A Process to Calculate Travel Time to a Trauma Center and Assess Trauma Center Coverage in Virginia

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Introduction

Travel time is a major hurdle to the utilization of all kinds of health services. Although health outcomes are dependent on factors including injury severity, patients who do not receive care in a timely fashion are at increased risk of death. Longer travel times to hospitals can lead to negative patient outcomes, especially for patients with time sensitive conditions like trauma.

Trauma is always unexpected. It is one of the foremost causes of mortality in the United States for people aged 45 and below and also the fourth leading cause of mortality for all ages [1]. Access to trauma care is not uniform in the United States and as such many trauma victims do not get the required medical attention in time. Critically injured patients require timely Emergency Medical Service (EMS) transport to the nearest trauma center as the following minutes are critical with regard to saving the victim’s life and minimizing the effects of injuries. If trauma patients do not arrive at a trauma center within an hour on injury, it leads to suboptimal health outcomes [2]. The reason often cited for delayed transportation of trauma patients is the travel time to the nearest trauma center which is further compounded by adverse traffic conditions, if ground EMS transport is used.

Motor vehicle crash records do not include transport times between crash location and trauma care centers. EMS records are not easily available but they contain information on transport time from the crash location. There is no unique identifier to link the Crash records to EMS records. In this case, a method that can estimate transport time from the crash location to the nearest trauma care facility could provide valuable information to assess the coverage of trauma care centers for victims in motor vehicle crashes.

The goal of this project was to assess the coverage of trauma care centers in Virginia by developing and validating a method that can estimate the transport time between crash location and the nearest trauma center. This is evaluated using statistical analysis; Pearson's correlation, t-test and ANOVA test to determine if it provides a reasonable representation of the actual EMS reported transport times. This will help draw inferences using both crash records and EMS records which can help improve crash related safety.

Background

This section explains the role of EMS in responding to motor vehicle crashes and the urgency of transporting critical patients to the nearest treatment facility. Trauma care centers and their benefits by level are discussed. Description of service areas, methods used in prior researches to calculate travel times to a facility and techniques used to test two datasets have been discussed briefly in this section.

Role of EMS

Emergency Medical Services are one of the "4Es" of a successful transportation safety management system: Engineering, education, enforcement and EMS (FHWA, HSIP). In the event of a motor vehicle crash, as soon as dispatch is notified, they notify the nearest EMS unit who then respond the site. The paramedic onboard performs a triage of the injured so they can be transported to the appropriate trauma center at the earliest. "Implement and enhance trauma systems in at least 25 states", is one of the 22 emphasis areas in the American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan [3]. This initiative aims at improving trauma care by helping the states assess the requirements needed to achieve an adequate level of performance in their trauma centers, improve protocols for destination triage, lifesaving treatments, inter hospital transfers and verify the adequacy of air and ground transportation systems. EMS performance has been evaluated extensively using response time as a prominent performance index. A common tenet in EMS is that faster response time equates to better patient survival outcomes. Most related research communities have established response time standards of 8 minutes or less for Advanced Life Support (ALS) service [4]. According to the American Heart Association (AHA), necessary defibrillation must be performed within 8 minutes of a cardiac arrest. AHA also suggests that CPR initiation should begin within 4 minutes and defibrillation within 8 minutes of the initial cardiac arrest. It is critical to get the trauma victims to definitive care within 60 minutes of the accident often referred to as the golden hour where prompt medical attention has the most likelihood to prevent death.

What is a trauma center?

A trauma center is a hospital which has a department specifically dedicated to handle trauma related cases with trauma healthcare specialists available 24 hours a day. Usually there are 3 levels of trauma centers; Level I, Level II and Level III but some states have up to Level V [5]. The standards are based upon guidelines put forth by the American College of Surgeons (ACS). Level I is the highest designation as it has access to trauma specialists, emergency medicine, trauma surgery, critical care and other specialized care. Level III or Level V have the lowest designation as they can only provide initial care to stabilize a traumatic injury before being transferred to a trauma care of a higher designation. A 25% reduction in mortality for severely injured adult patients who received care at a Level I trauma center as opposed to a non-trauma center was identified by the National Study on the Costs and Outcomes of Trauma (NSCOT) [6]. There are large disparities in access between rural and urban areas due to the proximity of medical care facilities to motor vehicle crashes.

Trauma center service areas

Service areas are geographic areas within a region, divided into categories based on ease of access. In past research, access to trauma centers has been divided into three discrete categories based on distance from the population centroid to the nearest trauma center [7];

- Easy Access (< 10 miles)

- Moderate Access (10 – 30 miles)
- Difficult Access (> 30 miles)

Distance and travel time are both important factors of service area accessibility. This helps determine, if the population in a region have adequate coverage in case of a crash.

Calculating travel times

There have been multiple cases where the exact location of the crash was not available and hence a lot of researches have used average travel distance for the entire population of an area. Past studies have shown that estimate of distance from population centroid is superior to estimates based on geometric centroid and polygon centroid when exact addresses are not known [8]. Although distance or travel time to medical care facilities have shown to affect receipt of proper treatment in a variety of settings [9, 10, 11], the relationships have been inconsistent probably due to variability on how distance to medical care facility was calculated. Several methodological approaches have been used to estimate travel time or distance in health service research over the years. Wheeler et al. [12] studied the effects of distance to care centers with radiation therapy facilities on women with breast cancer in North Carolina. They calculated the travel distance from each patient's residential address by zip code to the nearest facility with radiation therapy which were geocoded by their address. A model with logit link function was developed to examine the effect of geospatial measures on receipt of radiation therapy after breast conserving surgery. It was found that, in urban areas, increasing distance to the nearest facility was associated with a lower likelihood of receiving treatment for patients living 20 miles away from the nearest provider as compared to those living less than 10 miles away (95% CI 0.3 – 0.97). Street data from Esri's street map premium for ArcGIS was used as they have been previously found to be more accurate even though they computed Euclidian distances between providers and patients. Euclidian distances are subjected to a large measurement error when compared to road network distances even if certain instrumental variables (IV) are used to ameliorate the error [13, 14]. So, if a model uses Euclidian distances to study the impact of distance on usage of health facilities, it could draw incorrect inferences from a regression model even after using IV. Shahid et al. [15] used Euclidian, Manhattan and Minkowski distance metrics to estimate distances from residential addresses of patient's with cardiac catheterization to a hospital. They assumed that speed is 1 km/min for their entire network. They observed that Euclidian distance and Manhattan distance tend to underestimate and overestimate road distance and travel time respectively. Minkowski distance partially overcomes the shortcomings of both the Euclidian and Manhattan distances and can provide a reliable estimate. Raknes and Hunskaar [16] used Google maps and crowd sourced postal coordinates to estimate average distance for inhabitants of a municipality to a casualty clinic in Norway. This method used Pearson's correlation coefficient which showed good correlation with mean travel time and distance at short distances. Road distance provides an accurate measure but it is prone to local features [15].

Testing two datasets

In this project, the coverage of trauma care centers in Virginia will be assessed by comparing average calculated transport time to average EMS reported transport time using statistical analysis. Pearson's correlation is a measure of the linear correlation between two variables. A value of 0 indicates that there is no association between the two variables. A value greater than 0 indicates a positive association which means that if the value of one variable increases, the value of the other variable increases as well. SA two tailed t-test is appropriate if the calculated value is more or less than the actual value and it computes the statistical significance of a parameter in terms of a test statistic. The most commonly used test statistic is termed as 'p value' or calculated probability and it is statistically significant at $p<0.05$ at a 95% Confidence Interval. Statistical significance is the relationship between two or more datasets. The more similar the values are, higher is the statistical significance. The one way analysis of variance (ANOVA) is used to determine whether there are any statistically significant differences between the means of two or more independent groups; in this case the calculated transport time and the EMS reported time. To the author's knowledge, no published studies have validated calculated transport time from crash scene to the nearest trauma center using actual EMS reported travel times in Virginia. This project also aims to overcome limitations in prior studies by using a road network which is comprehensive and also includes the speed limits for every functional class of road in the network.

Study Area

Coverage of trauma centers for the Commonwealth of Virginia is being assessed in this project. Virginia Trauma Center designations are based upon national standards put forth by the American College of Surgeons (ACS) and the American College of Emergency Physicians (ACEP).

As of 2017, there are 17 designated trauma centers in Virginia [17]. There are 5 Level I and Level III trauma centers and 7 Level II trauma centers in Virginia. The trauma centers are shown in Figure 1.

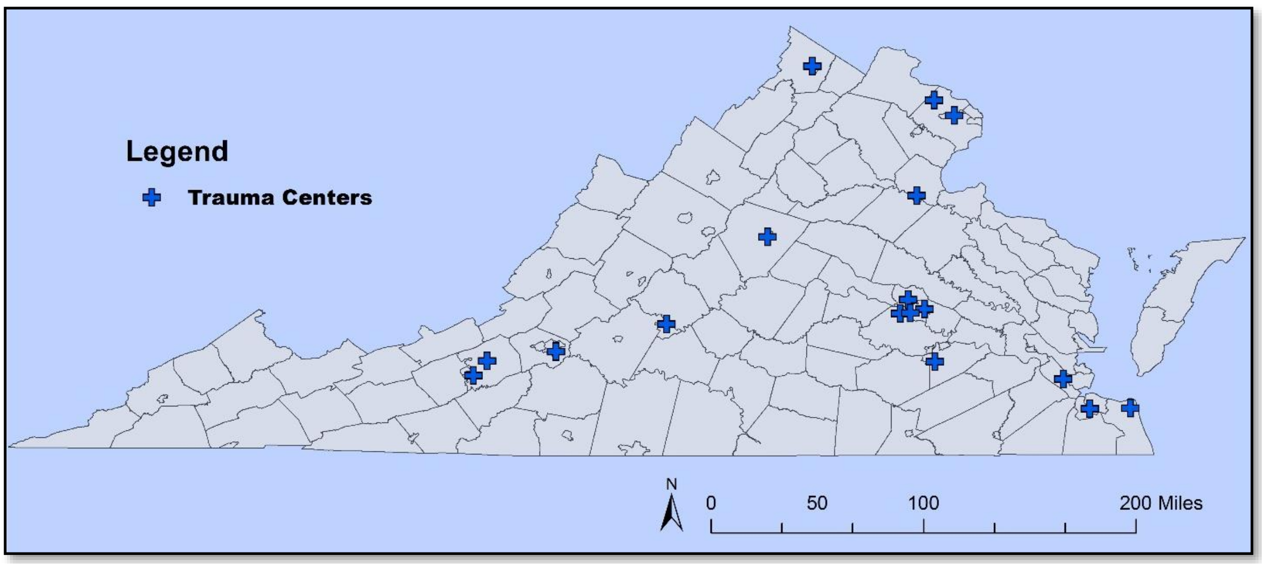

Figure 1. Trauma Centers in Virginia

Data

Datasets obtained from different sources are discussed in this section. Data used for this project includes EMS data, motor vehicle crash data, road network data, trauma center data and zip code data.

EMS data

EMS data for three years (2013 – 2015) was obtained from the Virginia Department of Health (VDH). The data includes incident location, response time, on scene time, transport time to destination as well as patient demographics. The variables used were incident date, incident zip code, dispatch/unit notification time, EMS unit arrival on scene time, EMS left scene time, time arrived at destination and response disposition. Response disposition includes incidents with cancelled EMS, dead at scene, patient refused care or transport, treated and released or transferred, treated and referred to law enforcement, treated and transported and no patient found. Crash records have only one EMS related field, 'EMS transport' which can be used for comparison with EMS records. Hence, the EMS data was further narrowed by response disposition. For the analysis, only patients who were treated and transported were selected. The records which did not have any EMS time related data were discarded. Since this data is manually entered into the database, there are typographical errors in the data. By going over the data systematically, an attempt was made to fix the potential typographical errors. The changes made to the data are shown in Table 1 and Table 2 and the fields used to narrow down the EMS records for the analysis are shown in Table 3 respectively.

Table 1. Cleaning of EMS Records - I

Action	Number of records
Deleted records with no EMS data	27
Switched dispatch and unit notification times	122
Invalid dispatch notification time	21
Switched unit notification time and unit enroute time	76
Switched left scene time and arrived destination time	73
Invalid arrived destination values	13
Changed the dates of fields	560

Table 2. Cleaning of EMS Records - II

EMS data (911 response, location - Street or Highway)	128,128 Records	
	Number of records	Blank fields
Dispatch notified	108,672	19,456*
Unit notified	128,103	25
Unit enroute	127,934	194
Scene Arrival	127,969	159
Left Scene	124,124	4,004
Arrived destination	91,156	36,972**
Total time (dispatch notification to destination arrival)	128,085	43

* 19,433 Unit notified fields were used instead of the blank Dispatch notified fields and 10 Unit enroute fields were used instead of the blank Dispatch notified and Unit notified fields.

** 36,929 Unit back in service fields were used instead of the blank arrived destination fields

The records of patients transported by EMS were aggregated by zip code. Only 5 digit zip codes were selected. A macro was developed for calculating outliers in transport time by zip code. It considered records below the first quartile and records above the third quartile as outliers and were discarded.

Table 3. EMS fields used for analysis

Originials EMS Records	146,747
EMS Records (911 response, location - Street/Highway)	128,128
EMS Records (Transported, 5 digit zip codes)	83,299
EMS Records used for analysis	80,533

Motor vehicle crash data

Virginia motor vehicle crash data for three years (2013 – 2015) have been acquired through the Department of Motor Vehicles (DMV), Virginia [18]. The variables used in this project were incident date, latitude, longitude, injury severity type and ems transport. With the additional field of EMS responses provided by the DMV, the crashes were joined to the responses. For this project, only the records for the patients who were transported were used and the changes made to the motor vehicle crash data are shown in Table 4.

Table 4. Crash records used for analysis

Virginia Motor vehicle Crash Data	**Number of Crashes**	**EMS Records**
Original Number of crashes (2013 - 2015)	401,162	-
Number of EMS responses	367,844	**720,522**
Number of crash records with EMS transport	73,511	**81,565**

Road Network data

The Virginia road centerline data was obtained from the Virginia Geographic Information Network (VGIN) which are part of the Virginia Base Mapping Program. It contains the address, road name, coordinates, route numbers and speed limit attributes. A network was created for analysis using the road centerline data. For this project, the posted road speed limits assigned to the roads were not used as EMS have the right of way in case of an incident and they do not have to adhere to the speed limit. No published guidelines were found by the authors to compute EMS speeds except that EMS should not exceed posted speed limit signs by more than 10 mph unless the driver deems it safe. Some assumptions were made where the default speed limits on interstates, US routes and state routes were increased by 10 mph. Speed limits less than 25 mph were kept as is. Speed limits of 25 mph (not considering interstates, US routes and state routes) and greater were reduced by 5 mph considering signals, stop signs and congestion. The lengths of the road segment was already included in the road centerline dataset and once the speed limits were addressed, the travel time to traverse that segment of the road was calculated.

Trauma Center data

The information on the trauma centers in Virginia were obtained from the VDH. The dataset contained names and locations of all the licensed hospitals in Virginia. A list of 17 designated trauma centers were obtained from the VDH website and were extracted from the hospitals dataset.

Zip codes

United States postal service zip codes for Virginia were obtained for this project. Zip codes were used to compare both crash records and EMS records and all the changes are shown in Table 5. The difference between average calculated transport time and average EMS reported transport time was calculated. Once the differences were computed, it was found that southwest Virginia had

Table 5. Zip code changes for analysis

Zip code Changes	Number of Zip codes
Crash Records with EMS Transport	823
EMS Records with transport	813
Records in common	798
Records after discarding potential zips with Out of State transport	692
Records after discarding zips with $\leq$ 3 records (Used for Analysis)	617

significantly high differences (>40 min). It was assumed that, the crash victims in these areas are transported to the nearest out of state trauma centers as the in-state trauma centers are farther away as compared to the facilities from the neighboring state. These zip codes were discarded as they would potentially provide biased results. Finally zip codes with 3 or less records associated with EMS transport were disregarded as these records would have introduced very high variances when calculating average variances for the entire dataset. The zip codes used for analysis are shown in Figure 2.

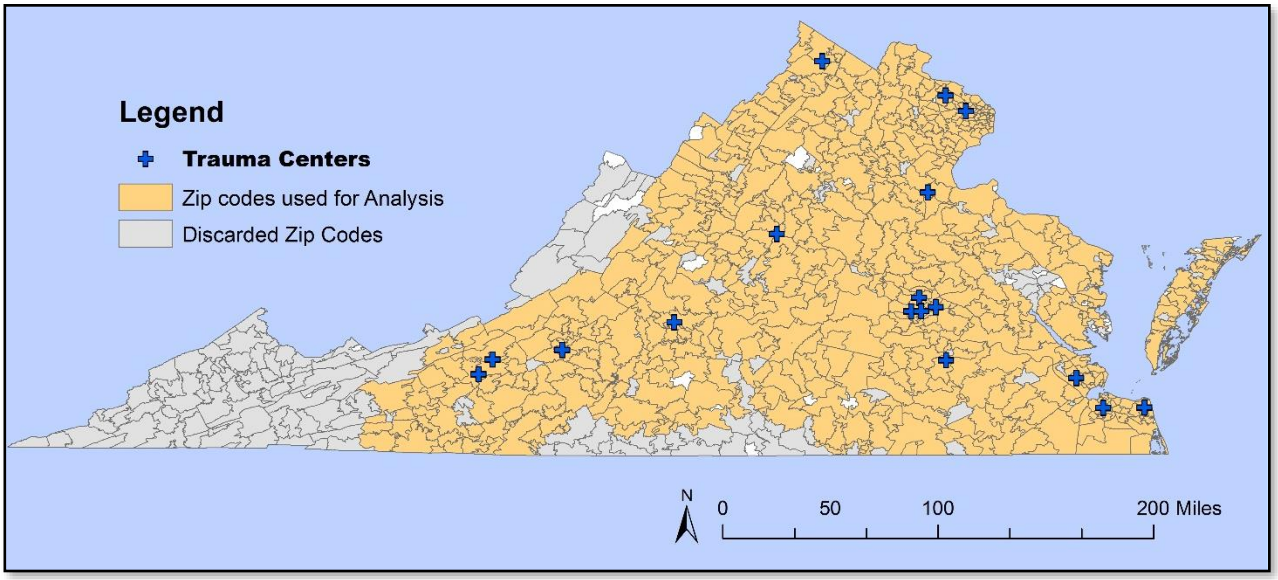

Figure 2. Selected Zip codes for Analysis

Methodology

This section includes detailed description of the steps taken to assess the coverage of trauma care centers in Virginia. The steps involved in validating a method that can estimate the transport time between crash location and the nearest trauma center have also been described.

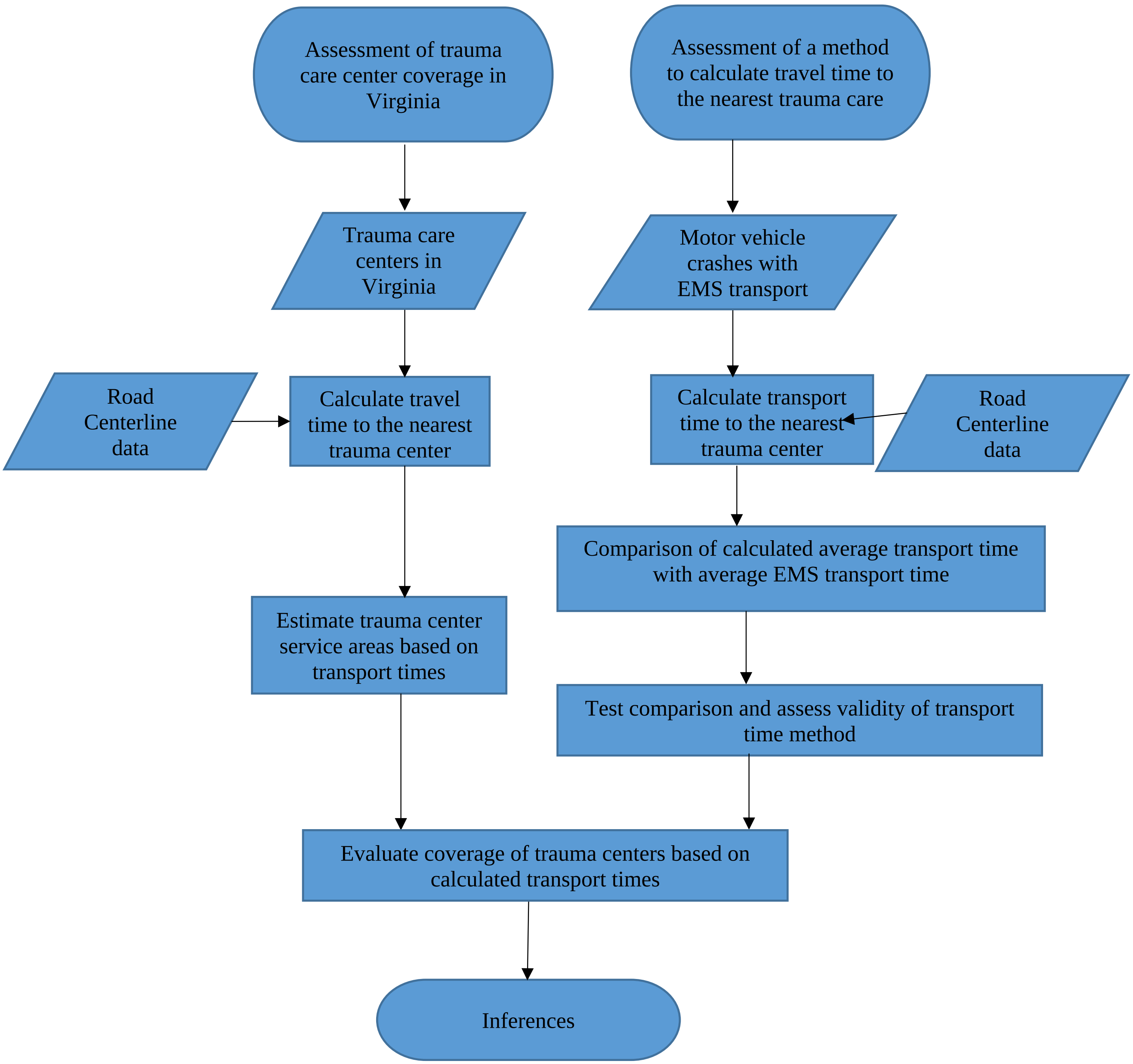

Figure 3. Steps to attain project objectives

Coverage of trauma care centers

To calculate the travel time to the nearest trauma center facility, the road network dataset was used. The travel time to the nearest trauma center for that segment of road was calculated using the road centerline data with the Network Analyst tool in ArcGIS. The crash records with EMS transport were overlaid on the road network to obtain the travel time attributes of that road segment. Service areas were created for each of the 17 trauma centers with travel times of up to 20 minutes, 20 to 60 minutes and greater than 60 minutes. Crash records were sorted by these service areas by injury severity.

Calculated transport time V/s actual EMS reported transport time

The transport time has already been calculated for crash records where victims were transported by EMS. EMS records do not have crash location coordinates, so they cannot not be compared directly with the crash records. In this case, the average EMS reported transport time for all EMS records with a response disposition of "*treated and transported*" were compared with the average calculated transport time of crash records where victims were transported by EMS by zip code. The difference in the number of crash records and EMS records are shown by zip code in Figure 4.

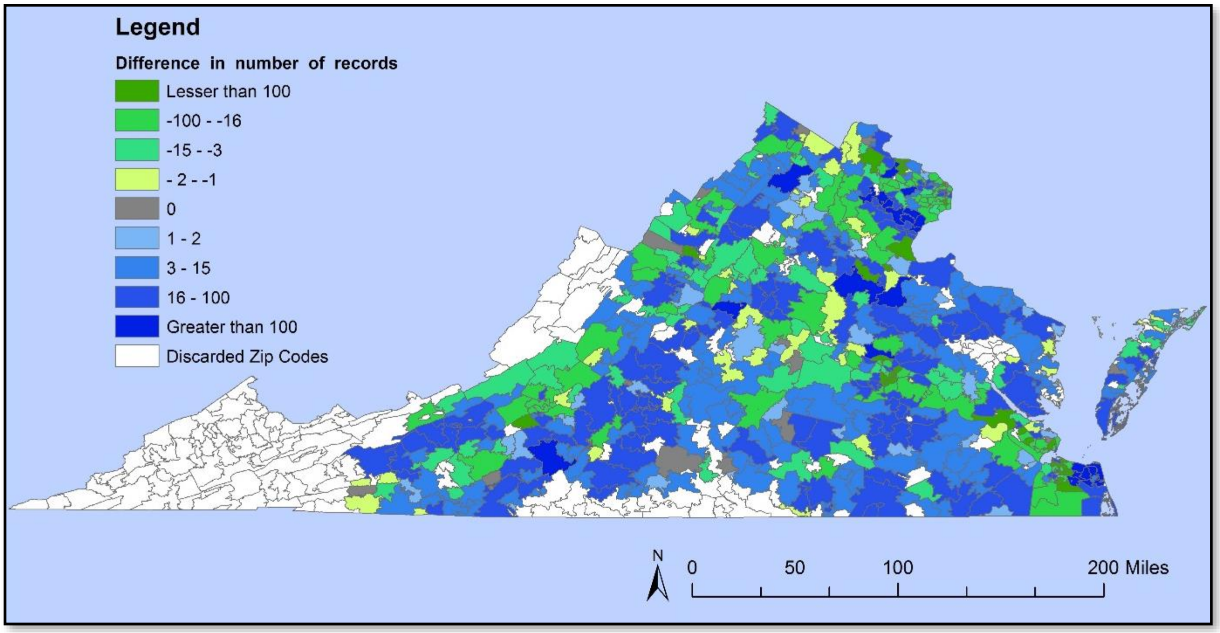

Figure 4. Difference in Crash and EMS records

Method Validation for calculated transport time

To estimate the correlation between the average calculated transport time and the average reported EMS transport time, Pearson's correlation and a two tailed T-test were used. To analyze the significance in detail, ANOVA and ANOVA Post-hoc (Tukey's honest significant difference) for mean comparison methods within the groups were used. ANOVA test describes an overall mean difference between the groups. The post hoc test describes specifically what category within the group had the lowest mean difference. Tukey's test compares the means of every category to the means of every other category; that is, it applies simultaneously to the set of all pairwise comparisons and identifies any difference between two means that is greater than the expected standard error.

Evaluation of coverage of trauma centers

In Virginia, calculating straight line distance using zip code centroids would be a misrepresentation as Virginia has mountains and areas which are connected by limited number of bridges. Considering that all the designated trauma centers are in urban areas and there will be congestion depending on the time of day, travel time was assessed in lieu of distance as coverage. A conservative speed limit of 30 mph, was used to calculate service areas of trauma centers in terms of travel time;

- Easy Access (0 – 20 minutes)
- Moderate Access (20 – 60 minutes)
- Difficult Access (> 60 minutes)

The average calculated transport times were categorized based on these values and coverage of the trauma centers were evaluated. The coverage is shown in Figure 5.

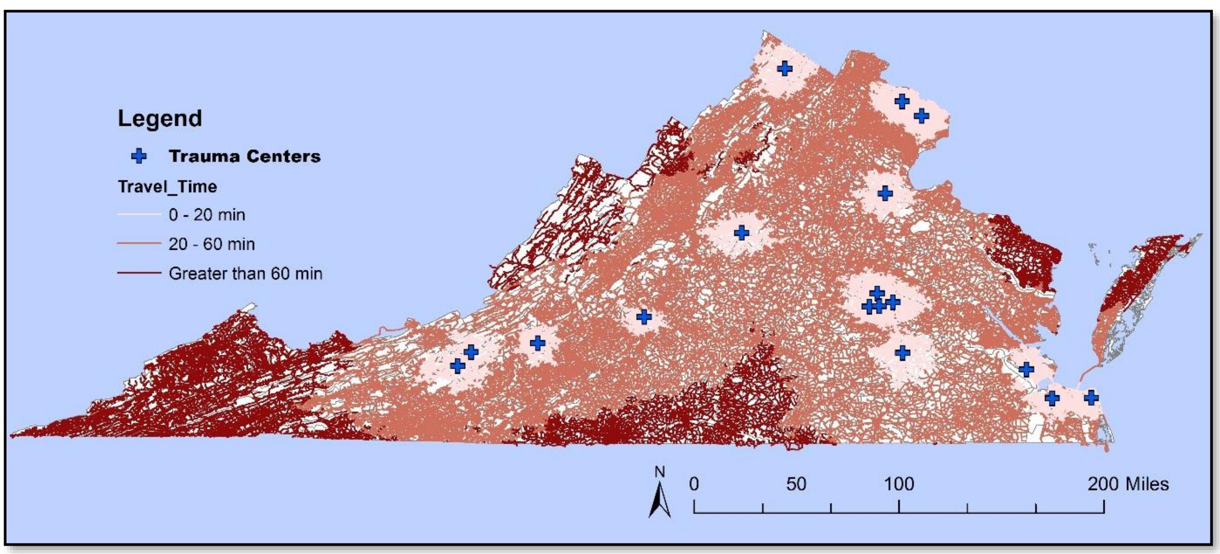

Figure 5. Coverage of Trauma Centers

Results

This sections contains results of the assessment of the coverage of trauma care centers in Virginia. Results for method validation that estimates the transport time between crash location and the nearest trauma center are also displayed in this section.

Coverage of trauma care centers

Crash records where victims were transported by EMS have been divided into categories based on trauma care coverage and are shown in Table 6.

Table 6. Trauma care center coverage by severity

Trauma Care Coverage	Fatal	Severe	Minor	Possible	PDO	Grand Total
0 - 20 min (Easy Access)	1.05%	17.61%	57.47%	23.10%	0.77%	**62.97%**
20 - 60 min (Moderate Access)	2.64%	26.95%	56.57%	13.56%	0.28%	**29.59%**
> 60 min (Difficult Access)	3.60%	32.69%	49.76%	13.84%	0.12%	**7.43%**
Grand Total	**1.71%**	**21.50%**	**56.63%**	**19.59%**	**0.58%**	**100.00%**

Number of crash and EMS records of victims who were transported by EMS are shown in Table 7. Based on the crash records, 2% of the overall EMS records of victims who were transported by EMS were probably misreported as the incident might have taken place in the neighboring jurisdiction.

Table 7. Number of Crash and EMS records with EMS transport by coverage

Trauma Care Coverage	Number of Crash Records	% (Crash Records)	Number of EMS Records	% (EMS Records)
0 - 20 min (Easy Access)	50,728	68.1%	53,546	73.5%
20 - 60 min (Moderate Access)	22,649	30.4%	18,593	25.5%
> 60 min (Difficult Access)	1,064	1.4%	745	1.0%

Crash records where victims were transported by EMS were assessed according to the severity level of their reported injuries are shown in Figure 6.

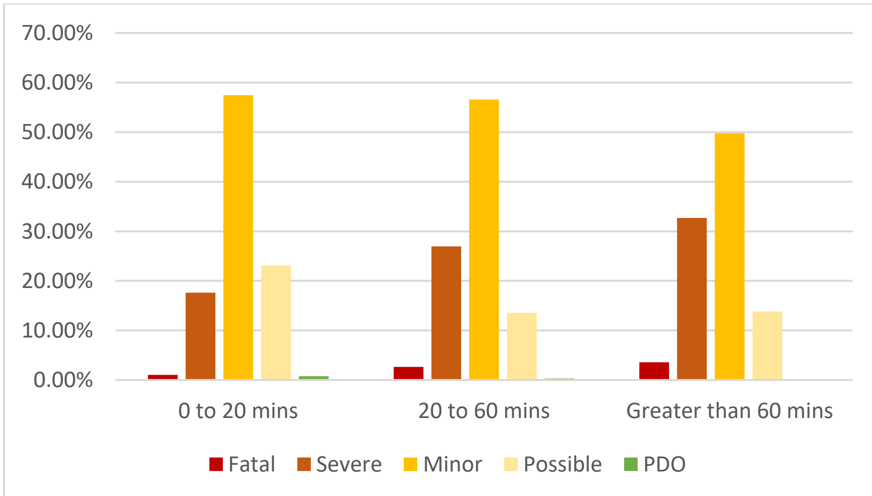

Figure 6. Coverage of Trauma Centers by transported victim severity

Approximately 63% of all crash records where victims were transported by EMS, fall within the 'Easy Access' area, 30% within 'Moderate Access' and 7% within the 'Difficult Access' area. 3% - 4% (61% of all fatal crash records) of these records where patients were transported by EMS were fatal crash records whereas 27% - 33% (48% of all severe injury crash records) were severe injury crash records and fall in the 'Moderate Access' to 'Difficult Access' area. The authors assume that, once EMS arrives at the scene and performs a triage, the patients are possibly airlifted or taken to local hospitals based on the injury severity as it is pre-established that the trauma centers are within moderate to difficult access of the incident area.

Method validation for calculated transport time

Pearson's correlation test was performed to find out the correlation between the average calculated transport time and the average EMS reported transport time.

Table 8. Pearson's correlation test

Correlations			
		Average Calculated transport time	Average EMS reported transport Time
Average Calculated transport time	Pearson Correlation	1	.464
	p value (2-tailed)		2.54E-13
	N	617	617

The Pearson correlation value of 0.464 from Table 8. suggests that, there is moderate to less than moderate relationship between the average calculated transport time and the estimated transport time, as ($p<0.05$ at 95% CI) [19]. To confirm this significance, a T-test was performed and the results are shown in Table 9.

Table 9: 2 tailed T - test

Paired Samples T Test								
	Paired Differences					t	df	P value (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Avg Calculated transport time - Avg EMS reported transport Time	9.746	16.571	.667	8.436	11.057	14.61	616	1.009E-41

T-test and Pearson's correlation test confirm that there is a relationship between the average calculated and average EMS reported transport times as the p value < 0.05 which means that it is statistically significant at 95% Confidence Interval. To determine the range of transport times to be selected for ANOVA, calculated average transport time was plotted against average EMS reported transport time as shown in Figure 7. It can be seen that, there is a high concentration of zip codes with records of calculated average and reported EMS average transport time in the 0 -

20 minutes category. Based on this, 0 – 20 minutes was selected from these ranges as the initial range. 20 – 40 minutes as the second range, 40 to 60 minutes as the third range and more than 60 minutes as the final range. The statistics from the ANOVA test are shown in Table 10.

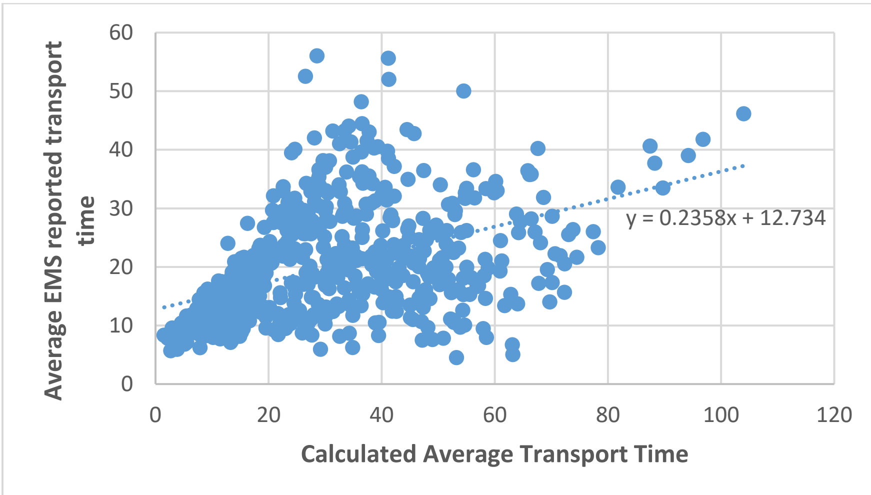

Figure 7. Calculated Average Transport Time V/s Average EMS Reported Transport Time

Table 10: Descriptive statistics from ANOVA test

Descriptive Statistics								
Average EMS reported transport Time								
Average Calculated transport time (Categories)	Number of Zip codes (N)	Mean of Actual Travel Time	Std. Deviation	Root Mean Square Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Less than 20 min	235	13.129	4.183	0.273	12.592	13.6666	5.67	27.42
20-40 min	211	24.140	9.660	0.665	22.829	25.4506	5.91	56
40-60 min	128	22.079	9.364	0.828	20.441	23.7166	4.5	55.6
More than 60 min	42	26.157	9.649	1.489	23.151	29.1642	5	46.12
Total	616	19.649	9.493	0.382	18.897	20.3997	4.5	56

The descriptive table shows that there are differences in the mean duration of average EMS reported transport time compared to the average calculated transport time between the categories. The root mean square gives an estimate of the standard deviation within the categories and it increases rapidly with each category. ANOVA compares two or more means between groups, in this case average calculated transport time and EMS reported transport time. The highest category of average calculated transport time of more than 60 minutes are spread across 42 zip codes (<7%)

Table 11: ANOVA Test results

ANOVA					
	Sum of Squares	df	Mean Square	F	p value
Between Groups	16779.646	3	5593.215	88.586	3.3E-34
Within Groups	38640.862	612	63.139		
Total	55420.508	615			

The p values from the ANOVA test is also statistically significant ($p<0.05$, 95% CI) as shown in Table 11. To estimate the categories which are statistically significant, Tukey's Post Hoc test for ANOVA was conducted. The results from the post hoc test are shown in Table 12.

Table 12: Tukey's Honest Significant Difference (HSD) post hoc test

Post HOC ANOVA						
Dependent Variable: Average EMS reported transport Time						
Tukey HSD						
Average Calculated transport time (I)	Average Calculated transport time (J)	Mean Difference (I-J)	Std. Error	p value	95% Confidence Interval	
					Lower Bound	Upper Bound
≤ 20 min	20-40 min	-11.010*	0.754	5.6E-42	-12.952	-9.069
	40-60 min	-8.949*	0.873	3.09E-29	-11.198	-6.701
	More than 60 min	-13.028*	1.331	1.46E-13	-16.458	-9.599
20-40 min	≤ 20 min	11.010*	0.754	2.46E-26	9.069	12.952
	40-60 min	2.06	0.890	0.096	-0.232	4.354
	More than 60 min	-2.017	1.343	0.436	-5.476	1.441

40-60 min	≤ 20 min	8.949*	0.873	1.5E-7	6.701	11.198
	20-40 min	-2.06	0.890	0.096	-4.354	0.232
	More than 60 min	-4.078*	1.413	0.021	-7.719	-0.439
More than 60 min	≤ 20 min	13.028*	1.331	2.66E-18	9.599	16.458
	20-40	2.017	1.343	0.436	-1.441	5.476
	40-60	4.078*	1.413	0.021	0.439	7.719
*. The mean difference is significant at the 0.05 level.						

It can be seen that the average calculated transport time ≤ 20 min is statistically significant throughout ($p<0.05$, 95% CI). Average EMS reported transport time varies by more than 11 minutes between > 20 min and 20–40 min in the average calculated transport time. 40 – 60 min shows statistical significance ($p<0.05$, 95% CI) which is analyzed in the homogeneous subset analysis for the post hoc test shown in Table 13.

Table 13: Homogenous Subset table for post hoc test

Average EMS reported transport Time				
Tukey HSD				
Calculated transport time	# Zip codes	Subset for alpha = 0.05		
		1	2	3
≤ 20 min	235	13.1291		
40-60 min	128		22.0789	
20-40 min	211		24.1397	24.1397
More than 60 min	42			26.1575
Means for groups in homogeneous subsets are displayed.				

The Homogenous Subsets output is produced for post hoc tests and addresses the same questions as the ANOVA post hoc table for post hoc analysis, i.e. which pairs of groups have significantly different means on the dependent variable. Like the post hoc ANOVA table, the Homogenous Subsets output would not be interpreted if the main effect (ANOVA) was not significant. For each requested post hoc test that does provide homogenous subset results, the groups are listed in order of ascending means. The means that are listed under each subset comprise a set of means that are not significantly different from each other.

Based on the above results, it can be seen that even though there is a moderate statistical significance between the 40 – 60 minutes transport time ($p<0.05$, 95% CI), it is grouped under subset 2 of the homogenous subset table and the means are very similar. Subset 1 ($\leq$ 20 min) has the lowest mean difference and the p values ($p < 0.05$) in the post hoc table justify that.

Evaluation of coverage of trauma centers

According to the statistical analysis, the method used to calculate average transport time for the category of $\leq$ 20 minutes has a significant relationship with the Average EMS reported transport time. The mean difference of the calculated average transport time (11.58 min) is significantly low as compared to the Average EMS reported transport time (13.12 min). 68.1% of the crash records and 73.5% of the EMS records where patients were transported by EMS fall in the category of the calculated average transport time of $\leq$ 20 minutes. This could mean that, victims of incidents that take place within 20 minutes of a designated trauma center are potentially transported to this nearest facility regardless of severity. This method provides a good estimate to calculate average transport times between crash locations to the nearest trauma care center if the crash location is within a 20 minute coverage area of a trauma center.

The method used to calculate average transport time for the category of 20 min – 60 min has an insignificant relationship with the average EMS reported transport time as $p>0.05$, 95% CI. This means that, there is high variability in the calculated average transport time and the average reported EMS transport time. The mean difference of the calculated average transport time (36.5

min) is high as compared to the Average EMS reported transport time (23.3 min). 30.4% of the crash records and 25.5% of the EMS records where patients were transported by EMS fall in the category of the calculated average transport time of 20 - 60 minutes. This could mean that, the assumptions to calculate speed for the road network for this category were incorrect or the reported EMS records are not a good measure for comparison. This is not a good method to calculate trauma center coverage in the 20 – 60 minute range.

The method used to calculate average transport time for the category of greater than 60 min has an insignificant relationship with the average EMS reported transport time as $p>0.05$, 95% CI. This means that, there is significant variability in the calculated average transport time and the average reported EMS transport time. The mean difference of the calculated average transport time (71.4 min) is significantly high as compared to the Average EMS reported transport time (26.1 min). 1.4% of the crash records and 1% of the EMS records where patients were transported by EMS fall in the category of the calculated average transport time of greater than 60 minutes. This is not a good method to calculate trauma center coverage in the more than 60 minute range. Figure 7 shows the average EMS reported transport time when the calculated average transport time is greater than 20 minutes. It can be deduced that, based on the injury severity, patients are taken to nearby local hospitals even though they are not designated trauma centers. If the injuries are non-critical, patients are probably transported by ground and cases that are critical are airlifted.

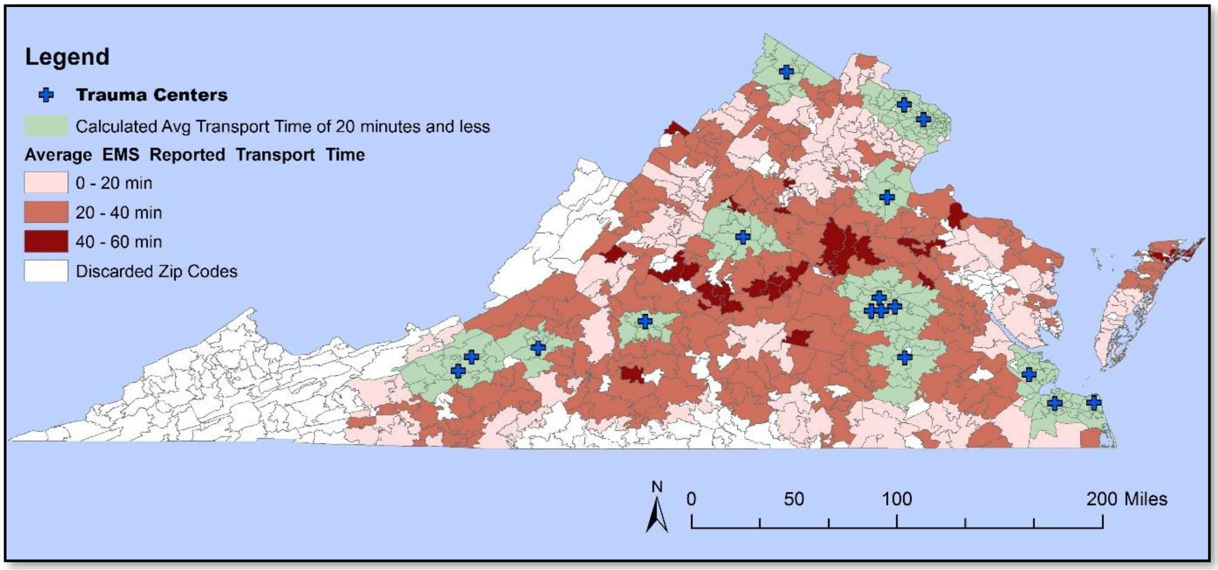

Figure 8. Average EMS reported Transport time (Calculated average transport time > 20 min)

Discussion

Findings from this project reveal that, not all the transported victims from crashes are taken to the designated trauma centers. The 17 designated trauma centers in Virginia cover a major part of the Commonwealth within 60 minutes travel time except for some parts on the Eastern shore, West and South Virginia. Southwest Virginia Emergency medical Council has a tie up with trauma care facilities in the neighboring states of North Carolina, Tennessee, Kentucky and West Virginia [20]. The neighboring trauma centers to southwest Virginia are shown in Figure 8. This tie up helps save the need to be transported to in-state trauma centers which are farther away as compared to these out of state trauma centers. On the eastern shore in Accomack County, crash victims are taken to the Riverside Shore memorial Hospital [21]. If the injury is critical, the patients are flown

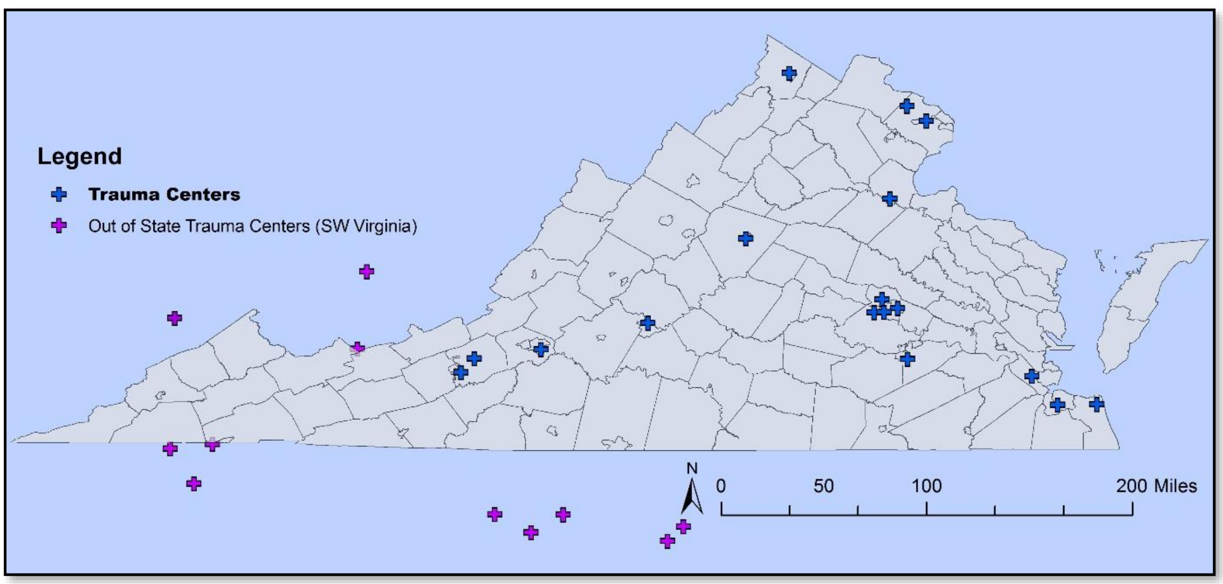

Figure 9. Out of State trauma centers neighboring SW Virginia

to the Riverside Emergency and Trauma Center in Newport News. 0.58% of all crashes where victims were transported by EMS were apparently Property Damage only crashes. Their distribution is shown in Figure 9. It can be seen that a major part of the PDO crash records are concentrated in the Roanoke, Fairfax, Newport News, Richmond and Hampton areas; very near to the trauma center and are possible misentries.

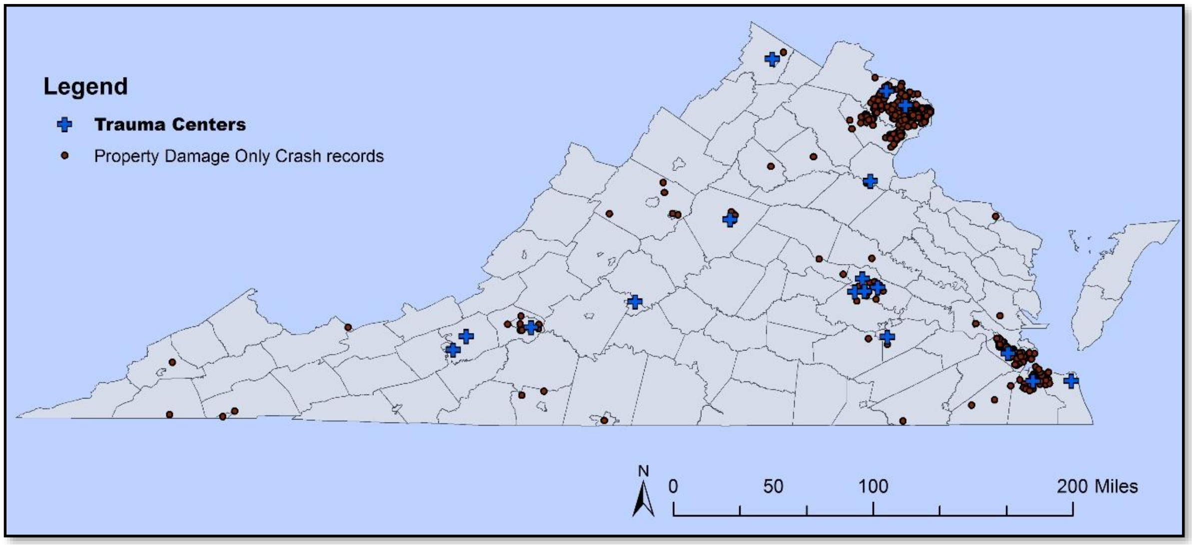

Figure 10. Property Damage Only Crashes

Limitations of the project

Actual EMS speeds vary from the posted speed limits. It is up to the driver and urgency of the situation which dictates the speed, considering safety. The EMS speeds were assumed keeping the posted speed limit in mind. The roads in the network were modeled as two way, irrespective of it being one way. So, the travel time to and from the trauma care center is the same. Since crash records were compared with EMS records by zip code, not all EMS records could be used for analysis due to potential misentries of zip codes. The major limitation in this project was the unavailability of destination location of victims transported by EMS. Hence, the farther away the incident location from the trauma center, more likely the destination is local and not the designated in-state trauma center. Environmental conditions like weather and daytime or nighttime visibility were not considered. Traffic conditions by time of the day, road construction and road geometry were also not considered for this project.

Policy Implications

Service areas are a common way to support policies associated with adequate coverage. Potential policy implications could include allocation of funds to improve air transport and upgrade facilities at existing hospitals to qualify for trauma center designations. Bolstering finances to increase capacity at existing trauma centers so that patients are not turned away due to non-availability of beds.

Conclusion

This project provides insight into the use of crash records and ems records for understanding one characteristic of emergency response, the time from the crash site to the trauma center. Relating travel times from crashes to trauma centers with trauma center coverage provides important information for associating policy to actual experience. Crash records do not include transport times between crash location and treatment facility, so having a method that can estimate this with an understanding of its validity could provide the necessary information to assess the coverage of the treatment facility. Considering all the limitations of this project, this method will be useful for estimating average transport time between crash location and the treatment facility when the facility is located within 20 minutes of the incident location. Combining EMS records with crash records would potentially lead to better information and would be a project for future research.

References:

1. "Trauma Facts." American Association for the Surgery of Trauma. N.p., n.d. Web. 17 July 2017. <http://www.aast.org/trauma-facts>.

2. Audit, Joint Legislative. "Review Commission of the Virginia General Assembly." *The Use and Financing of Trauma Centers in Virginia", House Document* 62 (2004).

3. Neuman, Timothy R., et al. "NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 4: A Guide for Addressing Head-On Collisions." Transportation Research Board of the National Academies, Washington, DC (2003).

4. About Heart Attacks. American Heart Association, 2015.

5. Trauma Center Levels Explained. (n.d.). Retrieved July 25, 2017, from http://www.amtrauma.org/?page=traumalevels

6. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812384

7. Hsia, Renee Yuen-Jan, and Yu-Chu Shen. "Rising closures of hospital trauma centers disproportionately burden vulnerable populations." *Health Affairs* 30.10 (2011): 1912-1920.

8. Berke EM, Shi X (2009) Computing travel time when the exact address is unknown: a comparison of point and polygon ZIP code approximation methods. Int J Health Geogr 8: 23. doi: 10.1186/1476-072X-8-23.

9. Wheeler SB, Carpenter WR, Peppercorn J, Schenck AP, Weinberger M, Biddle AK. Structural/organizational characteristics of health services partly explain racial variation in timeliness of radiation therapy among elderly breast cancer patients. Breast Cancer Res Treat. 2012;133(1):333-345.

10. Holmes JA, Carpenter WR, Wu Y, et al. Impact of distance to a urologist on early diagnosis of prostate cancer among black and white patients. J Urol. 2012;187(3):883-888.

11. Schroen AT, Lohr ME. Travel distance to mammography and the early detection of breast cancer. Breast J. 2009;15(2):216-217.

12. Wheeler, Stephanie B., et al. "Effects of distance to care and rural or urban residence on receipt of radiation therapy among North Carolina Medicare enrollees with breast cancer." North Carolina medical journal 75.4 (2014): 239-246.

13. Gibson, John, et al. "Which households are most distant from health centers in rural China? Evidence from a GIS network analysis." GeoJournal 76.3 (2011): 245-255.

14. Bertazzon, Stefania, and Scott Olson. "Alternative distance metrics for enhanced reliability of spatial regression analysis of health data." Computational Science and Its Applications–ICCSA 2008 (2008): 361-374.

15. Shahid, Rizwan, et al. "Comparison of distance measures in spatial analytical modeling for health service planning." BMC health services research 9.1 (2009): 200.

16. Raknes, Guttorm, and Steinar Hunskaar. "Method paper–distance and travel time to casualty clinics in Norway based on crowdsourced postcode coordinates: A comparison with other methods." PloS one 9.2 (2014): e89287.

17. "Virginia Department of Health." *Virginia Department of Health.* N.p., n.d. Web. 29 July 2017. <http://www.vdh.virginia.gov/emergency-medical-services/trauma-critical-care/virginia-trauma-centers/>.

18. "TREDS - Traffic Records Electronic Data System." *TREDS - Traffic Records Electronic Data System*. N.p., n.d. Web. 29 July 2017. <https://www.treds.virginia.gov/>.

19. Zou, Kelly H., Kemal Tuncali, and Stuart G. Silverman. "Correlation and simple linear regression." *Radiology* 227.3 (2003): 617-628.

20. "Pre-Hospital Patient Care Protocols - 2015." *Http://www.southwest.vaems.org*. N.p., n.d. Web.

21. "Emergency and Trauma Services." *Riverside Emergency & Trauma Services*. N.p., n.d. Web. 27 July 2017. <https://www.riversideonline.com/services/emergency_medicine/our-services.cfm>.