Spatial Clustering of Fatal and Severe Automobile Crashes in Idaho and Analysis of Emergency Medical Service Response Times

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Geography

in the

College of Graduate Studies

University of Idaho

by

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May 2021

Authorization to Submit Thesis

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Abstract

Automobile crashes are a leading cause of death in the United States. The timely response of Emergency Medical Services (EMS) to these events is critical for the survival of crash victims. Drawing upon fatal and severe crash data in Idaho, this research aims to measure the Accessibility of EMS to fatal and severe crashes using actual and predicted temporal response intervals. Geographical approaches are utilized to identify statistically significant differences among these intervals between Urban, Rural, and Roadway classifications and identify areas that could benefit from a more rapid EMS response in Idaho. This study investigates the spatial clustering of Fatal and Severe crashes in Idaho over a 6-year period and analyzes the Emergency Medical Service Response times for those crashes.

Results demonstrate that while the number of crashes (49.7% and 50.3%) and the number of injuries (48.6% and 51.4%) were distributed relatively evenly between rural and urban areas, most fatalities occurred on rural roadways (76.0% and 24.0%). Both the Response Interval and Critical Interval in rural areas were more than double those in urban areas, with 72% of crashes on urban roadways in Idaho having a Critical Interval less than or equal to 8 minutes. In contrast, only 24% of crashes on rural roadways had a Critical Interval within this threshold. The results also show that the EMS response Interval is consistently underpredicted within the potential accessibility framework by 3.3 minutes in rural areas and 1.6 minutes in urban areas. Underprediction appears to be concentrated in areas adjacent to urban metropolitan regions.

Acknowledgments

I could not have completed my graduate studies without the help and support of my academic professors, professional advisors, committee members, and staff at the University of Idaho. First, I would like to thank Dr. Felix (Haifeng) Liao for serving as my major professor within the Department of Geography and Geological Sciences. He encouraged me to pursue my interests in Emergency Medical Services and helped me learn how to be a better researcher and scientist by pursuing this unfamiliar topic.

I would also like to thank Dr. Michael Lowry for serving as my co-major professor outside of the department. He taught me how to write better code using Python and apply those programming skills to create useful tools. I would also like to thank Dr. Kevin Chang and Dr. Chao Fan for their valuable suggestions during the development of my thesis.

I would like to thank Dr. Ahmed Abdel-Rahim for providing me with my first opportunity to work at the University of Idaho as a GIS Technician. I would also like to thank Dr. Raymond Dezzani for the opportunity to teach Physical Geography for the department. Finally, I would like to thank my partner Celiannie for her love and support.

Dedication

To my parents Norbert and Patricia

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Chapter 1. Introduction

1.1. Background

Emergency Medical Services (EMS) are an integrated system of public and private organizations, trained medical professionals, communication networks, and medical providers designed to provide life-saving medical care to the public (NHTSA, 2020). Rapid EMS response is important because it determines how effectively medical professionals can administer life support and save lives. One situation that would require such care is a motor vehicle crash (MVC), which was the largest contributor to fatal accidents in the United States in 2017 and the third leading cause of death. That year crashes resulted in 40,231 fatalities nationwide (National Vital Statistics Reports, 2019). During that same year in Idaho, 25,851 MVCs resulted in 245 deaths and 1,246 serious injuries (Idaho Transportation Department, 2017).

Studies on EMS access time are relevant to the fields of transportation, health planning, and geography. EMS planning, in a wide range of contexts, also entails spatial planning for public health facilities (Baldwin et al., 2004; Von Reichert et al., 1995), primary care providers (Lin et al., 2018), and emergency medical care (J. Lee et al., 2018). For example, Hajameeran (2019) evaluated the accessibility to crash sites from medical facilities in Virginia and identified areas as hotspots of crashes and little access to EMS services.

As illustrated in Figure 1.1, there are four different EMS stages (J. Lee et al., 2018). First responders are notified during the Notification Interval. The Response Interval is the amount of time required for an ambulance or paramedic to arrive at the MVC. The time spent on the scene administering patient care is the On-Scene Interval. These intervals are followed by the Transport Interval, during which the patient is transported to the nearest medical facility for definitive care. Two different Intervals are used in this research. The Critical Interval is the combined Notification and Response Interval. The Prehospital Interval is the total amount of time between when the MVC occurs and patients are delivered to definitive care.

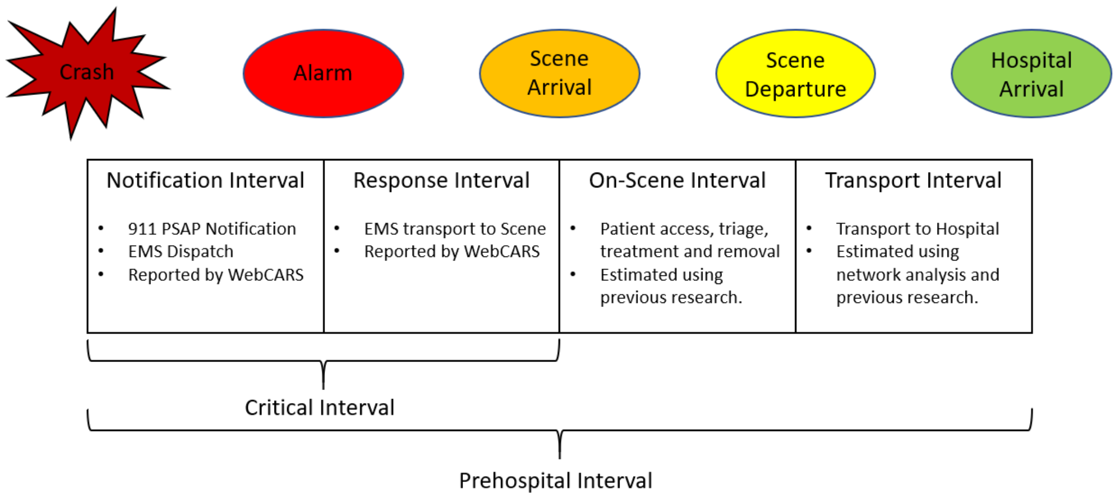


Figure 1.1 Intervals of EMS response to Motor Vehicle Crashes

These four intervals, along with the redeployment of EMS resources, are known as the EMS Cycle. Among the four intervals, the Response Interval and the Transport Interval are especially relevant to transportation studies (e.g., Clark et al., 2012; O'Keeffe et al., 2011; Pell, 2001). Many studies have concluded that an increase in any one of these EMS intervals would increase the proportion of fatal outcomes (Carr et al., 2017; Gonzalez et al., 2009; Newgard et al., 2010).

1.2. Research Objectives and Hypotheses

This thesis will achieve four objectives:

1. Assess whether crashes are clustered or dispersed at multiple spatial scales
2. Calculate the actual Notification, Response, and Critical Intervals for crashes
3. Calculate the estimated Response and Critical Intervals for crashes
4. Calculate the estimated Transport and total Prehospital Intervals for crashes

Specifically, I define two quantitative measures for identifying areas or segments isolated from a timely EMS response. First, I combine the Notification and Response Intervals, which I call the Critical Interval (Equation 1), and assume is that the Critical Response Interval is less than 8 minutes (Equation 3). Second, I assume the Total Response Interval (Equation 2) is less than 60 minutes (Equation 4).

$$t_{critical} = t_{notification} + t_{response} \tag{1}$$

$$t_{total} = t_{notification} + t_{response} + t_{transport} \tag{2}$$

$$t_{critical} < 8\ minutes \tag{3}$$

$$t_{total} < 60\ minutes \tag{4}$$

I also test four hypotheses:

1. Crashes will be more clustered in urban areas and less clustered in rural areas.
2. The percentage of crashes in which the critical interval exceeds 8 minutes will be greater on rural roads.
3. The mean actual Response Interval will be greater than the mean estimated Response Interval.
4. The percentage of crashes in which the total Prehospital Interval exceeds 60 minutes will be greater on rural roads.

1.3. Study Area

The study area consists of the State of Idaho, shown in Figure 1.2. Idaho consists of urban areas extending from the capital city of Boise east along the Snake River Valley with additional urban development in Idaho's northern panhandle in the greater Spokane/Coeur D'Alene area. Interstate 84 and Interstate 86 merge in the southeastern portion of the state and extend west through Boise to comprise the most accessible and developed part of the region, characterized by its path parallel to the Snake River Valley. This highly developed urban environment is contrasted by large swaths of rural mountainous areas, especially along the northeastern border with Montana. These rural and isolated areas pose a significant challenge for EMS responses.

Medical Facilities and EMS providers in states surrounding Idaho (Montana, Oregon, Utah, Washington, and Wyoming) sometimes respond to MVCs in Idaho. Interstate response is especially relevant in isolated areas that often require air rescue. While some EMS providers and hospitals in surrounding states were included to provide a context in interpreting the research results, they were not used in the analysis because an Interstate road network would be required for travel time analysis.

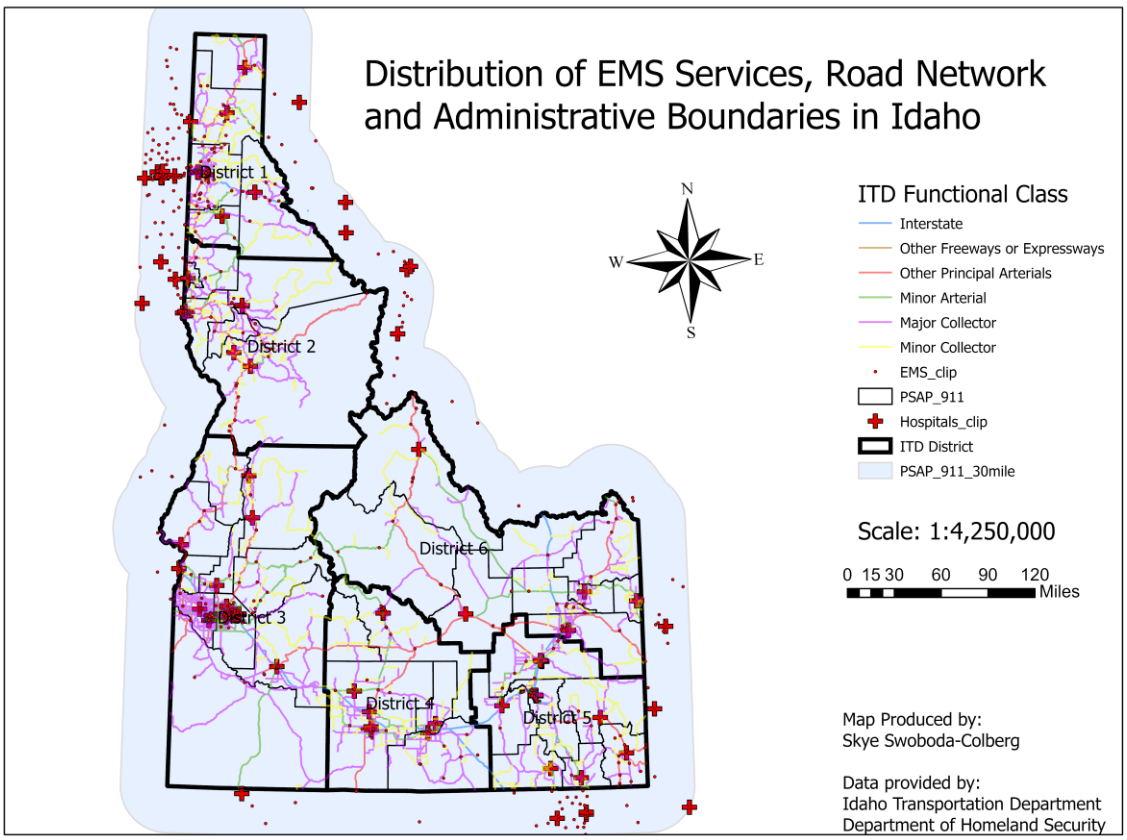


Figure 1.2. Spatial distribution of EMS facilities and transportation network in Idaho

1.4. Thesis Organization

Chapter 2 presents a review of the literature relevant to this research. Section 2.1 focuses on Motor Vehicle Crashes (MVCs) and some of the import variables of analysis for this type of data. Section 2.2 explores characteristics of the temporal response of Emergency Medical Services (EMS). Section 2.3 describes how Network Screening can identify specific sites that could benefit from a reduction in either the number or severity of crashes. It also summarizes the performance measures used to rank the sites.

Chapter 3 describes the data and methods used to address thesis objectives and hypotheses. Section 3.1 summarizes the Crash Data, Road Network Data, Medical Facility Data, and Administrative Boundary Data. Section 3.2 describes the methods used to perform Clustering and Hotspot Analysis at multiple spatial scales, including Kernel Density Visualization, Global Moran's *I*, Local Moran's *I*, Getis-Ord Gi*, and Network Screening. Section 3.3 describes and compares the methods used to analyze actual and network-based estimated Response Intervals. Chapter 4 presents the Clustering and Hotpot Analysis results (Section 4.1) and the Response Time Analysis results (Section 4.2). Chapter 5 discusses analysis results within the context of policy implications, research significance, and limitations, and future studies.

Chapter 2. Literature Review

2.1. Motor Vehicle Crashes (MVC)

Emergency Medical Services (EMS) provides essential services to save lives, with automobile accidents being one of the most relevant yet understudied of such events. According to the Idaho Transportation Department's crash data from 2018, a crash occurred every 22 minutes; every 37 hours, one crash resulted in a fatality (ITD, 2018). Between 2014 and 2018, there was an annual average of 209 fatal crashes with 227 deaths. In 2019, Idaho's accident mortality rate was 49.8 per 100,000 residents, which is slightly higher than the average United States rate of 49.4 (*Statistics of the State of Idaho*, 2019).

2.2. Emergency Medical Services (EMS)

Several investigators have analyzed medical response times to automobile crashes to determine statistically relevant social and environmental factors, e.g., (J. Lee et al., 2018)). Travel times to crash sites may vary due to congestion (Hajameeran, 2019), weather conditions (Medina et al., 2017), and month of the year (Call et al., 2019). Automobile crash severity varies significantly between urban and rural areas, with rural areas experiencing a higher rate of fatal crashes. Sources of variation may result from higher travel speeds, less signage, and less rule enforcement (Nunn & Newby, 2015).

There are different stages of an EMS response, including the time required for first responders to be notified, respond, treat, and transport patients from an MVC site for definitive medical care. Many studies have found that an increase in either the Response or Transport Intervals may result in more fatalities. For example, Blackwell & Kaufman found that Critical Intervals not exceeding five minutes (between notification and arrival of EMS responders) were associated with improved survival (Blackwell & Kaufman, 2002).

Lee et al. (2018) provided more quantitative evidence than the average Notification and Response Intervals were longest on conventional roads in rural areas, while they were much shorter in urban areas. The combined time of all intervals should be less than one hour. This threshold is referred to in trauma care as the "golden hour" (Lerner & Moscati, 2001). Dr. R. Adams Cowley is credited with coining this term; however, he never provided empirical evidence that early medical response to trauma significantly impacts mortality (MacKenzie et al., 2006; Newgard et al., 2010). That said, this threshold is the industry standard for judging adequate response times and is routinely cited in peer-reviewed literature.

In an EMS Master Plan published by a consulting firm for the City of Boise Fire Department, the recommended threshold for the Critical Interval of an EMS response is less than 8 minutes (ESCI, 2011). The plan also emphasized that small changes in response time requirements can significantly impact the cost of meeting those requirements. Shorter Response Intervals have been shown to reduce cardiac patients' mortality, although the impact of Response Intervals on trauma patients remains unknown.

The concept of accessibility can be traced back to (Penchansky & Thomas, 1981), who proposed a set of taxonomic definitions for access as defined by stages and dimensions. They defined five dimensions by which accessibility and consumer satisfaction may be measured: availability, accessibility, affordability, acceptability, and accommodation. These dimensions may be spatial or aspatial. Since the availability and accessibility of service are inherently spatial, these concepts are often combined to define Spatial Accessibility (Guagliardo 2004). Additionally, Spatial Accessibility may be further categorized as Potential accessibility and Realized accessibility.

A national assessment of trauma center accessibility found that only 49.4% of Idaho residents live within an hour of a Level I/II Trauma Center. In comparison, 69.9% of residents live within the "golden hour" of a Level I/II/III Trauma Center. Idaho accessibility scores are well below regional averages for the western U.S. of 76.5% and 86.0% and national accessibility scores of 69.2% and 84.1% for Level I/II Trauma Center and Level I/II/II Trauma Center, respectively (Branas et al., 2005).

In general, 88.3% of Americans live within one hour of a Level I/II Trauma Center if accessed by ground or helicopter transport, with rural areas having less access to trauma care. In comparison, metropolitan and suburban areas are associated with higher access levels (Carr et al., 2017).

Another study found that Emergency Departments (ED) are generally more accessible than trauma centers, even for Idaho residents (Carr et al., 2009). Some 71.2% of western state residents live within 30 minutes of an ED; the national and Idaho averages are comparable at 70.8% and 69.5%, respectively. About 97% of western state residents and 98.4% of U.S. residents live within one hour of an ED; Idahoan's access is only slightly less at 95.6%. Despite these seemingly favorable comparisons, Idaho EDs are less accessible than regional and national facilities after patient volume (measured in visits per hour) is considered.

It is worth noting that besides a more straightforward transportation time analysis, other methods of accessibility analysis have been developed, primarily in the area of GIScience and health care planning. A two-step flow catchment analysis (2SFCA) was designed to integrate both provider-to-population ratios and distance-based measures. Under the 2SFCA, provider-to-population ratios may be calculated within a jurisdictional area or within a floating catchment set using theory based on the gravity model (Wang, 2014). Distance-based SA measures may include: mean distance to a set of providers, distance to nearest provider, Unit Hour Utilization of EMS provider, or Unit Distance Utilization (Guagliardo, 2004; Neutens, 2015). Despite significant advances, this technique is not particularly relevant in assessing EMS accessibility. As Lu and Davidson (2017) argued, the "2SFCA method is more suitable for analyzing access to healthcare services complementary to each other across multiple facilities rather than services [such as EMS] that need to be instant and reasonable self-sufficient."

Lu & Davidson (2017) studied the distribution and spatial accessibility of fatal crashes to emergency medical services (EMS) in Texas between 2006 and 2008. They analyzed the revealed accessibility (or actual transportation times) of four response intervals for Urban/Rural classifications and eight regional health service regions. These results were compared to potential accessibility estimated using service areas to identify shortage areas and explore how resource allocation could be improved at a regional level.

Additionally, the EMS literature emphasizes the speed of response pertinent to motor vehicle accidents given the instant need; therefore, a more closely related concept to EMS would distinguish between actual and potential accessibility. In a case study in the Calgary area of Canada, (Patel et al., 2012) applied GIS methods such as the Network Analyst of ESRI ArcGIS 10.0 in conjunction with EMS trip data to develop modeled EMS response intervals (or potential access to EMS) and compared them to actual EMS intervals. Their findings suggest that actual median on-scene intervals were much longer than the modeled transportation times; the models also underestimated the total prehospital times.

Access to healthcare, including EMS, is also influenced by regional settings. For example, spatial inequality of access to healthcare in rural and urban areas has been widely studied (Hu et al., 2013; Joseph & Bantock, 1982; G. Lee & Hong, 2013; McGrail & Humphreys, 2015; Tao et al., 2018). Results of transportation time analysis using FARS datasets further indicates that the average prehospital time is 25 minutes in urban areas, and the counterpart in rural areas is approximately 40 minutes (Minge, 2013). McGrail and Humphrey (2015) demonstrated that remote and rural areas often exhibit poor spatial accessibility to healthcare, but this accessibility occurred unevenly across the county. Surprisingly, some areas outside of metropolitan areas received lower accessibility scores than some very rural areas.

2.3. Highway Safety Management

The Roadway Safety Management Process (RMSP) consists of steps to identify and diagnose a set of site improvements to improve their safety in an economically viable manner. It also provides guidelines for site and area-level programming, which may be evaluated over time. The first step in RSMP, known as Network Screening, plays a vital role in the financial assessment that occurs later. Network Screening has been combined with Kernel Density to identify Hotspots in Canada (Young & Park, 2014).

Network Screening is a preliminary examination of a road network to identify suitable locations for a more detailed engineering study. These locations may be referred to as high accident locations, sites with promise, or priority investigation locations (Hauer et al., 2002). Location identification is achieved using Hot Spot Identification, sometimes called Black Spot Identification. Network Screening produces a list of locations that would accrue the most significant benefits of implementing countermeasures to reduce crashes' frequency or severity (AASHTO, 2010). Benefits are characterized by a ratio of both the cost of mitigation and the economic value of reducing accidents. A list produced by Network Screening should be complementary to the one created by the economic appraisal stage of the RSMP.

There is an underlying principle in the RSMP process known as "most-bang-for-the-buck" (Hauer et al., 2002), which states that financial resources should go to a combination of projects that results in the most significant increase in safety. One way to evaluate the quality of a list of ranked sites produced by Network Screening is to compare it to a list of sites ranked by their cost-benefit ratio. The purpose of Network Screening is to identify all candidate sites that merit a more detailed engineering study. Sites that have a high cost-benefit ratio but are not identified in the screening are lost opportunities. In contrast, a detailed engineering study of sites that are not economically viable or cost-effective is a waste of the screening effort it was designed to prevent. This process plays an integral part in the RSMP. Moreover, the quality of performance measures used depends on its potential to improve safety and its cost-effectiveness relative to the improvements.

The potential for crash reduction at a site is evaluated using a performance measure. The Highway Safety Manual defines 13 performance measures used to rank segments or intersections in Network Screening. Each method requires a set of at least two data inputs: Crash Data and Roadway Categorization Data. Additional data such as Traffic Volume, Safety Performance Functions, or Overdispersion Factors are sometimes used in more elaborate measures to increase the reliability of the performance measures by accounting for regression-to-the-mean bias, data variance. Three methods account for crash severity using either Equivalent Property Damage Only weighting factors or Relative Severity Indices. They can also be used to establish performance thresholds such as expected average crash frequency. In this study, four performance measures are developed to rank segments according to their EMS response intervals.

Chapter 3. Methods

3.1. Data

This research considered Crash data, Road Network data, Medical Facility data, U.S. Census Boundary data, and ITD Administrative District Boundaries. A summary of these data sources, their spatial and temporal scope, and their sources is presented in Table 3.1.

Table 3.1 Data Layers and Sources

Data	Description	Type	Period	Source
Crash Data	Fatal and 'A' Severity crashes in Idaho	Point	2013-2018	itd.idaho.gov
Road Network	All road centerlines in Idaho	Line	2020	itd.idaho.gov
Hospitals	Hospital locations	Point	2019	dhs.gov/HIFLD
EMS Stations	EMS locations	Point	2019	dhs.gov/HIFLD
TIGER/Line Shapefiles	State, County, Census Tract, and Block Group Census Boundaries	Polygon	2019	Census.gov
Administrative Boundaries	ITD Administrative District Boundaries	Line	2020	itd.idaho.gov

Automobile crash data for six years (2013-2019) were obtained from the Idaho Transportation Department through the WEBCARS Crash Analysis Reporting System. Crashes are classified according to the KABCO injury scale developed by the National Safety Council. According to this classification, 'K' refers to Fatal Crashes, 'A' refers to Disabling Injuries, 'B' refers to Evident Injuries, 'C' to Possible Injuries, and 'O' to crashes that result in property damage. This study included all Fatal and A Severity crashes between 2013 and 2018. Crash data summarized by district is presented in Table 3.2.

The Notification Interval, Response Interval, and Critical Response Interval were calculated from the records. The Transport Interval was estimated using a network distance model and the distance between the accident location and hospital location.

Table 3.2 summarizes attributes of these crashes for all six ITD districts. EMS response times were used for this study instead of law enforcement response times. Hospital arrival times are not recorded in crash data to protect medical privacy, but the hospital name is usually included. Some 30.5% of crash records did not have a hospital identified in the attributes but were matched to the nearest hospital. Only 3.2% of crash records had the EMS record attributed as Other/Unknown, so they were also matched to the nearest facility when the Response Interval was calculated.

Table 3.2 Crash Data Organized by Severity, Rurality, and Highway Function Classification

District	Total	Fatal	Severe	Urban	Rural	Interstate	Arterial	Collector	Local
1	828	156	672	291	537	39	453	206	130
2	501	111	390	118	383	0	333	102	66
3	3371	397	2974	2397	974	180	2525	391	275
4	906	205	701	237	669	160	348	220	178
5	681	160	521	229	452	159	306	119	97
6	588	121	467	171	417	27	355	112	94
Total	6875	1150	5725	3443	3432	565	4320	1150	840

The Idaho Transportation Department is the primary source of Road Network and Highway classification data. This network was stored as a Feature class within a Geodatabase and was used to create the network dataset for calculating network travel times using the ArcGIS network analyst tool. Speed limits were estimated using Urban and Rural classifications.

Medical Facility Data were obtained from the Homeland Infrastructure Foundation-Level Data (HIFLD) provided by the Department of Homeland Security (DHS). Medical service locations in Idaho consist of Hospitals and EMS Stations; DHS defines EMS stations as *"any location where EMS personnel are stationed or based out of, or where equipment that such personnel use in carrying out their jobs is stored for ready use."* This distinction is essential because many rural Idaho communities do not have the resources to support dedicated paramedics and often rely on local fire department personnel. Some 268 EMS provider locations representing 116 EMS providers were identified as operating within Idaho or routinely responding to vehicle crashes in Idaho. It was important to standardize the EMS provider and EMS station names to match them to crash records. In Ada County, for example, paramedics work in many different fire departments and metropolitan jurisdictions.

There are 55 hospitals and clinics in Idaho, 40 of which provide general acute care. This list was validated using 51 facilities provided by the Idaho Hospital Association (IHA) as of January 28, 2020. A total of 65 hospitals and clinics were used in this study. Not all of the hospitals described in the crash data were in the HIFLD and IHA datasets and had to be manually geocoded using data from other sources.

Shapefiles for Idaho were obtained from the U.S. Census Bureau to delineate the Counties, Census Tracts, and Block groups and Blocks. Counties were categorized by Administrative District Boundaries provided by the Idaho Department of Transportation. Clustering and Hotspot analysis was performed using these different spatial scales.

3.2. Clustering and Hotspot Analysis

Two methods were used to evaluate the clustering or dispersal of fatal and severe crashes in Idaho: Kernel Density Estimation and The Global Moran's *I* Statistic. Three methods were used to identify Hot and Cold Spots at multiple spatial scales. The Local Moran's *I* Statistic and the Getis-Ord Gi* Statistic were used to identify hot and cold spots at the Block Group level. In contrast, Network Screening was used to identify hotspots at the road segment level.

The spatial distribution of crashes was investigated using the Kernel Density visualization technique to measure a random variable's density. This technique calculates the density of points within a neighborhood (15 km) to generate a raster surface (2,000 m x 2,000 m cells), representing the clustering of points within that neighborhood. This method allows comparison of Fatal, Severe, and Total crashes. This analysis was performed twice: once for District 3, which accounts for nearly half of Idaho's crashes, and a second time for the remaining ITD districts. Results of both analyses were combined and symbolized using a six-category Jenks (Natural Breaks) classification method. Performing this analysis twice allowed for an unbiased comparison of crash clustering between these two areas.

The Global Moran's *I* Statistic measures spatial autocorrelation and produces an index value (Moran's *I*) and associated z-score and p-values to describe its statistical significance (Anselin, 1995). This score ranks an attribute as clustered (value close to 1), dispersed (values close to 1), or randomly distributed (values close to 0) among a set of neighboring features. This statistic was applied twice to Fatal and Severe crashes and a second time to a subset of Fatal crashes. Moran's *I* may also vary according to what spatial scale is used for the analysis; in this analysis, five different spatial scales evaluated autocorrelation among crashes: County, County Subdivision, Census Tract, Block Group, and Block. The equation for Moran's *I* is shown in Equation 4. The weighting factor is shown in Equation 5, where *n* is the number of observations, $\bar{x}$ is the variable mean, x_i is the variable value at location i, and x_j is the variable value at location j:

$$I = \frac{n}{w} \frac{\sum_i \sum_j w_{ij} \ (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2} \tag{4}$$

$$w = \sum_i \sum_j w_{ij} \tag{5}$$

There are at least eight ways to conceptualize neighborhoods among features, which can influence the analysis results. This analysis employs three neighborhood conceptualizations. The first conceptualization uses inverse distance weighting to make features closer to the analyzed location having a more significant influence than those farther away. The threshold for defining a neighborhood was generated using the Global Moran's *I* Spatial Statistics Tool in ArcGIS Pro. The second conceptualization uses only the K-Nearest Neighbor Method to select the features used to analyze the location; in all of the examples that follow, the nearest eight neighbors were used. The final conceptualization uses all features that share a contiguous edge with the site being analyzed.

The Anselin Local Moran's *I* Spatial Statistic is one method for identifying statistically significant Hot Spots and Cold Spots. This method identifies clusters and spatial outliers of fatalities at the Census Block Group level. Features are clustered if they are surrounded by similar values -- either high values surrounded by other high values or low values surrounded by different low values. Features are considered outliers if they are surrounded by different values -- either high values surrounded by low values (HL) or low values surrounded by high values. The equation for the Local Moran's *I* is shown in Equations 6 and 7:

$$I_i = \frac{x_i - \bar{x}}{S_i^2} \sum w_{ij}\left(x_j - \bar{x}\right) \tag{6}$$

$$S_i^2 = \frac{\sum\left(x_j - \bar{x}\right)^2}{n - 1} \tag{7}$$

Another method for identifying statistically significant Hot Spots and Cold Spots is the Getis-Ord Gi* Spatial Statistic, which is shown as Equation 8, where x_j is the value of feature *j,* and w_{ij} is the weighted value between features *i* and *j.* This method identifies clusters of crashes with statistically shorter and longer Critical Intervals and Total Prehospital Intervals. This method requires a definition of a neighborhood similar to the Global and Local Moran's *I* Statistic; multiple ways were tested to ensure results' reliability.

$$G_i^* = \frac{\sum w_{ij}x_j - \bar{X}\sum w_{ij}}{S\sqrt{\frac{\sum x_j^2}{n} - (\bar{X})^2}} \tag{8}$$

The Roadway Safety Management Process known as Network Screening was used to rank features within the study area to identify the specific road segments that could benefit from a reduction in their overall EMS Response Interval. Four criteria were identified to describe the overall EMS service to a segment: the mean Critical Interval, the mean Prehospital Interval, the total Critical Interval, and the total Prehospital Interval. Segments were ranked by each of the four criteria listed above. A segment score was calculated by adding the sum of scores ranked by C1, C2, C3, and C4 to produce the total number of missing scores and 10 (Equation 9). Segments were then ranked according to those scores, which account for the most extended mean response times and the largest total response time allocation.

$$Segment_{score} = (C1 + C2 + C3 + C4) + (Missing_{Criteria} * 10) \tag{9}$$

3.3. Response Time Analysis

Two types of EMS intervals were used in this research -- actual EMS intervals and estimated EMS intervals. In this work, actual transportation time was analyzed using real-world response times, representing how long it took for an EMS provider to arrive at the location of a vehicle collision. Response times were aggregated and summarized using the same spatial scales used in the Clustering and Hotspot Analysis consisting of the road network, county, district, and state. Estimated Response Intervals were calculated using the locations of crashes and EMS providers.

Statistical techniques are required for determining whether differences in continuous variables between two groups (e.g., Urban and Rural) or across a few groups (e.g., jurisdictional boundaries) are significant. The Kruskal-Wallis test was used to determine whether differences across groups are significant, as shown in Equation 10 (Kruskal & Wallis, 1952). The Mann-Whitney-Wilcoxon test was used to determine whether differences between the two groups are significant, as shown in Equations 11a 11b (Mann and Whitney, 1947).

$$H = (N-1)\frac{\sum_{i=1}^{g} n_i(\bar{r}_{i.} - \bar{r})^2}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}(r_{ij} - \bar{r})^2} \tag{10}$$

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{11a}$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2 \tag{11b}$$

Crash data provided by the Idaho Department of Transportation included timestamps of when the accident occurred, the time EMS was notified, the time EMS arrived on the scene, and the time a patient was delivered to a hospital. Since hospital delivery times were not reliably recorded for crashes during the study period, they were excluded from the analysis; however, the EMS provider and the hospital's name were reliably recorded. Therefore, the Notification Interval and Transport Interval may be calculated using timestamps in the data. The Critical Interval may also be calculated using the sum of the previous two intervals.

Travel times between the EMS provider, crash location, and hospital location can be estimated using various methods, ranging from simple Euclidean distances to more advanced network travel time methods that incorporate types of impedance, including speed limits and traffic congestion. Transportation speeds have been shown to vary greatly between urban and rural areas. The most commonly cited study on this topic is by Carr (2006), who used a meta-analysis of 49 articles using data collected over 30 years. They analyzed helicopter ambulance responses and divided total response time in all cases into activation, on-scene, response, and Transport intervals and determined the mean transportation speed for urban areas to be 20.1 mph and 56.4 mph for rural areas. Finally, they calculated mean travel speeds for all factors mentioned above. They acknowledged that geography influenced their results, and Prehospital Intervals were likely underestimated due to limitations of meta-analysis. Notably, Idaho, Nevada, Utah, Wyoming, and Montana were excluded from their study.

Mean travel values have been used to calculate regional access to trauma centers both in the United States (Branas et al., 2005) and other countries (Patel et al., 2012). Revealed and potential accessibility were compared by looking at differences between the actual and predicted Notification Intervals, Response Intervals, and Critical Intervals. Point data were converted to a raster format using Inverse Distance Weighted Interpolation to calculate a surface showing the layers' differences. The mean, median, and standard deviations of these error values were computed for the Response Interval. Mapping these mismatches serves two purposes. First, it identifies areas where the actual response values are less than those predicted by the road network model. This result would suggest that EMS is being provided by other modes (e.g., air-based rescue services) or out-of-state sources. It also identifies areas where the predicted response values are greater than those predicted by the road network model. This result would suggest that EMS is not being provided in an adequate amount of time and could result from inter-jurisdictional issues, poor cellular reception, or poor road conditions.

Total response times less than or equal to one hour are considered adequate according to the “golden hour.” In contrast, total response intervals greater than one hour indicate an untimely response that could be improved. Equation 12 shows how the Prehospital Interval was calculated:

$$t_{prehospital} = t_{notification} + t_{response} + t_{onscene} + t_{transport} \tag{12}$$

Actual Notification and Response Intervals are used for the first two terms. The On-Scene Interval is calculated using average values generated by a previous meta-analysis of Response Intervals (Carr et al., 2006), with 15.89 minutes used for urban crashes and 18.95 minutes for rural crashes. The Transport Interval was predicted using the network model. The Prehospital Interval distribution was compared between rural and urban areas, ITD districts, and road classifications.

Chapter 4. Results and Discussion

Section 4.1 presents an Exploratory Spatial Data Analysis of the spatial distribution of crashes, spatial autocorrelation among them, and persistent hotspots of areas with higher crash rates and more rapid response rates. Section 4.2 is a detailed analysis of the actual and estimated Notification, Response, On-Scene, and Transport Intervals.

4.1. Clustering and Hotspot Analysis

Five methods were used to evaluate the distribution of fatal and severe crashes in Idaho: (1) the Kernel Density Estimation, (2) Global Moran's *I* Statistic, (3) Local Moran's *I* Statistic, (4) Getis-Ord Gi* Statistic, and (5) the Network Screening method. These results test the first hypothesis that crashes will be more clustered in urban areas and less clustered in rural areas. This hypothesis was tested at multiple spatial scales.

4.1.1. Kernel Density Visualization

The spatial distribution of crashes was investigated using the Kernel Density Estimation technique. The results show that most crashes are concentrated in heavily populated areas that experience higher traffic volumes. The maps on the following pages visualize the distribution of Fatal Crashes and Kernel Density in Figure 4.1 and Severe Crashes in Figure 4.2. These include Coeur d'Alene in District 1, Moscow/Lewiston in District 2, The Boise-Nampa Metro area in District 3, Jerome/Twin Falls/Burley-Heyburn in District 4, Pocatello/Blackfoot in District 5, and Idaho Falls in District 6.

Fatal crashes appear to be more clustered than Severe crashes and are partially the result of a smaller sample size. The majority of crashes still occur along the I-84 corridor connecting the major metropolitan areas within districts three, four, and five; however, additional clusters of crashes appear outside of these areas, particularly along Highway 95, which serves as the major thoroughfare between north and south Idaho. Additional clusters are evident in the southeast corner of District 5, where communities tend to be very isolated. While this analysis serves as a preliminary exploration of the distribution of Fatal and Severe crashes in Idaho, a more rigorous analysis is required to determine whether these patterns are statistically significant.

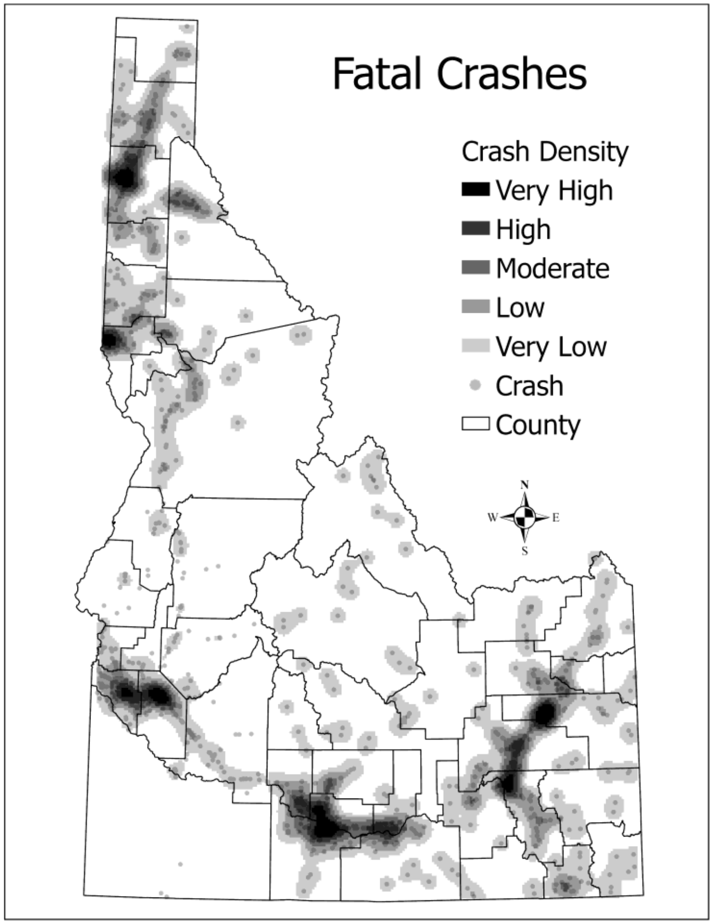


Figure 4.1 Kernel Density of Fatal Crashes

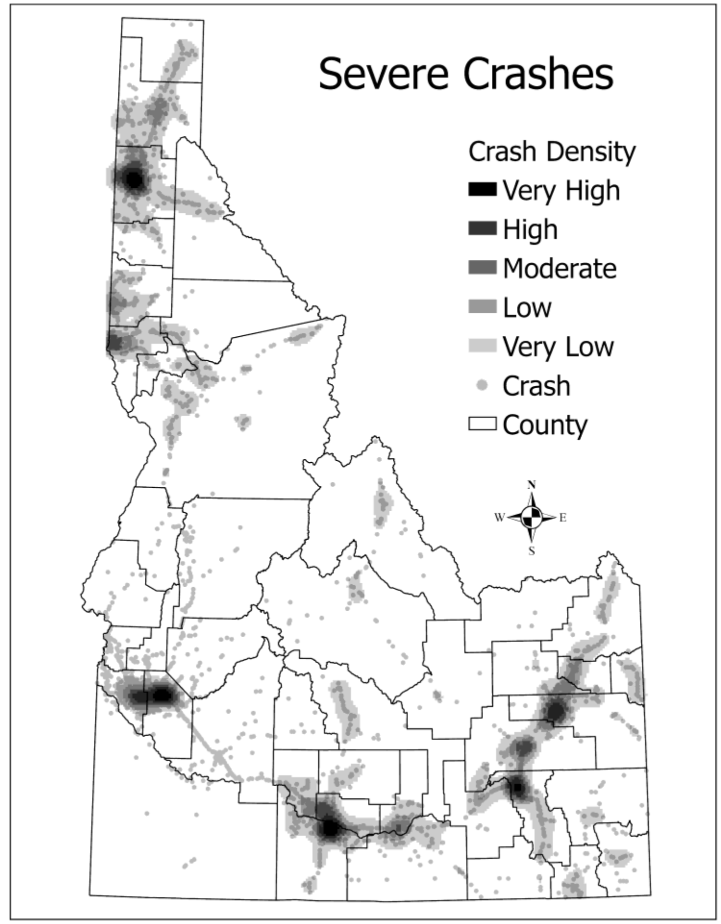


Figure 4.2 Kernel Density of Severe Crashes

4.1.2. Global Moran's I

The Global Moran's *I* Statistic measures spatial autocorrelation and produces an index value (Moran's *I*) and associated z-score and p-values to describe its statistical significance. This score is used to describe whether an attribute is clustered, dispersed, or randomly distributed among a set of features that neighbor one another. In this study, it was used to evaluate the number of crashes at different scales.

The Global Moran's *I* Statistic was also used to evaluate whether fatal and severe crashes were clustered or dispersed at five spatial scales as defined by the U.S. Census Bureau. The first step was to summarize both the number of crashes and number of fatalities within the census area and remove units containing any points. Moran's *I* does not produce reliable results if null values are present. For example, only 4,954 of the 149,842 blocks in Idaho contained one or more fatal or severe crashes. The next step was to run the analysis using three different neighborhood conceptualizations, including Inverse Distance Weighting, K-Nearest Neighbors, and Contiguity Edges. It is important to note that the Contiguity Edges conceptualization was not valid at the block level after blocks with no crashes were removed. Most of the blocks did not share an edge with other blocks. While car crashes are likely to occur across continuous groups of census blocks, fatal and severe crashes are infrequent enough to be less dispersed.

Statistical results of Moran's *I* Statistic for the total number of crashes at the county, county subdivision, census tract, block group, and block-level are presented in

Table 4.1. They show that crashes are slightly more clustered than would be expected to result from chance. The Contiguity Edge method most strongly suggests clustering at all five scales, particularly at the census tract and block group levels with $p < 0.0001$. The Contiguity Edge method was the only neighborhood conceptualization that produced marginally significant p-values at the county level. Inverse Distance and K-Nearest Neighbor methods produced similar results, with highly significant p-values at all spatial scales, except at the county level.

Table 4.1 Moran's I statistical results for fatal and severe crashes at given spatial scales

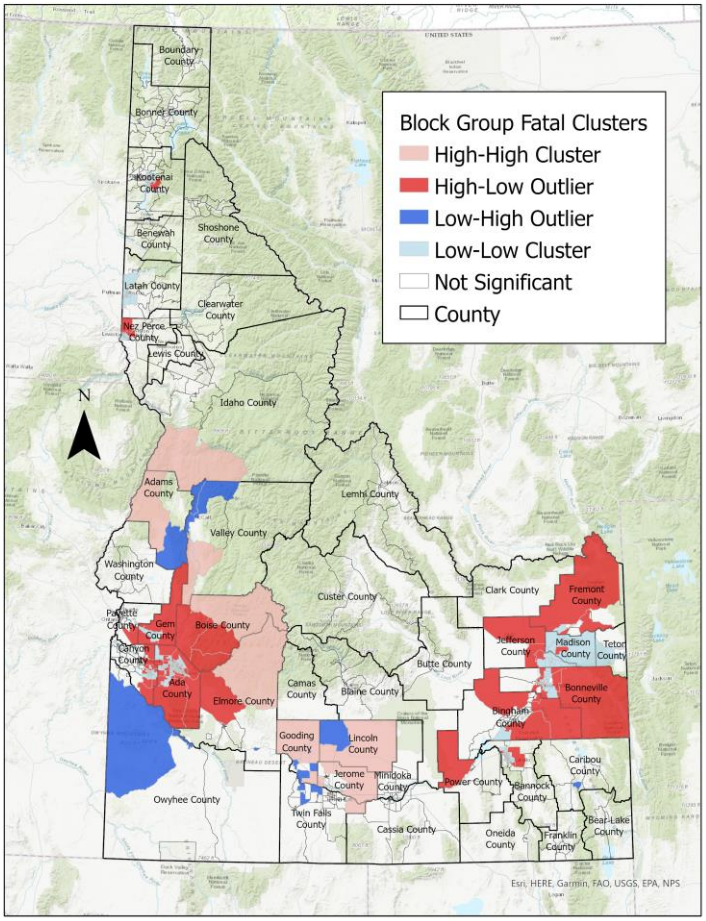
Moran's I Crashes	County	County Subdivision	Census Tract	Block Group	Block
Inverse Distance (meters)					
Moran's I	0.129	0.075	0.120	0.096	0.057
z-score	1.888	3.588	6.398	10.662	19.370
p-value	0.059	< 0.001	< 0.0001	< 0.0001	< 0.0001
K-Nearest Neighbor					
Moran's I	0.028	0.140	0.163	0.143	0.111
z-score	1.027	6.113	6.536	9.010	16.783
p-value	0.3042	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contiguity Edges Only					
Moran's I	0.126	0.180	0.268	0.306	Invalid
z-score	1.995	5.499	7.462	13.984	Invalid
p-value	< 0.05	< 0.001	< 0.0001	< 0.0001	Invalid

Statistical results of Moran's *I* Statistic for the total number of fatalities at the county, county subdivision, census tract, block group, and block-level are presented in Table 4.2. These results show that crashes were slightly more clustered than would be expected to result from chance, except for the K-Nearest Neighbor analysis at the county level. The p-values at the county level were not significant with any of the methods used. The Contiguity Edge method most strongly suggests clustering at all five scales, particularly at the county subdivision, census tract, and block group levels with $p < 0.0001$. The Inverse Distance and K-Nearest Neighbor methods produced similar results.

Table 4.2 Moran's I statistical results for fatalities at five spatial scales

Moran's I Fatalities	County	County Subdivision	Census Tract	Block Group	Block
Inverse Distance					
Moran's I	0.087	0.125	0.095	0.076	0.032
z-score	1.119	4.286	5.063	8.405	10.811
p-value	0.26	< 0.0001	< 0.0001	< 0.0001	< 0.0001
K-Nearest Neighbor					
Moran's I	-0.014	0.186	0.145	0.149	0.060
z-score	0.154	5.982	5.767	9.672	9.057
p-value	0.88	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Contiguity Edges Only					
Moran's I	0.085	0.219	0.329	0.267	Invalid
z-score	1.182	4.949	9.063	12.112	Invalid
p-value	0.24	< 0.0001	< 0.0001	< 0.0001	Invalid

4.1.3. Local Moran's *I*



The Anselin Local Moran's *I* Spatial Statistic identified 18 High-High Clusters and 334 Low-Low Clusters. An additional 85 High-Low Outliers and 17 Low-High Outliers were identified. The spatial distribution of these features is presented in Figure 4.3. Low-low clusters appear to be concentrated in urbanized areas, and high-high clusters appear to be concentrated in areas adjacent to urban areas in a pattern that was investigated through the perspective of EMS and Prehospital Response Times.

Figure 4.3 Local Moran's I result for fatalities at the block level

4.1.4. Getis-Ord Gi*

The Getis-Ord Gi* Statistic was also used to identify crash clusters according to the Critical Response Interval and Prehospital Interval. These results show specific segments of road that experience longer EMS intervals than their surrounding area. They also identify Cold Spots in urban areas that experience shorter EMS intervals, particularly for the Prehospital Interval. Figure 4.4 shows the Critical Interval Hot and Cold spots. Hot Spots tend to be concentrated in rural areas adjacent to metropolitan areas, whereas Cold Spots are concentrated in metropolitan areas. These Hot and Cold Spots are more pronounced in Figure 4.5, as the differences in total Prehospital Intervals are more pronounced.

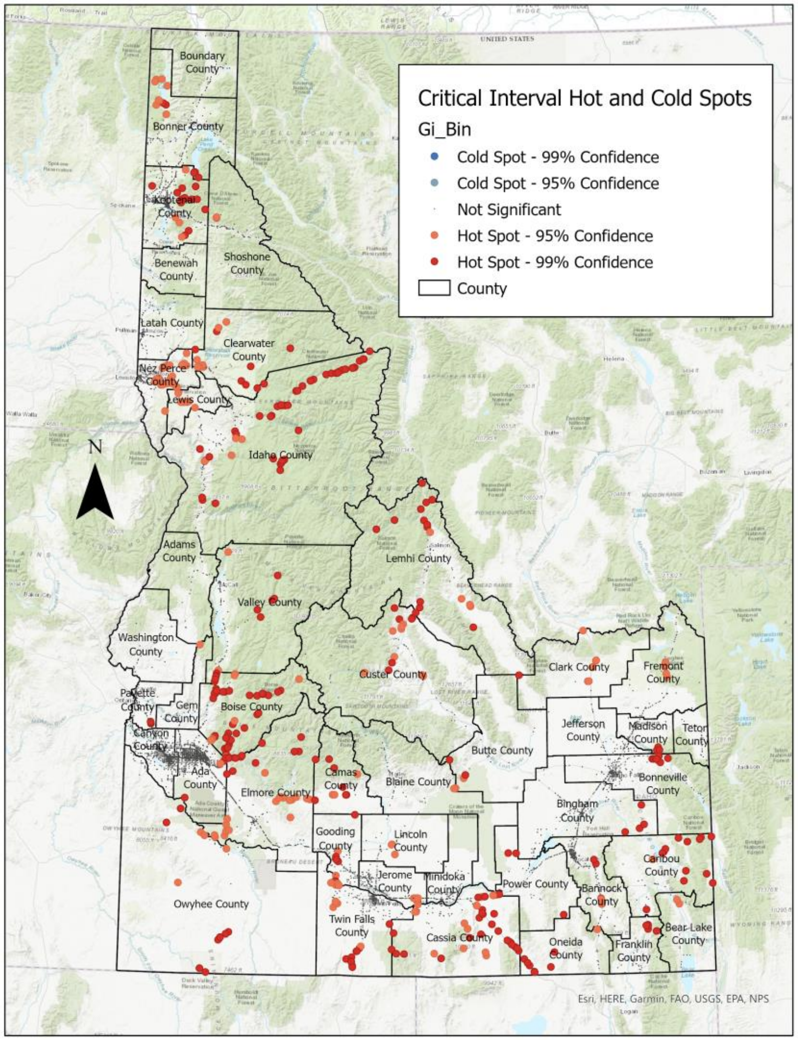


Figure 4.4 Gi for Critical Interval*

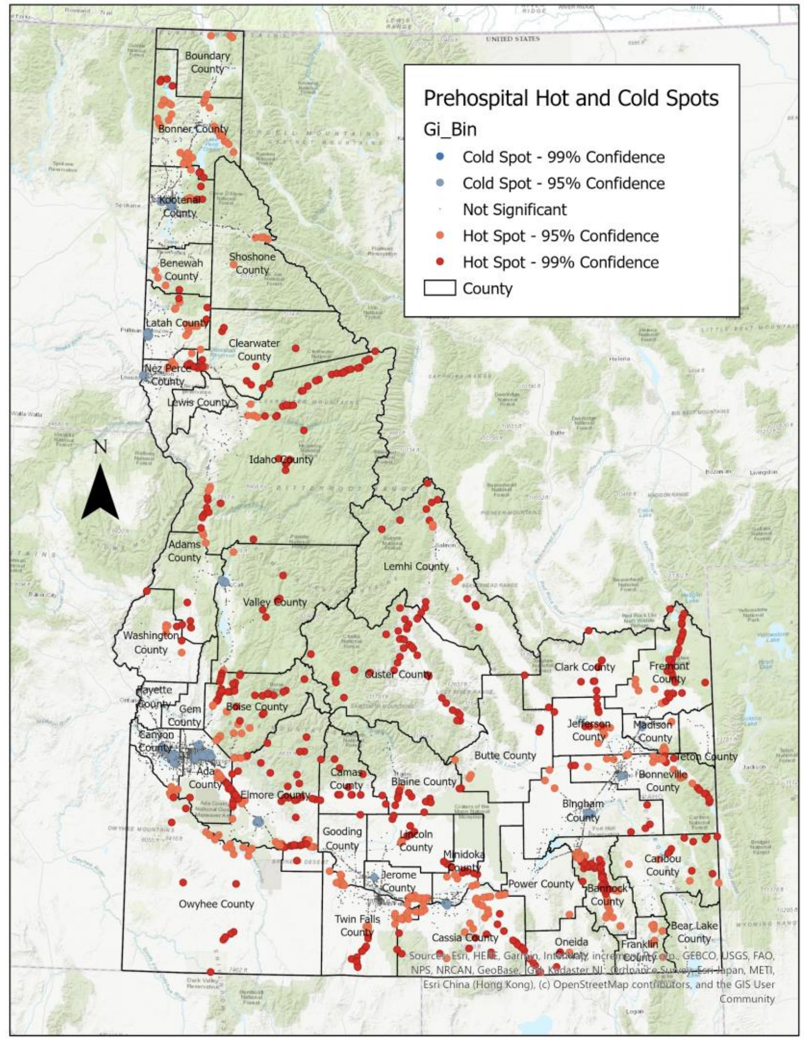


Figure 4.5 Gi for Prehospital Interval*

4.1.5. Network Screening

The final set of results produced by the clustering and hot spot analysis consists of a ranked list of segments generated by a new performance measure within the context of Network Screening. A new performance measure was developed to calculate a ranked score according to four criteria: (1) the mean Critical Interval, (2) the mean Prehospital Interval, (3) the sum of Critical Intervals, and (4) the sum of Prehospital Intervals. A list of the top ten segments ranked by each of these criteria is summarized in Table 4.4. First, the top ten segments are ranked by each of the four criteria listed above. If a segment is ranked by two or more criteria or ranked highly within one criterion, it was selected for a secondary ranking shown in Table 4.3. Segment 37 was ranked first by all four criteria and had 29 fatal and severe crashes. Its mean Critical Interval was just over 1 hour, and its mean Total Interval was just under 3 hours. Crashes on this segment have a total Critical Interval allocation of 30 hours and a total Prehospital Interval allocation of 85 hours, more than the sum of the next four ranked segments.

Table 4.3 Final Ranked segments according to performance measure

ID	# Crashes	Mean Critical	Mean Total	Sum Critical	Sum Total	Missing	Total	Rank
37	29	1	1	1	1	0	4	1
45	7	2	2	3	4	0	11	2
8	31			2	2	2	24	3
46	5	3	3			2	26	4
9	22			5	3	2	28	5
2	13	8		3	9	1	30	6
17	9	5		7		2	32	7
41	8	4		8		2	32	8
42	9		6		8	2	34	9
21	7		4			3	34	10
7	10		10	9	6	1	35	11
3	13				5	3	35	12
19	6	5				3	35	12
20	7		5			3	35	12
14	11			6	10	2	36	15

Table 4.4 Ranked Segments according to four criteria

C1				C2			
ID	**Crashes**	**Mean Critical**	**Rank**	**ID**	**Crashes**	**Mean Total**	**Rank**
37	29	61	1	37	29	177	1
45	7	45	2	45	7	160	2
46	5	31	3	46	5	101	3
41	8	29	4	21	7	79	4
19	6	27	5	20	7	78	5
17	9	27	5	42	9	76	6
44	8	26	7	27	6	73	7
28	6	24	8	10	7	71	8
2	13	24	8	22	8	70	9
15	7	24	8	7	10	69	10
C3				**C4**			
ID	**Crashes**	**Sum Critical**	**Rank**	**ID**	**Crashes**	**Sum Total**	**Rank**
37	29	1772	1	37	29	5128	1
8	31	483	2	8	31	1821	2
2	13	314	3	9	22	1119	3
45	7	314	3	45	7	1117	4
9	22	300	5	3	13	696	5
14	11	251	6	7	10	694	6
17	9	241	7	6	11	689	7
41	8	234	8	42	9	687	8
7	10	209	9	2	13	655	9
12	12	207	10	14	11	610	10

While all four criteria highly ranked segments 37 and 45, the remaining segments were only ranked by one or two criteria. A map showing the distribution of these segments is shown in Figure 4.6. Road segments are symbolized using graduated symbols to indicate the Mean Critical time in minutes and graduated colors to indicate the number of crashes. This method provides another way of identifying areas with long EMS Response Intervals.

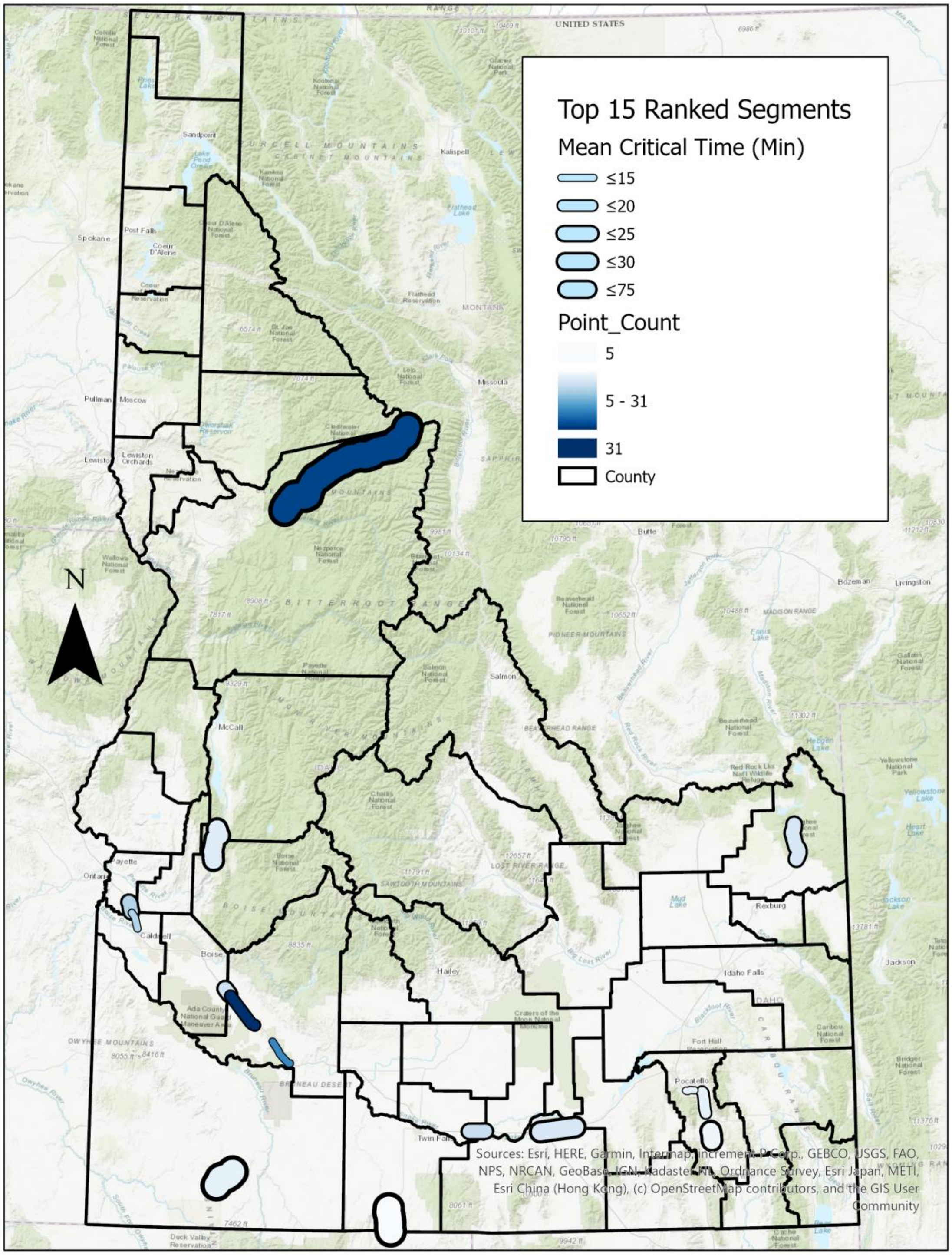


Figure 4.6 Results of EMS Performance Measure

4.2. Response Time Analysis

Emergency Medical Services response times were analyzed for six temporal intervals. Section 4.2.1 presents actual values for the Activation Interval, Response Interval, and Critical Interval. These results evaluate the second hypothesis, which states that the percentage of crashes in which the Critical Interval exceeds 8 minutes will be greater on rural roads. The mean Response Interval was calculated for rural and urban crashes and compared to the percentage of crashes for these classifications within the Critical Interval threshold values. Section 4.2.2 presents the estimated values of these same intervals given the MVC location, EMS facilities location, and road network properties. These results evaluate the third hypothesis, which states that the average actual Response Interval will be greater than the average estimated Response Interval.

The previous two sections' results are compared in Section 4.2.3 to demonstrate where discrepancies between the two exist spatially. Section 4.2.4 presents the estimated transport interval using facility locations and properties of the road network and the total Prehospital Interval for the four combined intervals. This result is used to test the fourth hypothesis, which states that the percentage of crashes where the total Prehospital Interval exceeds 60 minutes will be greater on rural roads. The percentage of crashes for urban and rural classifications is estimated within the *golden hour*.

4.2.1. Actual Notification, Response, and Critical Intervals

The actual Notification, Response, and Critical intervals were compared between rural and urban roadways to identify statistical disparities between the two classifications, as shown in Table 4.5. A total of 6,810 crashes were analyzed, which resulted in 1,224 fatalities and 11,018 injuries. While the number of crashes (49.7% and 50.3%) and the number of injuries (48.6% and 51.4%) were distributed relatively evenly between rural and urban areas, most fatalities occurred on rural roadways (76.0% and 24.0%). Both the Response Interval and Critical Interval in rural areas were more than double those in urban areas. The variance in both intervals was also more significant for rural areas compared to urban areas. The

Activation Interval in rural areas was also greater than the Activation Interval in urban areas. This result is difficult to interpret because the accuracy of the accident and notification times used to calculate these intervals are likely unreliable. The Mann-Whitney test results found statistically significant differences between the Rural and Urban classifications for all three response intervals, as indicated by a p-value less than 0.001.

Table 4.5 Distribution of crashes and actual activation, response, and critical intervals in rural and urban areas

Classification	No. of FA MVC	No. of Fatalities	No. of Injuries	Activation Interval (min)		Response Interval (min)		Critical Interval (min)	
				Mean	Variance	Mean	Variance	Mean	Variance
Rural	3383	931	5357	3.85	67.36	13.14	108.6	16.99	203.53
Urban	3427	293	5661	2.39	25.1	5.37	14.87	7.76	42.03
Urban and Rural	6810	1224	11018	3.11	46.61	9.23	76.52	12.34	143.53
Mann-Whitney test (Z/p-value)				6766900		9427200		9307100	
				< 0.001		< 0.001		< 0.001	

A more detailed analysis of the Critical Interval was performed to test *Hypothesis 3,* which states that rural roadways will have a higher percentage of crashes than urban roadways when the Critical Interval is greater than 8 minutes. This analysis supports this hypothesis and is shown in Figure 4.7, where the x-axis represents the Critical Interval in minutes. The y-axis represents the percentage of crashes within that interval for either the rural classification (blue bar) or urban classification (orange bar). As shown, 72% of crashes on urban roadways in Idaho had a Critical Interval of less than or equal to 8 minutes. In contrast, only 24% of crashes on rural roadways had a Critical Interval within this threshold.

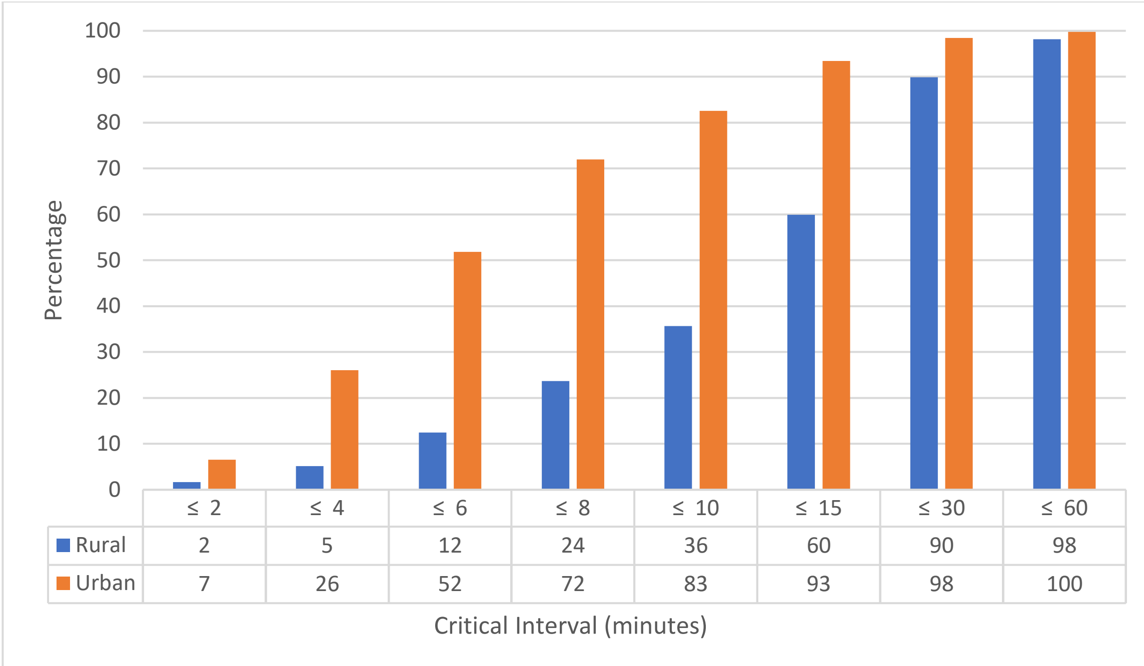


Figure 4.7 Percentage of crashes within the critical interval

In comparison, only half the time (4 minutes) was required to achieve a similar proportion of crash responses in urban areas. The percentage of rural and urban crashes continues to increase as the Critical Interval threshold increases. For a Critical Interval of 15 minutes, the cumulative percentage of rural and urban crashes increases to 60% and 93%, respectively, and for 30-minute Critical Intervals, the percentages increase to 90% and 98%. A tiny percentage of the rural (63 crashes) and urban crashes (7 crashes) had a Critical Interval greater than 60 minutes and are considered outliers.

A total of 6,810 crashes were also compared between rural and urban roadways among six ITD Districts, as shown in Table 4.6. While most fatalities occurred on rural roadways, many fatal crashes also occurred on urban roadways in District 3. District 3 is composed of ten counties in Southwest Idaho, including Ada County, and is home to nearly 40% of Idaho's population. Ada County is the only district with more crashes in urban areas than in rural areas; nevertheless, the number of fatal crashes in this district is still greater than in rural areas. Overall, the difference between the number of fatalities was smaller for crashes in rural areas than in urban areas, suggesting that many of these crashes involved a single vehicle.

Further analysis would be required to verify this observation. The remaining districts in Idaho have a greater number of crashes in rural areas than in urban areas. The proportion of crashes that result in fatalities is also greater in these districts. The Kruskal-Wallis test results found statistically significant differences between the Rural and Urban classifications for all three response intervals, indicated by a p-value of less than 0.001. Analysis of the Critical Interval is also presented graphically in Figure 4.10 to emphasize the variability among the six ITD districts. The x-axis in both figures represents the Critical Interval in minutes. The y-axis represents the percentage of crashes within that interval for either the Urban or Rural classification. While the district-level results verify trends identified in Table 4.5, districts present as outliers to these trends are presented and discussed.

Table 4.6 Rural and Urban MVC's and their revealed accessibility across six ITD Districts

ITD District Rural Crashes	Total Crashes	Fatal Crashes (Fatalities)	Severe Crashes	Activation Interval (min)		Response Interval (min)		Critical Interval (min)	
				Mean	Variance	Mean	Variance	Mean	Variance
1	529	131 (142)	398	4.7	102	11.4	76	16.0	211
2	375	94 (102)	281	6.7	128	17.1	213	23.8	434
3	965	216 (234)	749	3.0	45	12.8	96	15.8	152
4	658	184 (203)	474	2.7	37	13.3	85	16.0	140
5	447	133 (147)	314	4.2	85	12.5	99	16.7	198
6	409	96 (103)	313	3.5	37	13.2	115	16.8	168
Kruskal-Wallis test (df= 5) Chi-square/p-value				153.79		62.872		89.491	
				< 0.001		< 0.001		< 0.001	
ITD District Urban Crashes	**Total Crashes**	**Fatal Crashes (Fatalities)**	**Severe Crashes**	**Activation Interval (min)**		**Response Interval (min)**		**Critical Interval (min)**	
				Mean	Variance	Mean	Variance	Mean	Variance
1	289	24 (27)	265	2.8	16	5.6	9	8.3	30
2	117	13 (13)	104	3.0	10	4.9	14	7.9	30
3	2389	176 (188)	2213	2.2	26	5.3	11	7.5	40
4	236	18 (18)	218	3.6	46	5.8	24	9.4	70
5	227	23 (25)	204	3.0	17	4.8	10	8.0	24
6	169	21 (22)	148	1.2	8	6.3	72	7.5	79
Kruskal-Wallis test (df= 5) Chi-square/p-value				215.500		28.415		60.288	
				< 0.001		< 0.001		< 0.001	

Figure 4.8 shows the variability of the Critical Interval for crashes in urban areas for six ITD districts. District 6 has a consistently lower percentage of crashes within a given interval than the other five districts. While the percentage for the 8-minute Critical Interval fluctuates between around 65% for Districts 1-5, only 40% of crashes in District 6 meet this threshold.

Only 10% of crashes in District 6 experience a Critical Interval less than or equal to 4 minutes. The percentage of District 6 crashes with Critical Intervals of less than one hour only reaches 60%, far below the other districts that all meet this criterion nearly 100% of the time. It is important to note that District 3 has a significant influence on the statewide mean of critical values, as it constitutes almost half of the crash records. Most of the district's 8-minute Critical Interval thresholds are closer to 65% than the state average of 72%.

Figure 4.9 shows the variability in Critical Intervals for crashes in rural areas for the six ITD districts. District 2 has a consistently lower percentage of crashes within a given interval than the other five districts. While the percentage for the 8-minute Critical Interval fluctuates between around 25% for Districts 1,3,4,5 and 6; in contrast, only 5% of rural crashes in District 2 meet this threshold. Fewer than 10% of rural crashes in all districts experience a Critical Interval of 4 minutes or less. Interestingly, the percentage of crashes with a critical interval of less than one hour is very close to 100% for all districts.

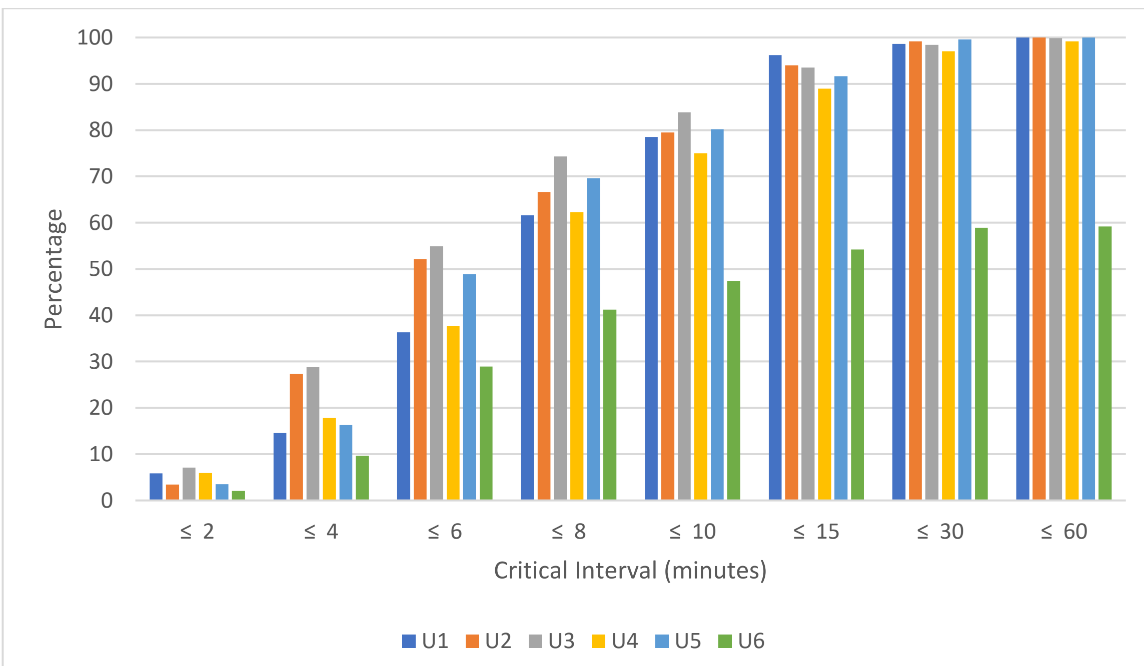


Figure 4.8 Percentage of urban crashes within critical interval for 6 ITD districts

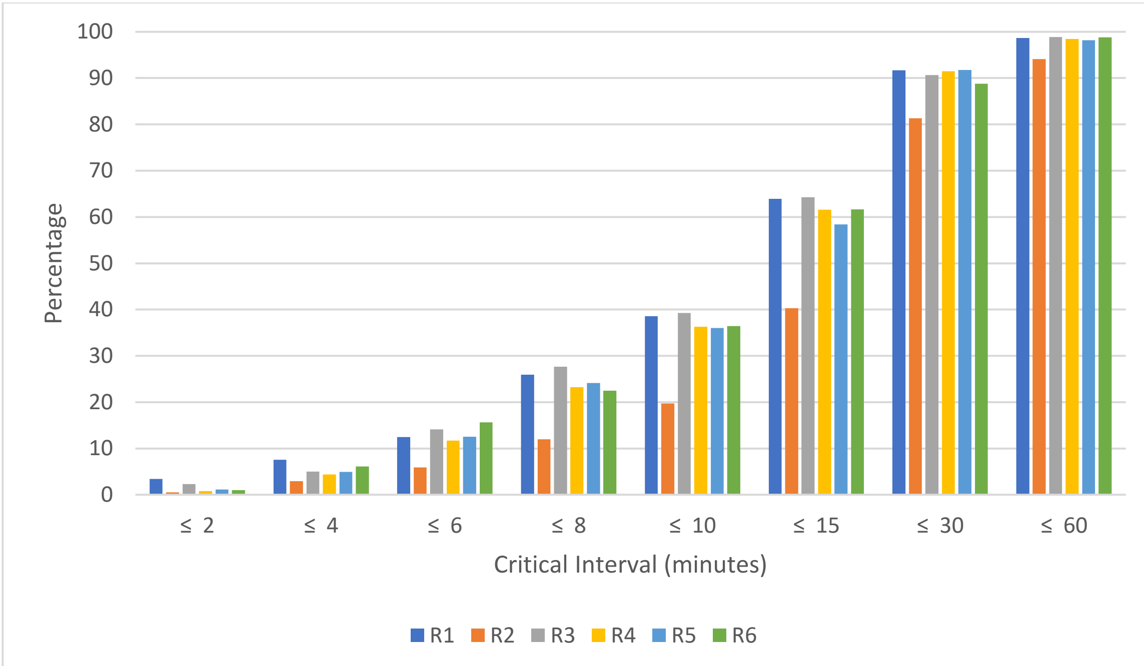


Figure 4.9 Percentage of rural crashes within critical interval for 6 ITD districts

Crashes were also compared between rural and urban roadways among six roadway functional classifications, as shown in Table 4.7. While crashes occurred on Local, Major Collector, Minor Arterial, and Principal Arterial in rural and urban settings, the Minor Collector and Interstate classifications were only present in crashes recorded as occurring in a rural setting.

The proportion of urban crashes on road classifications made up 30% of crashes, while 29% of fatalities occurred on principal arterials. The remaining crashes were distributed among Major Collectors (20%), Interstates (17%), Minor Arterials (15%), Local Roads (15%), and Minor Collectors (4%). Local roads and minor collectors had both the longest Response Intervals and Critical Interval values and the largest variability. The Kruskal-Wallis test showed statistically significant differences for the Activation Intervals across the six urban classifications, indicated by a $p < 0.002$, and statistically significant differences for the Response Intervals and Critical intervals indicated by $p < 0.001$.

Table 4.7 Revealed accessibility of crashes across six road classifications

Road Classification Rural Crashes	Total Crashes	Fatal Crashes (Fatalities)	Severe Crashes	Activation Interval (min)		Response Interval (min)		Critical Interval (min)	
				Mean	Variance	Mean	Variance	Mean	Variance
Local	491	144(155)	347	5.8	210	15.3	171	21.1	453
Minor Collector	136	28(30)	108	4.9	47	18.3	261	23.2	326
Major Collector	684	162(178)	522	3.25	48.15	12.7	92	15.9	150
Minor Arterial	500	122(131)	378	3.5	51	12.0	79	15.4	144
Principal Arterial	1010	244(271)	766	3.6	38	12.6	107	16.2	176
Interstate	562	154(166)	408	3.4	34	12.7	56	16.1	96
Kruskal-Wallis test (df= 5) Chi-square/p-value				19.255		41.655		50.801	
				0.002		< 0.001		< 0.001	
Road Classification Urban Crashes	**Total Crashes**	**Fatal Crashes (Fatalities)**	**Severe Crashes**	**Activation Interval (min)**		**Response Interval (min)**		**Critical Interval (min)**	
				Mean	Variance	Mean	Variance	Mean	Variance
Local	330	29(30)	301	2.7	23	5.4	10	8.1	30
Major Collector	311	18(18)	293	2.4	33	5.3	12	7.7	48
Minor Arterial	950	64(69)	886	2.5	29	5.5	26	8.0	56
Principal Arterial	1836	164(176)	1672	2.3	22	5.3	10	7.6	36
Kruskal-Wallis test (df= 3) Chi-square/p-value				14.642		1.036		7.961	
				0.002		0.793		0.047	

Rural crashes on road classifications made up some 54% of crashes, while 60% of fatalities occurred on principal arterials. Minor arterials also made up a large proportion of crashes (28%) and fatalities (23%). The remaining 20% of crashes and 18% of fatalities were divided equally between local and major collector roads. The Kruskal-Wallis test showed statistically significant differences among the four urban classifications for the Activation Intervals, indicated by a $p < 0.002$; however, test results did not find statistically significant differences among the Response Intervals as indicated by $p < 0.8$ and only slightly significant differences among the Critical Intervals as indicated by $p < 0.05$.

Analysis of the Critical Intervals is presented graphically for urban and rural classifications to emphasize the variability of road classifications. The x-axis in both figures represents the critical interval in minutes. The y-axis represents the percentage of crashes within that interval for either the urban classification or rural classification. Figure 4.10 shows the variability of the critical interval for crashes in rural and urban areas for six road classifications. The first six columns in each category show the critical interval for crashes in rural areas, and the remaining four columns represent crashes in urban areas. Urban crash percentages are higher and more consistent between classifications than rural crash results, which agrees with statistical tests.

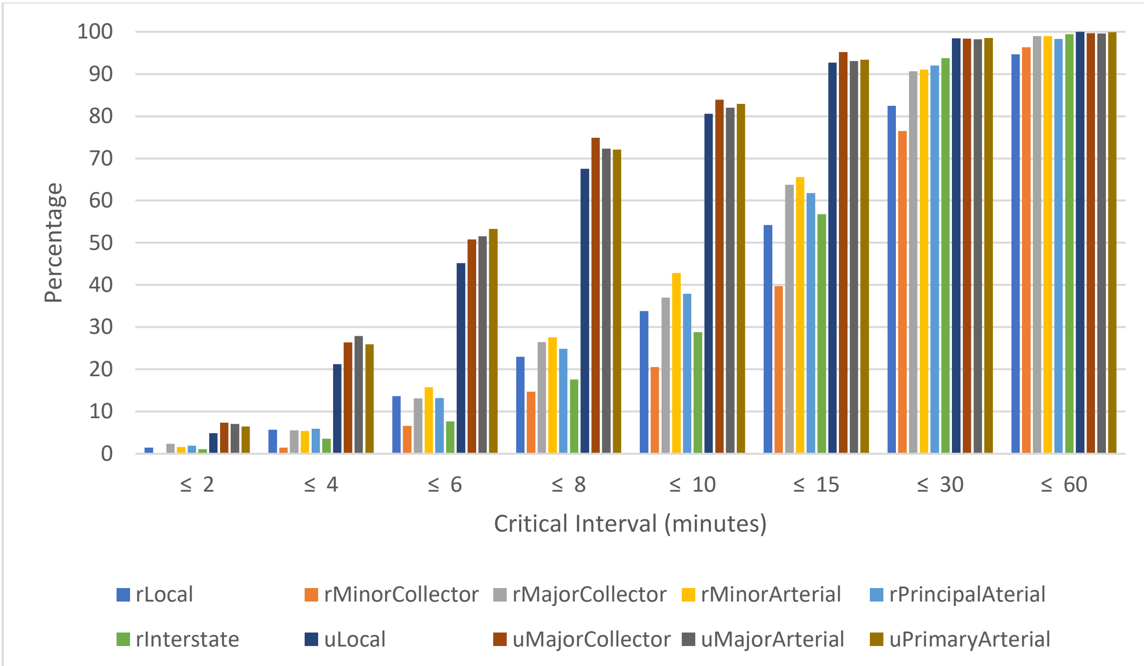


Figure 4.10 Percentage of urban and rural crashes within critical interval for six road classifications

4.2.2. Estimated EMS Response Intervals

The Response Interval is the amount of time it takes for an ambulance to travel to a crash scene. A road network model was developed to estimate the potential accessibility of EMS providers to these crashes. Roads were classified as either rural or urban according to whether they were located in a Census-defined urban area, and mean travel speeds were assigned to them. A summary of these results for urban, rural, and total areas is presented in Table 4.8. The results show that the Response Interval is consistently underpredicted within the potential accessibility framework by 3.3 minutes in rural areas and 1.6 minutes in urban areas. There was also less variance in the predicted values. Differences between the potential and revealed accessibility will be discussed more in Section 4.2.3.

Table 4.8 Potential EMS Accessibility and difference from actual response interval

Classification	No. of FA MVC	No. of Fatalities	No. of Injuries	Actual Response Interval (min)		Predicted Response Interval (min)		Difference (min)	
				Mean	Variance	Mean	Variance	Mean	Variance
Rural	3383	931	5357	13.14	108.6	9.82	99.84	-3.32	-8.76
Urban	3427	293	5661	5.37	14.87	3.81	4.94	-1.56	-9.93
Urban and Rural	6810	1224	11018	9.23	76.52	6.80	61.20	-2.43	-15.32

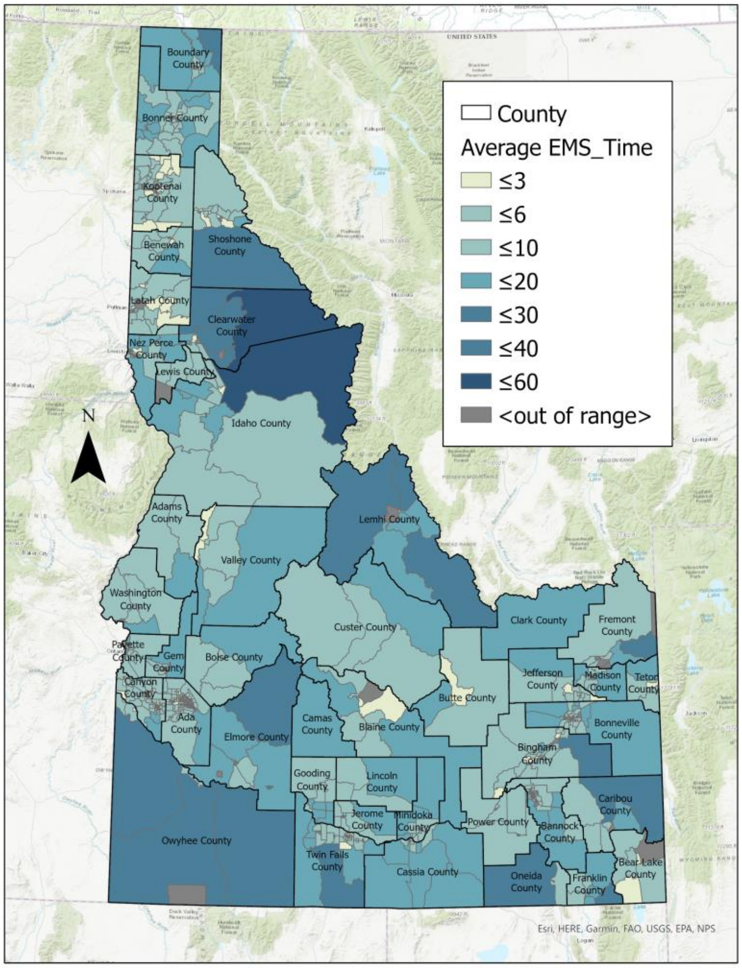


Figure 4.11 shows the spatial distribution of mean predicted response intervals at the Census Block Group level in Idaho. These results show that areas with higher values include the eastern regions of Clearwater and Idaho Counties and, to a lesser extent, Shoshone, Owyhee, Elmore, Lemhi, Oneida, and Caribou Counties. Areas with low response intervals are concentrated in Idaho's various urban block groups.

Figure 4.11 Mean Predicted Response Interval at the Block Group Level

4.2.3. Comparison of Actual and Estimated EMS Intervals

The next step in analyzing EMS accessibility to fatal and severe crashes is to compare the actual values revealed from data provided by ITD to the potential values generated by the network travel model. Both features were converted to a raster format using an Inverse Distance Weighted Interpolation model. One benefit of this model is that it is an exact interpolator, meaning extreme values in the created surface only occur at known data points. A statistical summary of the error between actual and predicted response intervals is presented in Figure 4.12. The error distribution appears to be normally distributed and slightly skewed to the right, indicated by a mean value of 2.4 minutes and a median value of 1.6 minutes. The standard deviation of error is 7.6 minutes.

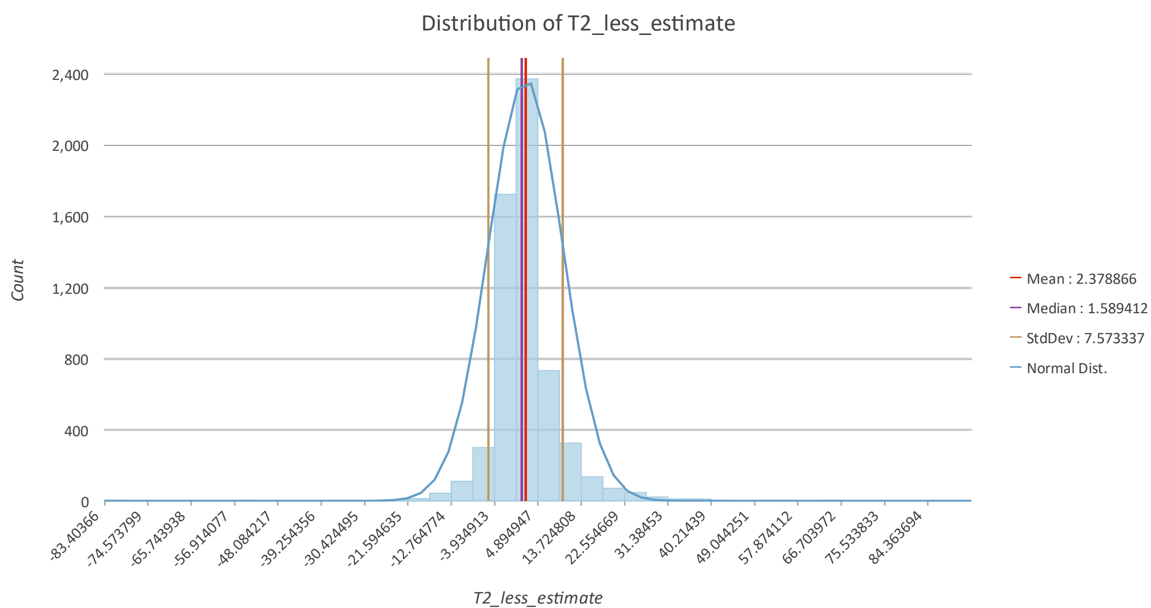


Figure 4.12 Statistical Distribution of response interval error values

Figure 4.13 shows the spatial distribution of the difference between actual and estimated response intervals. Areas in green indicate negative values that occur when the actual response times are less than those predicted by the network model. Overprediction occurs when EMS services are provided by air-based rescue services and EMS providers located outside Idaho. The large areas located in Idaho's northeast corner are accessed via Highway 12, which follows Lolo Pass over Montana’s border to Missoula. EMS providers and hospitals in surrounding states were not included in the road network model, although they likely respond to Idaho crashes close to state borders.

Another example of this is in southwest Idaho, where the Duck Valley Indian Reservation is located. Most of the reservation’s population resides in Nevada and are more likely to receive medical services in Elko, NV. About ten locations also appear to have rapid response times; however, very few crashes occur in these areas, and the resulting areas should be interpreted as artifacts of the analysis.

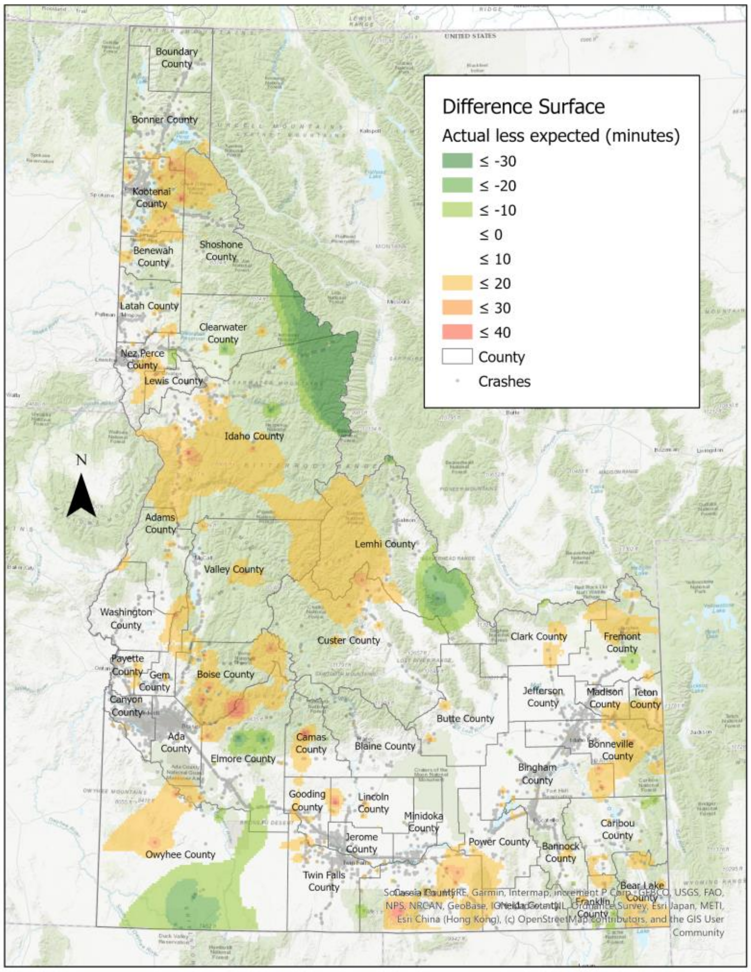
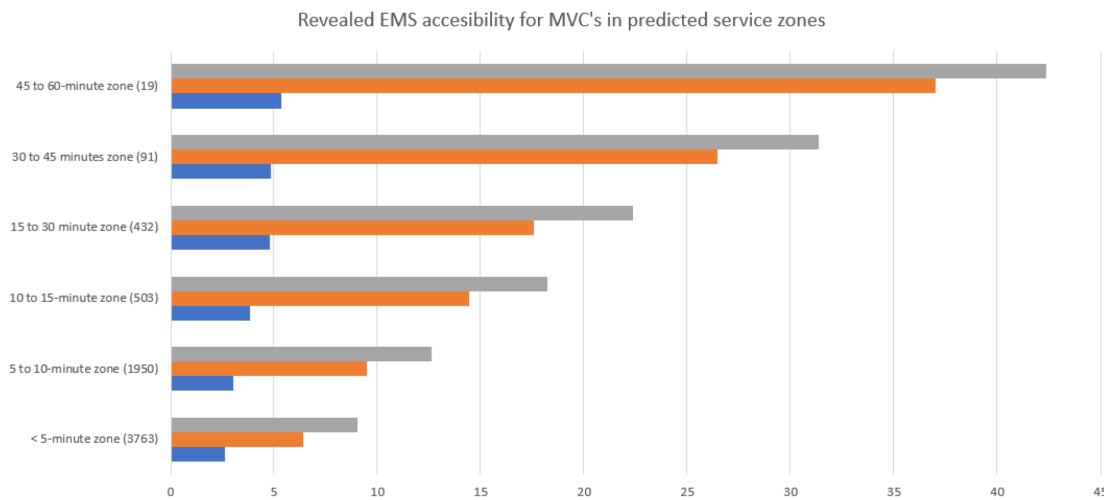


Figure 4.13 Interpolation of difference in actual and estimated EMS response intervals

Areas in orange/red indicate positive values that occur where the actual response times are greater than those predicted by the network model. Underprediction occurs when EMS services cannot respond to the crash in an adequate amount of time. Underprediction appears to be concentrated in areas adjacent to urban metropolitan regions. It could result from people traveling from heavily populated urban areas such as Coeur d'Alene, Boise, Twin Falls, and Idaho Falls to remote areas adjacent to them for recreational opportunities. Some areas appear to have longer response times due to jurisdictional issues along county or state boundaries. The borders of Kootenai and Shoshone Counties, Lemhi and Custer Counties, Boise & Elmore Counties, and Bonneville & Teton Counties all have potential jurisdictional issues that require further investigation. Finally, poor cellular reception and poor road conditions could also be contributing to the higher response intervals.

Figure 4.14 presents the number of crashes within predicted service zones and the mean Notification, Response, and Critical Intervals of those crashes. These results show that average response intervals for crashes within the <5-minute zone, 5-10-minute zone, and 10-15-minute zone tend to be very close to the zonal values. The differences between average response intervals and the zonal values increases for the predicted service zones greater than 15 minutes. The mean value for the 15-30-minute zone was 17 minutes; for the 30-45-minute zone, this value increased to 26 minutes, and for the 45-60-minute zone, the value was to 37 minutes. It is interesting to note that the mean notification time also increases within these zones, although only slightly.



	< 5-minute zone (3763)	5 to 10-minute zone (1950)	10 to 15-minute zone (503)	15 to 30 minute zone (432)	30 to 45 minutes zone (91)	45 to 60-minute zone (19)
Critical Time	9.06	12.62	18.24	22.38	31.34	42.37
Response Time	6.43	9.49	14.43	17.58	26.47	37
Notification Time	2.62	3.02	3.82	4.8	4.87	5.37

Figure 4.14 Summary of actual response times within predicted service zones

4.2.4. Estimated Hospital Transport Interval and Total Prehospital Interval

The potential accessibility of crashes was compared between rural and urban roadways to identify statistical disparities between the two classifications. The same sample of crashes was used to analyze revealed accessibility, and a summary of the number of crashes, fatalities, and injuries is shown in Table 4.8. For crashes as a whole, the mean Transport Interval was 15 minutes, and the mean total Response Interval was 39 minutes. Urban crashes had significantly shorter Transport (9 minutes) and Prehospital Intervals (28 minutes) than rural crashes. The Mann-Whitney test showed statistically significant differences between Rural and Urban classifications for both intervals, indicated by a p-value less than 0.001.

Table 4.9 Distribution of MVC's and their potential access to EMS in rural and urban areas

Classification	No. of FA MVC	No. of Fatalities	No. of Injuries	Transport Interval (min)		Total Response Interval (min)	
				Mean	Variance	Mean	Variance
Rural	3383	931	5357	21.78	240.75	50.54	519.34
Urban	3427	293	5661	8.66	55.10	28.36	66.01
Urban and Rural	6810	1224	11018	15.19	190.55	39.4	414.75
Mann-Whitney test (Z/p-value)				9984300 < 0.001		10437000 < 0.001	

The distribution of total prehospital time among 963 Census block groups is presented in Figure 4.15. Within a Block Group, the mean Prehospital Interval was 37.9 minutes, the median Prehospital Interval was 33.6 minutes, and the standard distribution was 16.9 minutes. This histogram is a preliminary investigation of this variable and allows two generalizations. First, the total mean and median are being made using average values and can be misleading. Second, these times reflect the combination of crashes in urban and rural areas.

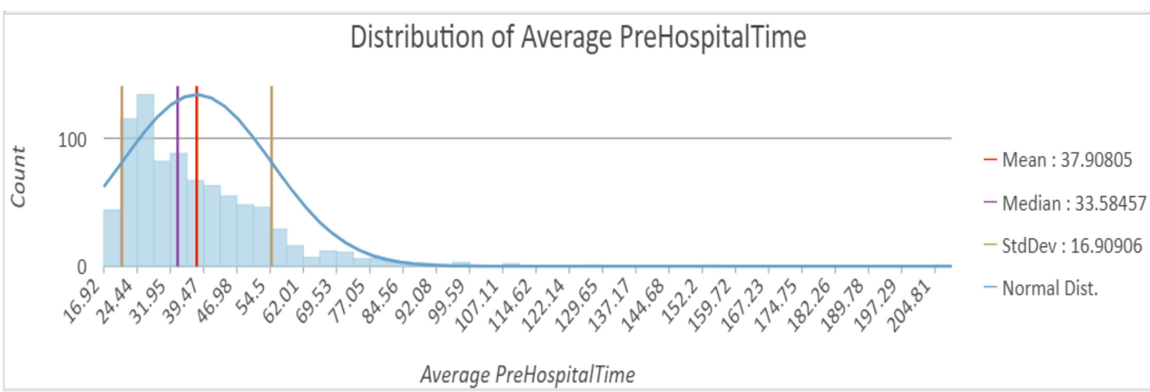


Figure 4.15 Histogram of Total Prehospital Time

A more detailed analysis of the Critical Interval was performed to test Hypothesis 4, which states that rural roadways will have a higher percentage of crashes. The total response interval is greater than 60 minutes compared to urban roadways. Results of this analysis support this hypothesis and are shown in Figure 4.16. The x-axis represents the total response interval in minutes. The y-axis represents the percentage of crashes within that interval for either the rural classification (blue bar) or urban classification (orange bar).

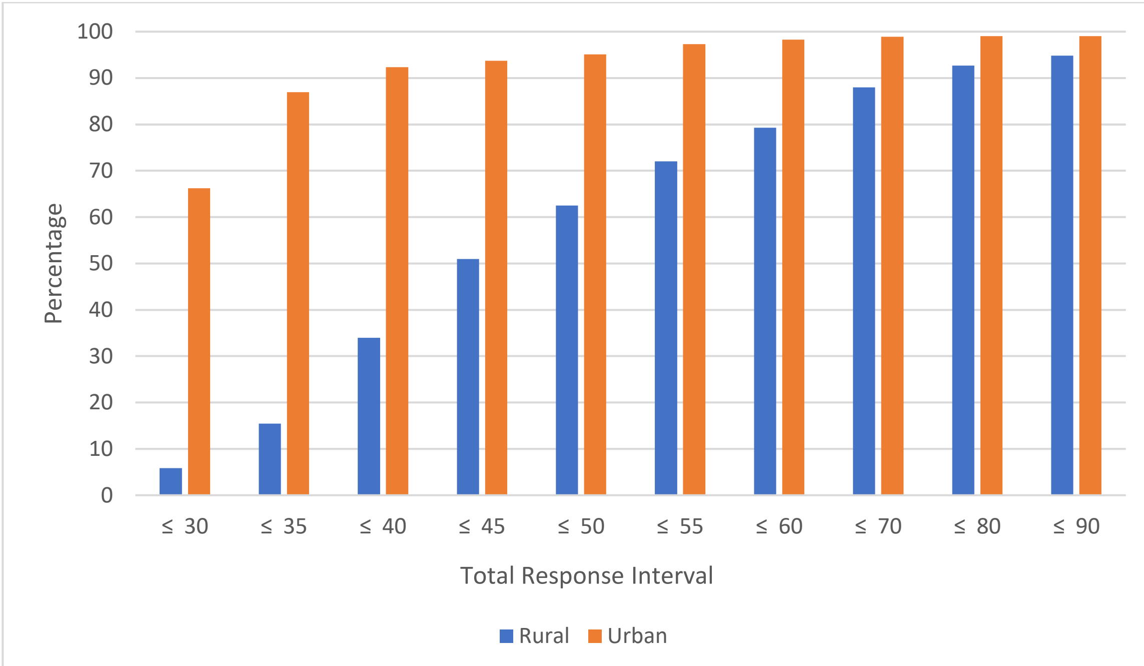


Figure 4.16 Cumulative percent of crashes within the total response interval

This graph shows that 65% of crashes on urban roadways had a total response time less than or equal to 30 minutes, whereas only 6% of crashes on rural roadways had a total response time within this threshold. At 45 minutes, over 94% of urban crashes were resolved, whereas only 51% of rural crashes met this same threshold. Regarding the fourth hypothesis, 98% of crashes in urban areas are resolved within the "golden hour" whereas only 79% of crashes in rural areas experience a complete EMS response within this time. However, only a small percentage of the rural (176 crashes) and urban crashes (33 crashes) had a critical interval greater than 90 minutes and are considered outliers.

Transport Intervals and Total Response Intervals were compared between rural and urban roadways among the six ITD Districts, as shown in Table 4.9. Districts 2 and 6 had the longest rural Transport and response intervals with 29 and 30 minutes, respectively. District 2 also had a very high amount of variance in the total response interval. District 5 also had a very long transport interval for urban crashes, three to four times greater than the other districts. The total response interval within this district was also much longer. The variance for both of these intervals was also significantly greater in District 5. The Kruskal-Wallis test had statistically significant differences between the six transportation districts for both intervals and both classifications indicated by $p < 0.001$.

Table 4.9 Potential accessibility of rural and urban crashes to hospitals across six ITD Districts

ITD District Rural Crashes	Total Crashes	Fatal Crashes (Fatalities)	Severe Crashes	Transport Interval (min)		Total Response Interval (min)	
				Mean	Variance	Mean	Variance
1	529	131 (142)	398	18.3	78	44.0	115
2	375	94 (102)	281	28.8	579	61.7	1748
3	965	216 (234)	749	20.5	185	49.4	421
4	658	184 (203)	474	19.2	122	47.7	225
5	447	133 (147)	314	19.6	156	48.2	339
6	409	96 (103)	313	29.5	417	58.6	568
Kruskal-Wallis test (df= 5) Chi-square/p-value				154.2 < 0.001		154.2 < 0.001	
ITD District Urban Crashes	**Total Crashes**	**Fatal Crashes (Fatalities)**	**Severe Crashes**	**Transport Interval (min)**		**Total Response Interval (min)**	
				Mean	Variance	Mean	Variance
1	289	24 (27)	265	6.6	18	26.4	25
2	117	13 (13)	104	6.3	30	26.0	64
3	2389	176 (188)	2213	7.2	17	26.8	28
4	236	18 (18)	218	9.4	28	28.7	31
5	227	23 (25)	204	27.2	189	47.1	191
6	169	21 (22)	148	9.2	27	29.6	44
Kruskal-Wallis test (df= 5) Chi-square/p-value				375.880 < 0.001		375.880 < 0.001	

Crashes were also compared between rural and urban roadways among six roadway functional classifications, as shown in Table 4.10. The transport interval among the road classifications was consistent, with values ranging between 20 and 25 minutes for rural crashes and 8 to 10 minutes for urban crashes. The total response interval was also consistent, with values ranging between 49 and 56 minutes for rural crashes and 28 to 21 minutes for urban crashes. The Kruskal-Wallis test showed statistically significant differences between the road classifications for the transport interval and total response interval for rural crashes indicated by a $p < 0.001$, but only a marginally significant statistical difference for urban crashes indicated by $p < 0.05$.

Table 4.10 Potential accessibility of crashes to hospitals across six road classifications

Road Classification	No. of FA MVC	No. of Fatalities	No. of Injuries	Transport Interval (min)		Total Response Interval (min)	
Rural Crashes				Mean	Variance	Mean	Variance
Local	491	155	665	22.1	222	51.2	481
Minor Collector	136	30	209	24.8	270	55.8	775
Major Collector	684	178	1040	20.2	149	48.7	282
Minor Arterial	500	131	772	22.0	319	49.3	574
Principal Arterial	1010	271	1734	22.3	331	50.9	792
Interstate	562	166	937	21.5	125	51.5	228
Kruskall-Wallis test (df= 5) Chi-square/p-value				60.514 <0.001		60.514 < 0.001	
Road Classification	**No. of FA MVC**	**No. of Fatalities**	**No. of Injuries**	**Transport Interval (min)**		**Total Response Interval (min)**	
Urban Crashes				Mean	Variance	Mean	Variance
Local	330	30	416	10.9	98	30.5	106
Major Collector	311	18	500	8.7	52	28.5	63
Minor Arterial	950	69	1597	8.2	43	27.8	54
Principal Arterial	1836	176	3148	8.5	53	28.2	65
Kruskall-Wallis test (df= 3) Chi-square/p-value				8.9 0.0305		8.9 0.0305	

Figure 4.17 shows the spatial distribution of average Prehospital Intervals at the Census Block Group Level. This data corresponds with the histogram that is presented in Figure 4.15. This map shows very long response intervals -- greater than three hours in the eastern part of Clearwater, Idaho County, southeast Owyhee, and northeast Elmore Counties in Districts 1 and 3. It also shows long response intervals in Oneida County, Custer County, southeast Lemhi County and Clark County in Districts 5 and 6. More specific patterns appear by presenting these results at the Block Group level instead of the County or District level. Areas with short total Prehospital Intervals are concentrated in Idaho's various urbanized block groups.

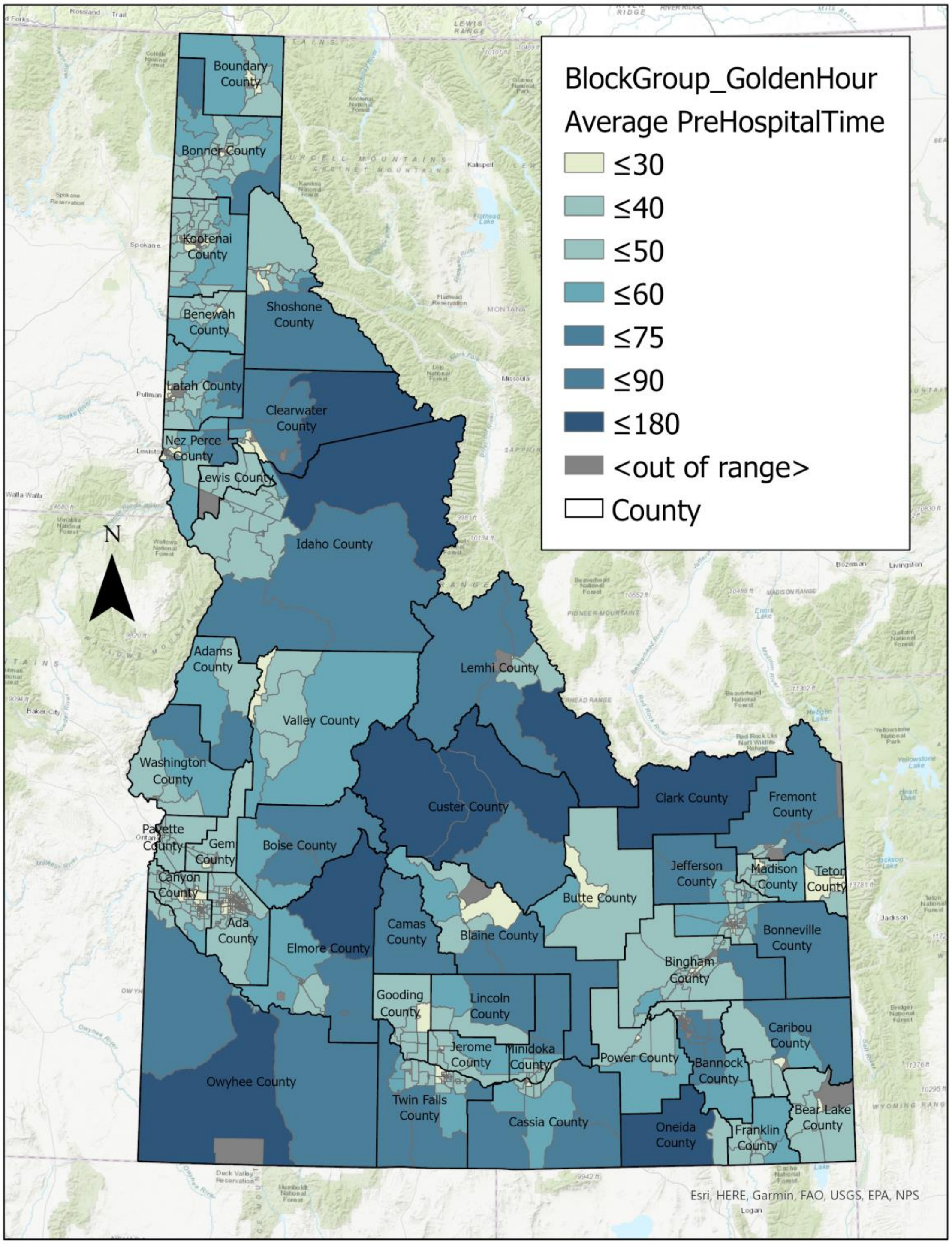


Figure 4.17 Average total prehospital interval at the census block group level

Chapter 5. Conclusions

Rapid EMS response is the most important factor in determining morbidity and mortality resulting from motor vehicle crashes. The EMS response cycle may be divided into four different stages, which can either be calculated using data recorded in crash reports or estimated using the locations of crashes relative to EMS and hospital care. This research explored the clustering of fatal and severe crashes in Idaho and analyzed the time required to respond to these crashes. Four objectives and hypotheses were addressed in this research better to understand the spatial and temporal components of these crashes.

This research is significant because it represents the first assessment of EMS Response Intervals in Idaho to the author's knowledge. While the Idaho Department of Transportation has studied the distribution and characteristics of crashes in detail, EMS Response Intervals are often overlooked. It also provides an assessment of EMS Response Intervals for both Fatal and Severe 'A' crashes; in other words, it is not restricted to Fatal crashes only. Finally, it incorporates EMS ambulances depots' locations on the statewide level to assess Response Intervals using actual travel times.

The first objective was to assess the clustering of fatal and severe crashes using five statistical methods at multiple spatial scales. The first hypothesis of this research stated that crashes would be more clustered in urban areas and less clustered in rural areas. Kernel Density analysis showed that fatal crashes tend to be more clustered than severe crashes, particularly along the I-84 corridor and metropolitan areas where most crashes occur. The Global Moran's *I* Statistic confirmed that fatal crashes tend to be more clustered than fatal and severe crashes at the County Subdivision, Census Tract, and Block Group level. This statistic, however, generates a single value for the whole study area and is not specific to smaller geographic units.

The Anselin Local Moran's *I* Statistic was used to identify statistical clusters and outliers at the Block Group level. This analysis showed a pattern of Low-Low Clusters centered in metropolitan areas, surrounded by High-Low Outliers. Low-High Outliers exist on the periphery of these areas in remote regions of Idaho. The Getis-Ord Gi* Statistic was also used to identify clusters of crashes classified according to their EMS Response Intervals. This method indicates that Hot Spots tend to be concentrated in rural areas adjacent to metropolitan areas, whereas Cold Spots are concentrated in those metropolitan areas. Finally, Network Screening was used to identify segments with a weighted score composed of the mean critical and total EMS intervals and the sum critical and total EMS intervals. This method produced a ranked list of segments with the poorest EMS responses in Idaho.

The second objective was to calculate the actual Notification, Response, and Critical intervals for Idaho crashes. An analysis showed that although crashes and injuries are distributed relatively evenly between rural and urban areas, 76% of fatalities occur on rural roadways; 24% occur on urban roadways. A statistically significant difference between the Rural and Urban classifications was found for all three Response Intervals using the Mann-Whitney test. Statistically significant differences between ITD districts were found among rural and urban crashes for all three response intervals using the Kruskal-Wallis test. Statistically significant differences for the Activation Interval among rural and urban crashes were not determined, but differences in the Response Interval and Critical Interval were significant among rural crashes.

The second hypothesis of this research stated that rural roadways would have a higher percentage of crashes than urban roadways when the Critical Interval is greater than 8 minutes. The analysis showed that 72% of crashes on urban roadways had a Critical Interval of less than or equal to 8 minutes. In comparison, only 24% of crashes on rural roadways had a critical interval within this threshold.

The third objective was to calculate the estimated Response and Critical Intervals for crashes. The third hypothesis stated that the mean actual Response Interval would be greater than the mean estimated Response Interval. A comparison of the two response intervals reveals a mean difference of 2.38 minutes with a standard deviation of 7.58 minutes, thereby supporting this hypothesis; however, three remote areas in Idaho had actual Response Intervals significantly less than the estimated Response Intervals. They occur along Idaho's borders with Montana and Nevada, where out-of-state EMS providers provide a more timely response than what can be provided by Idaho.

The fourth objective was to calculate the estimated Transport and total Prehospital Intervals for crashes. The Transport Interval was estimated using the road network model. The Prehospital Interval was calculated as the sum of the actual notification, actual response, mean on-scene, and estimated transport interval. The fourth hypothesis stated that the percentage of crashes in which the total Prehospital Interval exceeds 60 minutes would be greater than rural roads. Results show that urban crashes have significantly shorter Transport and Prehospital Intervals than rural crashes. More specifically, 98% of crashes in urban areas are resolved within the "golden hour", whereas only 79% of crashes in rural areas experience a complete EMS response within this time. Differences between urban and rural Prehospital Intervals were also evaluated among the six ITD districts and Road Classifications and were found to be significant using the Kruskal-Wallis test.

This project provides key information regarding the current status of EMS responses to crashes in Idaho. Results were presented through a detailed analysis of actual response times and estimated response times to highlight where improvements may be made. By comparing actual response times and estimated response times from EMS providers, planners and policymakers will better identify where improvements in statewide EMS responses could be made. Additionally, EMS intervals were visualized using maps at the County, Block Group, and Segment level to identify specific areas that could benefit from additional services to improve EMS response times. Visualization allows for a more comprehensive assessment of EMS service coverage in a spatially explicit manner.

Finally, it is important to note the limitations of this study and make recommendations for future research. First, this research was limited by the quality of the crash data available in Idaho. The On-Scene Intervals and Transport Intervals were unknown and needed to be estimated using previous research and a road network model. The road network model used two mean speed limit values developed in previous research and travel distance between the crash and provider to estimate the travel time. This process could be improved by using actual road speed limits.

There is certainly more to be learned about the time required by EMS to respond, treat, and transport patients. The perspective and experience of volunteer and professional personal collected through surveys or the organization of a town hall meeting could greatly improve the relevance of this research to produce actionable insights. A better understanding of the financial considerations at the Local, County, and State levels of government would be useful for identifying what measures could be put into place to reduce serious crashes and decrease the time required to respond to them in the future. A closer look at the factors contributing to these crashes and the length of their response times would be a prudent extension of this research. Road geometry, pavement conditions, weather conditions, and driver behavior all likely important factors for crash occurrence. EMS response intervals are likely influenced by cell service and conflicts between jurisdictions and other factors related to the road condition.

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