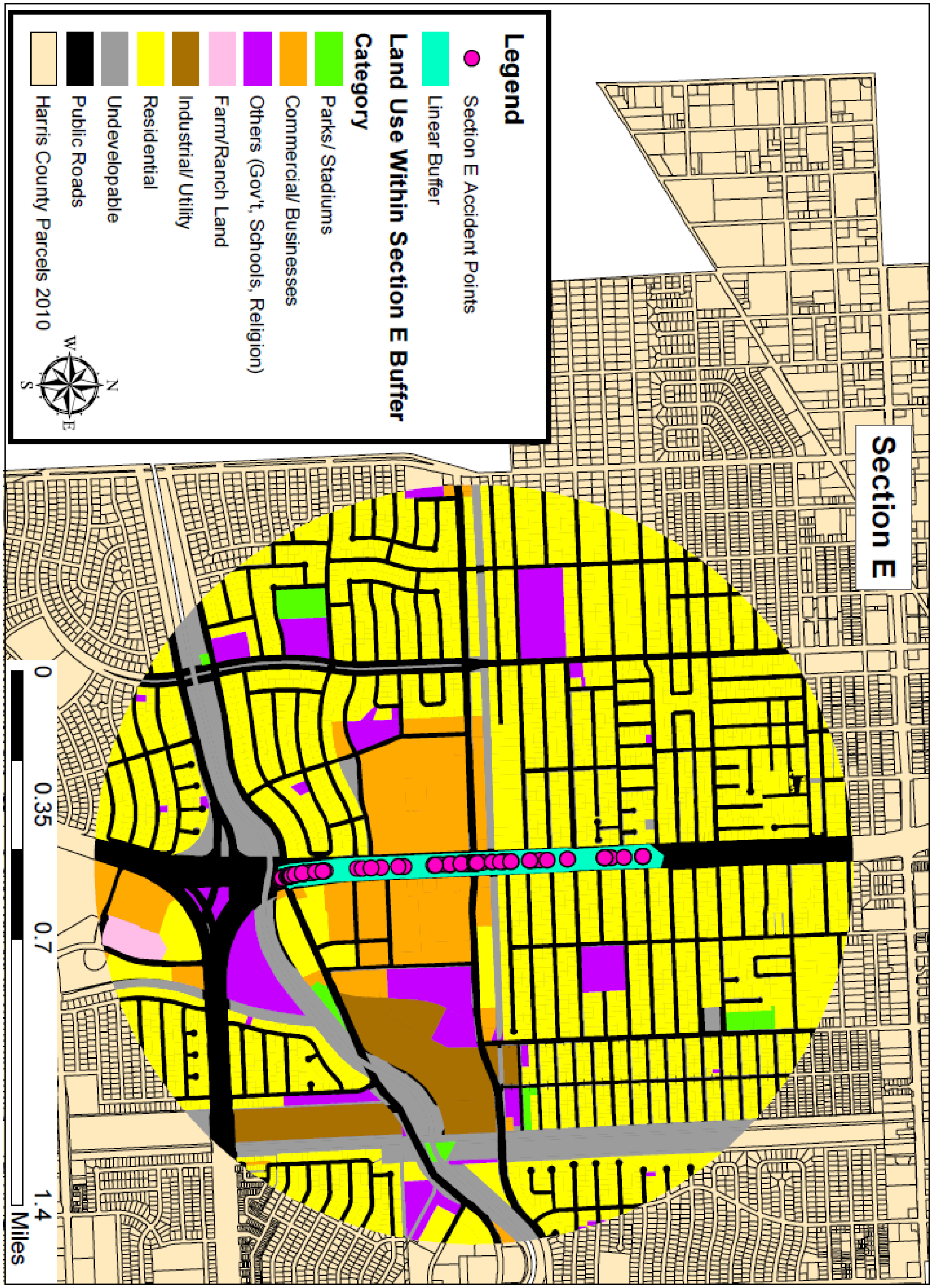

Figure 16 – Section E Frontage Road Cross-Section

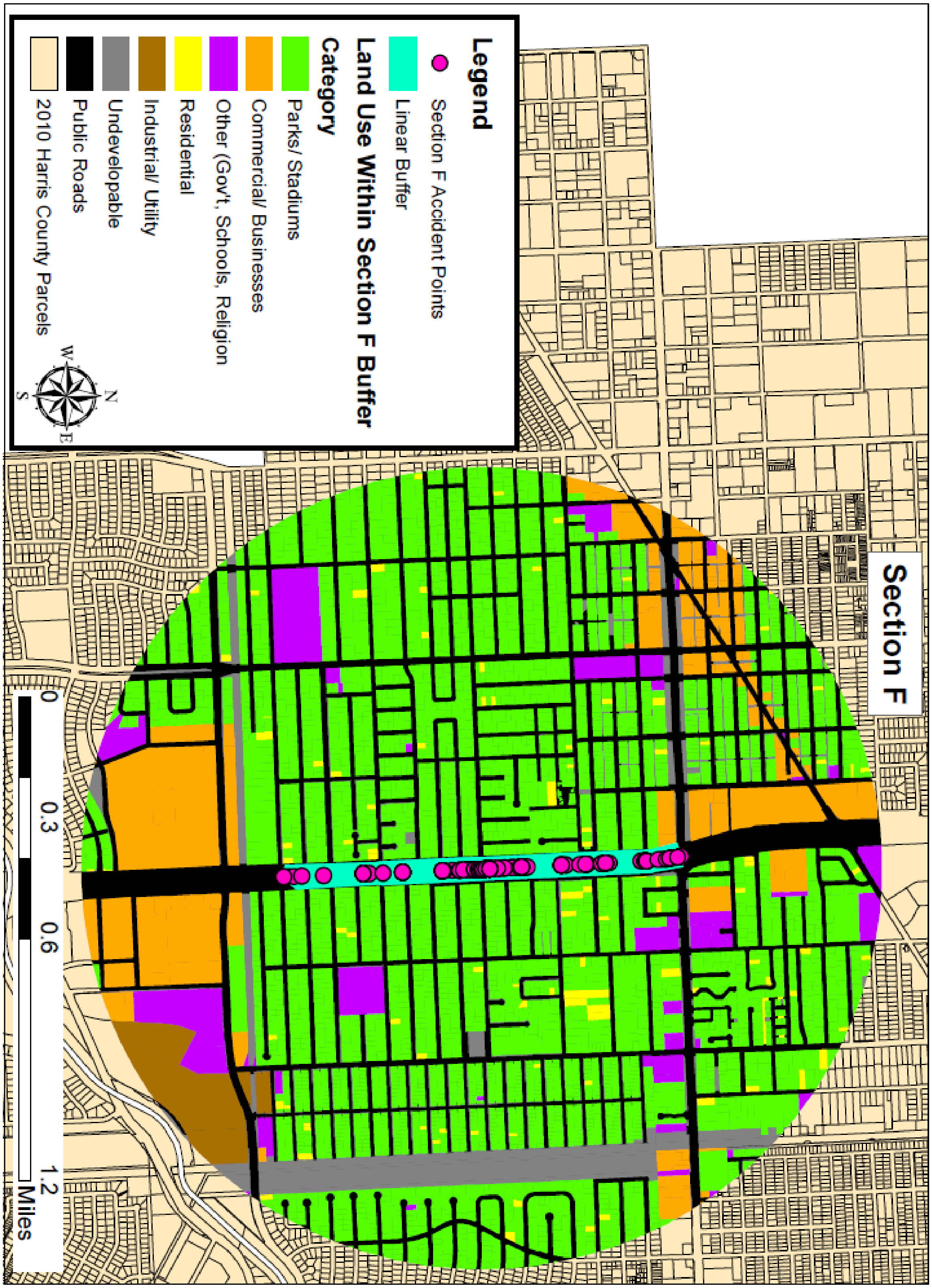

Figure 17 – Section F Frontage Road Cross-Section

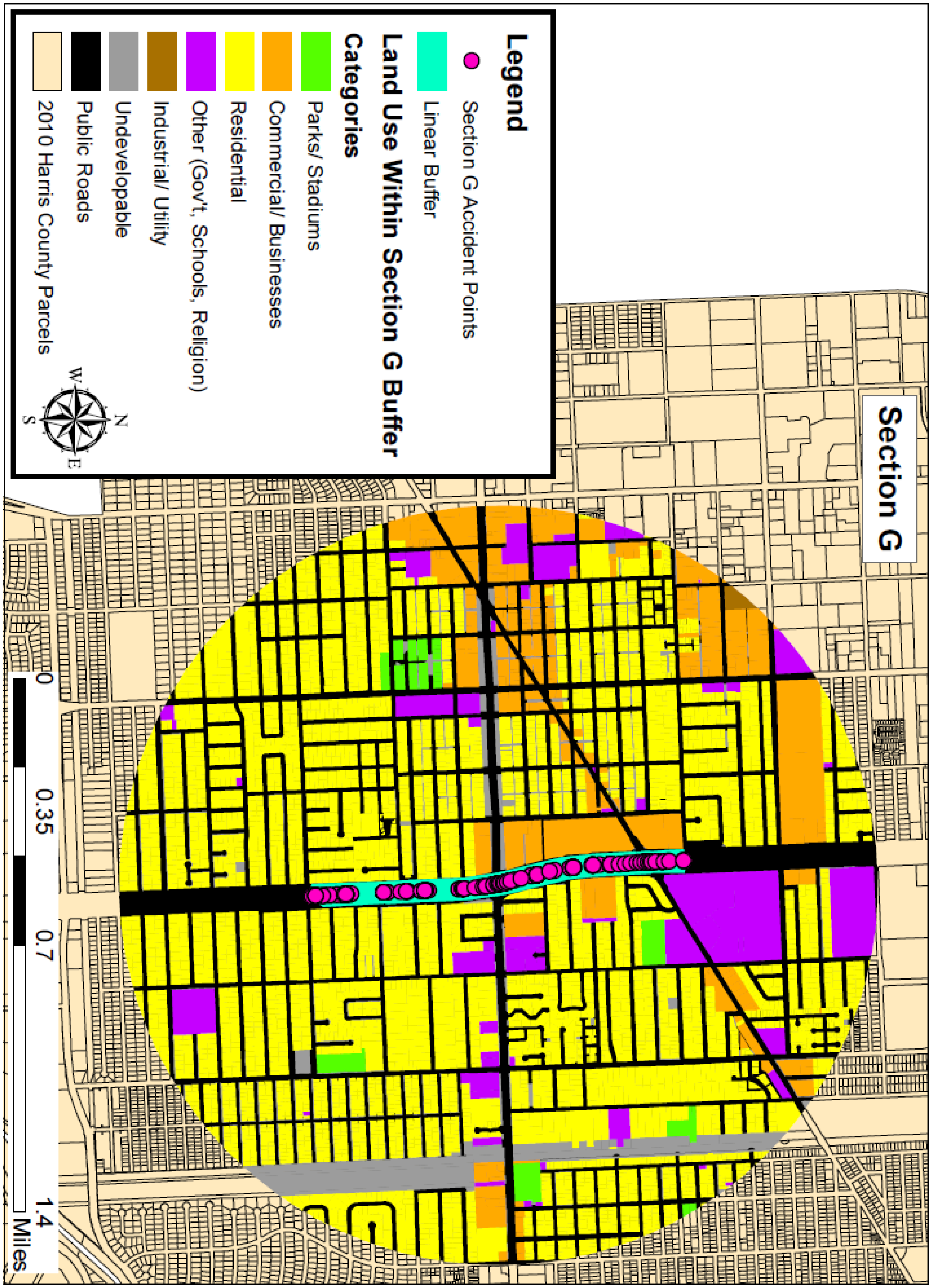

Figure 18 – Section G Frontage Road Cross-Section

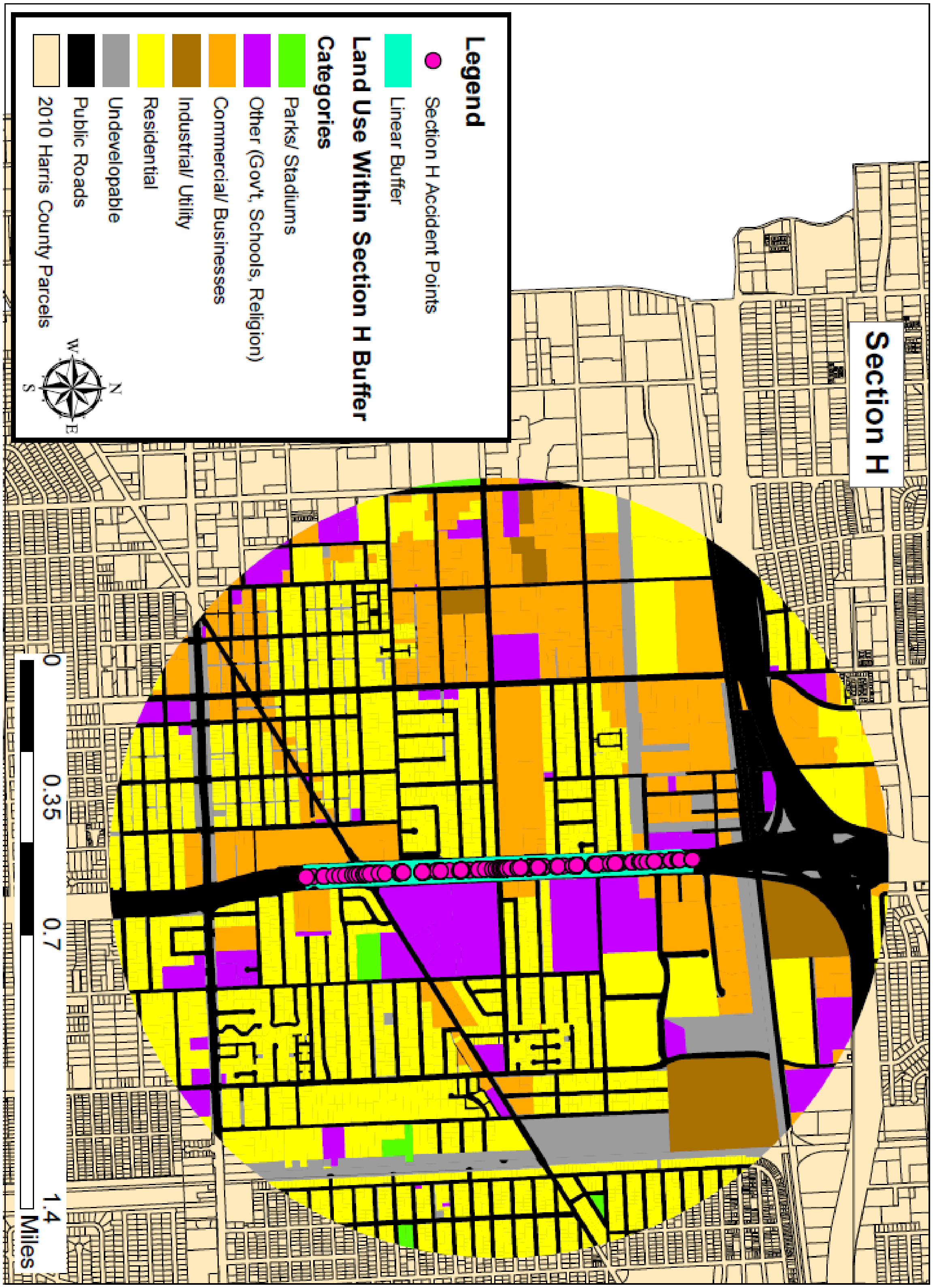

Figure 19 – Section H Frontage Road Cross-Section

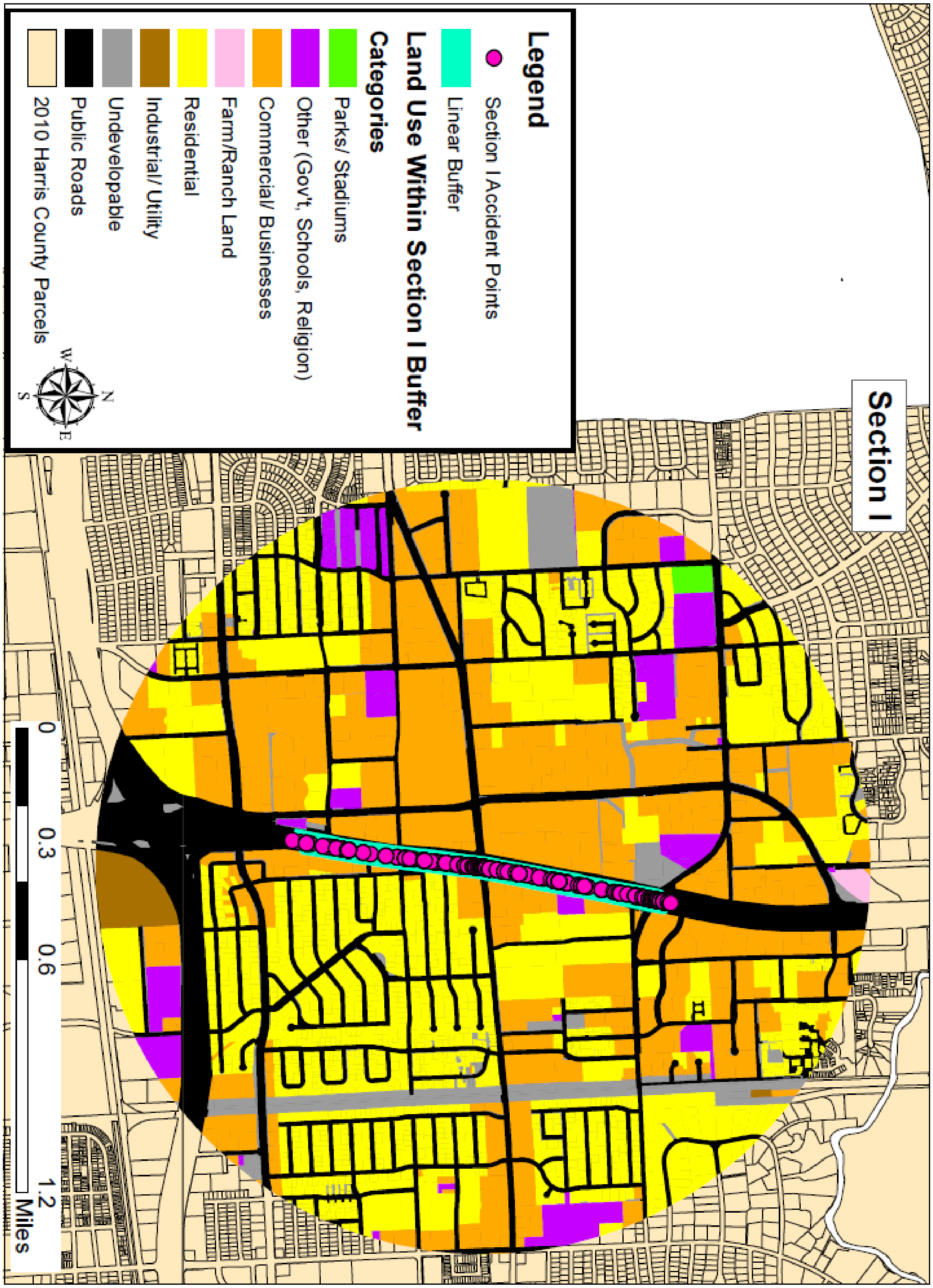

Figure 20 – Section I Frontage Road Cross-Section

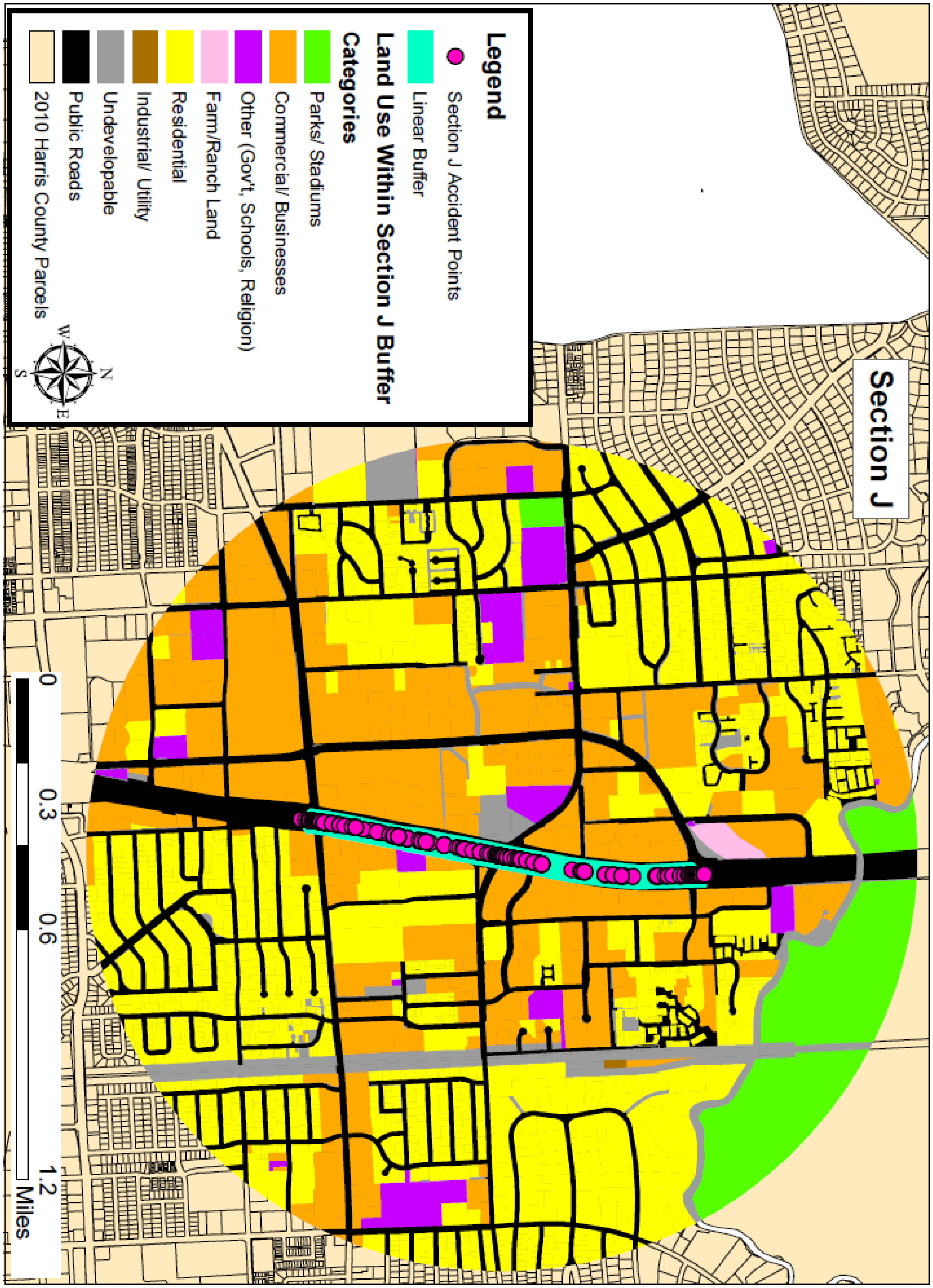

Figure 21 – Section J Frontage Road Cross-Section

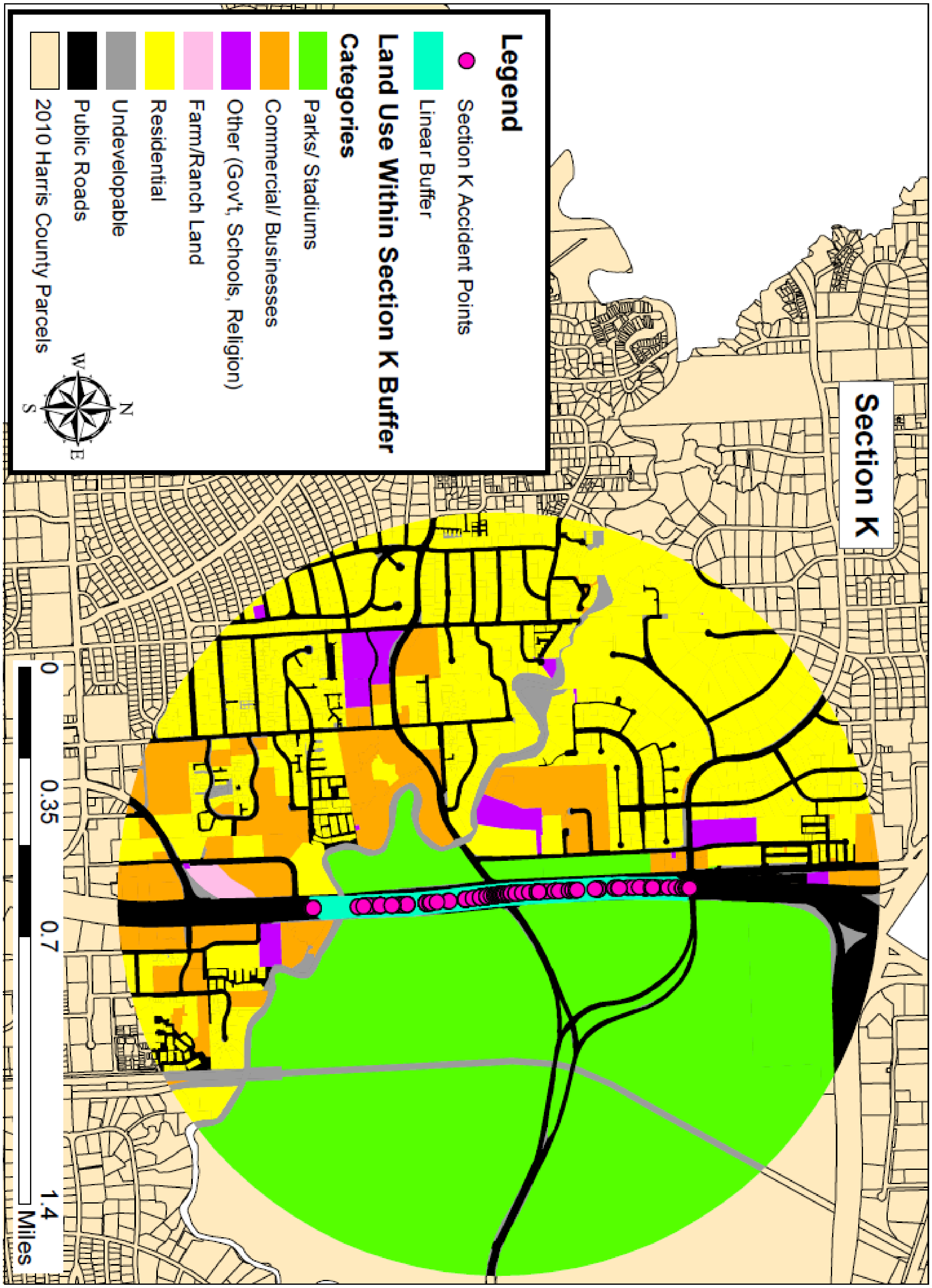

Figure 22 – Section K Frontage Road Cross-Section

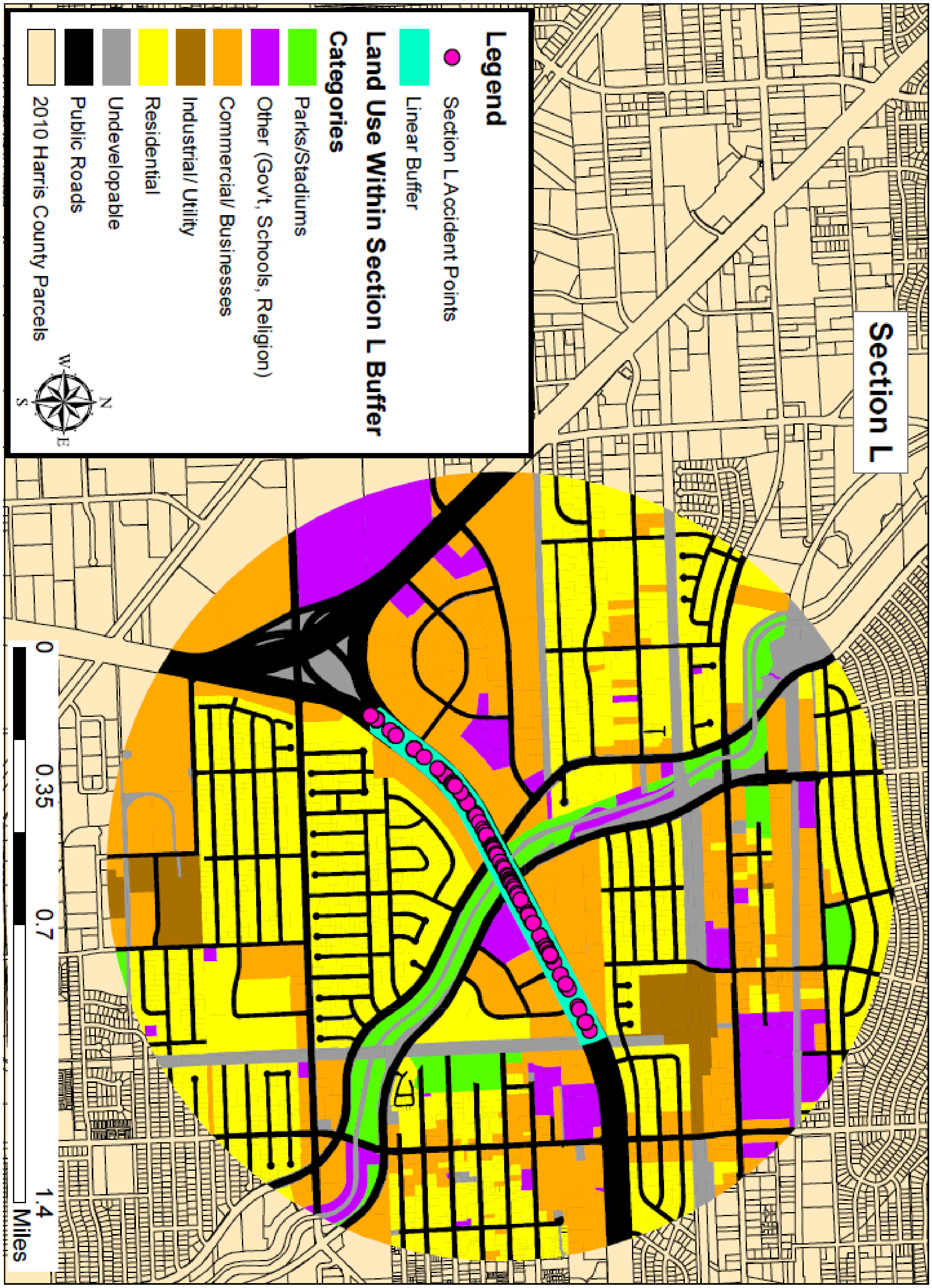

Figure 23 – Section L Frontage Road Cross-Section

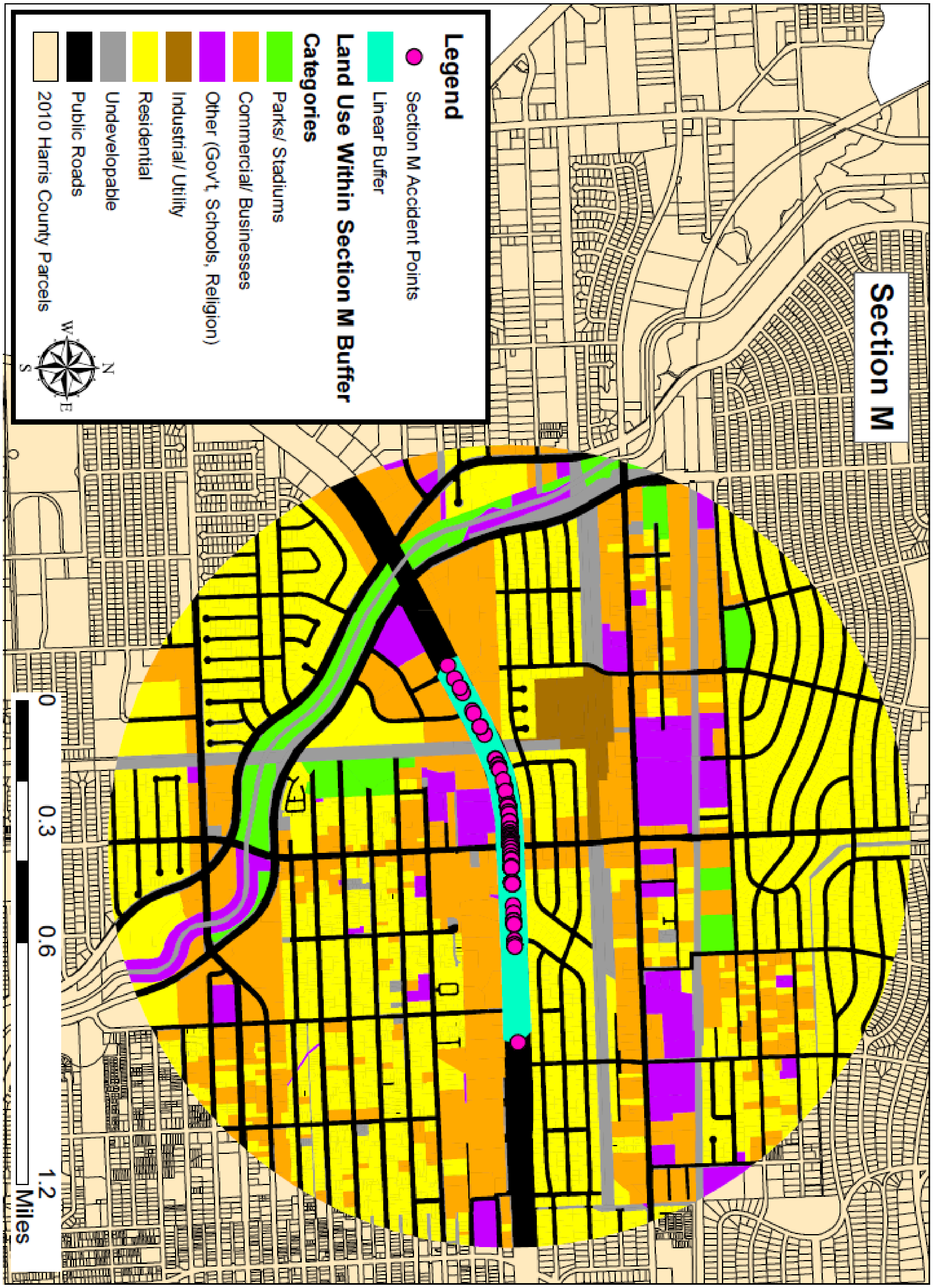

Figure 24 – Section M Frontage Road Cross-Section

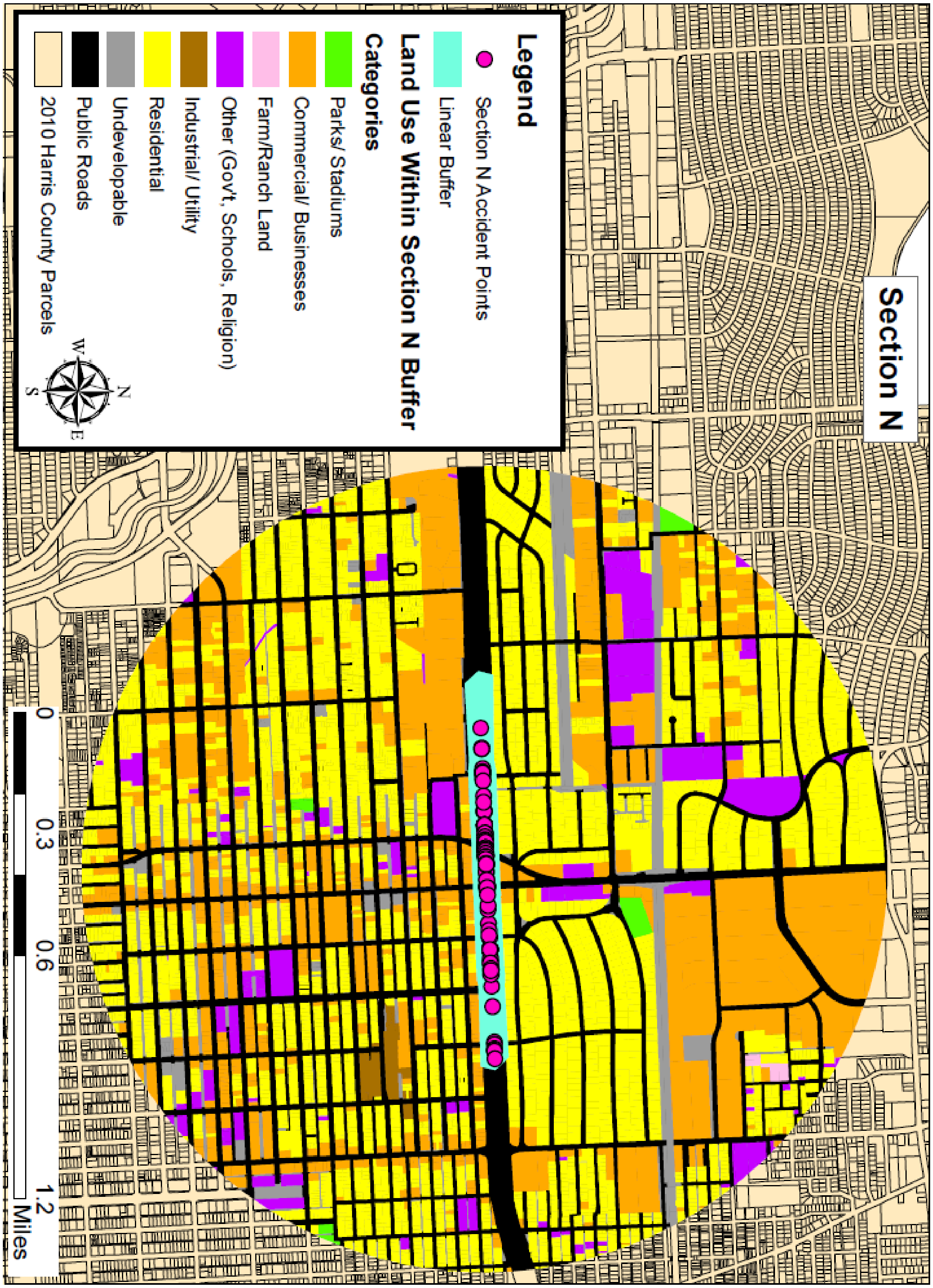

Figure 25 – Section N Frontage Road Cross-Section

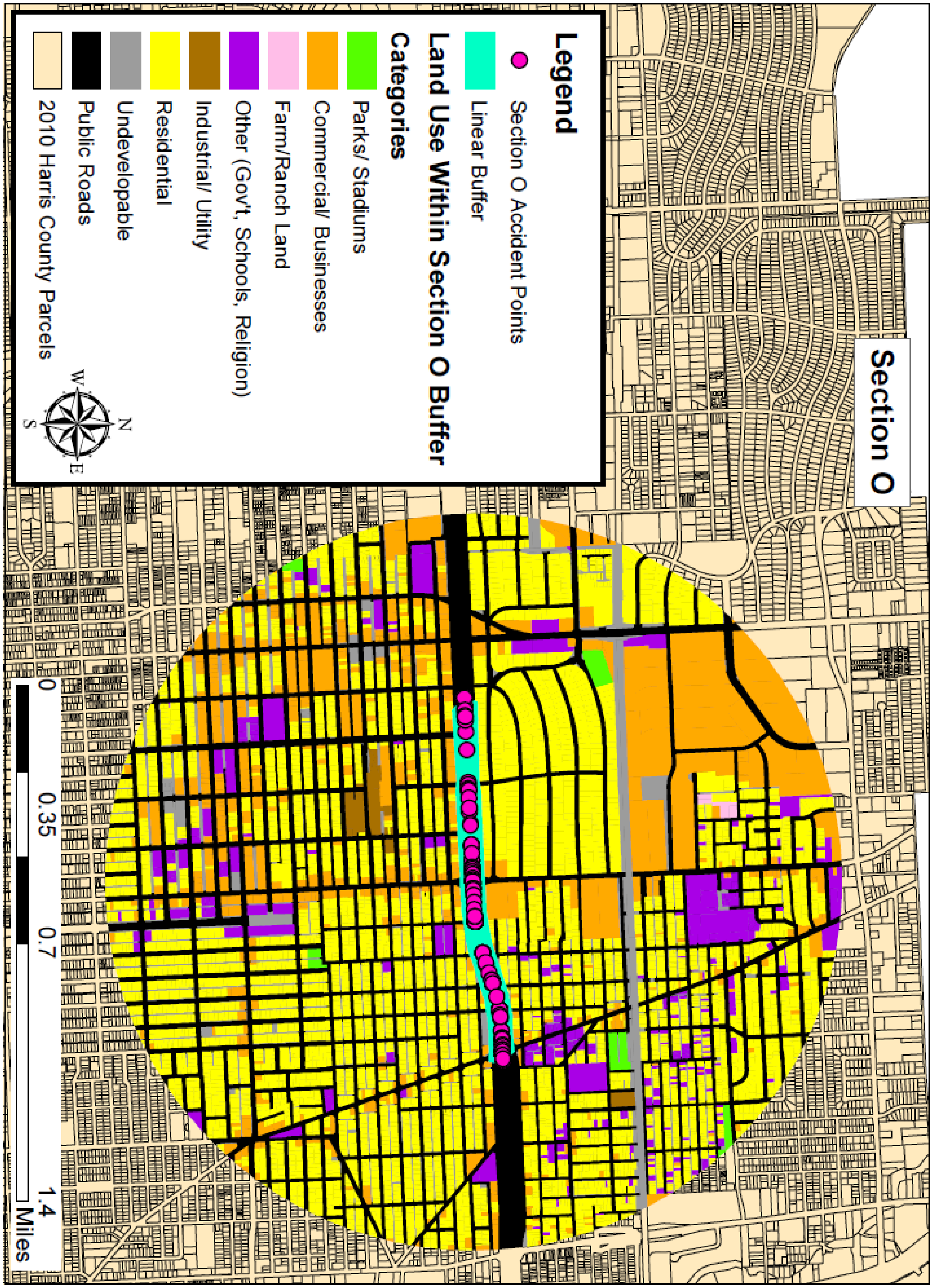

Figure 26 – Section O Frontage Road Cross-Section

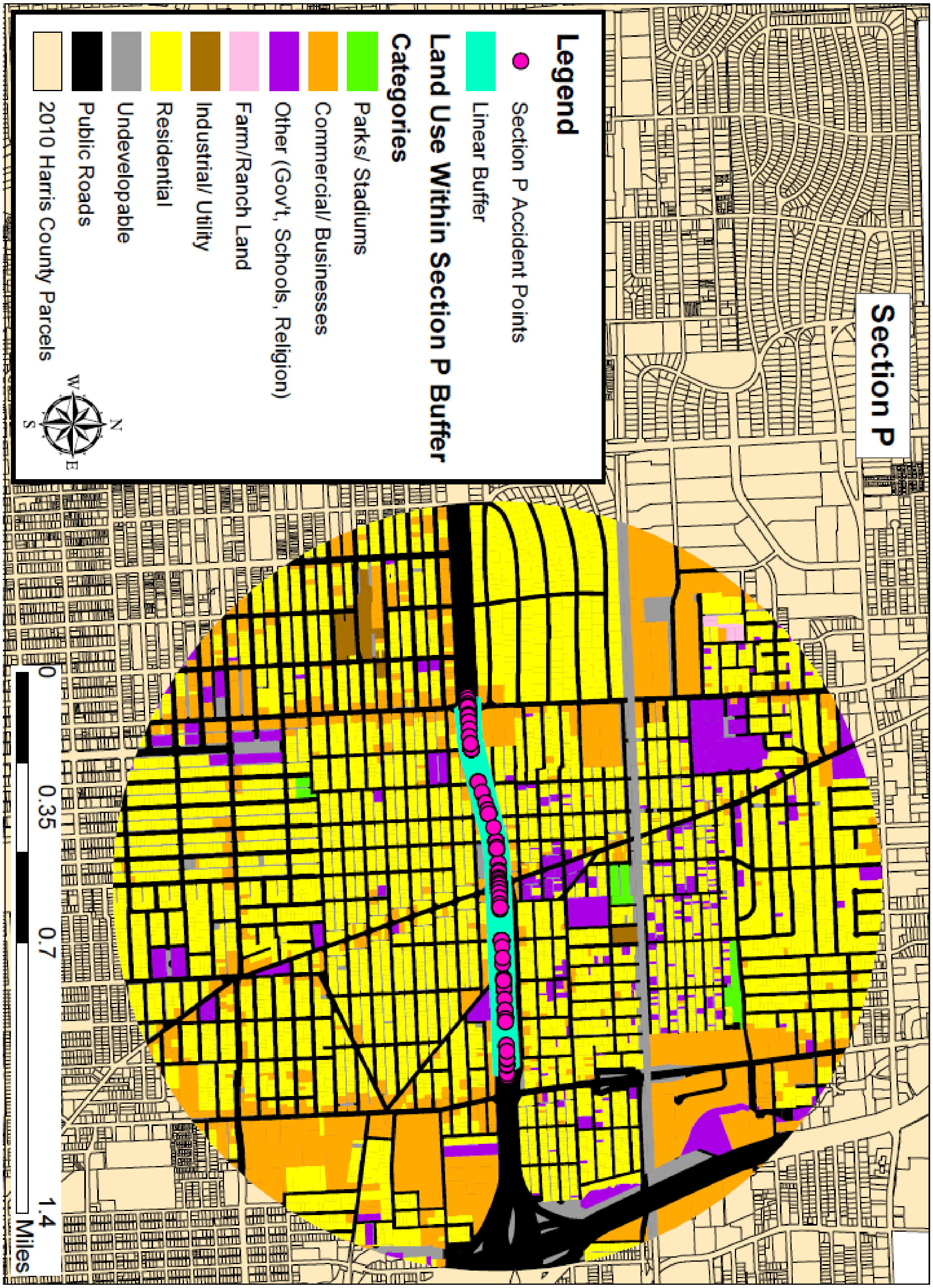

Figure 27 – Section P Frontage Road Cross-Section

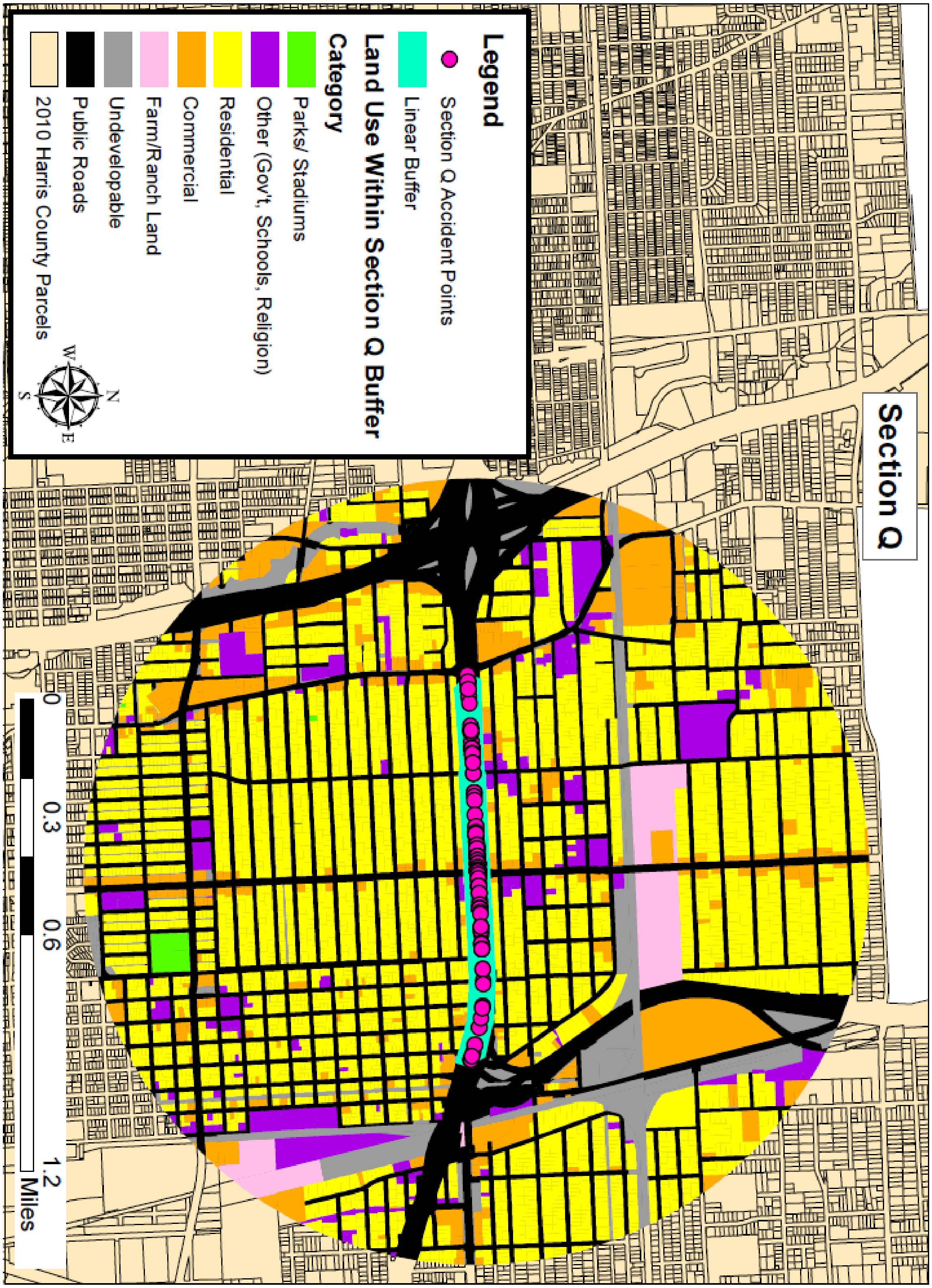

Figure 28 – Section Q Frontage Road Cross-Section

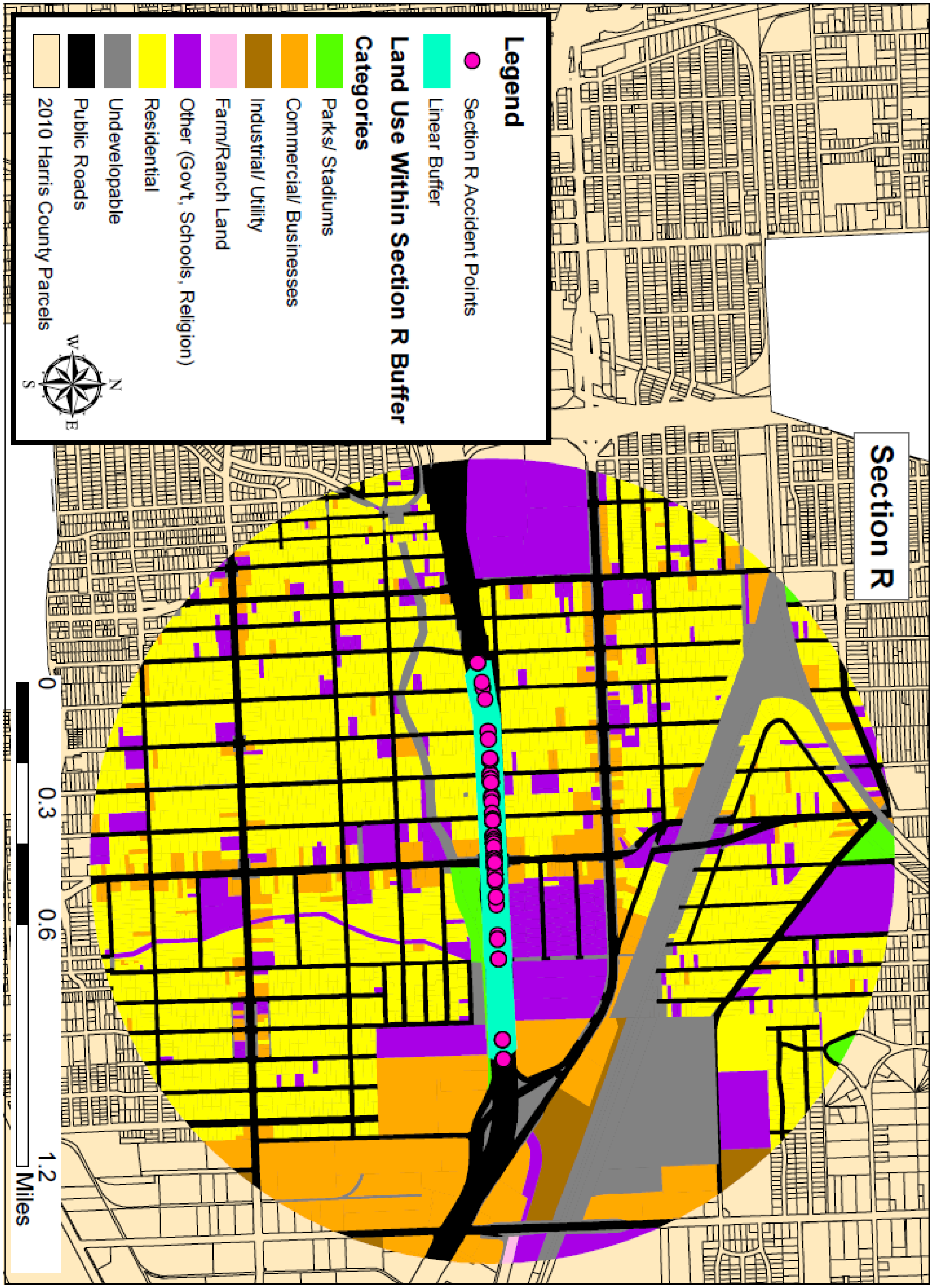

Figure 29 – Section R Frontage Road Cross-Section

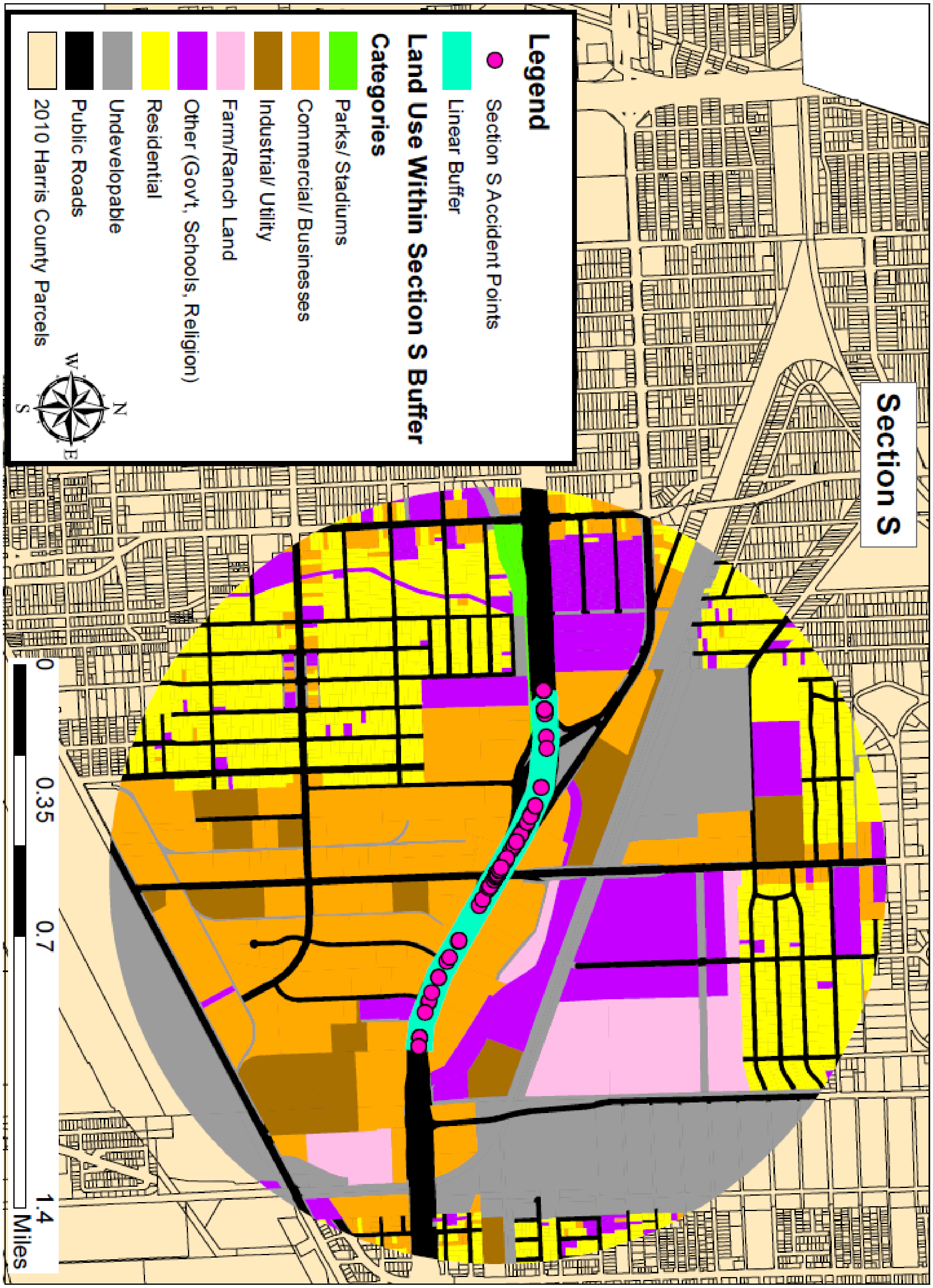

Figure 30 – Section S Frontage Road Cross-Section

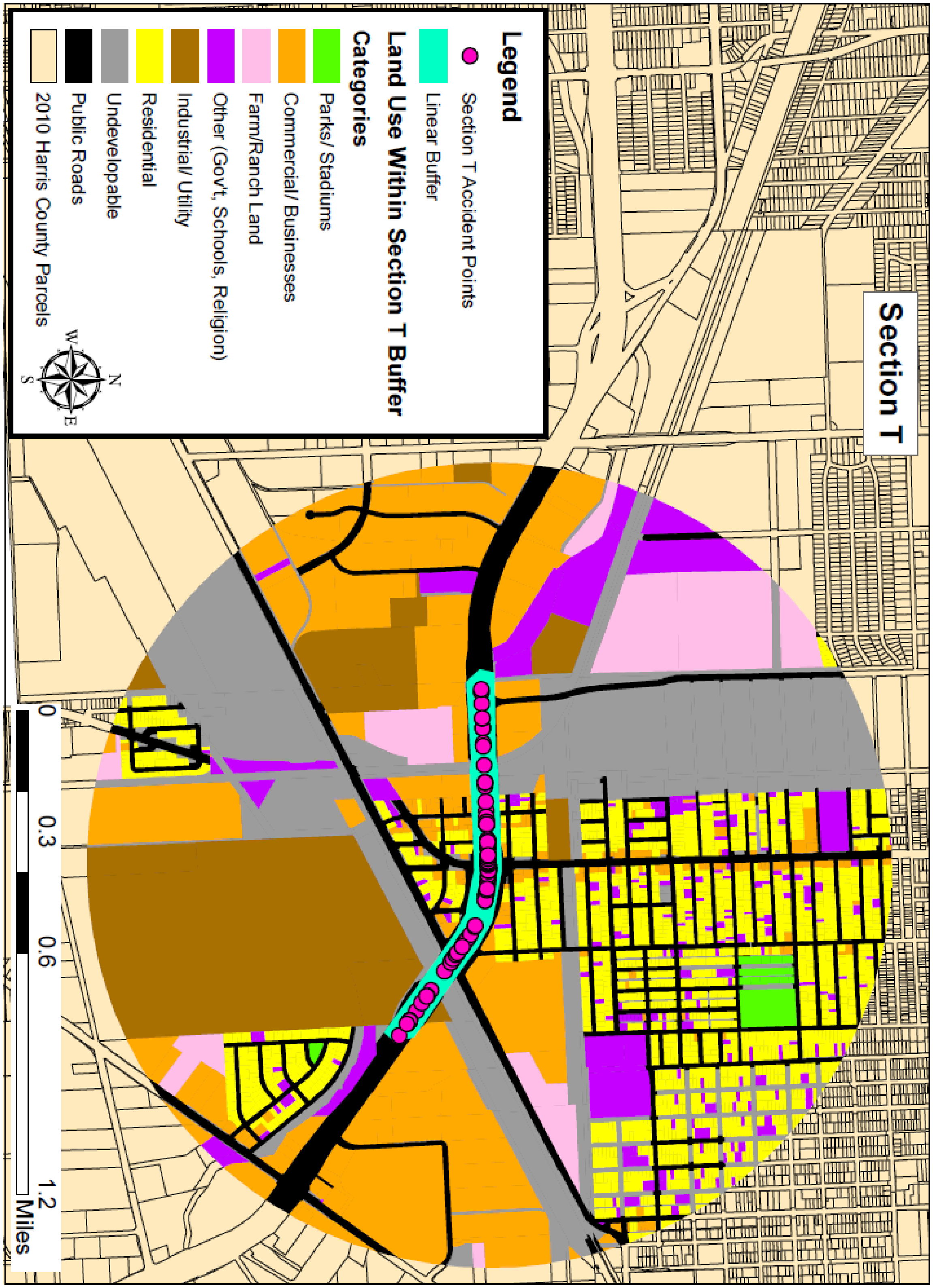

Figure 31 – Section T Frontage Road Cross-Section

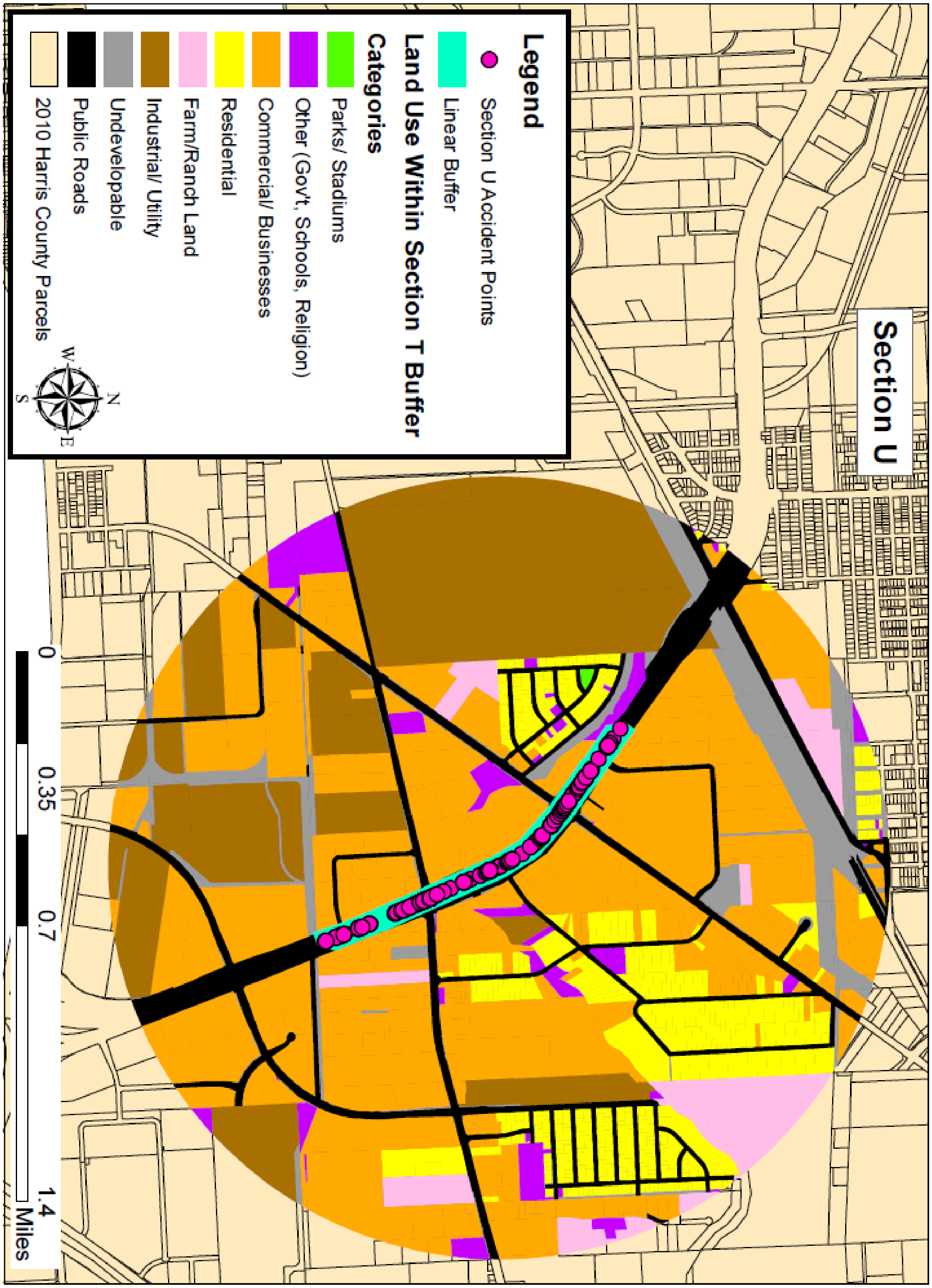

Figure 32 – Section U Frontage Road Cross-Section

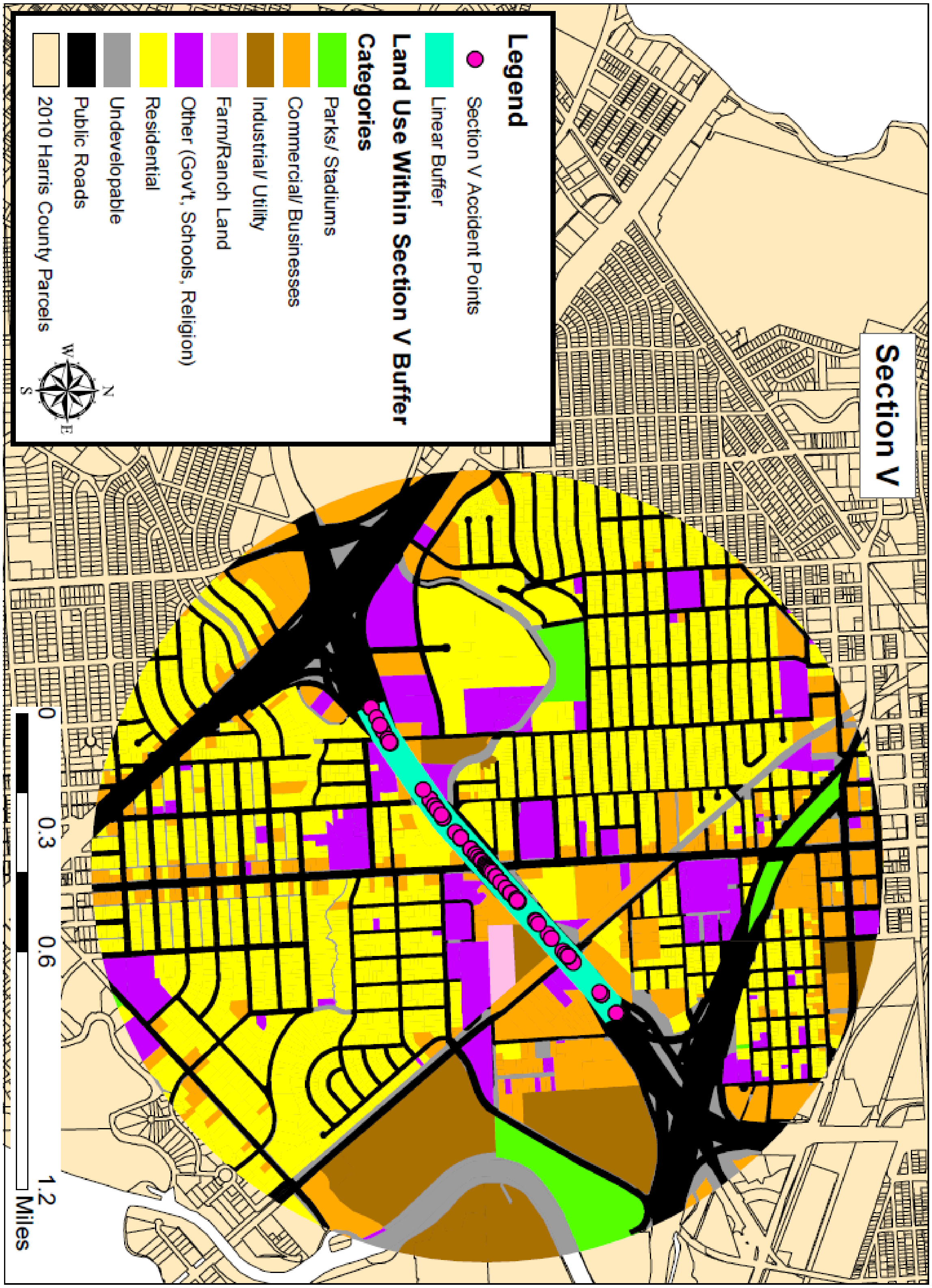

Figure 33 – Section V Frontage Road Cross-Section

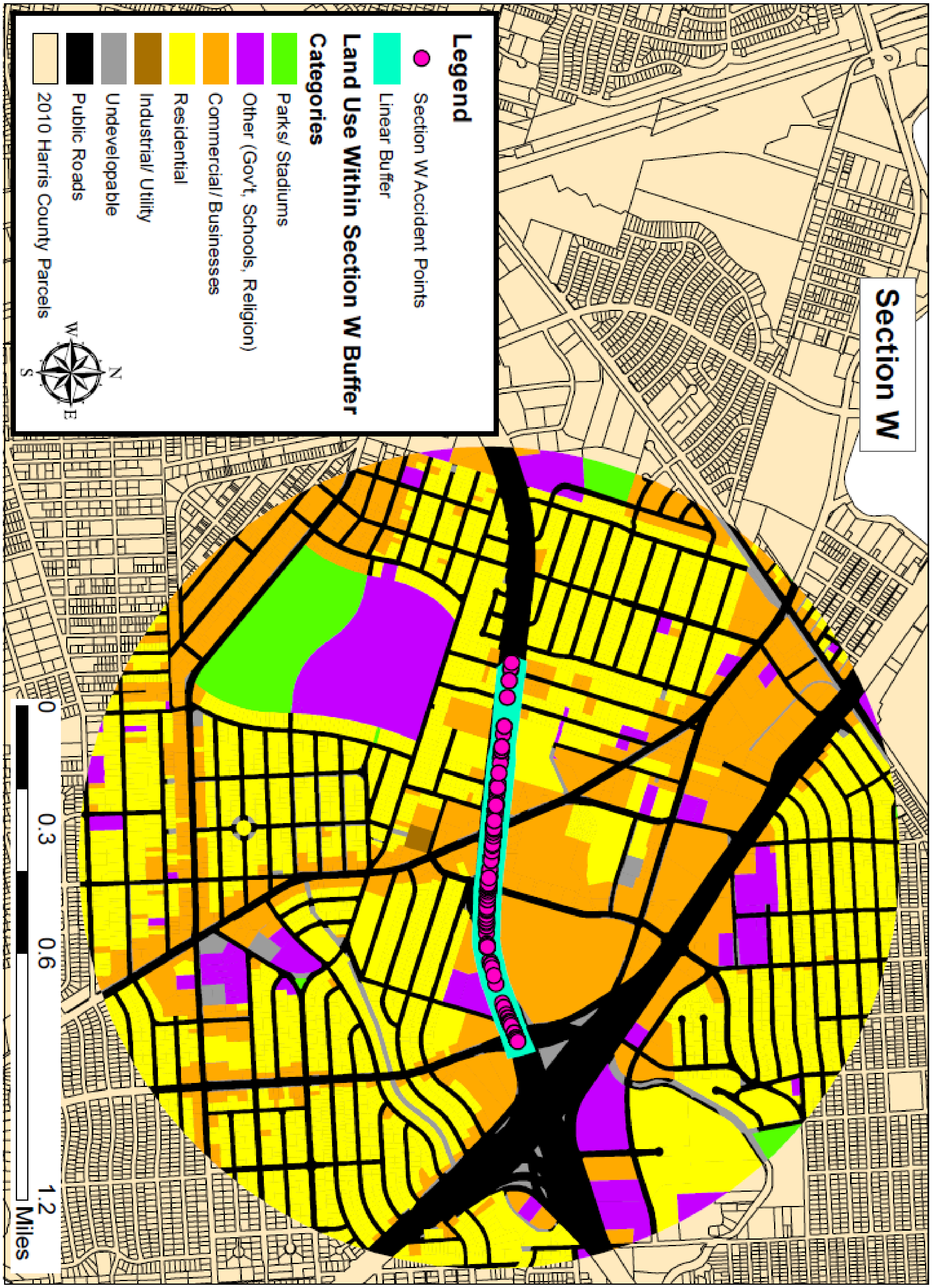

Figure 34 – Section W Frontage Road Cross-Section

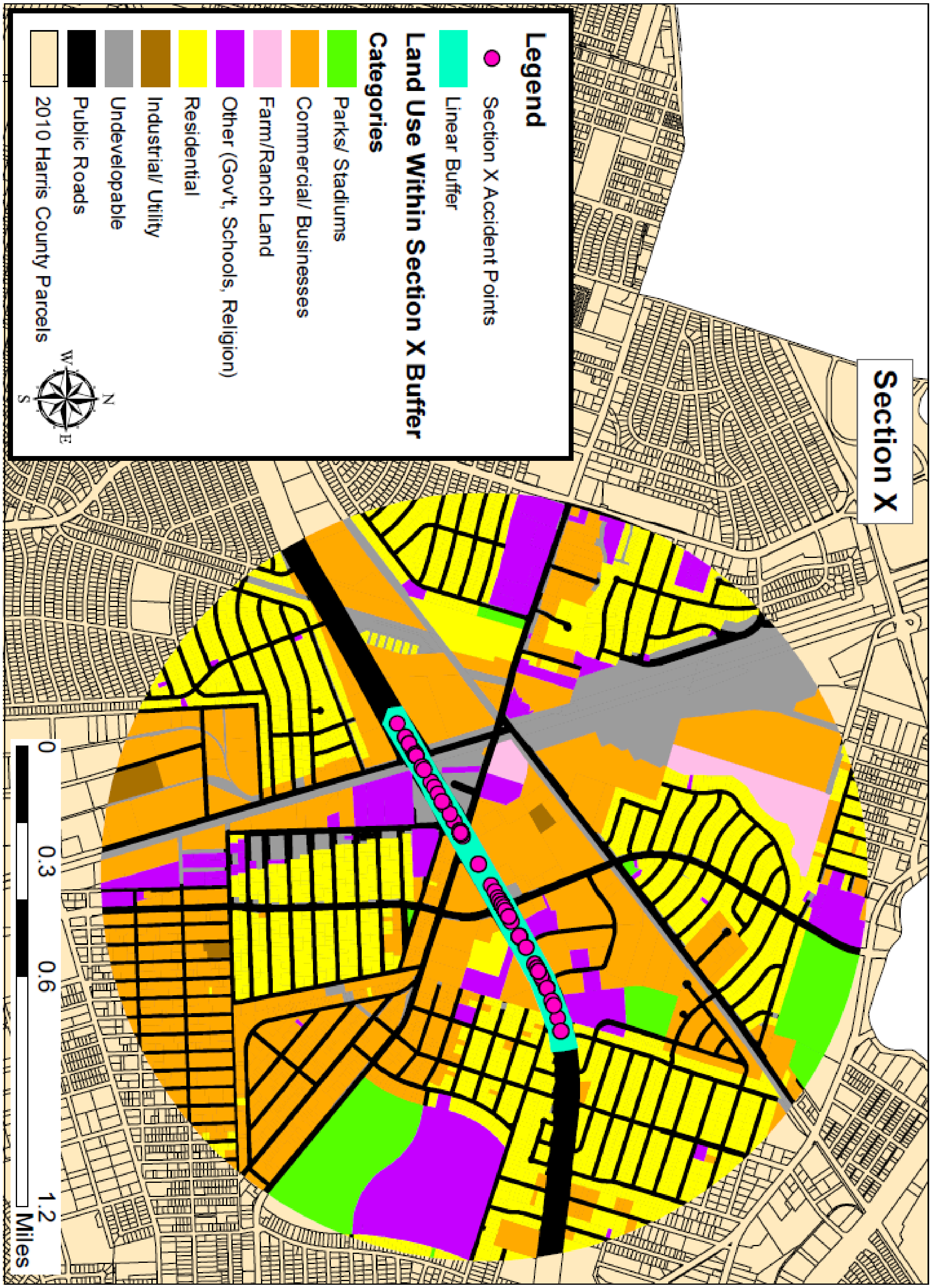

Figure 35 – Section X Frontage Road Cross-Section

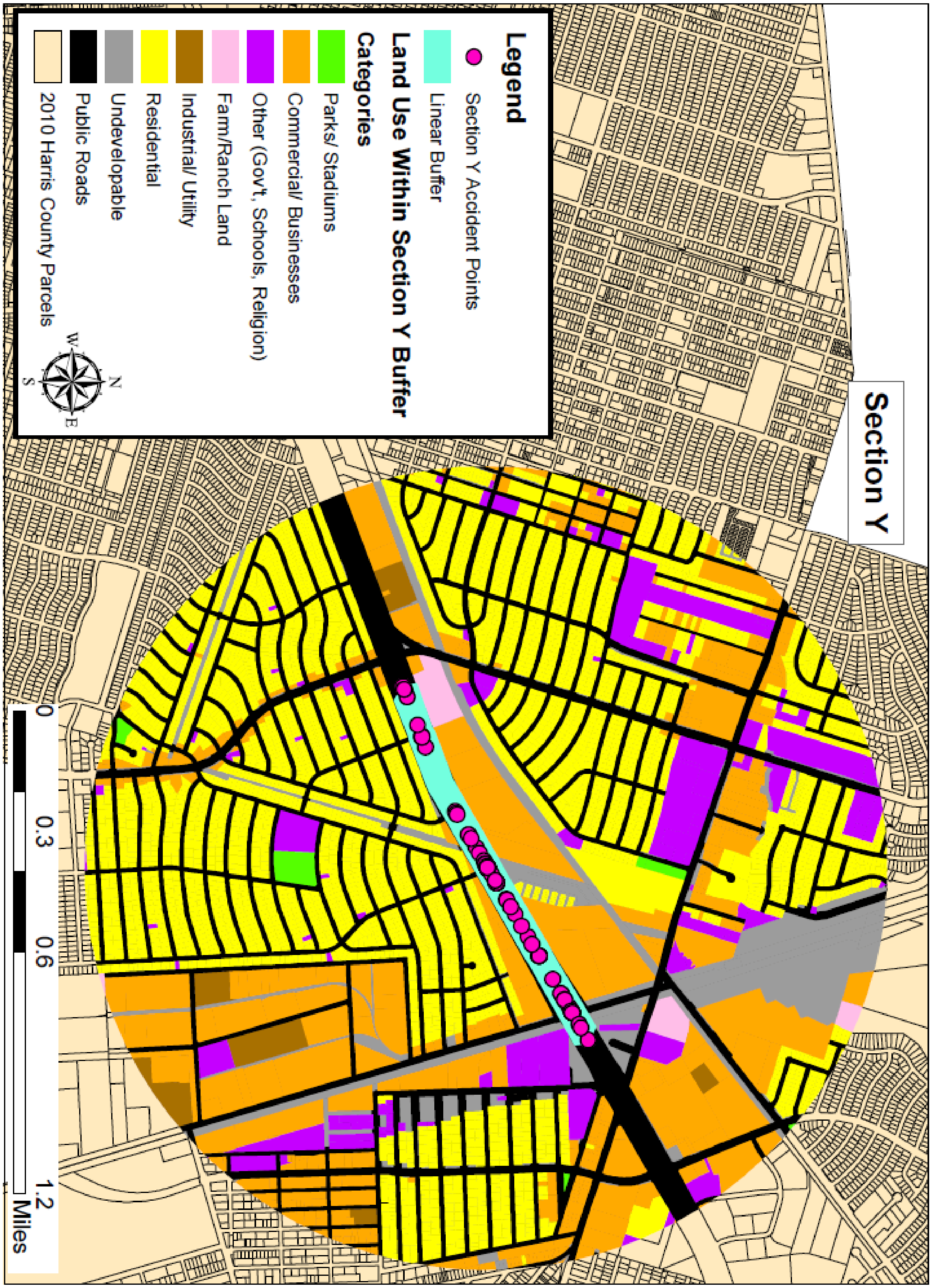

Figure 36 – Section Y Frontage Road Cross-Section

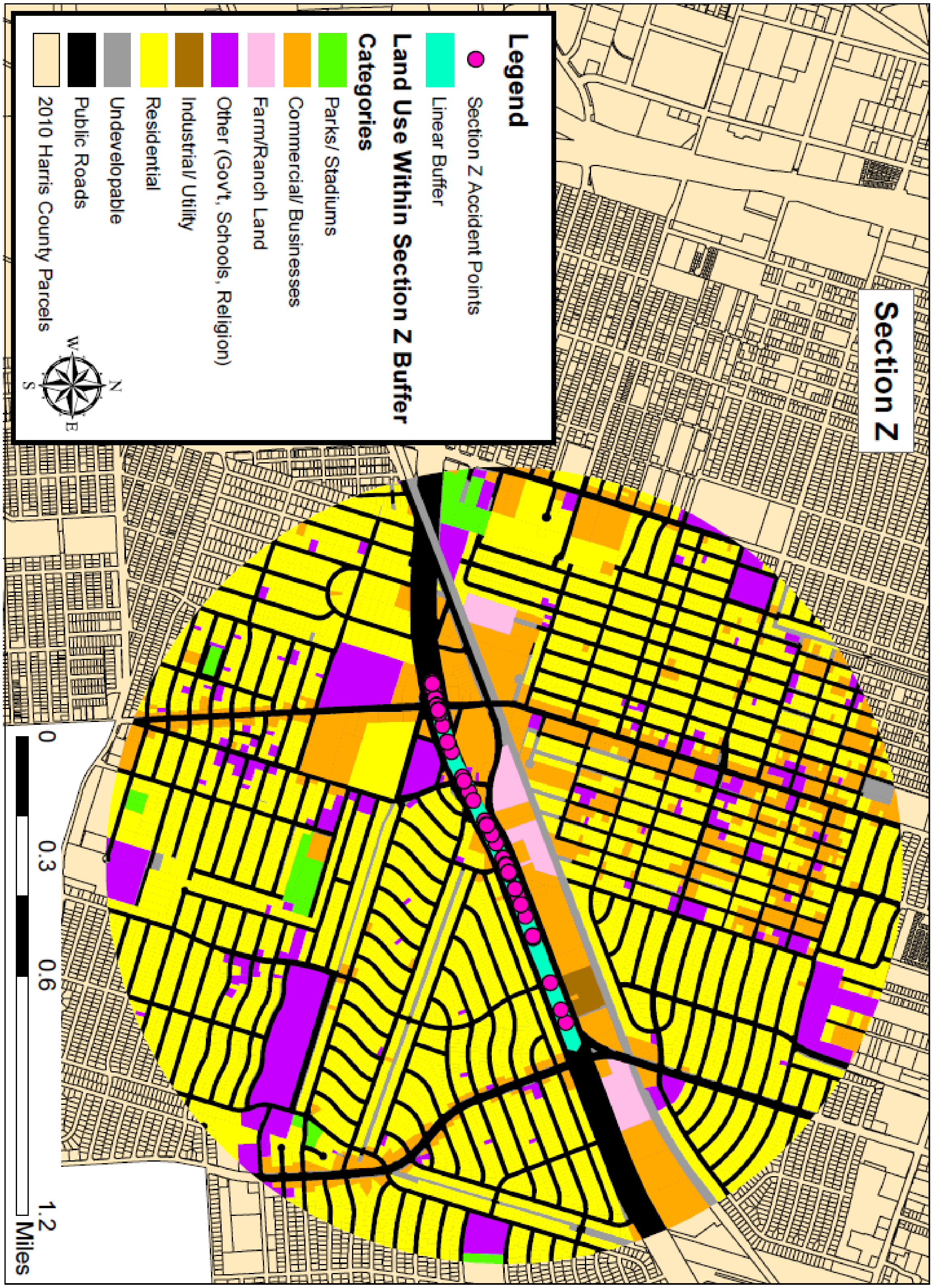

Figure 37 – Section Z Frontage Road Cross-Section

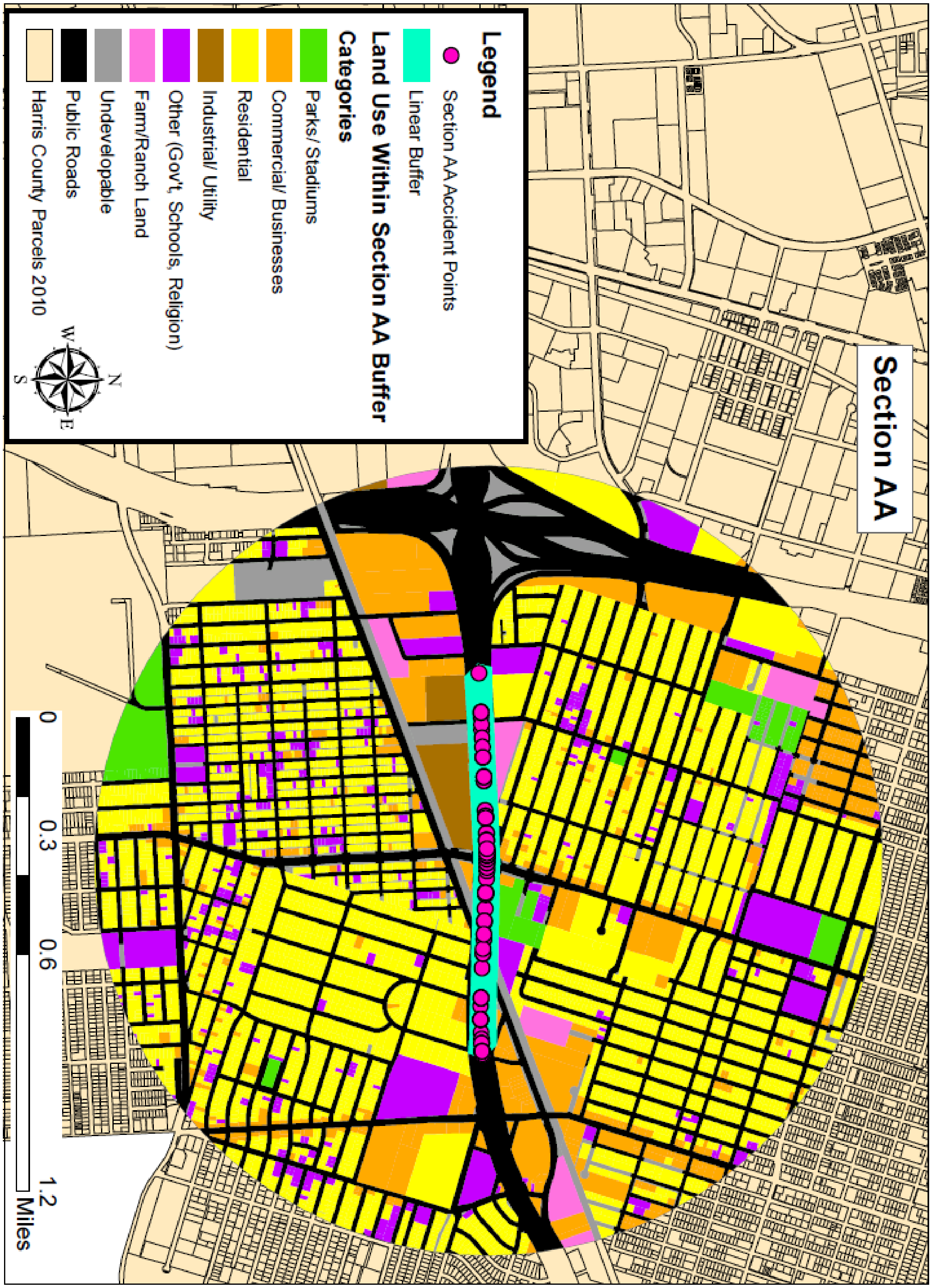

Figure 38 – Section AA Frontage Road Cross-Section

VITA

Scott Brian Kusselson

Candidate for the Degree of

Master of Science

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