

REVEALED ACCESSIBILITY TO EMERGENCY  
SERVICES FOR FATAL MOTOR VEHICLE  
CRASHES IN TEXAS  
THESIS

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REVEALED ACCESSIBILITY TO EMERGENCY  
SERVICES FOR FATAL MOTOR VEHICLE  
CRASH FATALITIES IN TEXAS

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## CHAPTER I

### INTRODUCTION AND BACKGROUND

Access can be defined as “providing the right service at the right time in the right place” (Rogers, Flowers, Pencheon 1999, 866). Penchansky and Thomas (1981) identified five dimensions that define access: availability, accessibility, accommodation, affordability, and acceptability. Accessibility and availability are inherently spatial issues (Guagliardo 2004) making them commonly studied dimensions of access in geographic research. Accessibility is defined as “the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance and cost” (Penchansky and Thomas 1981, 128). Availability is defined as “the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs” (Penchansky and Thomas 1981, 128). In combination, accessibility and availability are commonly referred to as *spatial accessibility* (Guagliardo 2004; Luo 2004; Luo and Wang 2003). The concept of spatial accessibility can be applied to the study of many types of services or resources including health care. Although access to multiple types of services is important, access to medical services is of particular interest because access to medical services can affect quality of life and, ultimately, mortality rates (Barry and Breen 2005). Access to emergency services is an essential aspect of access to medical services.

For emergency services, access to care is highly time sensitive because the optimal time frame for receiving emergency care is often a few minutes instead of a few hours or days, as is the case for other types of medical care (Trunkey 1983). Access to emergency care is critical for the survival of severely injured patients (Felder and Brinkmann 2002). Studies have shown that the time between physical injury and death occurs as a trimodal distribution. The first peak represents deaths that occur immediately or within minutes of the trauma, the second peak represents deaths that occur within the immediate hours following an injury, and the third peak represents deaths that occur days or weeks after an injury (Baker et al. 1980; Trunkey 1983). Many of the deaths that occur in the second peak are potentially preventable (Papadimitriou, Mathur, and Hill 1994). Some recent research suggests that trauma related deaths no longer occur in a trimodal distribution (Pang et al. 2008). However, the current studies still show a significant number of deaths occurring in the prehospital phase (first few hours), emphasizing the importance of prehospital care (Pang et al. 2008; Sauaia et al. 1995). Immediate prehospital care and rapid transport to a medical facility could reduce the number of these deaths (Kivell and Mason 1999).

To fully understand demand for emergency services, the location of emergencies must be considered. Emergencies often do not occur at a person's place of residence, but rather at another location such as in the workplace or on a roadway as a result of a motor vehicle crash (MVC) (Carr et al. 2009). When considering access to hospitals and emergency medical services (EMS) it is important to consider not just place of residence as the location of need, but also the location of emergency events such as MVCs. Access to emergency services for MVCs necessitates study for multiple reasons. MVCs are the

leading cause of injury related deaths for people ages one to forty-nine and are the second leading cause of injury related deaths for people over the age of fifty (National Center for Injury Prevention and Control 2006). In 2008, 1.27 fatalities occurred per 100 million vehicle miles driven in the United States (National Highway and Traffic Safety Administration 2008b). The U.S. experienced an estimated \$230.6 billion economic loss in 2000 as a result of MVCs (National Highway and Traffic Safety Administration 2008b). The loss of life and economic resources make MVCs a critical research issue.

The effect of emergency service access on MVC outcomes has implications for health care policy and emergency resource infrastructure planning. Prehospital time improvements can potentially decrease the number of MVC fatalities and increase the likelihood of survival in a severe MVC (Felder and Brinkmann 2002). For improvements to be made, more research is needed on the multiple spatial elements that contribute to emergency service accessibility.

The objective of this study is to combine data on supply of and demand for emergency services to achieve an understanding of emergency service accessibility in Texas. Specifically, this study will focus on the location of MVC fatalities and the spatial accessibility of hospitals and EMS services for these incidents. A geographic information system (GIS) combining spatial accessibility supply and demand variables will be created to identify and analyze disparities in access to emergency care.

By definition, spatial accessibility considers elements of both accessibility and availability (Guagliardo 2004; Luo 2004; Luo and Wang 2003). In this study, accessibility is studied by considering the location of clients, transportation resources,

and travel times. The location of clients is defined as the location of MVC fatalities; transportation resources are classified as the location of ambulances; and travel distance is assessed by travel time between ambulance locations, MVC fatalities, and hospitals. Availability is addressed by assessing the volume and types of available services (or resources) and the volume of clients. The available resources are EMS services and the clients are MVC victims. The combination of the availability and accessibility classifies this research as a spatial accessibility study.

## CHAPTER II

### LITERATURE REVIEW

This literature review is organized into four sections. First, research completed on the spatial accessibility of health care services is discussed to present a background for the progression of accessibility research in the healthcare field and to present relevant methods. Second, a review of literature on the availability and accessibility of emergency services is covered. The methods and results of these studies are highlighted. Third, fatality rates and accessibility disparities for MVCs are discussed. Fourth, the major contributions of existing research are summarized.

#### Spatial Accessibility of Health Care Services

Although the distance between the patient and the healthcare provider was identified as a barrier to healthcare access in the 19<sup>th</sup> century (Hunter, Shannon, and Sambrook 1986), major research identifying and measuring spatial accessibility was not common until the 1970s (Guagliardo 2004). The equitable dispersion of health care resources has recently been identified as a primary goal for many researchers, health care facility planners and policy makers (Yang, Goerge, and Mullner 2006). However, deciphering local population health needs and the ability of consumers to access health resources is complex. In 2005, the U.S. Federal Government funded nearly \$3 billion in programs designed to allocate resources to areas and groups of people lacking adequate

access to health care services (Government Accountability Office 2006). Despite the quantity of money being spent, health care services are not evenly distributed according to need or geography (Guagliardo et al. 2004; Monnet et al. 2008; Wright, Andres, and Davidson 1996).

When studying health care accessibility, the type of service can drive the research questions and methodology. In accessibility research, primary health care services are the most commonly studied services (Field 2000; Guagliardo 2004; Langford and Higgs 2006; Luo and Wang 2003; Monnet et al. 2008). Primary care services are often studied because primary care access has been recognized as a meaningful indicator of overall population health (Guagliardo 2004).

Multiple methods have been used to identify disparities in the spatial accessibility of primary care services (Guagliardo et al. 2004; Luo 2004; Luo and Wang 2003; Yang, Goerge, and Mullner 2006). Disparities in primary health care accessibility often exist because supply and demand are disproportionate (Luo and Wang 2003). One method used to assess supply and demand is through ratios or the “regional availability” approach (Joseph and Phillips 1984). This method measures accessibility by finding the ratio between the supply of services (e.g. physicians, dentists, mental health professionals) and the demand for services (e.g. population) in defined geographic areas (Susi and Mascarenhas 2002). Considerable research has been completed on patient to provider ratios (Guagliardo et al. 2004; Joseph and Phillips 1984). These studies typically focus on geographic units such as census tracts or zip codes and identify ratios within these units (Susi and Mascarenhas 2002). Although this type of study can help identify areas that are medically underserved, they lack the geographic dimension of distance.

Confining a study to definitive geographic units such as census tracts or counties does not account for the crossing of political boundaries to receive care (Guagliardo et al. 2004).

Guagliardo and colleagues (2004) addressed the boundary crossing issue by using a GIS to create a continuous raster surface rather than using discrete geographic units. Using the Gaussian Kernel method, raster surfaces with identical cell sizes were created for population density and physician density. The two surfaces were combined using map algebra and a continuous surface of spatial accessibility was derived. This method of analysis has multiple advantages: 1) both availability and accessibility are measured; 2) the measure of spatial accessibility gradually decreases as distance increases; and 3) equal units of analysis are used (e.g. raster cells), avoiding the boundary crossing issue (Guagliardo et al. 2004). Guagliardo and colleagues suggested some limitations to their research including the use of Euclidean distance to calculate travel time instead of network distance and the need to incorporate multiple travel mode options. Although the use of Euclidean distance to estimate travel times or service areas does not fully account for travel friction, it is widely used in health service research (Abbott 2008; Guagliardo et al. 2004; Langford and Higgs 2006; Love and Lindquist 1995; Luo and Wang 2003).

In the last decade, primary care accessibility research has become more spatially oriented, focusing on health care service areas (Luo 2004; Yang, Goerge, and Mullner 2006). Luo and Wang (2003) combined two GIS-based accessibility measures into one analysis method to study the spatial accessibility of primary care in Illinois. The authors combined the floating catchment area (FCA) method and a gravity-based method. The FCA method assigns service areas to physicians using a threshold travel time. The gravity-based method assumes that a nearby physician is more accessible than a distant

physician. The combination of these two methods was coined the two-step floating catchment area method (2SFCA) (Luo and Wang 2003). Yang and colleagues (2006) compared the 2SFCA method and a kernel density method to measure the spatial accessibility of primary care resources in Chicago. The authors concluded that the two methods produce markedly different results. Results from the 2SFCA method were less volatile and more easily interpretable for health care providers (Yang, Goerge, and Mullner 2006).

Spatial accessibility research covers two primary types of accessibility: potential and revealed (Guagliardo 2004). Most accessibility research, including all the accessibility studies discussed previously in this literature review measure the potential accessibility of health care services. Potential accessibility is the possible utilization of available health care services based on variables such as distance, transportation availability, insurance coverage, and socioeconomic characteristics (Langford and Higgs 2006; Meade and Earickson 2000). Because potential accessibility is a prediction, the use of available services is not ensured (Guagliardo 2004; Joseph and Phillips 1984). Revealed accessibility is the actual usage of health care services. Revealed accessibility studies are less common than potential accessibility studies because data on actual usage of healthcare services is difficult to obtain (Langford and Higgs 2006). Potential accessibility studies can be helpful for locating new health care facilities and implementing health care policy (McGregor et al. 2005). However, potential accessibility studies have a significant limitation. It is impossible to definitively predict how a patient will utilize health resources (Langford and Higgs 2006). In potential accessibility studies, it is generally assumed that a patient will visit the closest resource

(e.g. physician, trauma center, counseling center). In contrast, revealed accessibility studies uncover actual usage patterns and expose barriers and facilitators to receiving care (Khan 1992).

### Spatial Accessibility of Emergency Services

Although a significant body of research exists on the spatial accessibility of primary health care services, less academic research has been published on the spatial accessibility of emergency services. Emergency service accessibility research covers many components of emergency care (e.g. ambulance depot location, hospital location, quality of emergency care) and uses highly varying methods (Abbott 2008; Branas et al. 2005; Carr et al. 2009; Patterson, Probst, and Moore 2006).

Some emergency service accessibility studies focus on the location of trauma centers or emergency departments and the distance or travel time to these locations (Branas et al. 2005; Carr et al. 2009). Carr and colleagues (2009) measured accessibility of emergency care by estimating the number of census block groups in the U.S. that are within 30 minutes, 45 minutes, and 60 minutes of an emergency department (ED). Using estimated ambulance response times, time spent on scene, and hospital transport time, it was calculated that 94% of the U.S. population has access to an ED within 45 minutes and 98% have access within 60 minutes (Carr et al. 2009). The authors acknowledged several limitations. Average speed limits for urban, suburban, and rural areas were used to calculate drive times for ambulances instead of actual on-the-ground speed limits. The need for emergency services was considered based on where people live, not where an incident requiring emergency services occurred. Additionally, it was assumed that the probability of visiting any emergency department was equal (Carr et al. 2009).

Frequently, the probability of visiting emergency departments is not equal. Texas' trauma system is organized into four levels: Level I comprehensive trauma facilities, Level II major trauma facilities, Level III advanced trauma facilities, and Level IV basic trauma facilities (Texas Department of State Health Services 2010b). In emergencies, lower level hospitals are often bypassed in favor of Level I or Level II trauma centers that are better equipped to handle surgery and other major procedures (Pepe et al. 1987).

When only the locations of Level I and Level II trauma centers are considered, the percentage of people with timely access to emergency care greatly decreases (Branas et al. 2005; Carr et al. 2009). Branas and colleagues (2005) found that only 69.2% of Americans have access to a Level I or Level II trauma center within 45 minutes (considering both ground and air transportation) and 84.1% have access within 60 minutes. Branas and colleagues (2005) acknowledged two important limitations of the study similar to that of Carr et al. (2009). Access was based on place of residence, not where patients were injured. Assumptions were made about prehospital times and travel speeds. Research completed by Branas et al. (2005) and Carr et al. (2009) are the only known studies that combine the location of trauma centers, ambulances, and residences to measure accessibility. Although both studies had acknowledged limitations, the combination of multiple factors associated with accessibility to emergency services was a significant contribution to the literature.

Additional measures to assess the accessibility and availability of emergency services have been developed. An indicator of EMS resource availability was created combining four factors to predict the annual miles traveled per ambulance in a county (Patterson, Probst, and Moore 2006). The factors included: the number of ambulances

per county, EMS demand calculated from county population, estimated travel distance based on total land area, and demographic adjustments to account for variation in need. The travel distance predictions provided a broad view of potential ambulance availability (Patterson, Probst, and Moore 2006). Abbott (2008) assessed the efficiency of temporally based ambulance response systems as a reflection of access to emergency care services for Arkansas. Using a GIS, ambulance service areas were created using 4 minute and 8 minute response time buffers. Service areas were created using straight-line travel distances. A transition from a temporally oriented ambulance organization to a spatially focused organization was suggested, meaning ambulance performance improvements could be achieved by considering ambulance travel distance instead of travel time (Abbott 2008). Research comparing straight-line distance and street network distance from residences to emergency departments as a measure of accessibility revealed that the use of street network distance provides a more accurate estimate of access (McGregor et al. 2005). McGregor and colleagues (2005) found straight-line distance measures caused the misclassification of many British Columbia, Canada residents as having adequate emergency service accessibility.

It is clear that multiple methods exist to measure emergency service accessibility. Despite the highly differing methods used to assess the spatial accessibility of emergency services, all studies have found one common result: a disparity in access between rural and urban areas (Abbott 2008; Branas 2005; Carr 2009; McGregor et al. 2005; Patterson 2006). The pattern of disparity between urban and rural extends to MVC emergencies (Zwerling et al. 2005). Rural and urban disparities in outcomes and emergency service accessibility for MVCs are discussed further in the next section.

### Motor Vehicle Crash Fatalities and Emergency Service Accessibility

Disparities between urban and rural MVC emergencies have been identified (Brown, Khanna, and Hunt 2000; Carr et al. 2006; Donaldson et al. 2006; Gonzales et al. 2006; Gonzales et al. 2009; Grossman et al. 1997; Zwerling et al. 2005). Fatality rates are higher and prehospital times are longer for rural MVCs (Brown, Khanna, and Hunt 2000; Carr et al. 2006; Gonzales et al. 2006; Gonzales et al. 2009; Grossman et al. 1997; Zwerling et al. 2005). Rural ambulance response times were found to be as much as two times longer than urban ambulance response times in five counties in Washington (Grossman et al. 1997). A study of MVCs in Utah, found that rural MVCs are 4.5 times more likely to result in a fatality than urban MVCs (Donaldson et al. 2006). A recent study examining Alabama MVCs found that fatality rates for MVCs in rural areas were nearly twice as high as fatality rates in urban areas (Gonzales et al. 2009).

It is easy to assume that these findings demonstrate that longer prehospital times areas contribute to higher fatality rates. The rapid response of emergency services has been shown to be significantly related to survival rates in other types of traumas (Pell et al. 2001; Roth et al. 1984), but the effect of prehospital time on MVC outcomes is disputed. Gonzales et al. (2006) identified factors that contribute to higher MVC fatality rates in rural areas and found that prehospital times for fatalities were significantly longer than prehospital times for survivals. Gonzales and colleagues (2009) found that both transport distance and transport time were significantly longer in rural areas than urban areas where mortalities were involved. In contrast, Jones and Bentham (1995) assessed the odds of death versus serious injury and found that there was no relationship between MVC outcomes and prehospital time.

Despite the disputed impact of prehospital time on MVC outcomes, it has been repeatedly demonstrated that prehospital times and fatality rates vary significantly between urban and rural areas. Comparison of severely injured MVC victims that died and victims that survived suggests that many fatalities are potentially preventable with timely access to emergency care (Papadimitriou, Mathur, and Hill 1994). Overall, the literature suggests that prehospital times affect outcomes and should be considered when assessing MVC outcomes.

### Literature Conclusions

Methods and results from the literature are used to guide the objective of this research on accessibility to emergency services for fatal MVCs. Research on the accessibility of primary care services contributes to this study by establishing the usefulness of raster layers and map algebra (Guagliardo 2004) and highlighting the benefits of studying both revealed spatial accessibility and potential spatial accessibility (McGregor et al. 2005). In emergency service accessibility, Branas et al. (2005) and Carr et al. (2009) offer a useful method for combining the location of emergencies, ambulances and trauma centers to gain an overall understanding of access. The authors acknowledge two significant limitations in their studies that warrant further study. Access is based on place of residence, not the emergency event location, and a lack of real data necessitates assumptions about prehospital times and travel speeds. Research on MVCs has identified disparities in prehospital times for urban and rural areas (Brown, Khanna, and Hunt 2000; Carr et al. 2009; Gonzales et al. 2006; Gonzales et al. 2009; Grossman et al. 1997; Zwerling et al. 2005) and some research reveals elevated mortality rates when longer prehospital times occur (Gonzales et al. 2009).

This study will present a method that improves upon the weaknesses of existing studies and expands current research. A broad examination of the spatial accessibility of emergency services will be achieved by combining the location of MVC emergency events, the location of hospitals and ambulances, and prehospital time data. No assumptions will be made about prehospital time, because actual travel time data will be used.

## **CHAPTER III**

### **RESEARCH DESIGN**

#### Research Objective

This research aims to assess the accessibility of emergency services in Texas from 2006 through 2008 by defining demand as the location of MVC fatalities and supply as the location of ambulances and hospitals. This research will utilize GIS methods to visualize the distribution of MVC fatality locations and statistics to compare the spatial accessibility of emergency services for MVC fatality locations in urban and rural areas and among health service regions. Variations between the revealed and potential accessibility of hospitals will be explored. To the author's knowledge, no studies addressing the spatial accessibility of emergency services for MVC fatality locations have been published in the academic literature.

#### Research Questions

The questions to be answered are:

1. How are MVC fatalities and fatality rates spatially distributed? Are MVC fatality occurrences and rates different between urban areas and rural areas? Are MVC fatality rates different among Texas' eight health service regions?
2. What is the distribution of spatial accessibility to EMS services for MVC fatalities? Does accessibility differ between urban and rural areas? Does accessibility differ among health service regions?

3. What is the distribution of spatial accessibility to hospitals for MVC fatalities?  
Does accessibility differ between urban and rural areas? Does accessibility differ among health service regions?
4. What is the combined distribution of spatial accessibility to EMS services and hospitals for MVC fatalities? Does accessibility differ between urban and rural areas? Does accessibility differ among health service regions?
5. Is the revealed spatial accessibility of hospitals for MVC fatalities different from the potential accessibility of hospitals?

#### Hypotheses

Hypothesis I: MVC fatality occurrences and fatality rates differ between urban and rural areas and among the eight health service regions.

Hypothesis II: EMS service accessibility differs between urban and rural areas and among the eight health service regions.

Hypothesis III: Hospital accessibility differs between urban and rural areas and among the eight health service regions.

Hypothesis IV: Accessibility for the combination of EMS services and hospitals differs between urban and rural areas and among the eight health service regions.

Hypothesis V: The revealed spatial accessibility and potential spatial accessibility of hospitals for MVC fatalities are different.

The significance level for all statistical tests is 1% ( $p < 0.01$ ).

### Study Area

This study will focus on the spatial accessibility of emergency services for MVC fatality locations in the state of Texas (Figure 1). Texas has been chosen as a research area for several reasons. Texas had the second highest number of MVC fatalities of any state in the United States in 2008 (National Highway Traffic Safety Administration

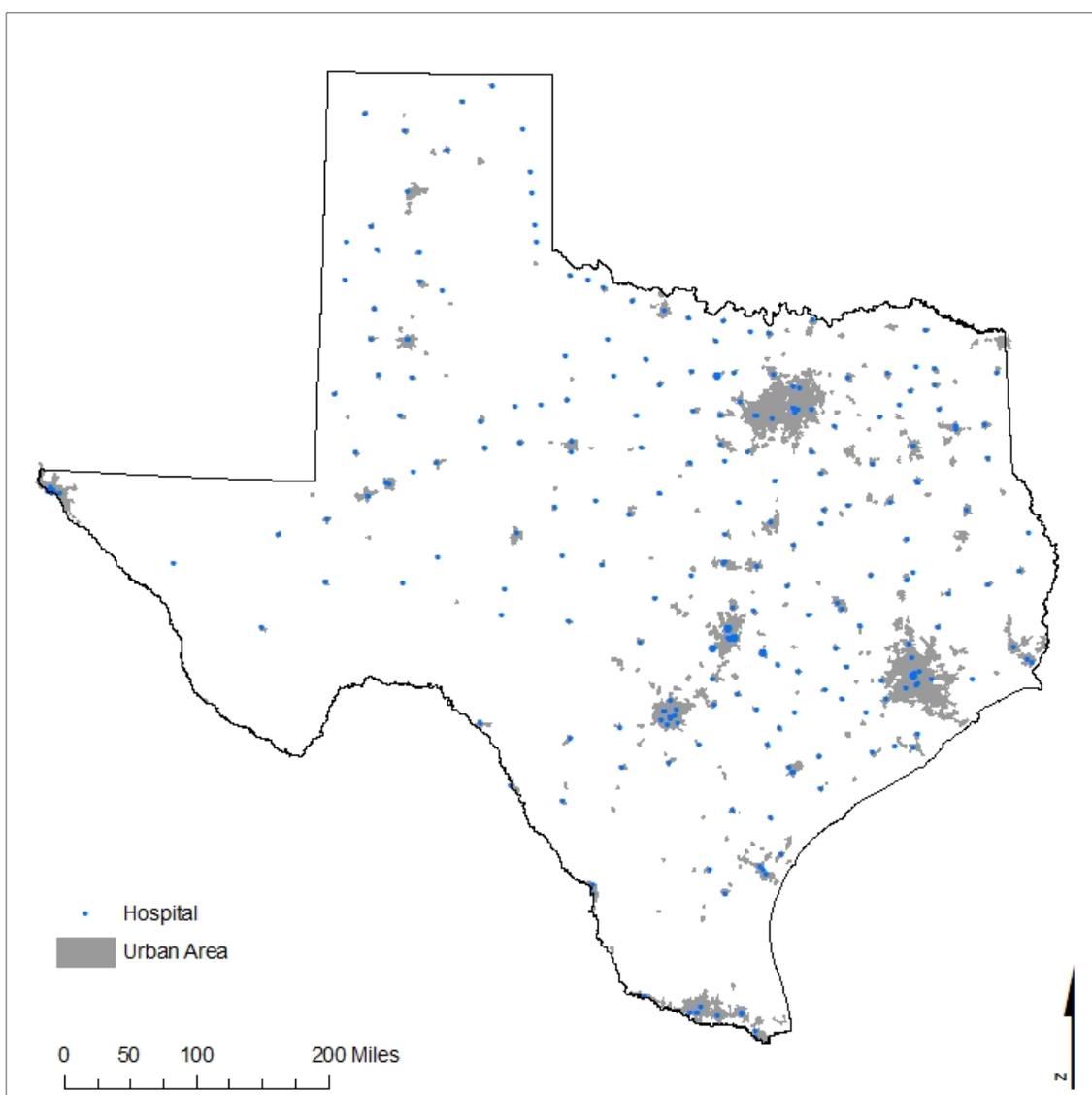


Figure 1. The study area of Texas (ESRI Data & Maps 2006; U.S Department of Health and Human Services Health Resources and Services Administration 2010; United States Bureau of the Census 2009a).

2008b). Texas had 61,954 serious MVCs occur in 2008 resulting in 84,508 people sustaining serious injuries. These serious MVCs resulted in 3,468 fatalities with an estimated economic loss of \$20.7 billion. This means that one person died every two-and-a-half hours as a result of a MVC (Texas Department of Transportation 2009). Texas has a fatality rate of 1.72 fatalities per 100 million vehicle miles driven, much higher than the national average of 1.27 fatalities per 100 million vehicle miles driven (National Highway Traffic Safety Administration 2008b). The average prehospital time for rural fatal MVCs in Texas was 5.68 minutes longer than the national average and the average prehospital time for urban fatal MVCs in Texas was 2.64 minutes longer than the national average (National Highway Traffic Safety Administration 2008b). Approximately 17.5% of the Texas population lives in rural areas (United States Bureau of the Census 2009b) and 23.6% of MVCs occurred in rural areas in 2009. Yet, over 54% of all MVC fatalities occurred in rural areas (Texas Department of Transportation 2009). These differences in MVC prehospital times and fatality rates suggest that research is needed in Texas to identify disparities in spatial accessibility to emergency services.

### Data

To complete the analyses, several types of data were assembled from secondary data sources. The variable used to define the location of emergency events is the location of MVC fatality events. For simplicity, the phrase “MVC fatality” is used for the remainder of this study to refer to the location of an MVC event that ultimately resulted in a fatality. The phrase is not an indication of where the victim died, but rather where the MVC event occurred that ultimately resulted in the fatality. It should be noted that

the assessment of all MVC locations, not just MVC fatality locations, could provide a more thorough evaluation of emergency service accessibility. However, the data required to complete this study is only available for MVC fatality events.

Data on MVC fatality events was acquired from the Fatality Analysis Reporting System (FARS) (National Highway Traffic Safety Administration 2010). FARS documents all MVCs that occur on a road open to the public and result in at least one death within thirty days of the crash. Data in the FARS is collected from police accident/crash reports (National Highway Traffic Safety Administration 2008a) and is regulated by the National Highway Traffic Safety Administration. FARS is a national database that houses MVC fatality data dating back to 1994. The FARS online database provides a query system to extract MVC fatality data by year. For this study, data on MVCs in Texas occurring from 2006 through 2008 are used. These years were chosen because they represent the most recently available data and provide a sufficient sample size for analysis. A total of 10,379 MVC fatalities occurred from 2006 to 2008 and were extracted from the FARS for analysis. When extracting data, the user can query the database to extract specific variables describing each fatality event. The extracted variables that identify the location of MVC fatalities are latitude and longitude. Latitude and longitude are given in decimal degrees, and are available for most MVC fatalities. All MVC fatalities lacking latitude and longitude data are omitted from the analysis. Latitude and longitude data is missing for 247 records (Table 1).

In addition to latitude and longitude data, the FARS dataset contains multiple time variables. The dataset includes information on MVC crash time, EMS notification time, EMS arrival time on scene, and EMS arrival time at hospital. From these distinct times,

three time frames were calculated for analysis. The time between EMS notification and EMS arrival on scene was calculated and is referred to as EMS response time. For this study, EMS service accessibility is defined by EMS response time. The time it takes for EMS to arrive at the scene of an MVC fatality is an indicator of the distance between the MVC and the ambulance depot location. Although the actual geographic location of ambulance depots would be useful for this analysis, a dataset with the location of all ambulance depot locations in the state of Texas is not currently available.

The time calculated between EMS arrival on scene and EMS arrival at the hospital is referred to as hospital transport time. Hospital transport time defines hospital accessibility. The distance traveled to a hospital is indicated by the time required to travel from the location of a MVC to a hospital. In this study, EMS scene time was included in the hospital transport time variable because EMS scene time is part of hospital transport time in the FARS dataset. Although lack of EMS scene time has been noted as a limitation in several EMS response time and transport time studies (Blackwell and Kaufman 2002; Pepe 1987; Pons et al. 2005) and use of EMS scene time could

Table 1. Total records retrieved from the FARS<sup>1</sup> and records removed from analysis due to missing data.

	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>All Data</b>
<b>Total Fatalities</b>	3531	3466	3382	10379
<b>Records missing Latitude and Longitude Data</b>	49	82	116	247
<b>Records missing at least one time element</b>	1867	1976	1732	5575
<b>Total usable records</b>	1615	1408	1534	<b>4557*</b>

<sup>1</sup>(National Highway Traffic Safety Administration 2010)

\* Total records used for analysis.

improve the accuracy of analysis, the more important factor to consider for patient outcomes is the total time elapsed before receiving definitive care (Pepe 1987). In this study, total prehospital time was used in the analysis completed to answer research question four. Analysis proceeded without the consideration of EMS scene time, but its absence will be acknowledged as a limitation.

Total prehospital time was used to assess the overall accessibility of emergency services. Total prehospital time was calculated as the total time between the MVC and EMS arrival at the hospital. The time between the MVC and EMS notification was calculated and combined with EMS response time and hospital transport time to obtain total prehospital time. The time between the occurrence of an MVC and EMS notification will be referred to as activation time (Carr et al. 2006). Some MVC fatalities do not have the four time components necessary to calculate activation time, EMS response time, and hospital transport time. Only MVC fatalities with all time components were used in the analysis. One or more time components were missing for 5,575 records (Table 1). After removing all records that were missing latitude and longitude data or time data, a total of 4,557 MVC fatalities remained and were used for analysis. The cases totaled 44% of all MVC fatalities for 2006 through 2008.

An urban boundaries polygon shapefile was obtained from the U.S. Census Bureau (United States Bureau of the Census 2009a). Urban areas were delineated from 2000 census data. Urban areas are classified as all territories within an urbanized area (UA) or an urbanized cluster (UC). UAs and UCs are defined as census block groups or blocks having a density of at least 1,000 people per square mile and surrounding census blocks with a population density of at least 500 people per square mile. Rural areas are

classified as any territory that is not classified as urban (United States Bureau of the Census 2009b). Different definitions can cause variations in the geographic representation of urban areas. For the purpose of this study, United States Bureau of the Census defined urban areas were used because they have been used in previous emergency accessibility studies (Carr et al. 2009). Additional boundary shapefiles including the state of Texas and block groups were obtained from the U.S. Census Bureau (United States Bureau of the Census 2009a).

A population raster grid was acquired from the Center for International Earth Science Information Network (CIESIN) at Columbia University (Center for International Earth Science Information Network Columbia University 2000). The grid contains data from the 2000 U.S. Census Summary 1 file and has a cell resolution of 30 arc-seconds or approximately 800 meters squared. A population figure is associated with each raster cell and is assigned from block level data (Seirup and Yetman 2006). The population grid was used in the analysis of MVC fatality density.

The location of hospitals was obtained from a combination of sources. Hospital locations were primarily extracted from a shapefile included with the ESRI data available with ArcMap 9.2 (ESRI Data & Maps 2006). The shapefile contains the addresses of hospitals for the entire United States. The hospitals shapefile available from ESRI does not contain records for all Texas Department of State Health Services (DSHS) hospitals. Any hospitals not available from the ESRI shapefile were identified from a shapefile available from the U.S. Department of Health and Human Services Health Resources and Services Administration (2010). The ESRI dataset was the primary source of hospital data because the U.S. Department of Health and Human Services Health Resources and

Services Administration data was not available until late in the analysis process. Only hospitals with a trauma level designation were extracted from the shapefiles because trauma centers are equipped to handle trauma victims such as individuals involved in MVCs (Texas Department of State Health Services 2007). All hospital locations not designated as trauma facilities were excluded from analysis.

Texas' eight health service regions are found on the Texas DSHS website (Texas Department of State Health Services 2006). A shapefile of the boundaries was created, because no shapefile of the regions is available for download. The eight health service regions are: Region 1-Lubbock, Region 2/3-Arlington, Region 4/5 North-Tyler, Region 6/5 South-Houston, Region 7-Temple, Region 8-San Antonio, Region 9/10-El Paso, Region 11-Harlingen.

### Data Analysis

#### *Distribution of MVC Fatalities and Fatality Rates*

To answer the first research question, a raster surface of MVC fatality density was created. The Kernel Density tool in ArcGIS (ESRI 2009) was used to visually identify patterns of MVC fatality occurrence. The raster cell resolution chosen was 30 arc-seconds, or 800.37 meters squared, for simple integration into additional analysis with the population raster grid from the CIESIN. The default Kernel Density search radius of 39151.25 was used to calculate density. The default search radius is defined as the smallest of the height or width of the extent of the input layer (location of all MVC fatality events), divided by 30 (ESRI 2010). The MVC fatality rate raster extended beyond the borders of Texas, so the Extract by Mask tool was used to extract only raster cells that fell within Texas borders. To develop a clear understanding of MVC fatality

distribution, a normalized density surface was created that considered both the location of MVC fatalities and population. MVC fatality density raster cell values were divided by the population raster cell values using the Raster Calculator tool. The combined raster presented a visual representation of MVC fatality rates across the state.

To evaluate if MVC fatality rates are statistically different between urban areas and rural areas, it was necessary to identify urban and rural blocks groups. To delineate urban and rural block groups, the boundaries of the Urban Areas shapefile retrieved from the U.S. Census Bureau was used. All block groups that overlapped the urban shapefile by more than fifty percent were designated urban. The remaining blocks were coded rural.

MVC fatality rates for each block group were calculated by dividing the number of MVC fatalities that occurred in a block group by the population of the block group. Fatality rates and urban or rural classification for each block group was imported into SPSS statistical software. A Mann-Whitney test, the non-parametric equivalent of a T-test, was performed on the data. The test variable was the MVC fatality rate per block group and the grouping variable was urban or rural. The Mann-Whitney test assumes that two samples are randomly and independently drawn from source populations, that there is independence within samples and between samples, and that the measures within the populations are of at least an ordinal scale. The data do not need to be normally distributed (Lowry 1999). The data fulfill these assumptions.

Block group MVC fatality rates were compiled for Texas' eight health service regions (Figure 2). The statistical significance of the difference in MVC fatality rates for

the eight health service regions was determined with a Kruskal-Wallis test. Like the Mann-Whitney test, the Kruskal-Wallis test makes no assumptions about normal distribution and the samples must be randomly and independently drawn from source populations (Lowry 1999). However, the Kruskal-Wallis test is used to test more than two independent samples, eight in this instance. The test variable was the MVC fatality rate for each block group and the grouping variable was the eight health service regions.

#### *Revealed EMS Accessibility*

EMS response time was used to measure EMS accessibility for MVC fatalities and answer research question two. It was assumed, for the purposes of this study, that a

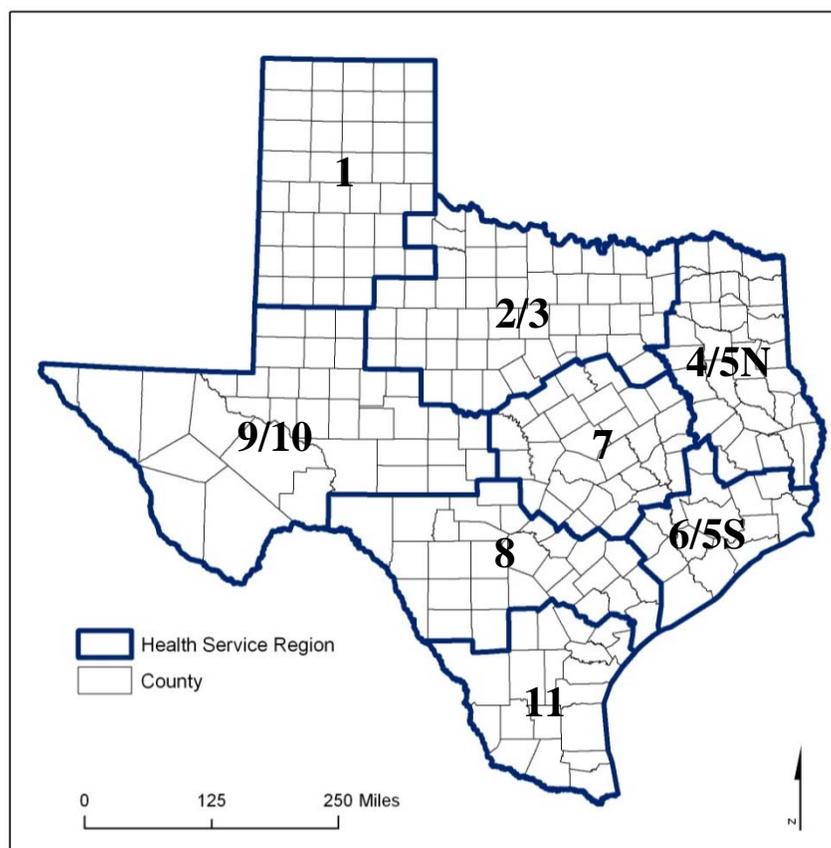


Figure 2. Eight Texas health service regions (United States Bureau of the Census 2009a; Texas Department of State Health Services 2006).

longer EMS response time indicates more limited access to EMS services than a shorter EMS response time. A raster surface was created using Kriging Interpolation in ArcGIS. Kriging interpolation allows value predictions to be made at locations where no data is present. EMS response time values associated with each MVC fatality were used to interpolate response time values for all of Texas. The ordinary Kriging method was used, the semivariogram model selected was spherical, the output cell size was 800.37 meters (equal to all other raster cell resolutions used in this study), the search radius was variable, and the number of points was twelve. After the raster was created, the Extract by Mask tool was used to select only the raster cells that fell within Texas. The raster surface created by Kriging interpolation visually represented the revealed spatial accessibility of EMS services. The urban areas shapefile was overlaid on the raster surface to visually assess accessibility difference for urban and rural areas.

A Mann Whitney test determined if there is a statistically significant difference for EMS response times between urban and rural areas. Existing research suggests that rural EMS response times are significantly longer than urban EMS response times. A Kruskal-Wallis test evaluated the presence of a significant difference for EMS response times among health service regions. The Kruskal-Wallis test provided statistics on the mean rank value of EMS response times for each health service region.

#### *Revealed Hospital Accessibility*

To address question three, the revealed spatial accessibility to hospitals was assessed using hospital transport time for MVC fatalities. The same GIS analysis used to assess EMS response times was used for hospital transport time. Kriging interpolation was used to simulate hospital transport times for all of Texas based on known transport

times for MVC fatalities. The raster surface produced by kriging interpolation highlighted variations in accessibility across the state. The raster surface was reduced to the boundaries of Texas using the Extract by Mask tool.

A Mann-Whitney test was performed on hospital transport times to determine if urban and rural transport times are statistically different. Statistical differences in hospital transport times among health service regions were assessed using the Kruskal-Wallis test. Like the analysis for EMS accessibility, mean rank values calculated in the Kruskal-Wallis test were used to rank the accessibility to EMS services for each health service region.

#### *Total Spatial Accessibility*

Question number four was answered by creating a raster surface combining the accessibility of EMS services and hospitals, as well as the time between the occurrence of a MVC and EMS notification for the activation time. Activation time was included because the outcome for trauma victims is affected by the entire time elapsed between injury and definitive care (Pepe 1987) and should be included to obtain an overall understanding of emergency service accessibility. The total combined time between MVC occurrence and arrival at the hospital is referred to as prehospital time and represents total accessibility to emergency services. The urban areas shapefile was overlaid on the total accessibility layer for a visual representation of accessibility differences between urban and rural areas. An identical visual assessment was completed for the eight health service regions.

A Mann-Whitney test determined if there is a statistical difference in prehospital times for MVC fatalities occurring in urban areas and rural areas. The Kruskal-Wallis

test compared prehospital times for MVC fatalities occurring in the eight health service areas to assess if a statistical difference in prehospital times exists. Relative accessibility rankings were assigned to each health service regions, using the calculated mean rank values from the Kruskal-Wallis test.

#### *Potential Spatial Accessibility of Hospitals*

To further explore the spatial accessibility of emergency services and answer question five, the potential accessibility of hospitals was evaluated and compared to the revealed accessibility of hospitals. The potential accessibility analysis assessed the potential accessibility of hospitals for all of Texas. Comparison of the potential and revealed accessibility of hospitals in relation to MVC fatalities was completed to explore variation between the potential use of services and the revealed use of services.

The potential accessibility of hospitals was estimated by creating hospital service areas. Service area buffers were calculated around all hospitals designated as trauma centers. The analysis was limited to trauma centers because they are best equipped to handle patients requiring advanced emergency care (Texas Department of State Health Services 2007). This study followed previous research and used travel time intervals of 30, 45, and 60 minutes to determine service areas (Carr et al. 2009). Drawing from past research, average ambulance driving speeds of 20.1 and 56.4 miles per hour for urban and rural areas, respectively, were used (Carr et al. 2006; Carr et al. 2009). Average time spent at scene was also included when estimating hospital service areas. Previously established on scene times for EMS in urban and rural areas are 13.5 and 15.1, respectively (Branas et al. 2005; Carr et al. 2006; Carr et al. 2009). Average ambulance travel speed and average scene time were combined with service area time intervals to

estimate the areas served by each hospital (Table 2). The equation used to find buffer distances was:

$$\text{Buffer radius} = \left[ \frac{\text{service area time interval} - \text{scene time}}{60 \text{ min.}} \right] \times \text{driving speed}$$

The resulting service areas do not represent an average accessibility time, but rather a maximum service time. The time interval used to describe a hospital's potential service area describes the accessibility time for the outer edge of the service area. This means that it cannot be assumed that potential accessibility times for an entire service area are 30, 45, or 60 minutes. The average potential prehospital time for each service area is actually less than the time interval used to describe the service area. The 30, 45, and 60 minute times refer to the maximum accessibility times in the service areas.

The buffers were created as rings, meaning that no service areas for a single hospital overlapped. For example, the 45 minute service area for a rural hospital extended from the outer edge of the 30 minute service area to a distance of 28.1 miles (the maximum 45 minute drive distance). Service areas for two or more hospitals sometimes overlapped because of their proximity. In instances of service area overlap, the portion of service area with the shortest accessibility time interval was retained and the portion of the service area with the longer time interval was removed. The service area with the shortest time was retained because it was assumed that an injured victim is

Table 2. Buffer distances used to define service areas for hospitals in urban and rural areas.

	<b>30 Minute Service Area</b>	<b>45 Minute Service Area</b>	<b>60 Minute Service Area</b>
<b>Rural</b>	14.0 mi.	28.1 mi.	42.2 mi.
<b>Urban</b>	5.5 mi.	10.6 mi.	15.6 mi.

more likely to be taken to a nearer hospital than a more distant hospital. Although, this is not always the case, the analysis called for a solution for areas of overlap and this was deemed the most suitable.

The EMS response and hospital transport time raster layers calculated from FARs data for the revealed accessibility analysis were combined to create one accessibility measure. For clarity, the combined time frame of EMS response time and hospital transport time is referred to as EMS/hospital time. EMS response time and hospital transport time were combined because the calculations for potential service area buffers combine EMS response, EMS scene time, and hospital transport time. Recall that hospital transport time from FARs data includes scene time. Combining the EMS response time and hospital transport time revealed accessibility rasters allowed for a more symmetrical comparison of potential and revealed accessibility. The cell values of the revealed accessibility raster were reclassified. The default “Value” field was reclassified to reflect average time values. For example, the field with a “Value” of 1 was reclassified as the shortest EMS/hospital time of 15 minutes. The reclassification was completed for use in Zonal statistics analysis. In the Zonal statistics tool, statistics are calculated based on the “Value field”.

The 30, 45, and 60 minute potential hospital service areas layers were rasterized. The raster layer was created based on potential service area times (Figure 3). In Spatial Analyst, the “Zonal statistics as Table” tool was used to calculate average raster cell values from the EMS/hospital time raster for each potential accessibility service area.

The Zonal statistics tool combines cell values from a raster within the borders of another raster to calculate statistics. For this analysis, the mean, median, maximum and minimum revealed accessibility EMS/hospital time values were calculated within each potential accessibility service area. The statistics output table was joined to the potential service areas raster to produce a table with both potential service area times and revealed

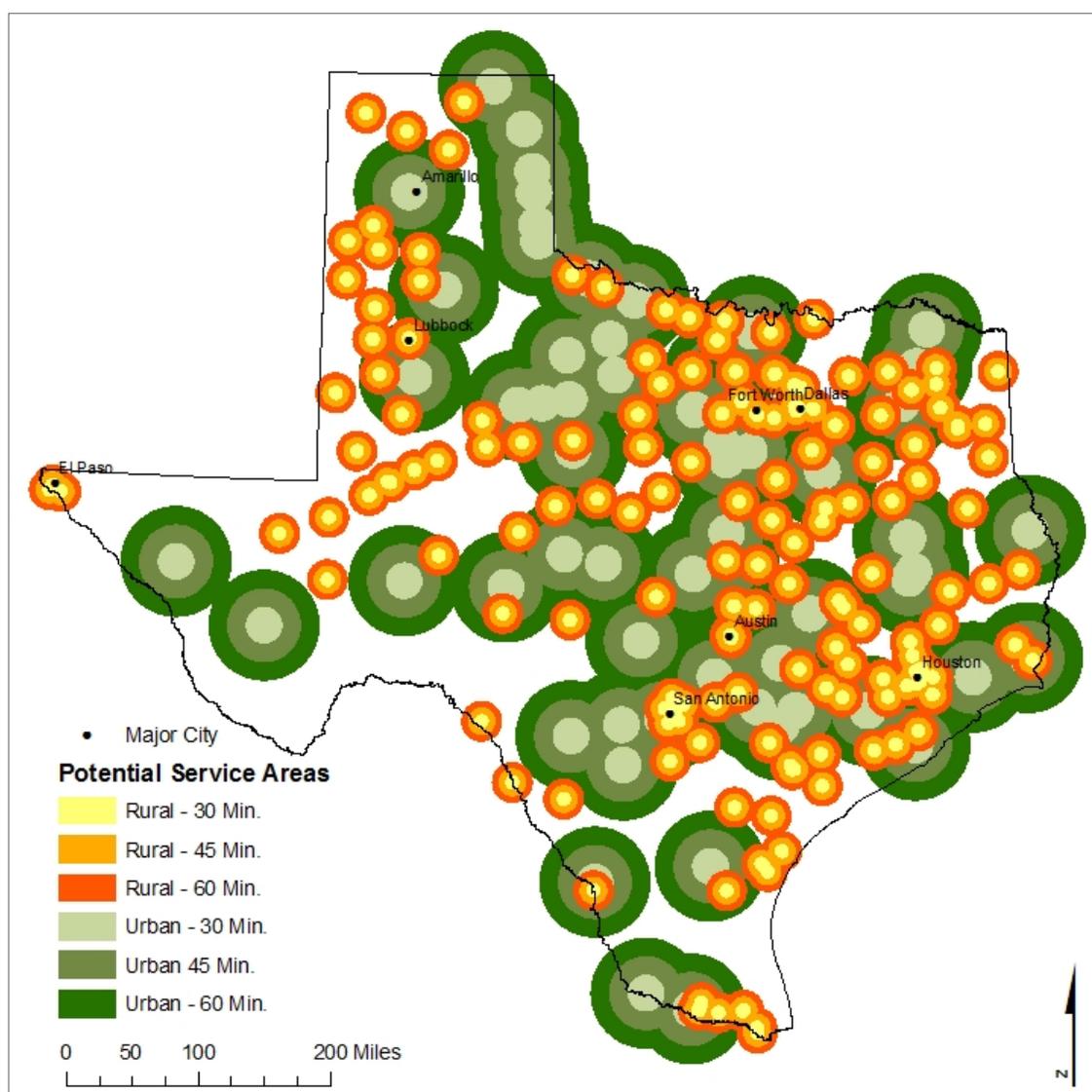


Figure 3. Potential service areas for urban and rural hospitals (ESRI Data & Maps 2006; U.S Department of Health and Human Services Health Resources and Services Administration 2010; United States Bureau of the Census 2009a).

service area times. Revealed EMS/hospital times were compared to the potential accessibility service area buffer times.

## CHAPTER IV

### RESULTS

#### *Distribution of MVC Fatalities and Fatality Rates*

The distribution of MVC fatalities and fatality rates were evaluated through visual interpretation and statistical tests. Visual analysis of the MCV fatality density raster surface shows dense clusters of MVC fatalities in and around the major urban areas of Texas. Clusters can be seen in urban locations such as Dallas, Fort Worth, Austin, San Antonio, and Houston (Figure 4). Rural areas appear to have fewer occurrences of fatal MVCs.

The spatial distribution of MVC fatality rates does not occur in clusters (Figure 5). Visual interpretation of the MVC fatality rate raster overlaid with the urban areas shapefile reveals higher fatality rates in the less densely populated western part of the state. Fatality rates appear lower for most of the eastern portion of the state, particularly in and around urban areas.

MVC fatality rates for block groups are different among urban and rural areas. Descriptive statistics reveal different MVC fatality rate means for urban and rural areas. The average fatality rate for urban areas is 33.7 per 100,000 population and the average fatality rate for rural areas is 105.6 per 100,000 population. The Mann-Whitney test comparing fatality rates reveals that there is a significant difference between urban and rural areas at the 1% confidence level ( $p < 0.01$ ).

MVC fatality rates between the eight health service areas are different. The fatality rates per 100,000 population for each of the eight health service regions are 39.8 in Region 1, 77.6 in Region 2/3, 42.2 in Region 4/5N, 37.8 in Region 6/5S, 65.5 in Region 7, 48.3 in Region 8, 30.0 in Region 9/10, and 21.9 in Region 11 (Table 3 and Figure 5). Visual inspection of fatality rate distribution for health service regions reveals variation among regions. Health service regions in the western half of the state have

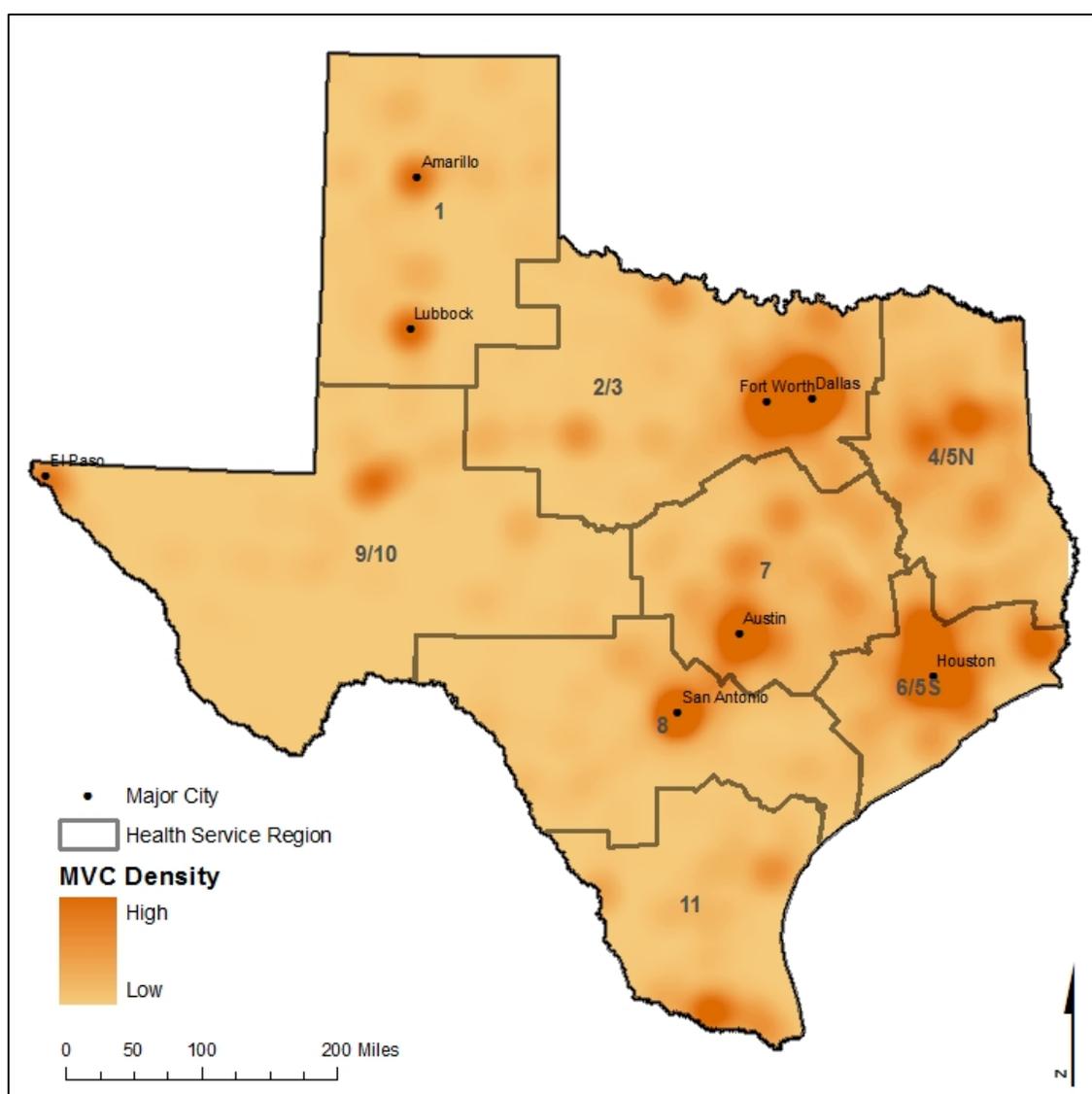


Figure 4. Motor vehicle fatality distribution for 2006-2008 (National Highway Traffic Safety Administration 2010; United States Bureau of the Census 2009a).

Table 3. MVC fatality rates for the eight Health Service Regions.

Health Service Region	MVC Fatalities Per 100,000 Population	Number of MVCs
1 (Lubbock)	39.8	278
2/3 (Arlington)	77.6	1234
4/5N (Tyler)	42.2	572
6/5S (Houston)	37.8	832
7 (Temple)	65.5	681
8 (San Antonio)	48.3	378
9/10 (El Paso)	30.3	266
11 (Harlingen)	21.9	316

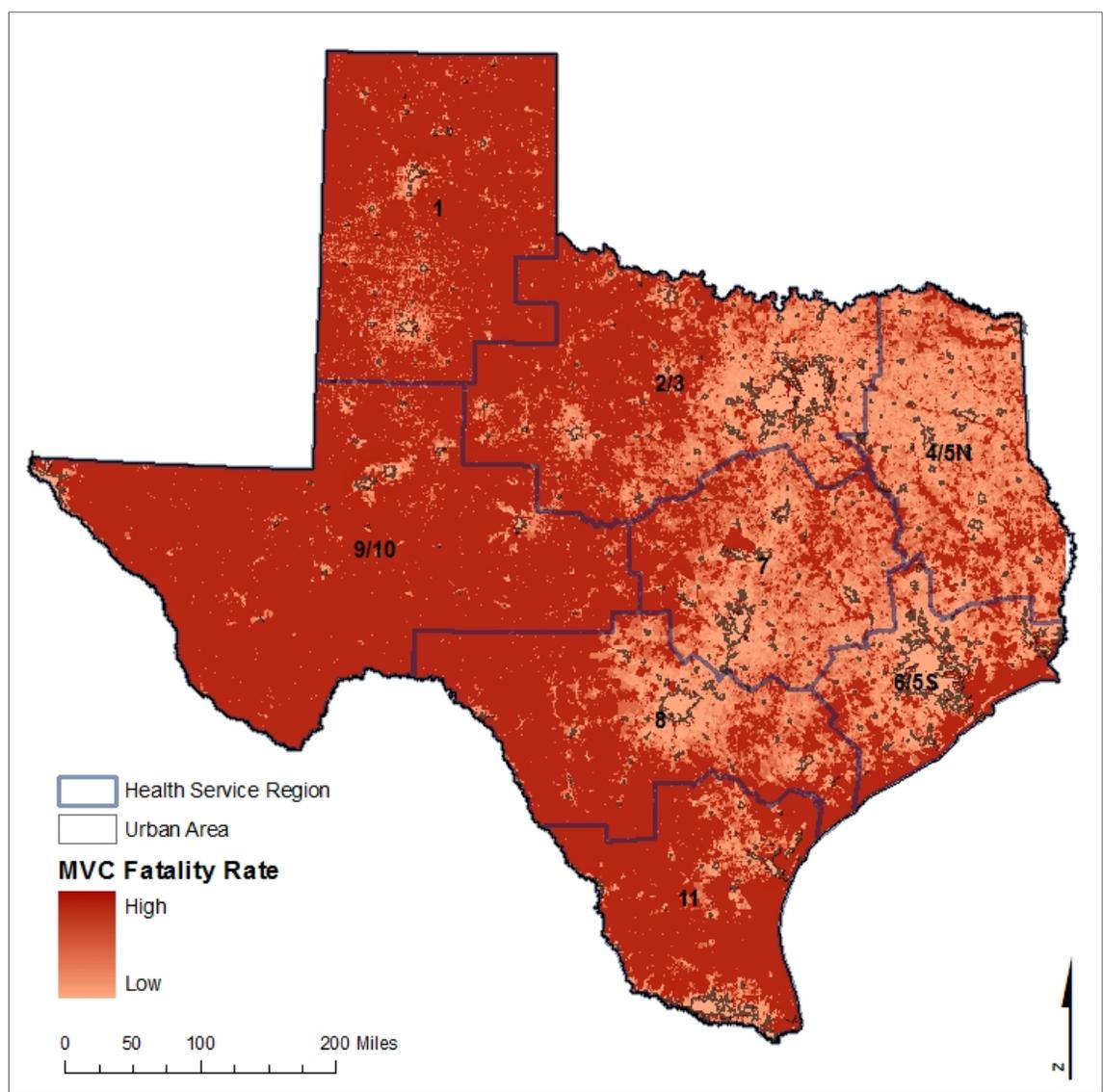


Figure 5. Motor vehicle crash fatality rate distribution for 2006-2008 (National Highway Traffic Safety Administration 2010; United States Bureau of the Census 2009a).

higher fatality rates than health service regions in the eastern part of the state. A Kruskal-Wallis test confirms at the 1% confidence level ( $p < 0.01$ ) that mean fatality rates for the eight health service regions are significantly different.

#### *Revealed EMS Accessibility*

Spatial accessibility to EMS services varies. The average EMS response time for all MVC fatalities is 11.99 minutes. Response times range from 0 minutes to 81 minutes. The average response time for urban areas is 7.19 minutes and the average response time for rural areas is 14.85 minutes (Table 4). The interpolation raster of EMS response times shows variation for response times across the state. When urban areas are overlaid on the response time layer it appears that urban areas have some of the shortest response times (Figure 6). A Mann-Whitney test comparing response times revealed a significant difference between urban and rural areas at the 1% confidence level ( $p < 0.01$ ) (Table 5). Response times among the eight health service regions were compared in a Kruskal-Wallis test. The test determined at the 1% confidence level ( $p < 0.01$ ) that response times among the health service regions are significantly different (Table 6).

As described in the Data Analysis section, the mean rank values from the Kruskal-Wallis test were used to determine the relative accessibility to EMS services for

Table 4. Average prehospital times for MVC fatalities in rural areas, urban areas, and all of Texas.

	Activation Time (min.)		Response Time (min.)		Transport Time (min.)		Total Prehospital Time (min.)		Number of MVCs
	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance	
Urban	4.65	57.65	7.19	31.10	27.85	217.24	39.69	322.12	1698
Rural	13.70	5237.83	14.85	113.27	39.24	564.07	67.79	6196.39	2859
Total	10.33	3326.31	11.99	96.35	35.00	465.12	57.32	4191.57	4557

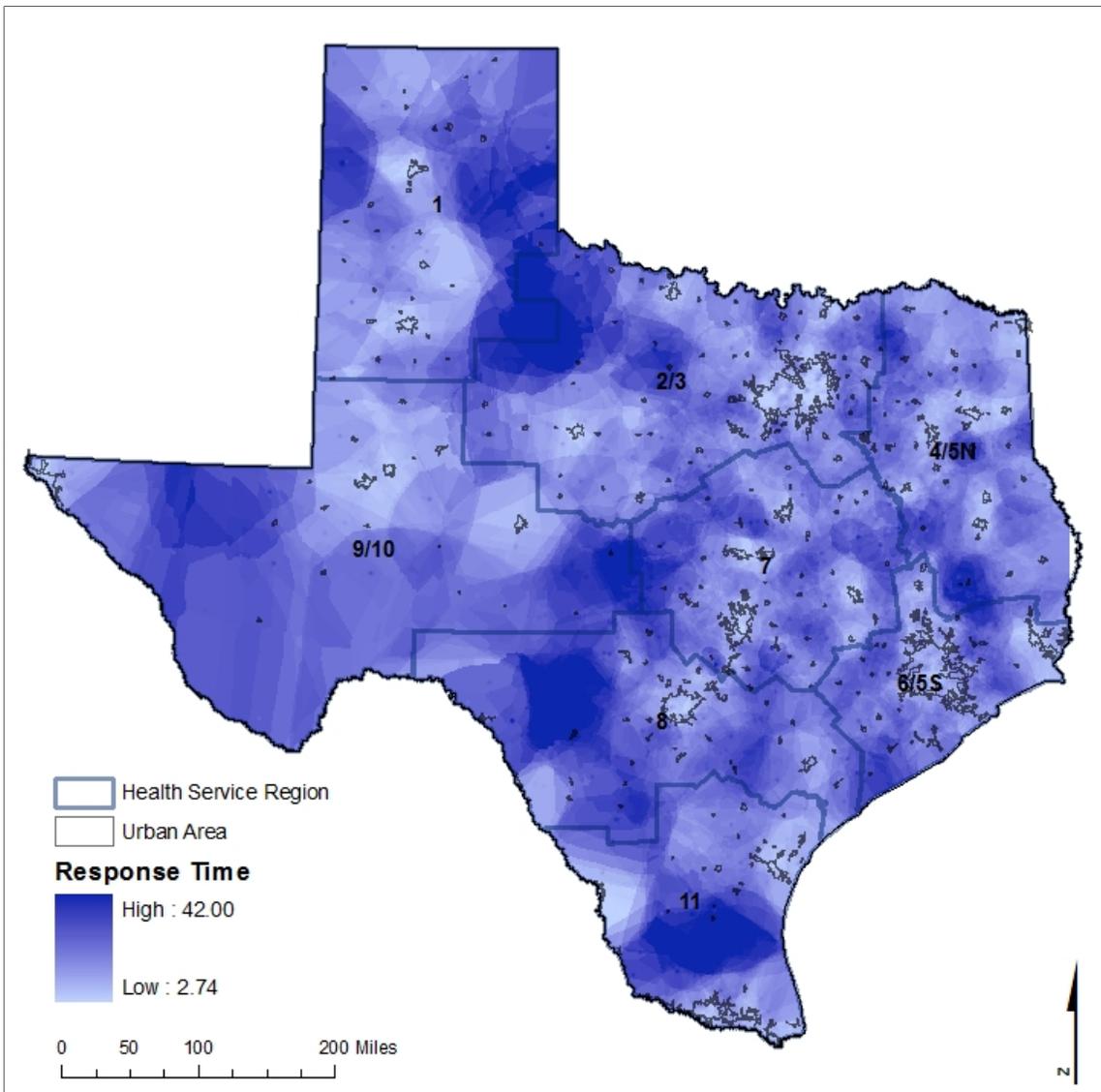


Figure 6. EMS response time for fatal MVCs in Texas ( National Highway Traffic Safety Administration 2010; United States Bureau of the Census 2009a).

Table 5. Results of Mann-Whitney test for accessibility differences between urban and rural areas.

	<b>z value</b>	<b>Significance (2-tailed)</b>
<b>EMS Response Time</b>	-29.696	.000
<b>Hospital Transport Time</b>	-22.546	.000
<b>Total Prehospital Time</b>	-31.001	.000

Table 6. Results of Kruskal-Wallis test for accessibility differences among the eight health service regions.

	Chi-Square	Significance (2-tailed)
<b>EMS Response Time</b>	117.022	.000
<b>Hospital Transport Time</b>	130.965	.000
<b>Total Prehospital Time</b>	176.458	.000

each health service region. When compared, the mean rank values indicate relative accessibility to EMS services for each health service region. With larger ranking numbers corresponding to longer transport times, a ranking of one for a health service region represents the greatest accessibility and eight represents the poorest accessibility. Note that the assigned accessibility values of one through eight do not represent a precise level of accessibility. Rather, they represent relative accessibility. For example, the health service region assigned a value of one has greater accessibility than the region assigned a value of two. The relative accessibility for EMS services in the eight health service regions, ranked from greatest to poorest, are: Region 7, Region 8, Region 4/5N, Region 11, Region 6/5S, Region 1, Region 9/10, and Region 2/3 (Table 7).

#### *Revealed Hospital Accessibility*

Spatial accessibility to hospitals for MVC fatalities is not equal in all locations. Average transport time for all of Texas is 35.0 minutes. Transport times range from 0 minutes to 209 minutes. The average transport time for rural areas is 39.24 minutes and the average transport time for urban areas is 27.85 minutes. Visual comparison of transport times and urban areas suggests variation in transport times between urban and rural areas (Figure 7). The Mann-Whitney test confirms with a 1% confidence level ( $p < 0.01$ ) that transport times for urban and rural areas are significantly different (Table 5).

Table 7. Ranked revealed accessibility for Texas' eight health service regions.

Health Service Region	MVC Fatalities Per 100,000 Population	EMS Accessibility Rank*	Hospital Accessibility Rank*	Total Accessibility Rank*
1 (Lubbock)	39.8	6	7	6
2/3 (Arlington)	77.6	8	8	8
4/5N (Tyler)	42.2	3	3	4
6/5S (Houston)	37.8	5	1	2
7 (Temple)	65.5	1	4	3
8 (San Antonio)	48.3	2	2	1
9/10 (El Paso)	30.3	7	6	7
11 (Harlingen)	21.9	4	5	5

\* A value of 1 represents the greatest accessibility. A value of 8 represents the poorest accessibility.

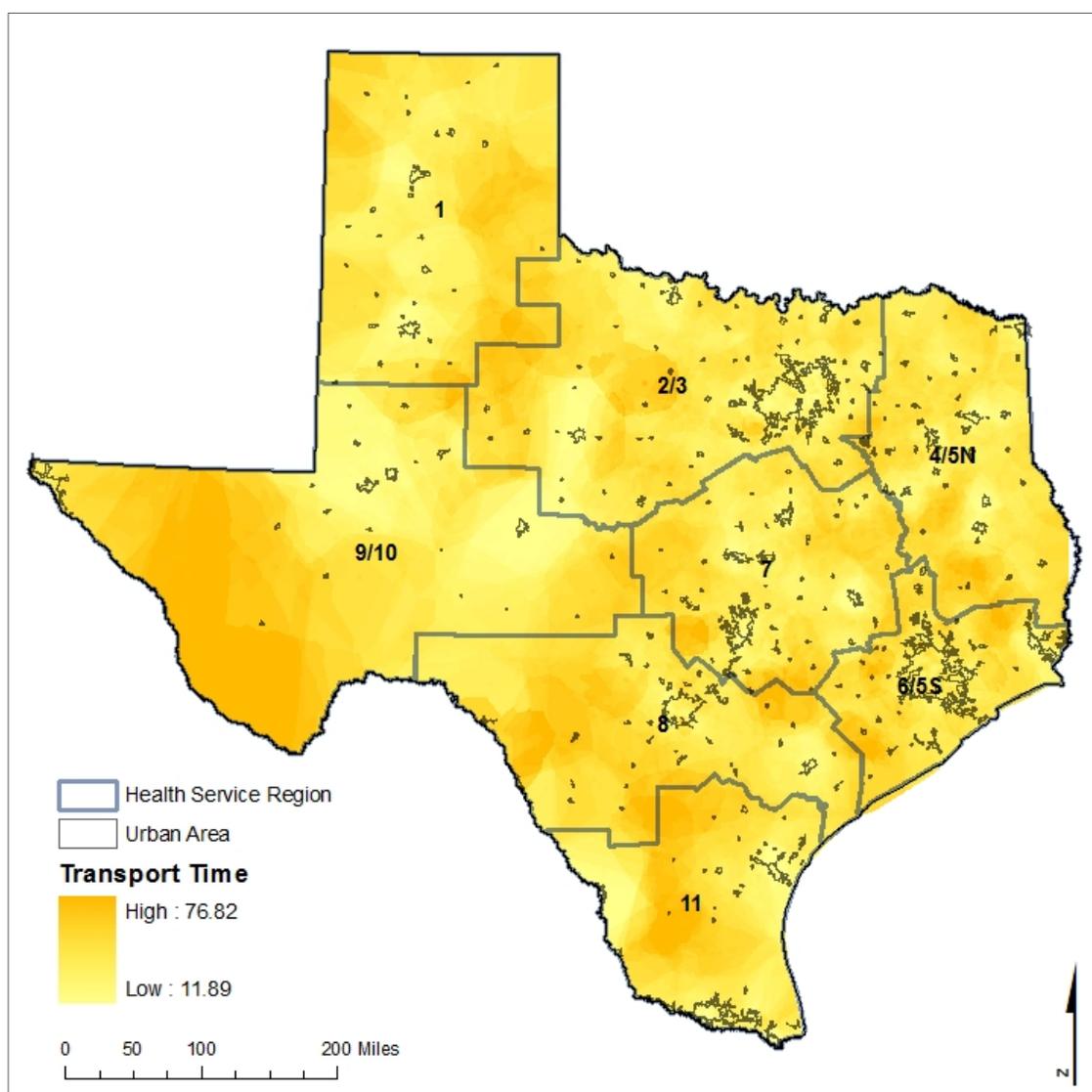


Figure 7. Hospital transport time for fatal MVCs in Texas (National Highway Traffic Safety Administration 2010; United States Bureau of the Census 2009a).

Comparison of transport times using the Kruskal-Wallis test reveals with a confidence level of 1% ( $p < 0.01$ ) that transport times are significantly different among the eight health service regions (Table 6). Using the mean rank value from the Kruskal-Wallis test, the eight health service regions were ranked to represent relative accessibility to hospitals. Ranked from greatest to poorest, the relative accessibility for hospitals in the eight health service regions are: Region 6/5S, Region 8, Region 4/5N, Region 7, Region 11, Region 9/10, Region 1, and Region 2/3 (Table 7).

#### *Total Spatial Accessibility*

Spatial accessibility to both EMS services and hospitals varies across the state (Figure 8). Total prehospital time calculations include verification time, EMS response time, and hospital transport time. The average verification time is 10.33 minutes for all MVC fatalities. The average verification time for rural and urban areas is 13.70 minutes and 4.65 minutes, respectively. The average total prehospital time for all fatal MVCs is 57.32 minutes. Average prehospital time is 39.69 minutes for urban areas and 67.79 for rural areas. Substantial spatial and temporal variation in the interpolated prehospital time raster makes visual interpretation of the results difficult. However, a Mann-Whitney test reveals with a confidence level of 1% ( $p < 0.01$ ) that mean prehospital times for urban and rural areas are significantly different (Table 5). A Kruskal-Wallis test with a confidence level of 1% ( $p < 0.01$ ) confirms that total prehospital times among the health service regions are significantly different (Table 6). Mean rank values from the Kruskal-Wallis test were used to rank the relative total accessibility to emergency services for the health service regions. The relative accessibility for EMS services in the eight health service regions, ranked from greatest to poorest, are: Region 8, Region 6/5S, Region

7, Region 4/5N, Region 11, Region 1, Region 9/10, and Region 2/3 (Table 7).

*Potential Spatial Accessibility of Hospitals*

Comparison of potential accessibility service areas for hospitals and revealed accessibility calculated from FARS data identifies variation between the two accessibility measures. In the 30 minutes potential accessibility buffer the mean revealed EMS/hospital time is 47.9 minutes with a minimum of 20.3 minutes and a maximum of

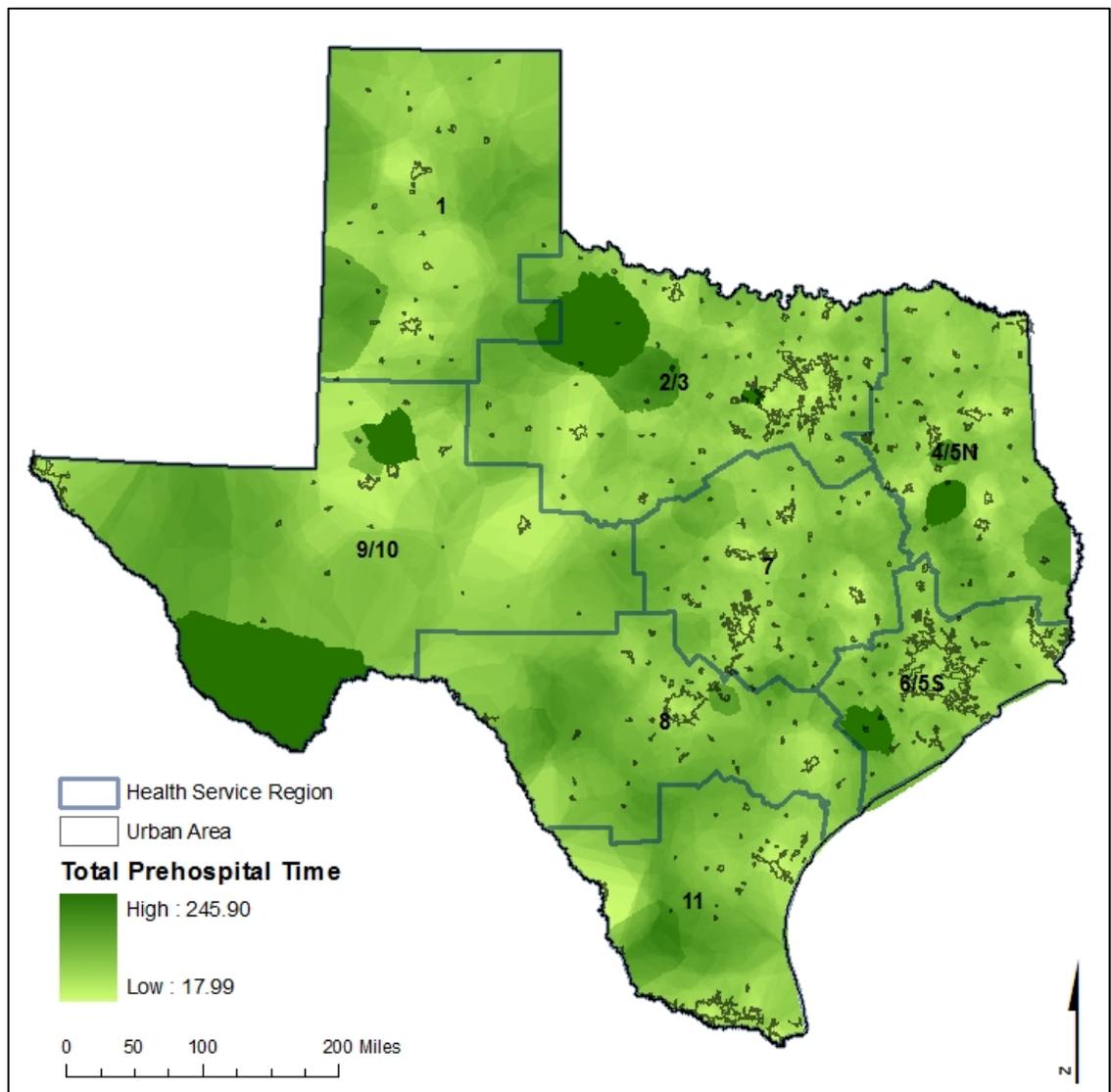


Figure 8. Total prehospital time for fatal MVCs in Texas (National Highway Traffic Safety Administration 2010; United States Bureau of the Census 2009a).

83.7 minutes. In the 45 minute potential accessibility buffer the mean revealed EMS/hospital time is 49.9 minutes, with a minimum of 24.7 minutes and a maximum of 82.3 minutes. Within the 60 minute potential accessibility buffer the mean revealed EMS/hospital time is 53.0 minutes, the minimum is 25.4 minutes and the maximum is 98.0 minutes (Table 8).

Table 8. Revealed accessibility EMS/hospital times within 30, 45, and 60 minute potential accessibility buffers.

Zone	Potential Time	Revealed Time			
		Mean	Median	Minimum	Maximum
A	30	47.9	48.4	20.3	83.7
B	45	49.9	49.2	24.7	82.3
C	60	53.0	52.2	25.4	98.0

## **CHAPTER V**

### **DISCUSSION**

The goal of this research was to evaluate emergency service accessibility in Texas by combining supply and demand, where demand is defined as the location of MVC fatalities and supply is measured as the travel time between the demand locations and EMS services and hospitals. Defining demand locations for emergency services as the location of MVC fatalities is a unique approach. Accessibility research generally uses place of residence as the demand location for emergency services (Branas et al. 2005; Carr 2009; McGregor et al. 2005; Patterson et al. 2006). Using place of residence for analysis assumes that events requiring emergency services always occur in the home. Although many emergencies occur in the home, work or motor vehicle related emergencies are common (Carr 2009). Evaluating demand for emergency services as the location of MVC fatalities does not provide a full picture of demand or accessibility. However, it provides an additional or supplementary perspective for researchers, policy makers, and planners. Understanding emergency service accessibility for specific types of emergency events such as MVCs can improve current EMS effectiveness and policies.

Visual interpretation of Kernel density results confirmed that fatal MVCs are concentrated in urban areas in Texas. A concentration of MVC fatalities in urban areas was expected because an event such as an MVC fatality is more likely to occur where population is greatest. A larger population increases the opportunities for an event to

occur. When MVC fatalities are normalized by population, to achieve a rate, a different pattern emerges. MVC fatality rates are higher in rural areas and lower in urban areas. This means that more MVC fatalities occur per 100,000 population in rural areas. These findings support previous analysis of FARS data that revealed higher MVC fatality rates in rural areas (Brown, Khanna, and Hunt 2000). The distinction between MVC fatality occurrence and MVC fatality rate highlights an important distinction for resource allocation. Urban areas have more MVC fatalities than rural areas, but rural areas have higher MVC fatality rates. Providing resources in urban areas has the potential to directly affect more MVC victims. Allocating additional resources in rural areas could affect a greater proportion of the local population. When providing resources for improving accessibility to services, the impact on outcomes must be considered.

It is important that the fatality rates calculated in this analysis are not confused with fatalities per MVC occurrence. Some research has used fatalities per MVC occurrence to evaluate the probability of a fatality occurring as the result of a MVC in a specific type of locations (e.g. urban, rural) (Clark 2003; Jones, Langford, and Bentham 1996; Papadimitriou, Mathur, and Hill 1994). The data was not available to complete this type of analysis. The probability of MVC fatalities or MVC outcomes cannot be established in this study.

Multiple factors have been identified that contribute to elevated fatality rates for MVCs (Clark 2003; Jones and Bentham 1995; Papadimitriou, Mathur, and Hill 1994). These contributing factors can generally be classified into three groups: factors that increase the severity or frequency of collisions (e.g. speed limits), factors that contribute to more serious injury during a collision (e.g. safety belt use), and factors that influence

effective treatment of injuries (e.g. prehospital times) (Clark 2003). Higher MVC fatality rates have been found among the old, pedestrians, and casualties on roads with higher speed limits (Jones and Bentham 1995). Additional contributing factors for elevated fatality rates in rural areas include extended prehospital times resulting from geographic isolation, difficult vehicle extractions, and inadequate prehospital care (Papadimitriou, Mathur, and Hill 1994). This study focuses on prehospital times as a contributor to MVC fatality rates and indicator for accessibility to emergency services. Higher fatality rates and longer pre-hospital times in rural areas suggest a connection between fatality rates and prehospital time. Studies have found higher MVC fatality rates are associated with longer prehospital times (Gonzales et al. 2006; Gonzales et al. 2009). The growing body of literature, including this study, confirming the disparity between urban and rural MVC fatality rates suggests the need for continued investigation into the gap between prehospital times in urban and rural areas.

Several studies have evaluated the spatial accessibility of emergency services (Abbott 2008; Branas et al. 2005; Carr et al. 2009; Patterson, Probst, and Moore 2006) and multiple researchers have examined prehospital times for MVCs and MVC fatalities (Carr et al. 2006; Gonzales et al. 2006; Jones and Bentham 1995). However, no prior research uses MVC prehospital times as a measure of accessibility to emergency services. The temporal component of access is often used to delineate service areas for health service facilities such as hospitals, physicians' offices, and acute care facilities (Abbott 2008; Branas et al. 2005; Carr et al. 2009). However, time is less often used to assess accessibility from the location of demand such as the location of MVC fatalities. Time has been used to create potential demand service areas for patients accessing primary care

(Luo and Wang 2003; Yang, Goerge, and Mullner 2006). Time has not been used previously to assess revealed accessibility for MVC fatality demand locations. This study contributes to existing research by using known prehospital times to determine emergency service accessibility.

This research defines emergency service accessibility through prehospital times. Longer prehospital times indicate poorer accessibility, while shorter prehospital times reveal greater accessibility. Spatial accessibility to emergency services varies significantly between urban and rural areas across the state of Texas. EMS response times, hospital transport times, and total prehospital times were significantly longer in rural areas than urban areas. The results indicate that rural areas have less accessibility to emergency services than urban areas, a circumstance that has been identified for many types of traumas including MVCs (Branas et al. 2005; Carr et al. 2006; Carr et al. 2009). Longer distances between the location of the MVC requiring emergency services and the location of the nearest hospital equipped to provide needed services is a likely contributor to extended prehospital times in rural areas. However, this factor alone may not explain the disparity between urban and rural areas. Availability of emergency services, quality of available services, training, and protocol could be additional contributing factors.

To appreciate the consequence of this and other health care accessibility studies, it is necessary to revisit the importance of studying accessibility. More specifically, the significance of evaluating revealed accessibility requires discussion. Access to emergency services is an integral component to survival for many trauma victims (Kivell and Mason 1999). The assessment of revealed spatial accessibility uncovers not only the availability of services, but more importantly, how they are utilized. In this study, the

comparison of potential and revealed accessibility for MVC fatalities shows that the revealed accessibility calculated from FARs data is not equivalent to the potential accessibility of hospitals estimated for 30, 45, and 60 minute service areas. The average revealed accessibility prehospital time was substantially longer than 30 minutes in the potential accessibility 30 minute service area and slightly longer than 45 minutes in the 45 minute service area. Recall, that the 30 and 45 minute service area values denote prehospital times for the outer edge of the potential service areas. For the 60 minute potential service area, the average revealed accessibility prehospital time was less than 60 minutes. Because an average potential prehospital time is unknown it is difficult to draw conclusions from this comparison.

Average revealed accessibility prehospital times were not consistent or simple to compare to potential accessibility prehospital times. Revealed accessibility mean prehospital times in the 30, 45, and 60 minutes potential accessibility service areas were 47.9, 49.9, and 53.0 minutes, respectively. The revealed accessibility mean prehospital times are similar across all potential accessibility service areas. The minimum and maximum revealed accessibility prehospital times are also similar across potential accessibility service areas. Several explanations could account for the similarities. It is possible that for accidents that occur within a specific or threshold distance of a hospital, prehospital times are similar. Further research would be required to investigate the threshold distance concept. Judgments made by EMS personnel can affect prehospital times. For example, an EMS worker might make the decision to remain at the MVC scene longer to stabilize a patient before transport to a hospital. Conversely, less time may be spent on the scene of an MVC to ensure the shortest possible time between injury

and definitive care. Another possible explanation is that a patient may not be transported to the nearest hospital. A patient may be taken to a more distant facility resulting in a longer prehospital time. The revealed accessibility analysis accounts for patients being taken to more distance hospitals because actual response times are used. The potential accessibility analysis assumes that a patient is taken to the closest hospital. This presents the potential for inaccuracy.

Health service regions are designed to provide and improve essential health services for the residents of a given region (Texas Department of State Health Services 2010a). No accessibility literature currently uses health service regions as a unit of analysis despite the importance of the regions in the Texas healthcare system. The inclusion of health service regions in research is essential because the regions are recognized as a level of governance within the Texas DSHS that has the responsibility to provide health services based on local needs (Texas Department of State Health Services 2010a). Research that focuses on spatial units utilized by the DSHS, such as health service regions, may increase real-world impacts.

This research has identified significant variation in both EMS and hospital accessibility for the eight health service regions. With the type of analysis completed, not enough is known to draw precise conclusions about the variations among the health service regions. However, general observations can be made. First, there does not appear to be a connection between MVC fatality rates and accessibility to EMS services or hospitals for the health service regions. Although the region with the highest fatality rate (Region 2/3) has the poorest total accessibility to emergency services, the region with the lowest fatality rate (Region 11) does not have the greatest accessibility rank. In fact,

four regions have better accessibility to emergency services than Region 11. Second, Region 1, Region 2/3, and Region 9/10 have the poorest overall accessibility to emergency services. These regions make up the north and west portions of the state and share spatial proximity. Third, the regions with the greatest overall accessibility to emergency services (Region 7, Region 6/5S, and Region 8) are all located near the center and southeast portion of the state. Evaluating the factors that contribute to variation in accessibility for the health service regions is beyond the scope of this study. However, the spatial proximity of regions with the greatest accessibility and the proximity of regions with the poorest accessibility suggest that regions located in the same part of the state may have similar accessibility conditions.

#### Limitations and Future Research

Certainly there are multiple factors contributing to accessibility differences among regions. Regions with poorer accessibility have the opportunity to evaluate regions with superior accessibility to identify potential areas of improvement. Possible variables to be considered in improvements and future studies include EMS policies and procedures, population distribution, ambulance depot locations, hospital locations, the layout of road networks, road conditions, injury severity, and total number of MVCs.

This study has several limitations that influenced methodology and may have impacted results. EMS scene time was not available from the FARS dataset. EMS scene time has been studied as an individual variable whenever possible (Carr et al. 2006) because scene time can affect outcomes (Blackwell and Kaufman 2002). Variations in EMS training, regulations, resource availability and expertise can affect EMS scene time

(Carr et al. 2006). Disagreements on the most effective and life saving techniques for EMS care can also affect scene time (Nichol et al. 1996).

An initial effort was made to use census blocks as spatial units of analysis instead of block groups because the blocks align more closely to the Urban Areas shapefile from the U.S. Bureau of the Census (2010). However, the limited computing capabilities of available software made the use of blocks unachievable. The use of block groups might introduce errors when only part of a block group belongs to an urban area.

This study used only the location of fatal MVCs to assess the accessibility of emergency services. The addition of all MVCs that did not result in a fatality would have facilitated additional analysis opportunities. Acquisition of locational and prehospital time data for all MVCs would allow comparison between fatal and non-fatal events.

Some variables within the FARS dataset presented the potential for inaccuracies. The analysis completed in this study required location (latitude and longitude) and time data for MVC fatalities. Some MVC fatalities were excluded because of missing location or time data. It was assumed that the excluded data was randomly distributed geographically and that exclusion would not affect analysis. It is possible that missing data is the result of inconsistent data collection methods in different locations. However, it was not possible to evaluate the distribution of the excluded data in time or space. Likewise, consideration of dead-on-scene data was not feasible. Some MVC victims were confirmed dead-on-scene before transport to a hospital. It is probable that some MVC victims that were declared dead-on-scene and subsequently transported to a hospital were transported more slowly than victims that had not yet died. Although

consideration of this variable may provide insight in future studies, the use of dead-on-scene data was beyond the scope of this research. Additionally, the objective of this study was to compare accessibility between urban and rural areas and across different health service areas. Any noise in transport times that may have been introduced by the “dead-on-scene scenario” is assumed present for MVCs in all areas and not to have greatly affected the results of this study.

Interpolation techniques, like the Kriging Interpolation used in this analysis, use known values for known locations to predict values in locations where a value is unknown. In this case, the location of MVC fatalities and prehospital times were used. Although nearly 4,500 individual data points were used, their geographic coverage varied. Most urban areas in Texas had many MVC fatality data points, while most rural areas had few. Logically, the fewer data points available for interpolation, the less accurate the results will be. Therefore, the quality of interpolation results varies across the study area.

The final portion of this study compared the potential and revealed accessibility of hospitals. Assessing the potential accessibility of hospitals was achievable because the location of hospitals was known. Analysis could have been expanded to include the potential accessibility of EMS services if the locations of ambulance depots were identified. Currently, no comprehensive database of ambulance depot locations for Texas is available. When the locations become available, their inclusion in emergency service accessibility studies will provide a broader understanding of accessibility.

## CHAPTER VI

### CONCLUSION

This study aimed to assess accessibility to emergency services for fatal MVCs. This was accomplished through the examination of supply and demand. Demand was defined by the location of MVC fatalities. Supply was defined as EMS services and hospitals. Accessibility variations between urban and rural areas and for Texas' eight health service regions were examined. In addition, the revealed and potential accessibility of hospitals was compared. This study is unique because no previous research has studied accessibility to emergency services for MVCs. Additionally, to the author's knowledge no study has used prehospital time data as the measure for accessibility. It is essential to consider alternate emergency service demand locations because many emergencies do not occur in the home. As the primary cause of injury related deaths for adults ages 1 to 49 (National Center for Injury Prevention and Control 2006), MVCs should be considered when assessing accessibility to emergency services. The use of prehospital time as a measure of accessibility is useful because it reflects the revealed use of services rather than the potential use. The study of revealed accessibility has benefits over potential accessibility studies because potential accessibility cannot always accurately predict how services are utilized.

This study confirms the hypotheses that although the number of MVC fatalities is higher in urban areas, rural areas experience higher MVC fatality rates based on population. The average fatality rate found in rural areas was more than three times higher than the average fatality rate in urban areas. MVC fatality rates also varied significantly among the eight health service regions. The variations indicate the need for additional research into EMS services and hospital distribution across health service regions. With more research, locations for new hospitals and ambulance depots could be identified and improved policies could be implemented. These changes have the potential to lower MVC fatality rates and improve outcomes.

Rural areas had longer prehospital times than urban areas. EMS response times, hospital transport times, and total prehospital times were significantly longer in rural areas. Because prehospital times were equated with emergency service accessibility in this study, it follows that rural areas have poorer EMS accessibility and hospital accessibility than urban areas. Prehospital times also varied significantly among the eight health service regions. This research does not provide explanations for these variations, but rather establishes their presence.

Comparison of potential and revealed accessibility for emergency services does not clearly confirm the hypothesis that there is a difference between potential and revealed accessibility. The hypothesis cannot be definitively accepted or rejected because the explanatory power of the analysis is weak. However, prior to this study, no research comparing potential and revealed accessibility had been completed. The comparison provides a foundation for future research.

This is the first study to analyze emergency service accessibility for the entire state of Texas. Overall, this research reflects previous findings for MVC fatality rates and prehospital times. However, this research expands existing research by assessing demand for emergency services as the location of MVC fatalities and by using prehospital times to determine accessibility.

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