A System-wide Planning Tool to Evaluate Access from Crash Sites to Medical Facilities in Virginia

AlimaJafreen HajaMeeran

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science

In

Civil Engineering

Kathleen L. Hancock

Hesham A. Rakha

Bryan J. Katz

February 20, 2019

Blacksburg, Virginia

Keywords: Crash Response Planning Tool, Medical Facilities,
Coverage Area, Planning Grid

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ABSTRACT

Crash response planning is a vital component of emergency management and highway emergency response planning. Evaluation of coverage of medical facilities is required to determine adequate access from crash sites to medical facilities. This study proposes a proof of concept for a planning tool that evaluates fatal and serious injury crash response coverage from crash sites to medical facilities in the Commonwealth of Virginia.

Calculated travel times from fatal crash sites to medical facilities are compared with reported travel times to better estimate travel time modification factors. The modified travel times are used to determine coverage areas and evaluate serious injury crash response coverage of medical facilities in Virginia.

A geo grid approach is used to demonstrate the proof of concept for a crash response planning tool. A risk grid is developed based on the aggregate number of fatal and serious injury crashes. This study includes serious injury crash response coverage because the number of serious injuries and serious injury rate are now included as reportable safety performance measures for state highway safety agencies. A mitigation grid is developed based on the travel time to the closest facility. Finally, a planning grid that combines risk and mitigation factors based on a decision matrix is presented. The resulting tool serves as a proof of concept for developing a crash response planning tool which enables planners to identify areas that do not have timely access from crash sites to medical facilities.

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GENERAL AUDIENCE ABSTRACT

An objective of emergency responders is to safely transport crash victims from crash sites to medical facilities. Ensuring adequate access is an important goal of highway safety professionals. This study proposes a proof of concept for a planning tool that evaluates this access in the Commonwealth of Virginia.

This study focuses on serious injury crash sites because the number of serious injuries and serious injury rate are now included as reportable safety performance measures for state highway safety agencies. Travel times from serious injury crash sites to medical facilities are used to identify areas that do not have timely access. Risk and mitigation assessments are performed by dividing the study area into equal sized cells. Risk and mitigation assessments are based on number of crashes and response travel times to the closest medical facility, respectively. These assessments are used to generate a proof of concept for a crash response planning tool which enables planners to identify areas that do not have timely access from crash sites to medical facilities.

Acknowledgements

I would like to thank my advisor Dr. Kathleen Hancock for her guidance and encouragement throughout my journey as a graduate student. Dr. Hancock's courses had been a motivation for me to pursue work in the field of crash safety. I would like to extend my gratitude to Dr. Hesham Rakha and Dr. Bryan Katz for their valuable inputs and suggestions.

I'm grateful to my parents, parents-in-law and brother for their support. I would like to thank my cousin, Dr. Azeemah Zulaikha for being my inspiration. I would like to thank my friends Sindhoora Kadya and Megha Ravishankar for being my family here in the United States. I extend my appreciation to Nawaz Mohammed, Harish Narayanan and Ganapathy Bharadwaj for lending a helping hand during the most difficult times.

Dedications

To my husband, Vasi Rajan

To my grandparents, Abu Syed Sahabudeen and Abul Jamalia

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CHAPTER 1 : INTRODUCTION

It is important for emergency responders to take crash victims who are severely injured to trauma centers within the golden hour (NHTSA 2012, Carr et al, 2017). Collection, analysis and evaluation of existing crash and medical facility data to identify areas that have limited access to medical facilities is a significant step in this process.

Because the number of serious injuries and serious injury rate have been included as safety performance measures along with number of fatalities, fatalities rate (FHWA 2018), it is important to assess crash response coverage from serious injury crash locations to trauma centers and hospitals. This study proposes a proof of concept for a planning tool that evaluates crash response coverage from crash sites to medical facilities. This tool could aid in identifying high risk areas that do not have adequate crash response coverage and hence serve as a decision-making system for planning agencies.

Crash response takes place in two sequential steps: EMS dispatches to the crash site, EMS travels from crash site to a medical facility. This study focuses on the latter, crash response times from crash locations to medical facilities.

1.1 BACKGROUND

The four E's of highway safety include Engineering, Enforcement, Education and Emergency Response. Emergency Response, which falls within the broader are of Emergency Management covers a variety of events like natural and man-made disasters, fire, and traffic accidents. In case of traffic crashes, it is necessary to determine the closest medical facility from the crash site to most effectively treat seriously injured victims and to minimize resulting fatalities. Crash response planning from crash locations to medical facilities is a small but vital component of emergency management and strategic highway emergency response planning. Analyzing response times from road segments to medical facilities would enable improved decision-making and provide input to a system-wide crash response planning tool from potential crash sites to medical facilities.

First responders, typically police officers, arrive at the scene of a vehicular crash and perform a primary assessment of the victims. The responder then calls for EMS service or during life threatening major trauma conditions, an Incident Commander or first responder may call for an air ambulance response. In case of fatal or serious injuries, the emergency responders decide which medical facility the crash victims are taken to. This decision is based on several factors such as the type of crash, severity of injury, distance or time taken to the closest facility, and congestion level in urban areas.

1.2 PROBLEM STATEMENT

Several research studies have explored evaluating the travel time taken by emergency vehicles from the crash sites to hospitals. Traditional methods have focused on analyzing high crash locations. However, most of these studies have used only fatal crash locations (CenTIR 2006, Branas et al. 2005). There is lack of information about accessibility to trauma centers from serious injury and other crash locations. Since serious injury crashes have been included as a performance measure, it is important to include serious injury crashes in evaluating emergency response for planning purposes (FHWA 2018, Flannagan et al. 2014).

Crashes in rural areas have not been studied as extensively as their urban counterparts. Since rural regions often have longer travel times to trauma care than urban regions, it is necessary to quantify the time taken from rural crash sites to medical facilities. In previous research, trauma center access has generally been based on distance from census blocks rather than the travel time from the crash location on the road network, particularly for studies that considered emergency response for injuries or fatalities resulting from any cause (Branas et al, 2005, Carr et al, 2017). Conversely, previous research has not necessarily distinguished the difference in capabilities of these medical facilities. When the analysis does not incorporate injury severity and level of service of the facility, consideration of transporting a victim from one level to another is not included (MacKenzie, EJ, et. al., 2006).

A systematic analysis is carried out in this study which takes into account the type of injury, designated level of available medical facilities, and location of crashes and facilities on the roadway system.

1.3 OBJECTIVES

The objectives of this study are:

1. To compare calculated response travel times with actual response times from fatal crash sites to medical facilities and determine modification factors for travel times on the roadway system.
2. To evaluate the coverage areas of medical facilities in Virginia based on the designated levels of the facilities and proximity of historical serious injury crash sites to these facilities.
3. To develop a proof of concept for a planning tool that evaluates the crash response coverage of a region.

1.4 RESEARCH CONTRIBUTION

The proof of concept provides the basis for a planning tool that allows agencies to weigh crash risk against emergency response mitigation options. Outcomes of the coverage evaluation provide measures for use in both risk and response to that risk. The ranking system-based planning tool would assist planners and state agencies in identifying high crash locations that have low access to appropriate medical care. Because of its flexibility and straightforward approach, the planning tool could be expanded to include any crash or medical facility characteristic. This would aid planning officials in emergency resource allocation.

1.5 THESIS ORGANIZATION

The thesis is organized into five chapters. Chapter 1 presents the introduction, background, problem statement, objectives and contribution of the research. Chapter 2 provides a review of literature that provides the basis for this study from past literature. It also identifies additional research needs. Chapter 3 explains the methodology used to evaluate travel times and facility coverage and to develop the planning tool. Chapter 4 summarizes the results and their implications. Chapter 5 presents the conclusions and recommendations for future research.

Appendix A.1 includes a sample of crash data and road centerline data used in this study. Appendix A.2 provides the urban and rural classification data for Virginia obtained from United States Census Bureau's cartographic GIS layer and VGIN (Virginia Geographic Information Network) respectively. Appendix A.3 provides the list of hospitals in Virginia used in this study. Appendix A.4 provides the sample model used in GIS for service area analysis. Appendix A.5 presents a pseudo code used in python environment in GIS to develop the planning tool.

CHAPTER 2 : LITERATURE REVIEW

Accessibility to medical facilities with respect to population distributions have been studied in the past (Branas et al. 2005, Accurso 2014). Almost 30 million residents in US do not have access to trauma center within an hour (Carr et al. 2017). Medical facility location planning is mainly based on population of the region and accessibility of trauma centers or hospitals from census blocks. This is due to the fact that trauma can be caused by factors such as underlying medical conditions, vehicular crashes, fire outbreaks, human and manmade disasters and so on. Research conducted by NHTSA established the association between crash proximity to Level I and Level II trauma centers and mortality rate of crash victims (NHTSA 2012). Therefore, there is a need for additional research to evaluate crash response coverage by which the accessibility to medical facilities from crash sites could be enhanced.

This section is split into three sub-sections. The first section 2.1 describes the various algorithms used to calculate travel times and the approach adopted in this study to evaluate travel times from crash sites to medical facilities based on existing literature. It also describes the difference in travel time calculation between urban and rural regions.

The second section 2.2 briefly describes literature review on crash data analysis, accessibility to medical facilities and emergency response coverage. The third section 2.3 describes a two-step grid process based on which the proof of concept for the planning tool to evaluate crash response coverage is developed.

2.1 EVALUATION OF TRAVEL TIMES FROM CRASH SITES TO MEDICAL FACILITIES

Various algorithms can be used to calculate the shortest path from an origin to a destination. One such tool is ArcGIS software that uses Dijkstra algorithm which searches for the shortest path from the starting point to every node until it reaches the destination point based on given impedances (ESRI) (Nicoară and Haidu 2014). Nicoară and Haidu demonstrated the usage of network analysis in finding the closest ambulance location from the crash site and then finding the shortest path to the medical facility from the crash site.

Here, shortest path analysis is used since there is only one emergency hospital in the study county. The actual travel times from fatal crash sites to medical facilities are compared to the calculated travel times in this study. Regression of predicted values in x-axis vs. observed values in y-axis can be used for model evaluation (Piñeiro et al. 2008). This approach is used in this study for travel time evaluation.

2.1.1 CONGESTION IN URBAN AREAS

Travel time calculation for urban regions is different from that of rural regions. Traffic congestion is one of the major challenges faced equally by commuters, transportation engineers, urban planners and state DOTs as it lowers productivity resulting in increased transportation time and economic costs. Congestion is a more significant threat to urban areas than rural ones due to increased usage of private vehicles, complexity in road network and densely packed urban centers. Intersections in urban areas exhibit different characteristics than their rural counterparts due to differences in traffic flow, number and location of lanes (Chodur, Ostrowski, and Tracz, 2016). There is an increase in emergency vehicle response time in urban areas because of congestion (Panahi and Delavar 2008). Although emergency vehicles can preempt signals at certain intersections, they suffer from the consequences of congestion in urban areas. A survey conducted by the Center of Injury Sciences and Department of Epidemiology at University of Alabama with emergency responders as participants revealed that traffic congestion lead to nearly an additional 10-minute increase in emergency response times (Griffin and McGwin 2013).

The travel time computation in this study is divided into two parts: for urban and rural links. For rural links it is assumed that Emergency vehicles travel close to speed limit in rural areas. The effect of congestion is considered while calculating emergency vehicle response times from crash locations to medical facilities in urban areas. The three performance measures of congestion are hours of congestion, Travel Time Index (TTI), Planning Time Index (PTI). Travel Time Index is defined as the ratio of travel time during peak period to that of travel time during uncongested flow (FHWA 2015). A travel time index of 1.25 denotes that there is 25 % increase in travel time during congestion. The three important urban regions in Virginia are Northern Virginia (NOVA), Richmond Area and

Virginia Beach Area. The TTI value for Northern Virginia is obtained from National Capital Region Congestion Quarterly Reports 2016 (NCRCR 2016). The TTI values for Richmond and Virginia Beach are taken from FHWA's Urban Congestion Quarterly Reports for the year 2016 (UCR, FHWA 2016). Table 1 summarizes the TTI values for the three urban regions in Virginia.

Table 1: Travel Time Indices for Urban Regions in Virginia

URBAN Region	**Quarterly Period (2016)**	**Travel Time Index (TTI)**	**Average TTI**
Northern Virginia	January – March	1.16	1.175
(obtained from NCR)	April – June	1.17	
	July – September	1.19	
	October – December	1.18	
Richmond	January – March	1.07	1.065
	April – June	1.06	
	July – September	1.06	
	October – December	1.07	
Virginia Beach	January – March	1.21	1.225
	April – June	1.25	
	July – September	1.23	
	October – December	1.21	

The average Travel Time Index for urban regions in Virginia in 2016 is found to be 1.155. Therefore, there was 15.5% increase in travel time during the year 2016 due to congestion in these regions. It is to be noted that the quarterly Travel Time Index values varies each year between different urban regions. Therefore, these values must be used with caution.

2.2 COVERAGE AREAS OF MEDICAL FACILITIES

Classifying injury levels A, B and C in crash reports is challenging and typically inconsistent (Charles M. Farmer 2003). This is caused due to variation in state classification systems and the complexity of the injury itself. Factors such as time of crash (day/night), gender and age of driver were found to influence the reporting of injury severity levels by law enforcement officials. The Moving Ahead for Progress in the 21st Century Act (MAP-21) law mandates the inclusion of serious injury crashes as a performance measure for safety along with fatal crashes (Flannagan et al. 2014). Hence, serious injury crash locations are included in coverage area evaluation to be consistent with state and federal performance measure metrics.

There were 2.3 lives lost per day in Virginia during the year 2017 due to vehicular crashes (DMV 2018). Hence, a significant proportion of the victims are from traffic crashes. Studies conducted by Center for Transportation Injury Research emphasized the fact that crash locations must be taken into consideration along with population distributions while planning trauma center locations (CenTIR 2006). However, these studies included only fatal crash locations. There is need for additional research in understanding trauma center and hospital resource allocation with respect to emergencies caused by serious injury crashes.

In order to evaluate coverage areas of medical facilities with respect to serious injury crash sites, it is necessary to determine whether to include all serious injury crashes that occurred in the entire network or not. A significant difference between crashes that occur in urban and rural areas is that the crashes that occur in urban areas are more clustered than the ones occurring in rural areas (FHWA 2017). Traditional methods like site selection and hot spot analyses involve focusing on locations with high number of crashes (FHWA 2017). One of the limitations of this approach is that rural areas where crash locations are spread along the entire network are overlooked. This results in investing in more safety improvement projects in urban localities (Walden et al. 2015). The traditional approach can be supplemented by other approaches like systematic approach, systemic approach (FHWA 2017). In this study, historic serious injury crash locations in both urban and rural areas are considered .

Emergency response depends on the level of crash severity. Crash victims would be flown to trauma centers if the condition of the patient is critical and the estimated time of arrival to medical facility exceeds 30 minutes through ground ambulance service. Hence, emergency response during a fatal or serious injury crash is dependent on the location and type of medical facility. Research conducted by NHTSA established the association between crash proximity to Level I and Level II trauma centers and mortality rate of crash victims (NHTSA 2012). The study concluded that increase in travel time from the crash site to trauma center resulted in increase in probability of the crash victim's death. The study was conducted based only on fatal crashes. Also, Level I and Level II trauma center coverage were analyzed together. Therefore, coverage area analysis is performed separately for each level of trauma center and hospital separately.

2.3 PROOF OF CONCEPT FOR PLANNING TOOL

A two-step geo-grid procedure can be used to identify high crash locations (Hancock et al. 2015). A screening grid which divides the study area into equal sized grids is created. The identified crashes are overlaid with the grid and values are assigned to each grid based on the aggregated value of the selected crashes. These grids are convenient as they allow the inclusion any crash characteristic. The size of the grids is determined by limited the number of grids to a maximum of 1000 (Hancock et al 2015). This two-step screening method can be applied to a large region or a small district.

Due to the flexibility of the screening grid, this study employs a similar grid named planning grid for the state of Virginia to develop a ranking system that enables planners to identify high risk locations that have low access to trauma centers.

A decision matrix can be used to evaluate and choose from a number of alternatives (Axelrod, 2009). This study employs a simple 2 x 2 decision matrix for the proof of concept.

Chapter 2 summarized the literature on evaluation of travel times from crash sites to medical facilities. Also, literature on medical facility accessibility is presented. Emergency response is dependent on the location and type of medical facility. Therefore, coverage area analysis is performed separately for each level of trauma center and hospital. Crash analysis used in conjunction with coverage area analysis paves way for better inputs for emergency response planning tool from crash sites to medical centers and preparedness at a macro-level.

CHAPTER 3 : METHODOLOGY

A fatal or serious injury crash victim has to be treated within 60 minutes of the accident (NHTSA 2012). There should be adequate access to a medical facility from the crash site. In this study, accessibility to a medical facility is determined by the time taken for the emergency vehicle to reach the medical facility from the crash site. After obtaining necessary data, travel times from the crash sites to medical facilities are calculated and compared to actual travel times reported by Fatality Analysis and Reporting System (FARS 2016). Adjustment factors for travel times are computed after comparison and are used to determine coverage areas of medical facilities.

Serious injury victims benefit from receiving medical care at a trauma center (MacKenzie EJ et. al, 2006). Therefore, serious injury crash response coverage areas of medical facilities are determined separately for each level of trauma center and hospital. The crash response coverage could be used as input for a decision-making planning tool based on risk and mitigation assessment of the study area.

Section 3.1 describes the sources from which data was obtained and the characteristics of data. Section 3.2 defines the study area. Section 3.3 provides the methodology followed to calculate travel times and modification factors for travel times. Section 3.4 elucidates how coverage areas of medical facilities were determined with respect to serious injury crashes. Finally, Section 3.5 outlines the proof of concept for developing a crash response planning tool. Figure 1 provides overview of the methodology adopted in this study.

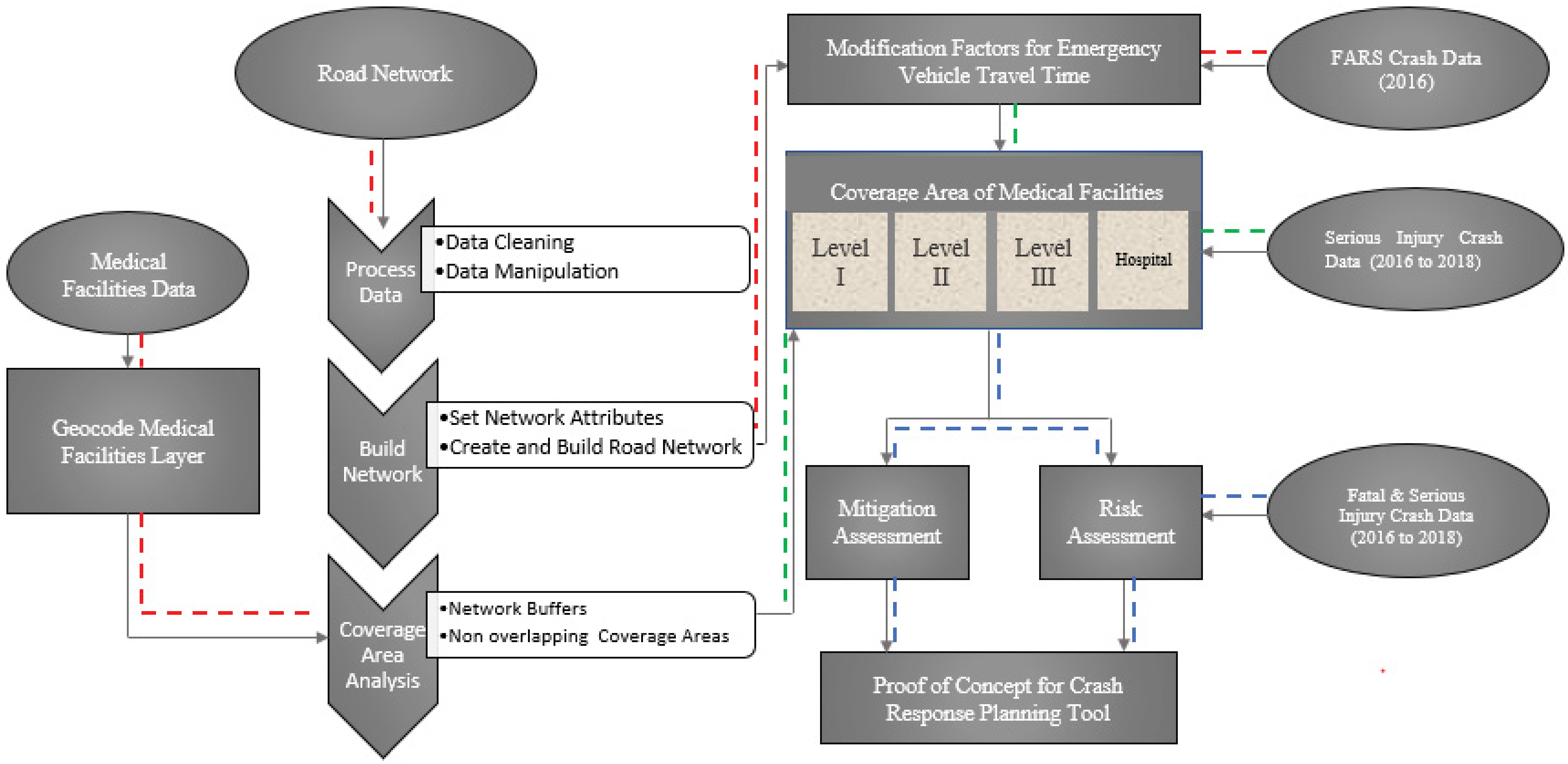


Figure 1: Study Methodology

The red , green and blue dotted lines represent the work flow adopted for objectives 1 , 2 and 3 respectively.

3.1 DATA SOURCES

3.1.1 Crash data

Crash data from 2016 to 2018 was obtained from the Virginia Department of Motor Vehicles (DMV). Appendix A.1 provides a sample of crash data. Virginia Tech locates crashes in Virginia obtained from crash reports by police in accordance with FR300P. Fatal crash records for the year 2016 was obtained from FARS (Fatality Analysis Reporting System). The latest data available from FARS is for the year 2016 and hence this study uses 2016 FARS crash data for evaluating travel times.

3.1.1.1 Crash Characteristics

The manual on Classification of Motor Vehicles Traffic Crashes (ATSIP 2017) outlines a standard that has been established to classify crashes across jurisdictions. Crashes can be classified based on the location, number of vehicles, transport vehicle type and so on. Based on the severity of injury, crashes can be classified into 5 categories - Fatal Injury crash (K), Suspected Serious Injury crash (A), Suspected Minor Injury crash (B), Possible Injury crash (C), Property Damage Crash (O). FR300P uses injury codes to identify crash severity level as shown in Table 2.

Table 2: Levels of Injury Severity

CODE	Injury Type (FR-300P)	Crash Severity
1	Dead	Fatal (K)
2	Serious Injury	Serious Injury (A)
3	Minor Injury	Minor Injury (B)
4	No Apparent Injury	Possible Injury (C)
6	No Injury	Property Damage(O)

Data Source: VDOT Crash Data Analytics Manual

The crash information used in this study is outlined in Table 3. Table 4 summarizes the fatal and serious injury crashes that occurred in Virginia from 2016 to 2018 used in this study.

Table 3: Crash Attributes from FR300P

Attribute	Description	Possible Values
Document Number	Document Number from Police Crash Report (FR300P)	Numerical value
Crash Type Name	Indicates type of crash	Fatal, Injury, Property Damage
Latitude and Longitude	Location Details for Geocoding	Any valid Latitude and Longitude in decimal degree format
Minimum Injury Type Id	Indicates the severity of crash	1 – Fatal 2- Serious Injury 3- Major Injury 4- Minor Injury 9- No injury
Route Type	Indicates the type of road where the crash occurred	Interstate, Primary, Secondary, Urban Street
Location Type Name	Indicates whether the crash occurred in urban or rural area	Rural, Urban

Table 4: Fatal and Serious Injury Crashes in Virginia from 2016 to 2018

Year	Number of Crashes	
	Fatal	Serious Injury
2016	722	6595
2017	787	6332
2018	769	5893
Total	2278	18820

Data Source: Virginia Department of Motor Vehicles

3.1.2 Road Network

The road network (Road Centerline) and the administrative boundary (counties) for Virginia was obtained from VITA's (Virginia Information Technologies Agency) VGIN (Virginia Geographic Information Network) geospatial layers. The urban/rural classification of Virginia is taken from the United States Census Bureau's cartographic GIS file. The layers use the projected coordinate system Lambert Conformal Conic Virginia (VGIN Geospatial Data Standard, 2016).

3.1.2.1 Street Center Line Characteristics

The VGIN Road Centerline attributes that were necessary for building the network and coverage area analysis are outlined in Table 5.

Table 5: Street Network Characteristics

Attribute	Description
Road Centerline ID	Unique Id for each road segment
Street Name	Standardized Street Name
Local Speed Limit	Speed limit information by VGIN
Dual Carriageway	Indicates whether the segment belongs to divided highway or not
One Way	Indicates whether the segment is one way or not (B - Bi-Directional FT – along the segment arc direction TF – against the segment arc direction)
Segment Exists	Indicates whether the segment is available for routing

The road centerline features that do not have speed limit data were given the speed limit of adjacent features that had speed limit information. Some of the road centerline features were scrutinized for arc direction information and were corrected.

3.1.3 Medical Facility Data

There are 17 designated trauma centers in Virginia (VDH 2018) out of which 5 are Level I, 7 are Level II and the remaining 5 are Level III designated trauma centers. Table 6 lists the trauma centers in Virginia.

Table 6: Designated Trauma Centers in Virginia

Trauma Center	City/Town	Level
Carilion Roanoke Memorial Hospital	Roanoke	1
Inova Fairfax Hospital	Fairfax	1
Sentara Norfolk General Hospital	Norfolk	1
University of Virginia Health System	Charlottesville	1
VCU Health System	Richmond	1
Centra Lynchburg General Hospital	Lynchburg	2
Chippenham Medical Center	Richmond	2
Henrico Doctors Hospital-Forest	Richmond	2
Mary Washington Hospital	Fredericksburg	2
Reston Hospital Center	Reston	2
Riverside Regional Medical Center	Newport News	2
Winchester Medical Center	Winchester	2
Carilion New River Valley Medical Center	Christiansburg	3
Johnston-Willis Hospital	Richmond	3
Lewis Gale Hospital	Blacksburg	3
Sentara Virginia Beach General	Virginia Beach	3
Southside Regional Medical Center	Petersburg	3

Data Source: Virginia Department of Health

17 out of all licensed hospitals in Virginia have been designated as trauma centers (VDH 2018). There are three levels (I, II and III) of trauma centers with Level I being the highest designation. While Level I centers are required to deliver total care for every aspect of injury, Level II designated centers must be able to initiate absolute care for all types of injuries. Level III trauma centers should be able to provide prompt assessment, resuscitation, stabilization and emergency operations (VDH Trauma Center Designation Manual, 2018). The hospital dataset is also obtained from Virginia Pre-Hospital Information Bridge. The list of hospitals used in this study is given in Appendix A.3.

3.2 STUDY AREA

The Commonwealth of Virginia with 95 counties and 38 independent cities was selected as the study area. Due to the nature of the project and the macro-level planning tool involved, the entire state of Virginia was selected. Also, crash location details for FARS data and DMV data were available for the state of Virginia which enabled geocoding of crash locations in the study area.

3.3 ACCESSIBILITY FROM CRASH SITES TO MEDICAL FACILITIES

Accessibility from a crash site to medical facility could be determined by calculating the time taken to reach the medical facility from the crash site. In order to achieve this, a network model was built to calculate the travel times. To compare the calculated travel times to actual response times from crash site to medical facility, data reported by Fatality Analysis and Reporting System is used. Fatal crash location data for the year 2016 was used for this purpose. This is due to the fact that the latest data available from Fatality Analysis and Reporting System is for the year 2016. The network calculated travel times were then compared with the actual travel times and modification factors were determined.

3.3.1 TRAVEL TIME CALCULATION

It is assumed that the VGIN road network represents the physical road network in the real world. The medical facilities geospatial layer was created by geocoding the addresses of the medical facilities in Virginia. Similarly, the historic crash locations from 2016 to 2018 were geocoded from the latitude, longitude values. The urban/ rural classification data obtained from the United States Census Bureau was added to the existing attribute table. The urban/ rural classification layer is shown in Appendix A.2.

The travel time information was added to the existing attribute table. It is assumed that emergency vehicles travel close to the speed limit in rural regions and in urban areas, the speed of emergency vehicles is significantly lower than speed limit due to the effect of congestion thus leading to an increased travel time. The travel time was calculated using 2 different formulas:

1) For Rural areas:

Travel Time = (Street Link Length/Local Speed Limit) * 1.005

2) For Urban areas:

Travel Time = (Street Link Length/Local Speed Limit) * 1.155

Where,

Street Link Length – length of the street line feature.

Local Speed Limit – local speed limit associated with the line feature.

Travel Time - time taken to traverse a link.

1.005 is used for rural areas since the emergency vehicles travel close to speed limit in these regions. 1.155 is the 2016 average Travel Time Index for Urban regions in Virginia as computed in section 2.1.1.

A network model is used for travel time calculations in GIS.

3.3.1.1 Network Attributes

The network follows a non – hierarchical approach where all types of roads from freeways to local roads will be involved in the process. Since the victim must reach the medical facility within minimum response time from the crash site, the entire road network must be utilized. The network attributes function as impedances over the network on which the analysis is based. The network attributes were defined as shown in Table 7.

Table 7: Network Attributes

Network Attribute	Field Name	Usage	Units
Travel Time	Travel_Time	Cost Impedance	Minutes
Travel Distance	Length	Cost Impedance	Feet
One-Way	One_Way	Restriction	None

The travel time is computed in minutes and used as the default cost impedance. One way is used as a restriction and takes three values, FT where travel is along the digitized direction of line feature, TF where travel is against the digitized direction of line feature and B is Bidirectional (ESRI Network Analyst Manual, 2010). Now the network dataset is built along with the system junctions and is ready for analysis.

3.3.2 TRAVEL TIME EVALUATION

Emergency Vehicle travel time from fatal crash sites to destination facilities reported by Fatality Analysis and Reporting System (FARS) for the year 2016 was used to evaluate the network model. The destination dataset was obtained from Virginia Pre-Hospital Information Bridge. Out of the 722 total fatal crashes in Virginia in 2016, 232 crashes (32%) were selected for analysis after filtering records that do not have travel time information and the crash victim was dead at scene. The records where victims were taken to medical facilities in other states were also eliminated and 218 records were selected out of which 113 were from rural crashes. The travel times from the fatal crash sites to the destination hospitals were calculated using the network model and compared with the actual values for urban and rural areas separately.

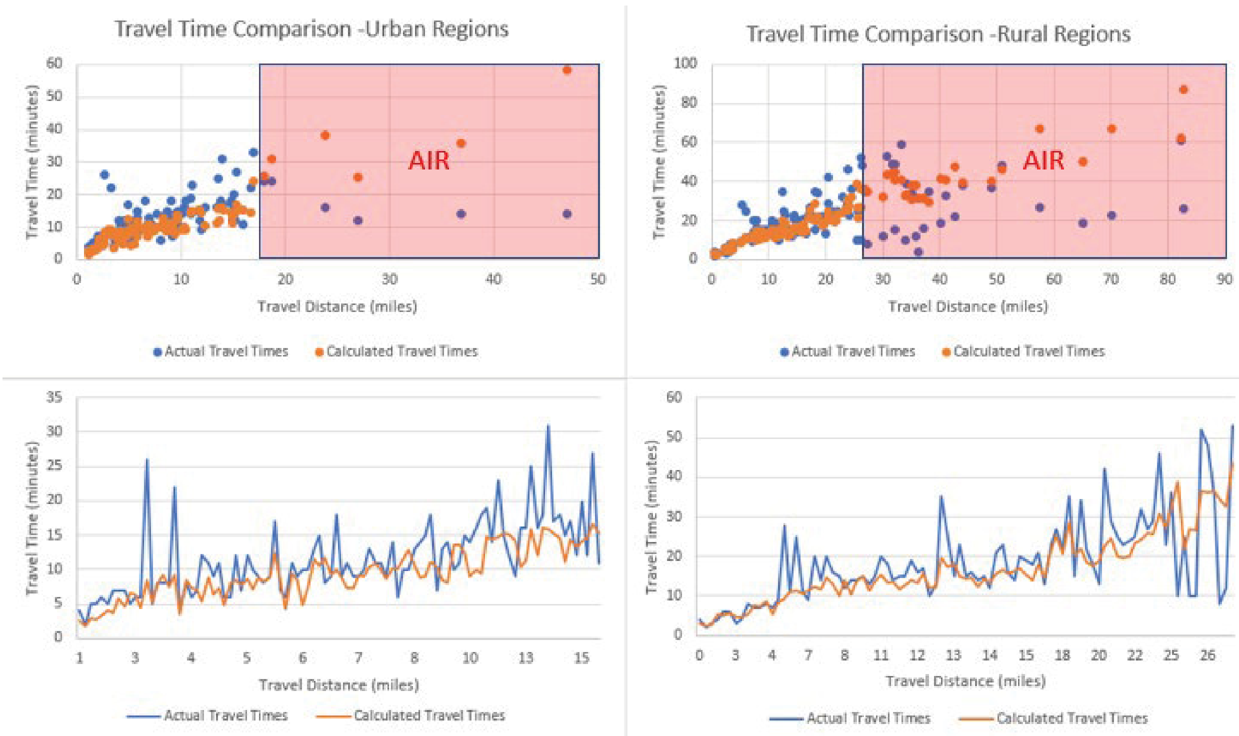


Figure 2: Comparison of Actual and Calculated Emergency Vehicle Travel Times between Urban and Rural Regions.

From Figure 2, we could infer that the difference between actual and calculated travel times increases with the distance. This is due to the inclusion of air ambulance travel times. The bottom graph shows the variation in actual and calculated travel times for smaller distances excluding the air ambulance travel times. The network model underestimates the travel times for urban regions. The calculated values overlap the actual values for rural regions. To understand the effect more precisely, the outliers and air ambulance travel time records were eliminated by interquartile range method. The actual and calculated travel times were plotted after sorting the actual travel times from lowest to highest. This helps in understanding the variation of calculated travel times with respect to actual travel times as shown in Figure 3. The variations in urban travel times are high and the travel times are always underestimated while the variations are smoother for rural travel times.

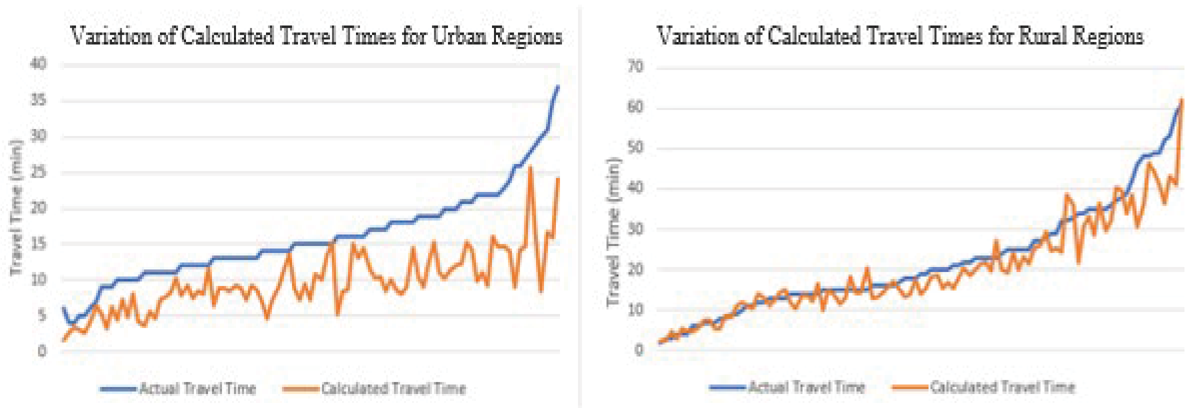


Figure 3:Variation of Calculated Travel Time Values for Urban and Rural Regions

3.3.3 TRAVEL TIME ADJUSTMENT

To calculate an adjustment factor for the network travel time, predicted values vs. actual values plot is used as shown in Figure 4. The outliers that do not have information about the mode of transport were included. These could be removed only when sufficient data is available.

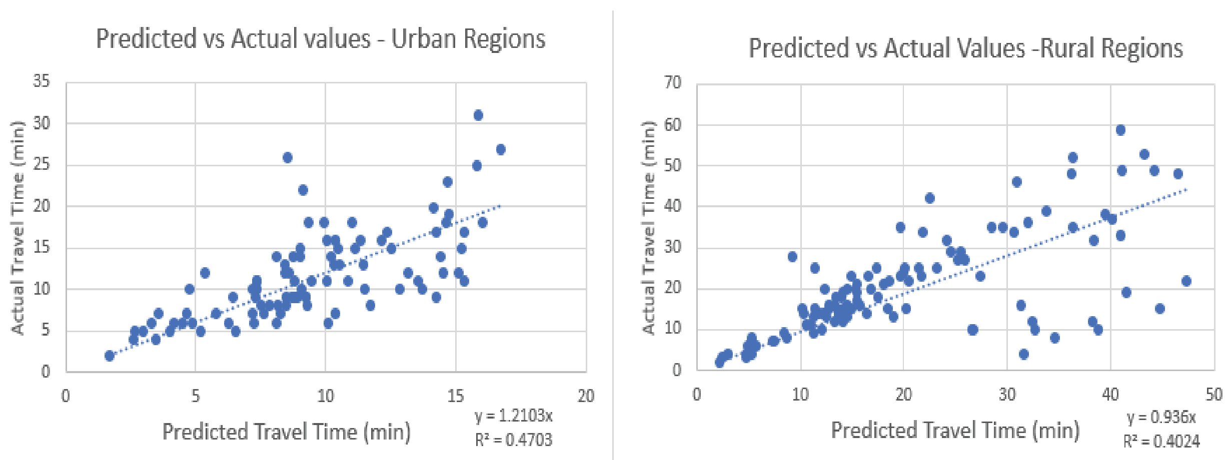


Figure 4: Predicted vs Actual Travel Time Values Plot for Urban and Rural Regions

The intercept value for the fitted line in Figure 3 is set to zero as the travel time is calculated as aggregation of link travel times in the network. The adjusted link travel times are calculated as follows:

1) For Urban Areas: Adjusted Travel Time = 1.2103 * (Calculated Travel Time)
2) For Rural Areas: Adjusted Travel Time = 0.936 * (Calculated Travel Time)

The travel time attribute is adjusted and accordingly, the network is built once again and is used for coverage area analysis.

3.4 COVERAGE OF MEDICAL FACILITIES

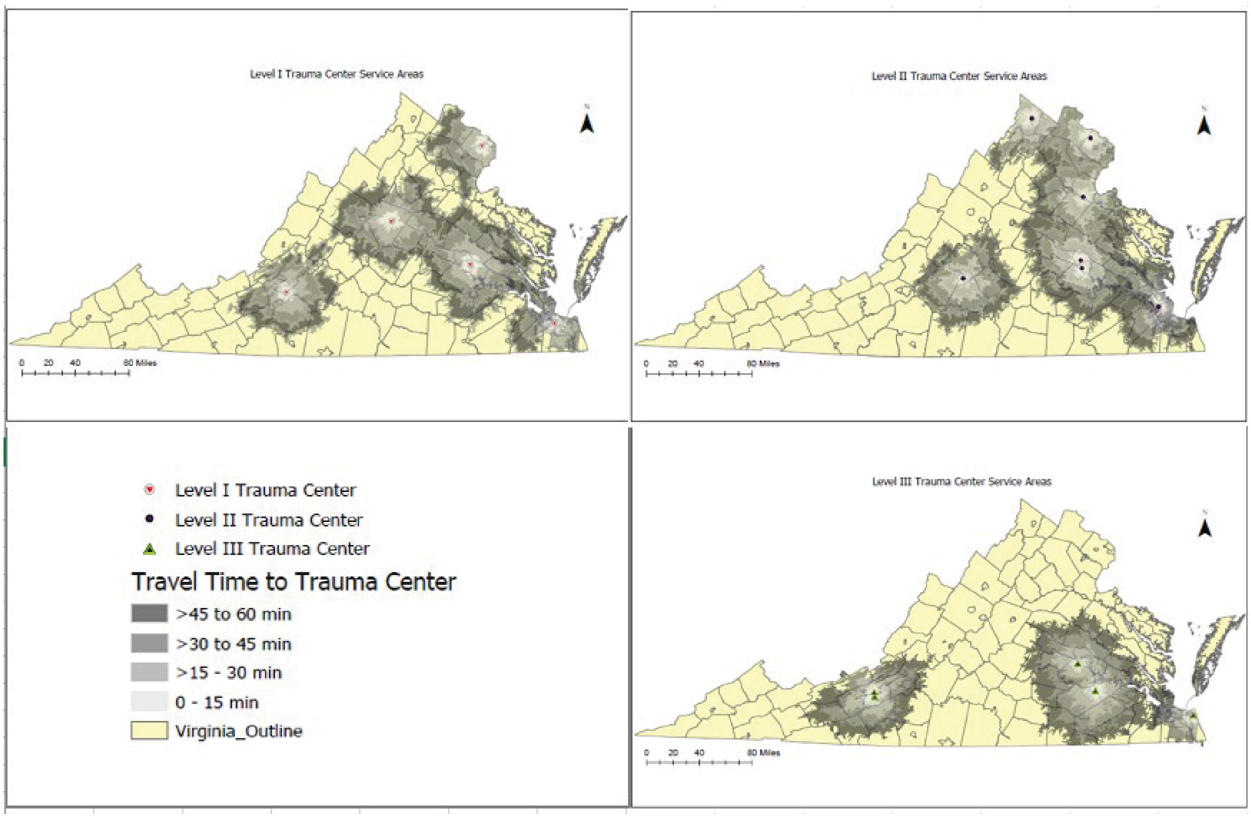
There is a need to evaluate coverage areas of medical facilities to predict serious injury crash response coverage. This would also help to understand risk and mitigation assessment better. The adjusted travel times from Section 3.3.3 are used as cost impedances to identify areas from which the medical facilities are accessible within the given time frame. Four bands of time frame windows are used. This would allow delineating the coverage areas from which the medical facilities can be reached within 15 , 30 , 45 and 60 minutes. Previous research has used two service area bands for trauma center access (Carr et al, 2017).

Hospitals have a wider coverage than trauma centers. Crash response coverage has to be studied separately for each level of trauma center and hospital. Therefore, coverage area analysis and evaluation are performed separately based on the level of medical facility. Each of the four coverage areas is evaluated individually to understand the crash response coverage for each level of trauma center and hospital separately. Serious injury crash data for three consecutive years from 2106 to 2018 is used for the purpose of evaluation. The crash locations were geocoded into the GIS database. The percentage of serious injury crashes that fall within each band and outside the coverage areas is calculated. This would give an indication of the level of access to the medical facility and would be an important factor in the decision-making process for crash response planning tool.

3.4.1 Model 1: Coverage Areas of Trauma Centers

Level I Trauma Centers offer extensive care for all types of injuries. Fatal or serious injury crash victims need immediate and total care within the golden hour. It is essential to identify whether the crash location falls within the coverage area of Level I trauma centers. If not, the time taken to Level I trauma centers from these critical locations has to be studied for planning purposes. This is achieved by using service area analysis. First, the five Level I trauma centers are designated as facilities for the service area analysis. Four bands of service areas representing 0 to 15 min, >15 to 30 min, >30 to 45 min and >45 to 60 min travel time to trauma center are created. Appendix A.4 provides the sample model used in GIS for Level I Trauma Center service area analysis

When a Level I trauma center is located far away from crash sites, there must be a mechanism by which planning agencies can identify the service areas of Level II or Level III trauma centers. Similar to Level I trauma center service areas, Level II and Level III service areas are created separately. This model would serve as an efficient planning tool in identifying urban/rural areas that fall within and outside the trauma center coverage areas. The resulting coverage areas are represented as illustrated in Figure 5.



3.4.2 Model 2: Coverage Areas of Hospitals

Figure 5: Coverage Areas of Level I , Level II and Level III Trauma Centers in Virginia

In certain cases, the crash victim could be taken to a hospital which is the closest facility when the crash site may be far from trauma center and the victim requires immediate attention. There is a need to analyze hospital coverage along with trauma center coverage. Therefore, service areas analysis was performed for hospitals in Virginia to understand crash response coverage from crash sites to hospitals. Figure 6 represents the same.

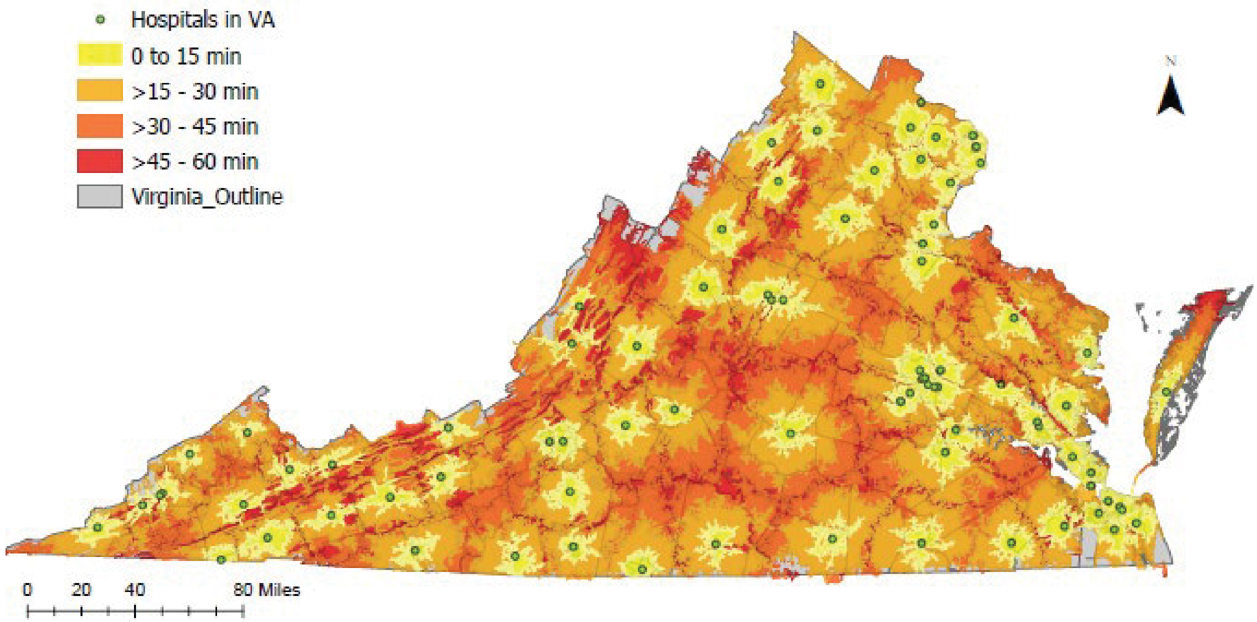


Figure 6: Coverage Areas of Hospitals in Virginia

3.4.3 Serious Injury Crash Response Coverage

Serious Crash response coverage of medical facilities is determined by evaluating the coverage areas obtained in Sections 3.4.1 and 3.4.2. The total number of serious injury crashes in Virginia from 2016 to 2018 is 18,820. Crashes are categorized according to the coverage area band they fall within. Since the coverage area bands are non-overlapping, each crash falls within a single band. The route from the crash sites to the closest medical facility is determined by closest facility analysis. This returns the travel distances and travel times from the crash sites. For example, in Level I coverage area evaluation, the travel time from the crash site to the closest Level I trauma center is captured. This process is repeated for the other two trauma center levels and hospital coverage area evaluation. The percentage of crashes covered within each band is computed for each of the four bands. The percentage of total serious injury crashes that fall outside the coverage areas are computed.

Cumulative coverage of medical facilities was computed by overlaying the coverage areas of different levels of medical facilities as shown in Figure 7.

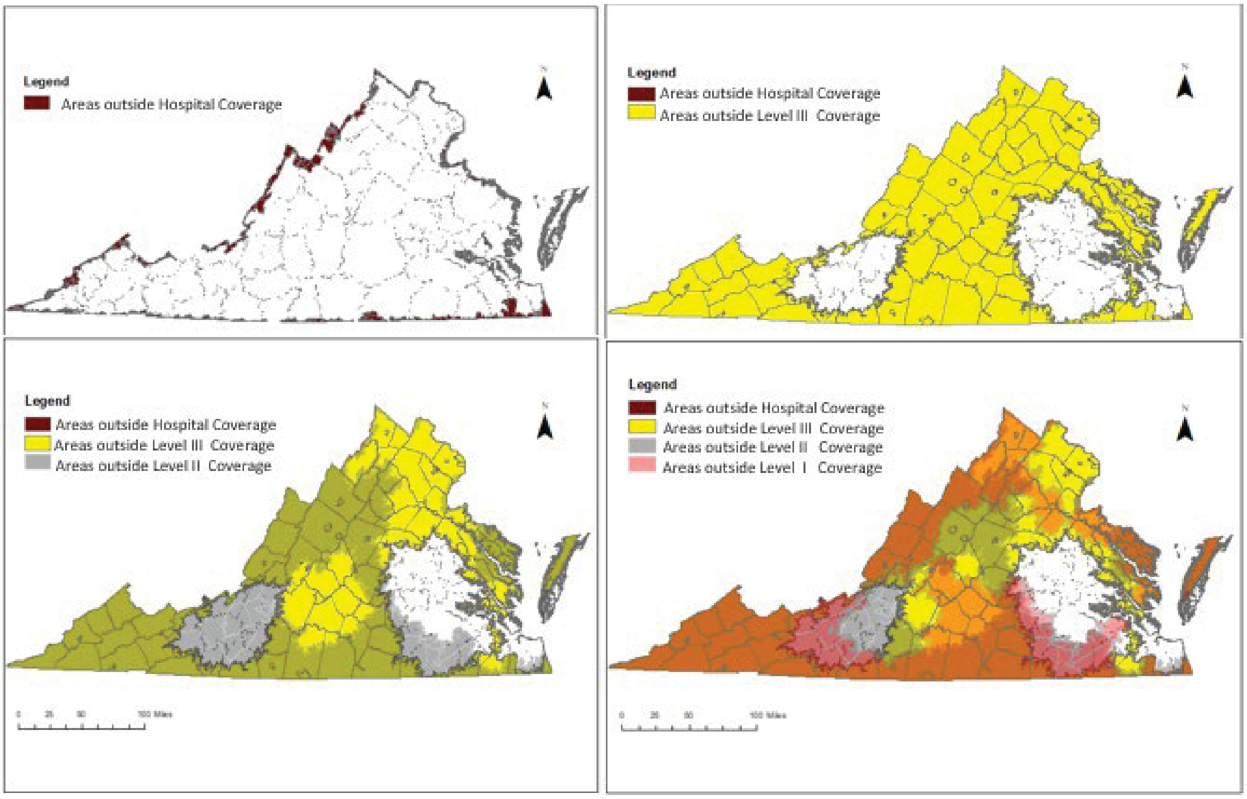


Figure 7: Cumulative Coverage of Medical Facilities in Virginia

The unshaded regions in the bottom right figure denote areas that have coverage of all levels of medical facilities while the dark brown shaded regions ( ) represent areas that do not have access to any level of trauma center within an hour.

3.5 PROOF OF CONCEPT FOR CRASH RESPONSE PLANNING TOOL

. To propose a proof of concept for a planning tool, risk and mitigation assessment has to be performed to evaluate crash response coverage in the region. The study area is divided into equal sized cells. Each cell is approximately 10-mile x 10-mile in size. This size would be a reasonable size to perform crash risk and response coverage assessment. First, a mitigation grid is developed, and each cell is assigned a value according to the time taken to access the closest trauma center from the grid area. Next, a risk grid is developed by assigning values to each cell based on the aggregate number of fatal and serious injury crash sites in each cell. Finally, a proof of concept for planning tool is developed by assigning ranks to individual cells based on the risk and mitigation grids.

3.5.1 Mitigation Grid

Response time from a cell to the closest trauma center is calculated by coverage area analysis. To develop coverage for entire Virginia, the coverage area bands were extended to the borders of the state in 15-minute increments. The maximum travel time was found to be 210 minutes. Hence 14 equal service area bands representing 15-minute interval each were selected. Each band is assigned a value from 1 to 14 with 1 and 14 representing 0 to 15-minute travel time and >195 to 210-minute travel time bands respectively. For example, value 3 represents >30 to 45-minute band. When the maximum area of a cell is occupied by a service area band, the grid is assigned the corresponding value. For the purpose of the mitigation grid, a coverage area analysis was carried out for all three levels of trauma centers simultaneously as shown in Figure 8:

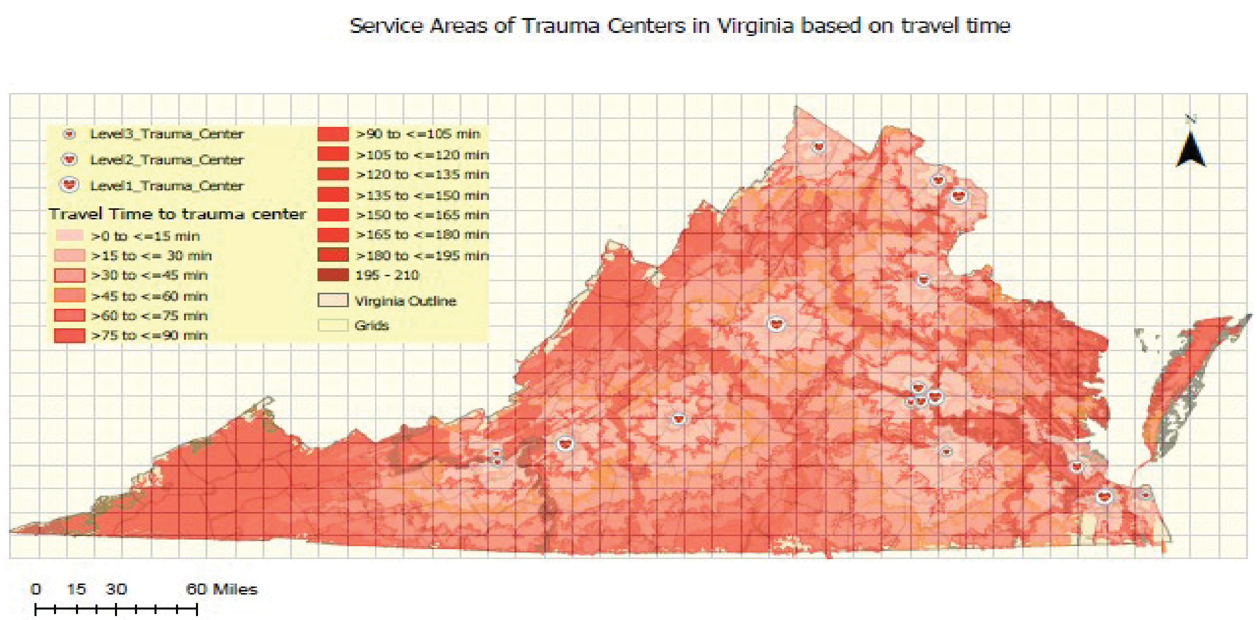


Figure 8: Coverage Areas of Trauma Centers in Virginia

A mitigation grid was developed based on travel times to trauma centers. As serious injury crash victims benefit from receiving trauma care, trauma centers were used here. Figure 9 shows the mitigation grid with values in each cell representing the time taken to reach the closest trauma center from the grid.

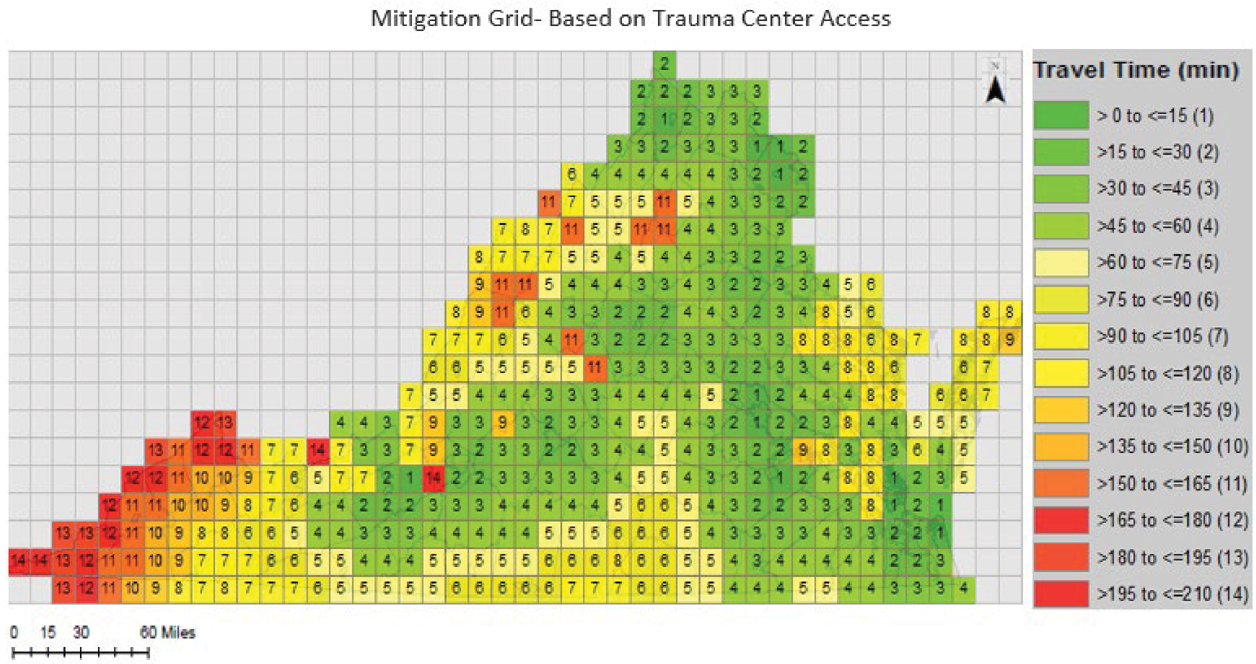


Figure 9: Mitigation Grid for Virginia Based on Trauma Center Access

3.5.2 Risk Grid

To evaluate the risk potential of a cell, the number of fatal and serious injury crashes that occurred inside the cell from 2016 to 2018 is calculated. Initially, each cell is assigned a value representing the aggregate number of fatal and serious injury crashes. Based on the cell with the largest number of crashes, cells are divided into fourteen equal intervals and each grid is assigned a single value from 1 to 14. The value is in order of increasing risk potential with 1 representing low risk grid and 14 being the highest. The number of intervals is chosen to be fourteen in order to be comparable with the number of classes used in mitigation grid described in section 3.5.1. The risk potential is a single value but can be extended to represent multiple factors of interest. The natural progression of crash densities was used to identify hot spots. Figure 10 shows the hot spots map in order of natural progression of crash densities below:

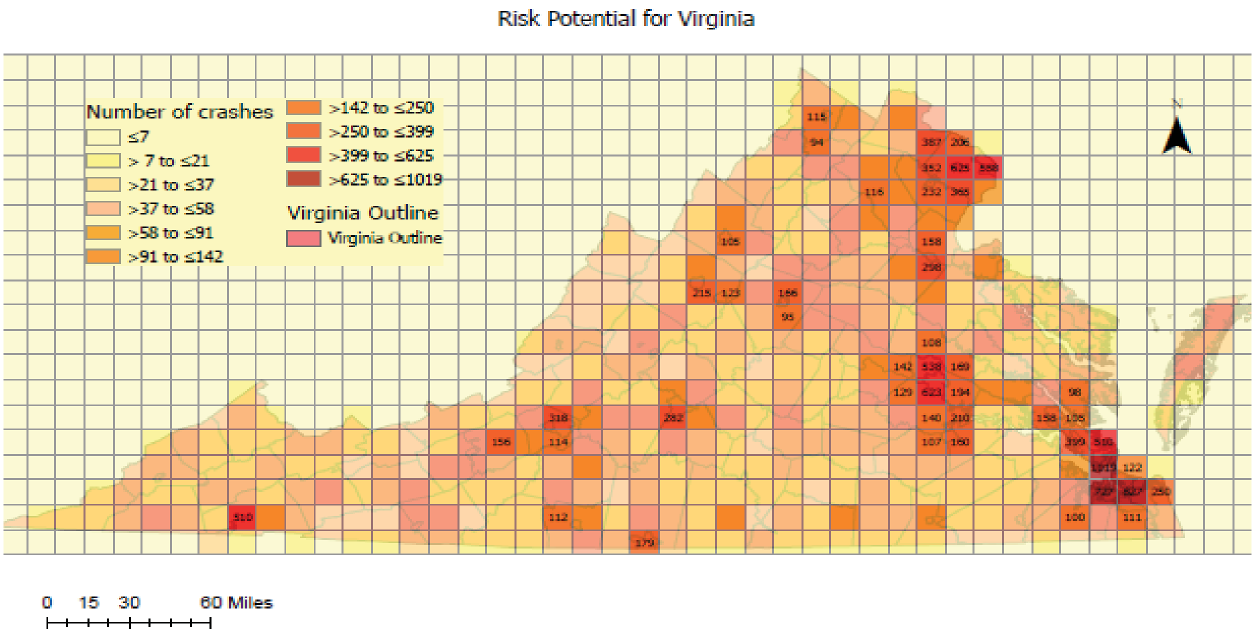


Figure 10: Hot Spot Map for Virginia based on historic fatal and serious injury crashes

The risk potential values range from 1 to 14, with 1 representing the lowest potential for crash occurrence. The risk grid depicting the risk potential values is shown in Figure 11.

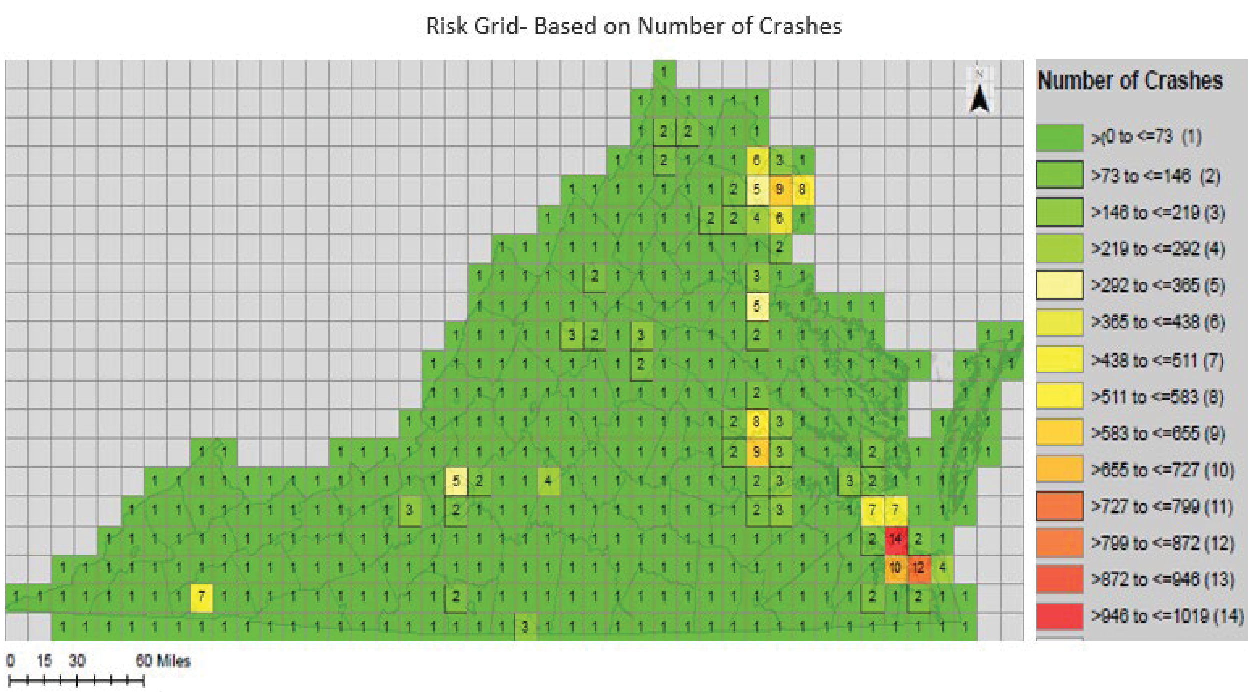


Figure 11: Risk Grid for Virginia Based on Number of Fatal and Serious Injury Crashes

3.5.3 Planning Grid

The risk and mitigation value of individual cells in the grids is used to determine the final rank of the cell. The rank of a cell is an indication of how good the crash response coverage is. The rank is determined according to the decision matrix shown in Figure 12:

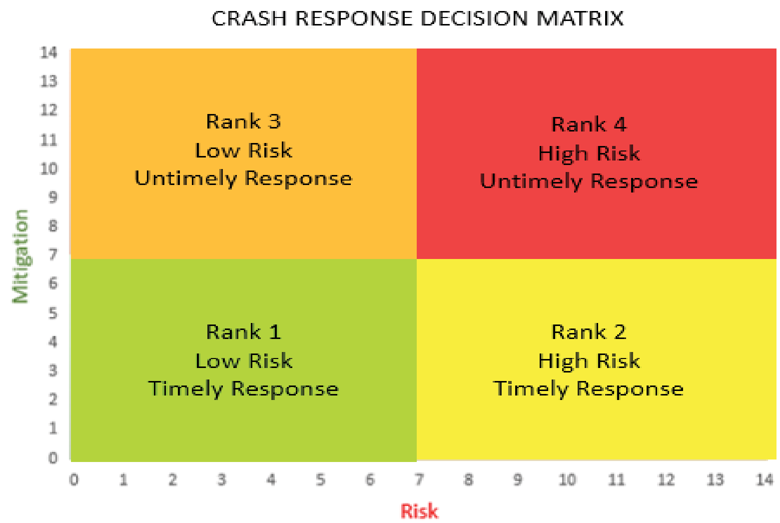


Figure 12: Decision Matrix for Planning Grid

If a cell has a risk value of 7 and mitigation value of 10, it is assigned rank 4 and would fall under high risk, untimely response quadrant. Planning agencies would be able to discern high risk areas that have untimely crash response. It is also easy to recognize areas that have low risk and timely crash response. Also, the decision matrix enables understanding crash response coverage with respect to medical facility access. Since this is a proof of concept, the tool is intended for demonstration purpose. Appendix A.5 lists the pseudo code used to develop the risk, mitigation and planning grids. The planning grid that represents the final ranking of each cell developed based on the values from the risk and mitigation grids is shown in Figure 13.

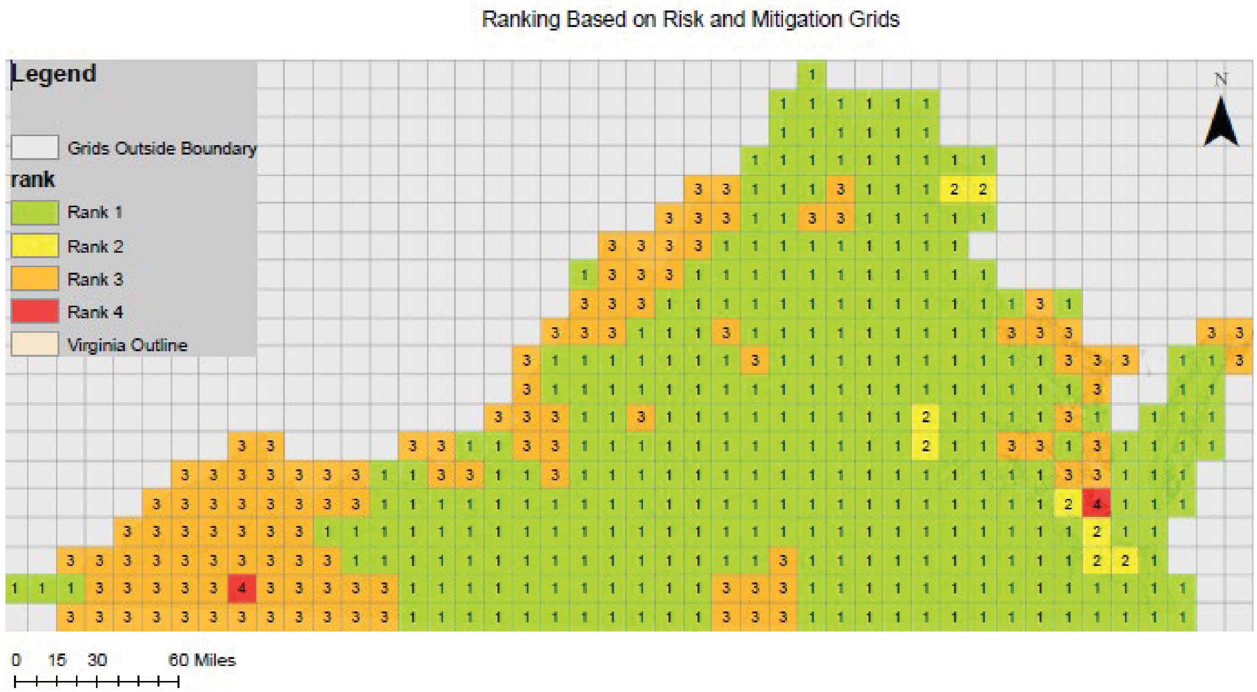


Figure 13: Crash Response Planning Grid for Virginia

This chapter described the methodology adopted in this study for developing a proof of concept for a crash response planning tool. First, the accessibility from crash sites to medical facilities is determined by calculating travel times from crash sites to medical facilities by means of a network model and adjusting the travel times after comparing them with the actual FARS reported travel times. Next, methodology adopted for evaluating the serious injury crash response coverage of medical facilities based on the level of medical facilities is discussed. Finally, the proof of concept for planning tool is outlined.

CHAPTER 4 : RESULTS AND DISCUSSION

Travel times were computed to study the accessibility of medical facilities from crash sites in Virginia. The modification factors that were computed by comparing the calculated travel times with the actual travel times are reported in Section 4.1. Section 4.2 summarizes the results of coverage of medical facilities for historic serious injury crashes. Section 4.3 presents the proof of concept for a crash response planning tool that could potentially serve as a decision-making tool for planning agencies.

4.1 MODIFICATION FACTORS FOR TRAVEL TIME

The calculated travel times from crash sites to medical facilities were compared to the actual travel times. The predicted values vs. actual values plot is used as shown in Figure 14.

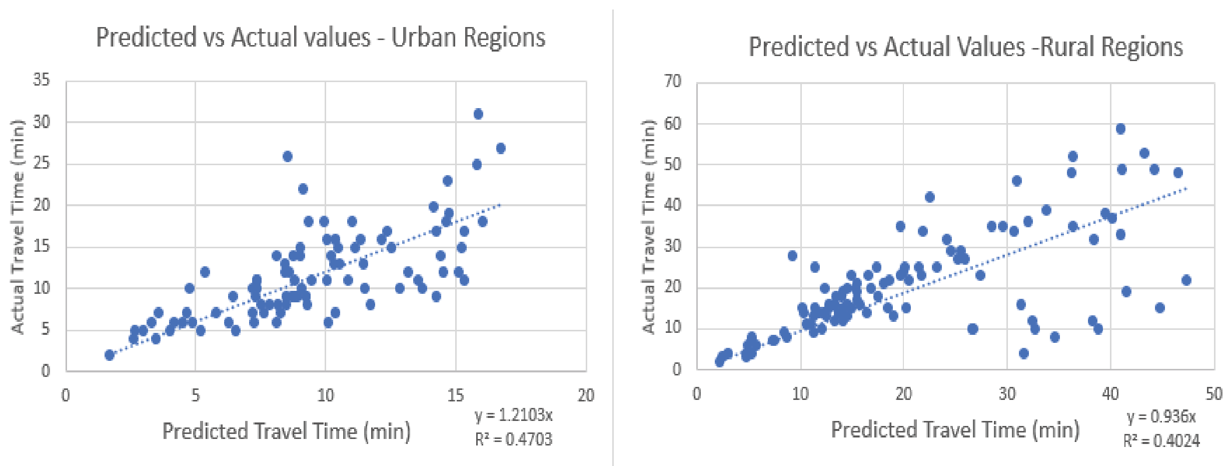


Figure 14: Predicted vs Actual Travel Time Values Plot for Urban and Rural Regions

The adjusted link travel time modification factors are determined as follows:

1) For Urban Areas: Adjusted Travel Time = 1.2103 * (Calculated Travel Time)
2) For Rural Areas: Adjusted Travel Time = 0.936 * (Calculated Travel Time)

4.2 SERIOUS INJURY CRASH RESPONSE COVERAGE

Coverage areas of medical facilities were evaluated based on the designated level of facilities and the proximity to historic serious injury crashes from 2016 to 2018. The total number of serious injury crashes in Virginia from 2016 to 2018 is 18,820. The percentage of total serious injury crashes that fall outside and within each band of the coverage areas is outlined in Table 8 below:

Table 8: Percentage of Serious Injury Crashes within and outside Medical Facilities Coverage Area Bands

Facility	Crashes Outside Coverage Areas (%)	Crashes within >45 to <= 60 min Coverage Area (%)	Crashes within >30 to <= 45 min Coverage Area (%)	Crashes within >15 to <= 30 min Coverage Area (%)	Crashes within >0 to <=15 min Coverage Area (%)
Level I	26.6	12.9	18.4	22.9	19.2
Level II	29.3	9.1	22.6	21.1	17.9
Level III	54.6	10.7	12.8	16.3	5.6
Hospital	0.4	0.3	5.8	27.1	66.4

26.6% of historic serious injury crash sites were outside the golden hour band of Level I Trauma Centers. This means that Level I trauma center could not be reached within 60 minutes from 26.6 % of crash sites. Hospitals offer coverage for a larger number of crashes, where the percentage of crashes outside the 60-minute band is 0.4%. Since hospitals are not the first choice in case of a life-threatening injury and relatively lower number of crashes occur outside the 60-minute travel time band of hospitals, it is practical to consider 30-minute travel time bands for hospitals rather than 60-minute bands. Level III trauma centers do not offer coverage for 54.6% of crashes outside the coverage area. It should also be noted that Level I Trauma centers can treat victims from any type of crash severity level.

The coverage areas were split into four bands within the golden hour. Level I trauma centers were accessible from 19.2% of historic serious injury crash sites within 15 minutes whereas 66.4% of crash sites fell within 0 to 15-minute coverage area band of hospitals. Only, 5.6% of crash sites had access to Level III trauma centers within 15 minutes. This could offer insights to planners when a proposal for a new medical facility or upgradation of existing medical facility arises. Figures 15 through 18 show the serious injury crash response coverage of medical facilities based on the level of medical facilities.

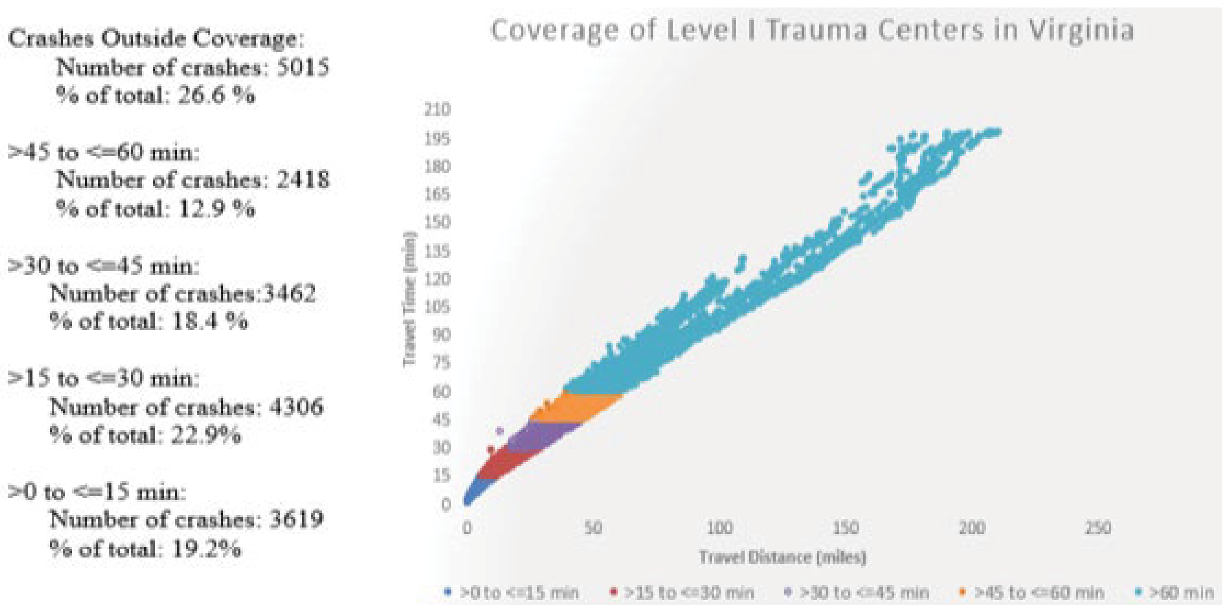


Figure 15: Serious Injury Crashes within Level I Trauma Center Coverage Area

26.6 % of historic serious injury crashes are not covered within Level I Trauma Center. This is a significant proportion of the historic crashes. The Level I Trauma Centers provide coverage for 19.2% of serious injury crashes within 15 minutes. Level I Trauma Centers are accessible from 22.9% of serious injury crashes within 15 to 30 minutes. The maximum travel time from historic serious injury crash site to Level I Trauma Center is found to be 209 minutes. Assuming that all serious injury crash victims require Level I Trauma Center care, it is to be noted that the highest percentage of crashes (26.6 %) fall outside one- hour coverage areas and hence there is no adequate coverage.

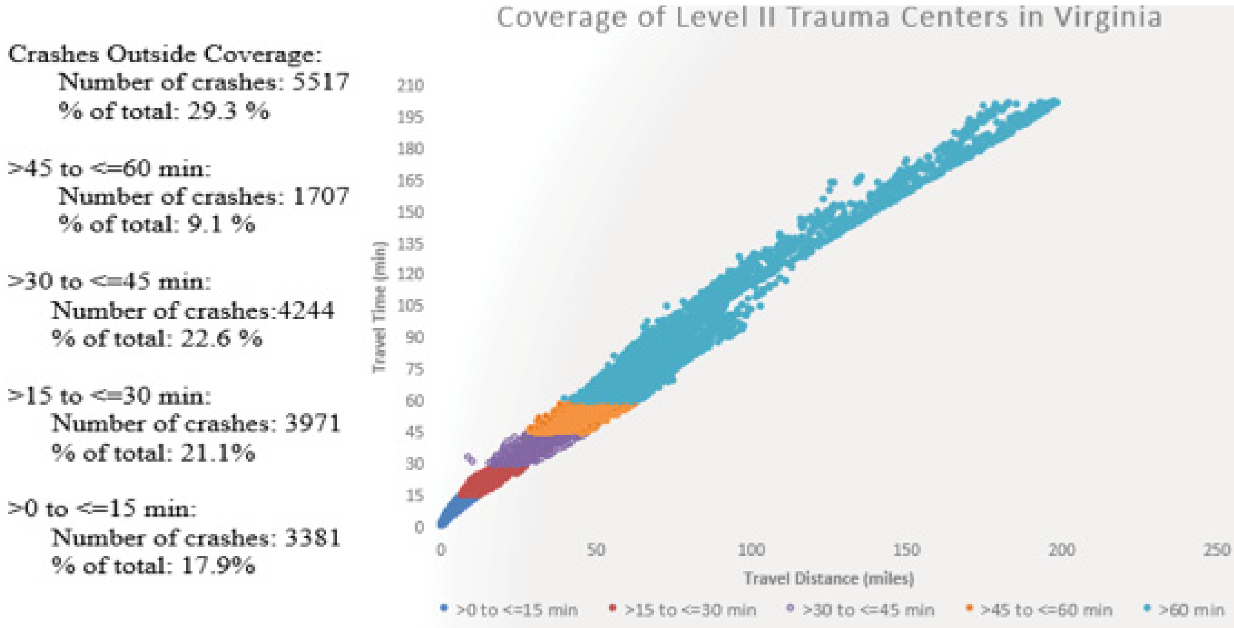


Figure 16: Serious Injury Crashes within Level II Trauma Center Coverage Area

17.9% of crashes are within 15 minutes coverage area bands while 29.3% of total crashes remain outside the coverage area of Level II Trauma Centers. The maximum travel time from historic serious injury crash site to a Level II Trauma Center is 202 minutes.

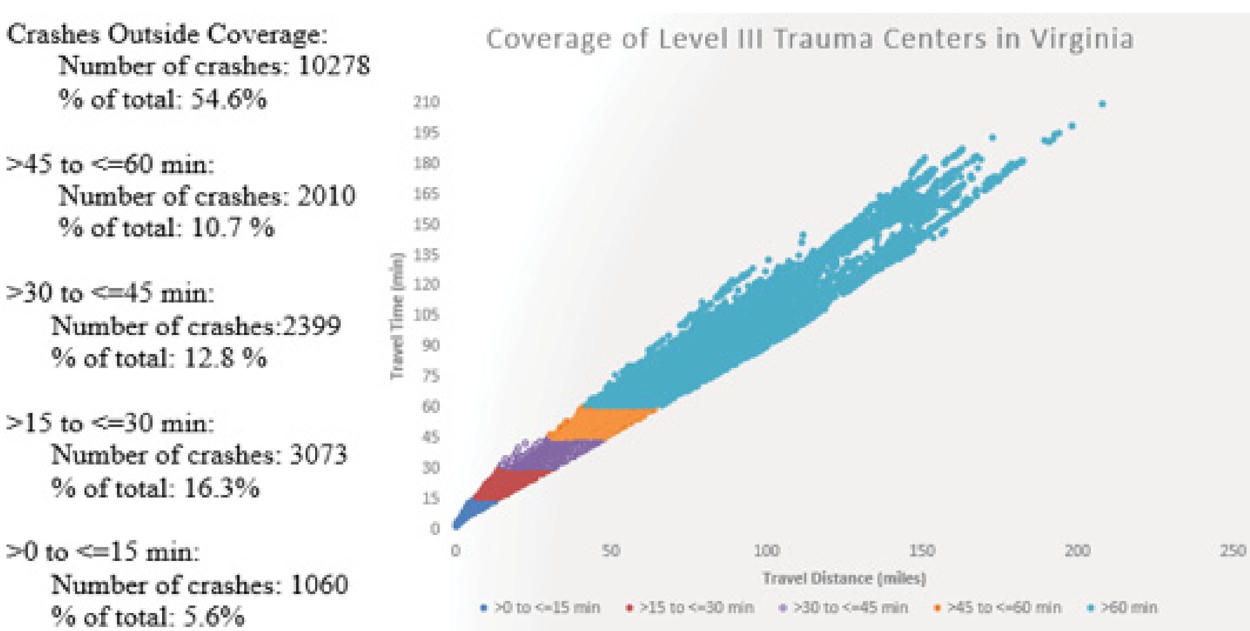


Figure 17: Serious Injury Crashes within Level III Trauma Center Coverage Area

Level III Trauma centers offer coverage for the lowest number of crashes with 54.6% of the crashes outside the coverage area. Also, only 5.6% of serious injury crashes is covered within the 15-minute coverage band. The maximum travel time from historic serious injury crash site to a Level III Trauma Center is 208 minutes.

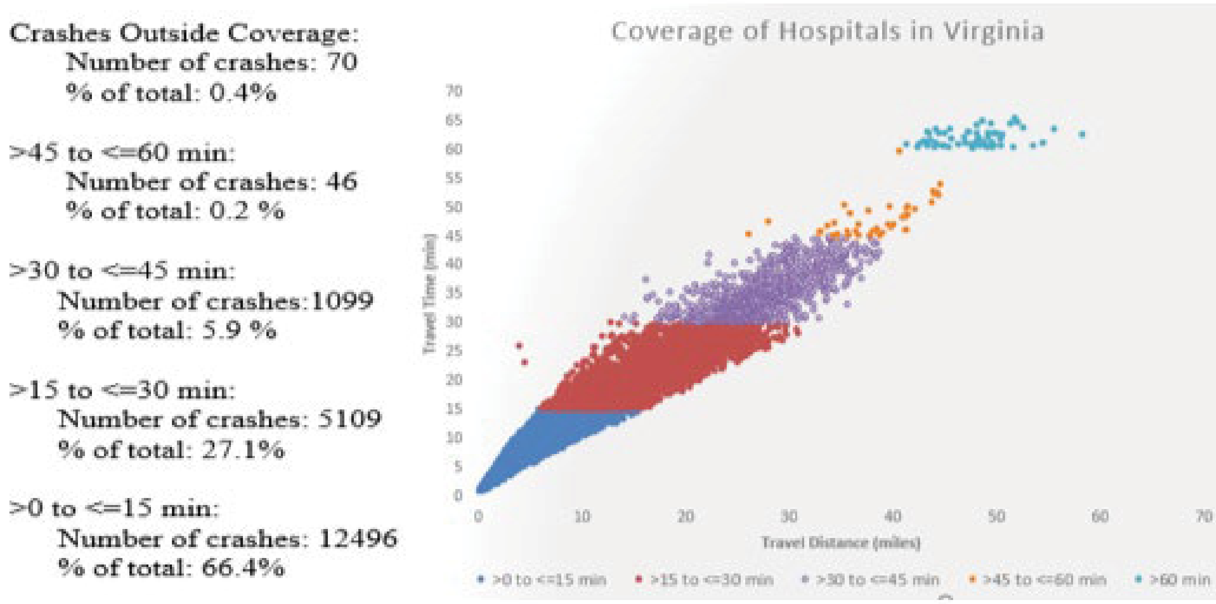


Figure 18: Serious Injury Crashes within Coverage Area of Hospitals

Hospitals offer coverage for the highest number of crashes with only 0.4% of crashes outside the coverage area. 66.4% of crashes are within 15-minute travel time from crash sites to hospitals. The maximum travel time from historic serious injury crash site to a hospital is 65 minutes. The detailed coverage area evaluation and crash response coverage could assist planners in choosing the travel time band above which the access to the medical facility is considered low. This might differ depending on whether the medical facility is a hospital or trauma center. It could also differ according to the level of trauma center and the urban/rural nature of the region being accessed.

4.3 PLANNING TOOL PROOF OF CONCEPT

A proof of concept was developed based on the risk and mitigation assessment in the study area. The proof of concept for developing a crash response planning tool is shown in Figure 18.

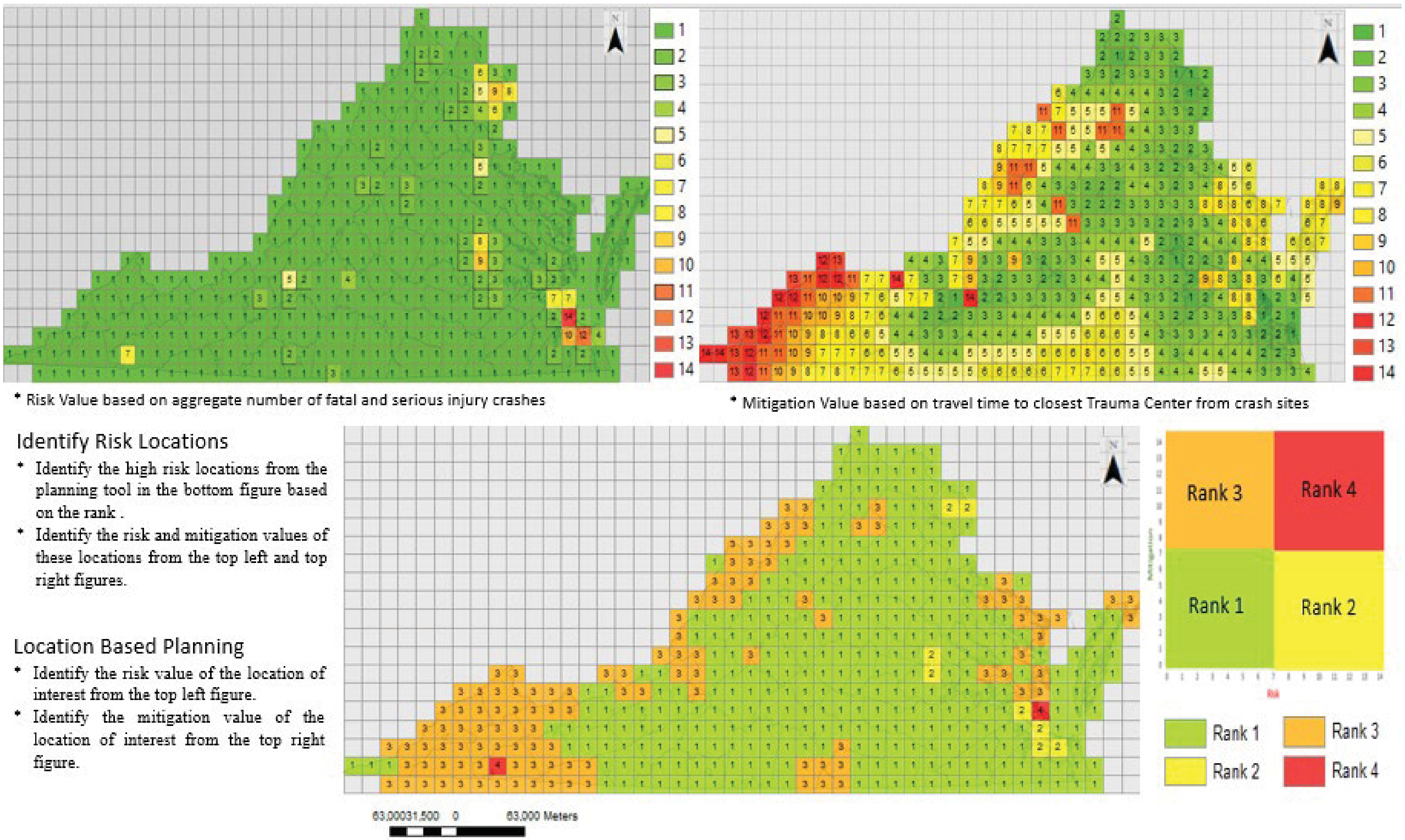


Figure 18: Proof of concept for Crash Response Planning Tool

The planning tool could be used in two ways. For location-based planning, the risk and mitigation values of the specific location can be identified using the top left and top right figures. This would help in identifying the crash response coverage specific to a location. Another way to use the tool is to use it to identify high risk locations based on the rank. The planning grid reveals the rank assigned to the cells based on the aggregate number of fatal and serious injury crashes and travel time to the closest medical facility. The planning grid would allow planning agencies to easily distinguish high risk regions that do not have timely crash response. It would also identify low risk zones that have timely crash response. Hence it could be used as a tool that would help planners in the decision-making process. For example, the crash response coverage might be studied with coverage area evaluation in case of upgradation of an existing medical facility to the next level. The mitigation grid could be developed based on the upgraded medical facility and the planning grid could be used to determine whether the upgradation meets the established requirements of upgradation.

From the risk grid in the top left, it is clear that Level III Trauma Centers cover a smaller number of crashes due to the absence of Level III trauma centers in Northern Virginia which is a high-risk potential zone. These crashes could be covered by Level I trauma center in the region. The risk grid shows the classification of cells in Fairfax, Richmond, Newport News, Hampton City and Virginia Beach as high crash risk zones. The mitigation grid in the top right shows that these high-risk zones have access to a trauma center within 30 minutes. Hence these grids are categorized as the ones that fall under the high-risk, untimely response quadrant and are assigned rank 2 in the planning tool developed from both the risk and mitigation grids.

The decision matrix used in this study is a 2 x 2 matrix. The origin can be shifted from (7,7) to any value that closely represents the real time facts in the study area. For example, if areas that could not access trauma centers within 30 minutes fall under poor coverage, the origin could be shifted to (7,2). The decision matrix can also be extended to represent n x n matrix. The number of intervals were chosen to be 14 only for convenience and can be replaced by any number of intervals. As this tool is flexible, any factor of interest could be used to represent the risk and mitigation value. In case of multiple factors, a single value could be determined by choosing appropriate weights.

This chapter reported the modification factors used for adjusting the calculated travel times from the crash sites to medical facilities. The serious injury crash response coverage of medical facilities was discussed. Level III Trauma Centers offered coverage for the lowest number of crashes while hospitals offered coverage for the highest number of crashes with only 0.4% of crashes outside the golden hour band. The maximum travel times to reach Level I, Level II , Level III trauma centers and hospitals from serious injury crash sites are 209, 202, 208 and 65 minutes respectively. For Trauma Centers, it is to be noted that the highest percentage of crashes fall outside one-hour coverage areas and hence there is no adequate coverage. Finally, the proof of concept for a crash response planning tool is presented.

CHAPTER 5 : CONCLUSIONS

This study demonstrates a proof of concept for a planning tool that could be used to evaluate the coverage areas of medical facilities. Because serious injury crashes and crash rates have been added to safety performance measures, more emphasis has been placed on understanding coverage for crashes involving serious injuries. Modification factors for travel times were determined by comparing the calculated travel times from crash sites to medical facilities to the reported response times in the Fatal Accident Reporting System (FARS).

Applying modified calculated travel times from serious injury crashes between 2016 and 2018 to medical facilities, the percentage of serious injury crash locations that fall outside the 60 minutes travel time coverage areas of medical facilities was computed based on the designated levels of medical facilities. Four coverage area bands were used. The time taken to reach the nearest medical facility from serious injury crash locations within each band was calculated to gain better perception of emergency vehicle response from crash site to medical facility across the network at a macro-level. Level I Trauma Centers were accessible from 19.2 % of historic serious injury crash sites within 15 minutes but were not accessible from 26.6% of crash sites within an hour. 17.9% of historic serious injury crash sites fell within 15-minute coverage areas of Level II Trauma Centers and 29.3% fell outside 60-minute Level II coverage areas. Level III Trauma Centers were accessible from 5.6 % of historic serious injury crash sites within 15 minutes but were not accessible from 54.6% of crash sites within an hour. These results indicate that Trauma Centers in Virginia offer reasonable coverage from historic serious injury crash sites within an hour but do not offer adequate coverage within 15 minutes from crash sites. Upgrading of an existing medical facility to a Level I Trauma Center could be considered since Level I centers offer complete care to crash victims. s, Emergency responders may decide to take the crash victim to a non-trauma hospital if the crash occurs in a heavily congested area when the travel time to the closest trauma center might be high. Therefore, coverage area evaluation was carried out for hospitals. Hospitals offer wider coverage than Trauma Centers. 66.4% of historic serious injury crash sites fell within 15-minute coverage areas of hospitals and only 0.4% fell outside 60-minute coverage areas indicating that hospitals in Virginia offer adequate coverage from serious injury crash sites.

One of the limitations of the study was that it did not include trauma centers or hospitals in neighboring states. This study included only historic serious injury crash sites from 2016 to 2018. Lack of availability of emergency vehicle dispatch locations in Virginia lead to the exclusion of response time calculations from the emergency vehicle location to the crash site. The study focused on the last leg of emergency response planning that involves transporting the crash victims from crash sites to medical facilities.

A proof of concept for planning tool based on risk and mitigation assessment was presented. This study used the aggregate number of fatal and serious injury crashes from 2016 to 2018 in Virginia to establish the risk value. Mitigation assessment was performed based on the travel time necessary to reach the closest medical facility. Any crash or response characteristic of interest could be chosen to develop the risk and mitigation grids. The planning tool could either be used to identify high risk locations or for enabling location-based planning.

The main goal of this research is to provide a platform that assists state agencies in evaluating crash response coverage and to aid in decision making for improved planning. This could be achieved by using the prototype application as a planning tool that enables planners to make better choices to enhance emergency response planning in Virginia. The risk and mitigations grids are flexible and can accommodate any crash or response characteristic of interest. For example, this approach could be used to justify upgrading an existing medical facility to the next trauma capability as a result of this analysis.

5.1 RECOMMENDATIONS FOR FUTURE RESEARCH

The fatal injury crash data used for travel time adjustments contained both ground and air ambulance records. The air ambulance records must be filtered to get a more accurate representation of real time data. Also, linking of crash data to EMS surveillance records would give more accurate injury data (NHTSA 2014) (Amorim et al, 2014). Further research is necessary to refine the methodology with the help of linked records. This study focused on access to medical facilities with respect to spatial distribution of crashes. Including temporal aspect of crashes would give further insights to improve access from the crash sites to medical facilities based on the time when the crash occurs.

The planning tool is a proof of concept intended for demonstration. This tool could be expanded to encompass multiple crash characteristics. Also, the travel time cut off used in the ranking system for trauma center access should be decided based on the study area. Further research concerning the decision factors for risk and response coverage is necessary as it is ideal to follow different ranking systems for urban and rural regions. This study could be extended to include emergency vehicle locations and the total emergency response time from EMS dispatch to crash site and then from crash location to medical facility could be computed. Instances of crash victims being taken to neighboring states according to reciprocity agreements between states with respect to cross-jurisdiction EMS has to be studied in detail.

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CHAPTER 6 : Appendix A

Appendix A gives details about crash data, urban and rural classification data and list of hospitals used in this study. A sample of the model used in GIS for coverage area analysis is presented. A pseudo code used for developing the risk, mitigation and planning grids is also outlined.

A.1. CRASH DATA SAMPLE

The crash data had spatial information used for geocoding the crash locations in GIS and used to link the crash data with FARS data. The type of crash and the level of injury severity was obtained from the data.

Table A.1: Crash Characteristics

S No.	Year	Crash Type Name	MinInjuryTypeID	County/City Name	Latitude	Longitude	Crash Date
1	2016	Property Damage Crash	9	Mathews County	37.49679	-76.4081	8/31/2016 11:05
2	2016	Injury Crash	3	Mathews County	37.49357	-76.4372	12/19/2016 9:01
3	2016	Property Damage Crash	9	Mathews County	37.49401	-76.438	9/25/2016 18:28
4	2016	Property Damage Crash	9	Mathews County	37.49412	-76.438	8/15/2016 13:46
5	2016	Injury Crash	2	Mathews County	37.46837	-76.4452	4/6/2016 18:00
6	2016	Property Damage Crash	9	Mathews County	37.43678	-76.3207	4/11/2016 11:57
7	2016	Injury Crash	3	Mathews County	37.47002	-76.3266	5/29/2016 12:50
8	2016	Injury Crash	4	Mathews County	37.43707	-76.3206	10/13/2016 14:09
9	2016	Property Damage Crash	9	Mathews County	37.46521	-76.4448	12/31/2016 10:52
10	2016	Injury Crash	3	Mathews County	37.47615	-76.4462	12/14/2016 8:50

A.2. URBAN/ RURAL CLASSIFICATION OF VIRGINIA

The urban and rural classification data for Virginia obtained from United States Census Bureau's cartographic GIS layer and VGIN (Virginia Geographic Information Network) is outlined in Figure A.1.

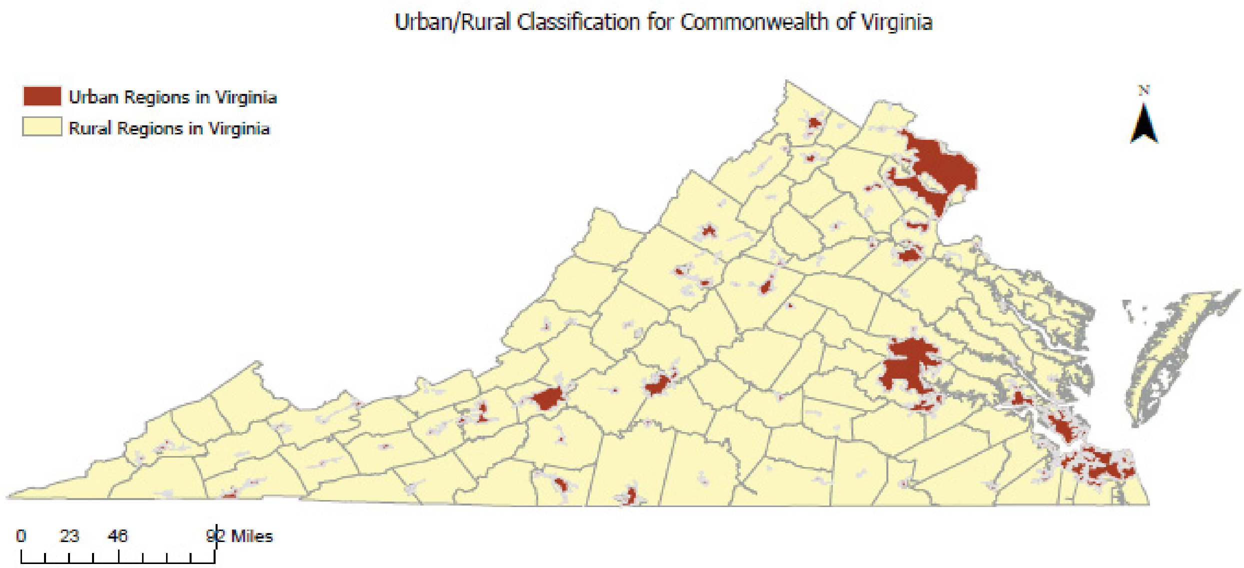

Figure A.1. Urban and Rural Regions in Virginia

A.3. LIST OF HOSPITALS

The list of hospitals in Virginia used in this study is shown in the Table A.2 below:

Table A.2: List of Hospitals in Virginia

S.No	HOSPITAL
1	AUGUSTA MEDICAL CENTER
2	BATH COUNTY COMMUNITY HOSPITAL
3	BEDFORD MEMORIAL HOSPITAL
4	BON SECOURS DEPAUL MEDICAL CENTER
5	BON SECOURS MARYVIEW MEDICAL CENTER
6	BON SECOURS MEMORIAL REGIONAL MEDICAL CENTER
7	BON SECOURS RICHMOND COMMUNITY HOSPITAL
8	BON SECOURS ST. FRANCIS MEDICAL CENTER
9	BON SECOURS ST. MARY'S HOSPITAL
10	BUCHANAN GENERAL HOSPITAL
11	CAPITAL HOSPICE
12	CARILION FRANKLIN MEMORIAL HOSPITAL
13	CARILION GILES COMMUNITY HOSPITAL
14	CARILION ROANOKE COMMUNITY HOSPITAL
15	CARILION STONEWALL JACKSON HOSPITAL
16	CARILION TAZEWELL COMMUNITY HOSPITAL
17	CENTRA VIRGINIA BAPTIST HOSPITAL
18	CHESAPEAKE REGIONAL MEDICAL CENTER
19	CJW MEDICAL CENTER- JOHNSTON-WILLIS CAMPUS
20	CLINCH VALLEY MEDICAL CENTER
21	COMMUNITY MEMORIAL HEALTHCENTER
22	CULPEPER REGIONAL HOSPITAL
23	CUMBERLAND HOSPITAL, LLC
24	DANVILLE REGIONAL MEDICAL CENTER
25	DICKENSON COMMUNITY HOSPITAL
26	FAUQUIER HOSPITAL
27	HALIFAX REGIONAL HOSPITAL
28	HAMPTON ROADS SPECIALTY HOSPITAL
29	HEALTHSOUTH REHABILIATION HOSPITAL OF FREDERICKSBURG
30	HEALTHSOUTH REHABILITATION HOSPITAL OF NORTHERN VIRGINIA

31	HEALTHSOUTH REHABILITATION HOSPITAL OF PETERSBURG
32	HEALTHSOUTH REHABILITATION HOSPITAL OF VIRGINIA
33	HENRICO DOCTORS' HOSPITAL - PARHAM
34	HENRICO DOCTOR’S HOSPITAL - RETREAT
35	INOVA ALEXANDRIA HOSPITAL
36	INOVA FAIR OAKS Hospital
37	INOVA LOUDOUN HOSPITAL
38	INOVA MOUNT VERNON HOSPITAL
39	JOHN RANDOLPH MEDICAL CENTER
40	JOHNSTON MEMORIAL HOSPITAL
41	KINDRED HOSPITAL
42	LAKE TAYLOR TRANSITIONAL CARE HOSPITAL
43	LEE REGIONAL MEDICAL CENTER
44	LEWIS-GALE MEDICAL CENTER
45	LEWIS-GALE HOSPITAL ALLEGHANY
46	LEWIS-GALE HOSPITAL PULASKI
47	LYNN HOUSE OF POTOMAC VALLEY
48	MARTHA JEFFERSON HOSPITAL
49	MARY IMMACULATE HOSPITAL
50	MEDICAL COLLEGE OF VIRGINIA HOSPITALS
51	MEMORIAL HOSPITAL OF MARTINSVILLE &HENRY COUNTY
52	MOUNTAIN VIEW REGIONAL MEDICAL CENTER
53	NORTON COMMUNITY HOSPITAL
54	PAGE MEMORIAL HOSPITAL
55	PAVILION AT WILLIAMSBURG PLACE
56	PIONEER HEALTH SERVICES OF PATRICK COUNTY
57	PRINCE WILLIAM HOSPITAL
58	RAPPAHANNOCK GENERAL HOSPITAL
59	REHABILITATION HOSPITAL OF SOUTHWEST VIRGINIA
60	RIVERSIDE REHABILITATION INSTITUTE
61	RIVERSIDE SHORE MEMORIAL HOSPITAL
62	RIVERSIDE TAPPAHANNOCK HOSPITAL
63	RIVERSIDE WALTER REED HOSPITAL
64	ROCKINGHAM MEMORIAL HOSPITAL
65	RUSSELL COUNTY MEDICAL CENTER
66	SENTARA PRINCESS ANNE HOSPITAL
67	SENTARA CAREPLEX HOSPITAL

68	SENTARA LEIGH HOSPITAL
69	SENTARA OBICI MEMORIAL HOSPITAL
70	SENTARA POTOMAC HOSPITAL
71	SENTARA WILLIAMSBURG REGIONAL HOSPITAL
72	SHELTERING ARMS REHABILITATION HOSPITAL
73	SHELTERING ARMS HOSPITAL SOUTH
74	SHENANDOAH MEMORIAL HOSPITAL
75	SMYTH COUNTY COMMUNITY HOSPITAL
76	SOUTHAMPTON MEMORIAL HOSPITAL
77	SOUTHERN VIRGINIA REGIONAL MEDICAL CENTER
78	SOUTHSIDE COMMUNITY HOSPITAL, INC
79	SPOTSYLVANIA REGIONAL MEDICAL CENTER
80	STAFFORD HOSPITAL
81	TWIN COUNTY REGIONAL HOSPITAL
82	UVA HEALTHSOUTH
83	UVA HEALTH SCIENCES CENTER
84	VIRGINIA HOSPITAL CENTER
85	WARREN MEMORIAL HOSPITAL
86	WELLMONT LONESOME PINE HOSPITAL
87	WINCHESTER REHABILITATION CENTER
88	WYTHE COUNTY COMMUNITY HOSPITAL

A.4. SERVICE AREA ANALYSIS MODEL

The first step is to create a network and build it.

Building the network:

Platform : ArcCatalog 10.6.1

Feature Class : Road Centerline from VGIN

Approach: Non- hierarchical

Network Attributes: Travel Time, Travel Distance, One Way Restriction

Service Area Analysis:

After building the network dataset, service area analysis was performed for each level of medical facility. Service area analysis was performed using network analyst in ArcGIS Pro platform. The geocoded trauma center or hospital locations are imported as facilities around which the service area analysis is executed. The platform and parameters used for the analysis is given below:

Platform : ArcGIS Pro 2.2

Feature Classes : Road Centerline from VGIN, Geocoded Medical facilities

Algorithm: Dijkstra's algorithm

Network Attributes: Travel Time, One Way Restriction

Service Area Bands: 15 min, 30 min, 45 min, 60 min

Direction: Towards Facility

Service Area Shape: Non-overlapping concentric Polygon (Ring Structure)

Non-overlapping polygons are used since the travel time is determined to the closest facility.

A sample model used to determine the service areas of Level I Trauma Centers is shown in Figure A.2.

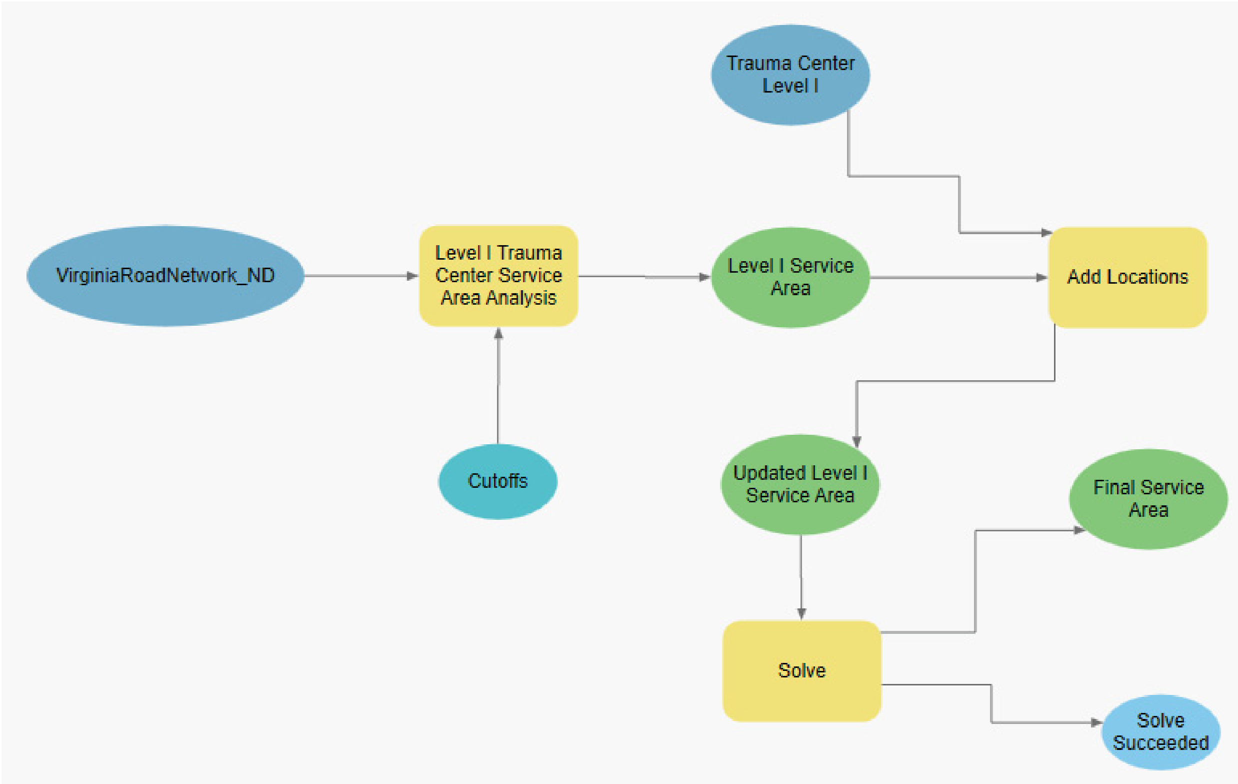

Figure A.2. Sample Service Area Analysis Model

A.5. PLANNING TOOL PSEUDO CODE

The risk and mitigation grids were developed using python in ARCGIS Pro environment. The pseudo used for developing the grids is shown below:

```
#Environment Used: arcgispro-py3
#create grids of size 10-mile X 10-mile
arcpy.management.CreateFishnet("geodatabasename.gdb\samplegrid",
                               "-55355.927199997 82782.5306000002",
                               "-55355.927199997 82792.5306000002",
                               16093.4, 16093.4, None, None,
                               "305694.072800003 335182.5306", "LABELS", "-
                               55355.927199997 82782.5306000002 305694.072800003
                               335182.5306",
                               "POLYGON")


# create risk grid # add a field crash count and set its value to 1.
arcpy.management.CalculateField("grids_risk", "crash_count", 1, "PYTHON3", None)
polygonLayer = "grids_risk"
inputPointLayer = "fatal_serious_crashes"
outPutPolygonLayer = "summarized_grids_risk.shp"

#aggregate the number of crashes within a grid
arcpy.analysis.SummarizeWithin(polygonLayer,inputPointLayer,outPutPolygonLayer,
                              "KEEP_ALL", "Crash_count Sum", "NO_SHAPE_SUM", None,
                               None, "NO_MIN_MAJ", "NO_PERCENT", None)

#create mitigation grid
inputGridLayer ="grids_mitigation"
inputLayer = "service_area_polygons"
outputGridLayer ="summarized_grid.shp"
summaryTable= "mitigation_summary"

#calculate the maximum area of service area band within each grid
arcpy.analysis.SummarizeWithin(inputGridLayer, inputLayer, outputGridLayer,
                               "KEEP_ALL", None, "ADD_SHAPE_SUM", "SQUAREKILOMETERS",
                               "Service_Band", "ADD_MIN_MAJ", "NO_PERCENT",
                               summaryTable)
```