Phase I: Positioning Emergency Medical Services for Trauma Response for Rural Traffic Crashes: Pilot Case of Williston Basin in North Dakota

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GOAL

Devise scenarios using system optimization to efficiently position and deploy limited resources to best meet medical trauma response goals in rural and frontier areas based on a logical assessment of the EMS community's ability to serving potential and actual traffic crash victims.

BACKGROUND

Traffic crashes are a leading cause of unintentional death and injury. More than 2,000 persons suffer crash injuries each year on North Dakota roads – with about 80% occurring on rural roads (Traffic Safety Office 2009). While education, engineering, and enforcement measures continue to reduce crash incidence, it is prudent to enlist the medical community in improving their emergency response and trauma preparedness. Rapid medical response is crucial to reducing mortality and morbidity resulting from traffic crashes (Feero 1995 and Centers for Disease Control and Prevention 2008).

PROBLEM STATEMENT

Emergency medical service (EMS) and trauma care involve ambulance response and initial treatment that is a critical nexus in the logistical path from crash event to medical center. The Division of Emergency Medical Services and Trauma (DEMST) at the North Dakota Department of Health reports that motor vehicle crashes (MVC) accounted for about one in every three trauma calls during 2008, the most recent year available (DEMST, 2009). While urban areas are generally well-supported by EMS services and preparedness, rural areas often depend on volunteer teams with limited opportunities for training. In North Dakota, more than 90% of ambulance team members are volunteers (DEMST 2009).
Given the episodic nature of crash injuries along rural roads, it is difficult to optimize service based on a needs-assessment based on EMS response history. While this type of analysis is beneficial in understanding performance and supplementing resource-knowledge planning, it is also important to consider larger accessibility and coverage issues. Problems inherent to limited resource distribution are evident in the EMS community, as with other public goods providers. The emphasis on efficiently using limited resources, such as the number of ambulances in EMS regions and physicians available at the trauma centers, creates a difficult decision environment because of the need to balance accessibility based solely in geography with exposure factors such as population level and travel activity.

> The National Study on the Costs and Outcomes of Trauma (NSCOT) evaluated the effect of trauma center care on mortality in moderately to severely injured patients and identified a 25% reduction in mortality for severely injured patients who received care at a Level I trauma center rather than at a nontrauma center. (CDCP 2008)

In some areas, regions take an advantage of overlapping service area by providing higher levels of accessibility and service (Figure 1). In other areas, residents are under-covered because of longer distance and "edge effects" which occur in fringe areas near the borders of service areas. Because of the long distance to emergency treatment, lives could be jeopardized in the under-served regions. Problems may also be caused by longer distances between demand points and responder services in predetermined EMS coverage areas as well as the capacity of infrastructure. This study provides an initial step for ongoing logistical analysis of the EMS community response to rural trauma victims based on current assets and a sample traffic crash cases.

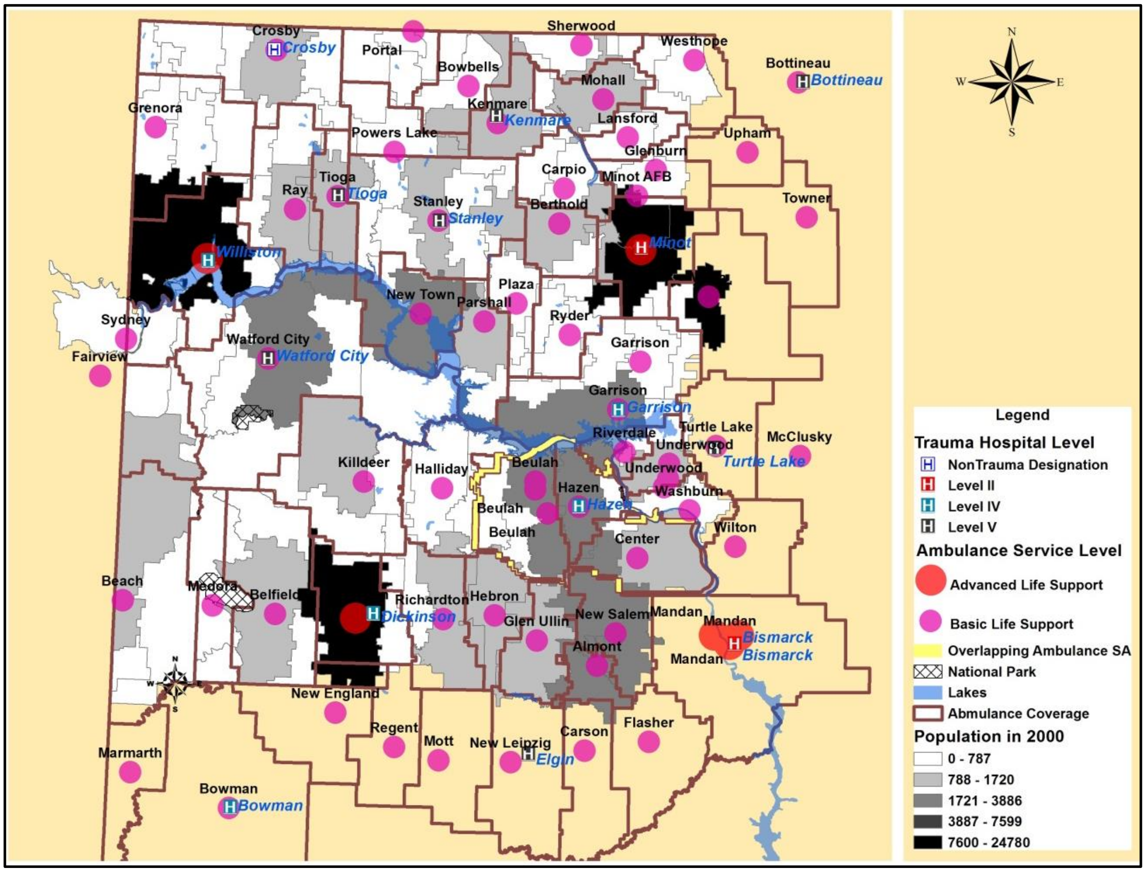


Figure 1 Overlapping ambulance service areas in the study region.

METHOD

Geospatial analysis and optimization modeling of current EMS coverage and historical response are used to analyze EMS coverage and response to traffic crashes in a rural region in northwest North Dakota. Base-case analysis, using travel distance, is conducted under the assumptions of constant travel speed of the service units through the homogeneous transportation networks. The assumption is not real, so the impediment factors affecting the travel speed are taken into account in the emergency response scenarios. Travel speed is estimated by road infrastructure and road conditions such as weather and construction as well as the Highway Performance Management Systems (HPMS). The impediment factors impact real-time emergency operations rather than long-term planning for accessibility. It is necessary to implement dynamic operations planning based on the capacity of road infrastructure as well as the service units. Based on the current road infrastructure, emergency service regions, and the population, the location of emergency service units and trauma centers can be discussed to balance the quick response and the equality of the service. To analyze the gap between the theoretically optimized accessibility and the current state of emergency response practices, geographic information systems and operations research approaches were employed in an empirical study and visualization.

EMS regions can be evaluated for spatial accessibility by measuring the regional availability and spatial proximity regardless of the organizational boundaries (e.g. county, zip code, or EMS coverage). To serve the people in rural areas in North Dakota, services would be equally distributed and planned empirically. Geographic Information Systems (GIS) are broadly utilized to analyze service equality and accessibility by optimizing the service routes and illustrating the service maps based on underlying exposure architecture such as land area and traffic density. The Operations Research (OR) techniques are integrated into GIS. OR techniques such as location set covering and maximal covering models were developed by Radke and Mu (2000) to meet the needs of powerful analytical approaches utilizing GIS (Parker and Campbell 1998).

OBJECTIVES

The main objective of this study is to develop scenarios which measure accessibility and efficiency in EMS community trauma response. Values generated create a scale indicator for quality of life as influenced by EMS accessibility. After developing these baseline scenarios and collecting accessibility measures, the total response time from the emergency service units to the primary care units through demand points is optimized. By doing so, the total response time to save lives would be optimized by adjusting accessibility under various characteristics of rural areas such as distance, travel time, and road conditions.

The response time of the service providers is first measured between the dispatching locations and a demand point, and then is accumulated to the response time from the demand point to a trauma center. To minimize the total response time, we do not consider the treatment time at the demand point or waiting time at hospital because those service times are not related to the transportation service. Performance is measured by the travel time between locations. The modeling will produce a prototype application for North Dakota to employ in decisions to improve the quality of life associated with medical response in MVC trauma cases.

In summary, the objectives of this study are:

1. Estimating accessibility measures for current EMS service areas in a rural region based on-road classification and on-response time goals in the EMS community,
2. Using spatial accessibility measures to create rational service area boundaries based on scenarios,
3. Validating the model by the historical crash response data – including current routing patterns and response times,
4. Measuring the response time components from dispatch service location to MVC site, then to trauma center, separating the dispatch preparation and travel-to-site time components, and
5. Estimating gains in potential efficiency and gains/losses in accessibility by comparing scenario response time of current practice and theoretical per-mile response time.

LITERATURE REVIEW

Taxonomy of Social Medical Service

Emergency response studies are broadly categorized into two issues: capacity of services and equity for social services (Figure 2). Capacity of services is related to the number of general practitioners (Parker and Campbell 1998; Jenkins and Campbell 1996) and ambulances (Geroliminis et al. 2009) as well as transportation infrastructure (Christie and Fone 2003; Murawski and Richard 2009). The capacity is directly measured by efficiency with utilization, serviceability, and availability for emergency response services (Felder and Brinkmann 2002; Beraldi et al. 2004; Luo and Wang 2003; Joseph and Phillips 1984). On the contrary, the equality of service in rural and urban areas was also at issue (Knox 1979) where the equality of EMS is largely in geographical dispersion resulting in longer distance and travel time. Socio-economic factors are also considered as important service location factors to allocate limited resources.

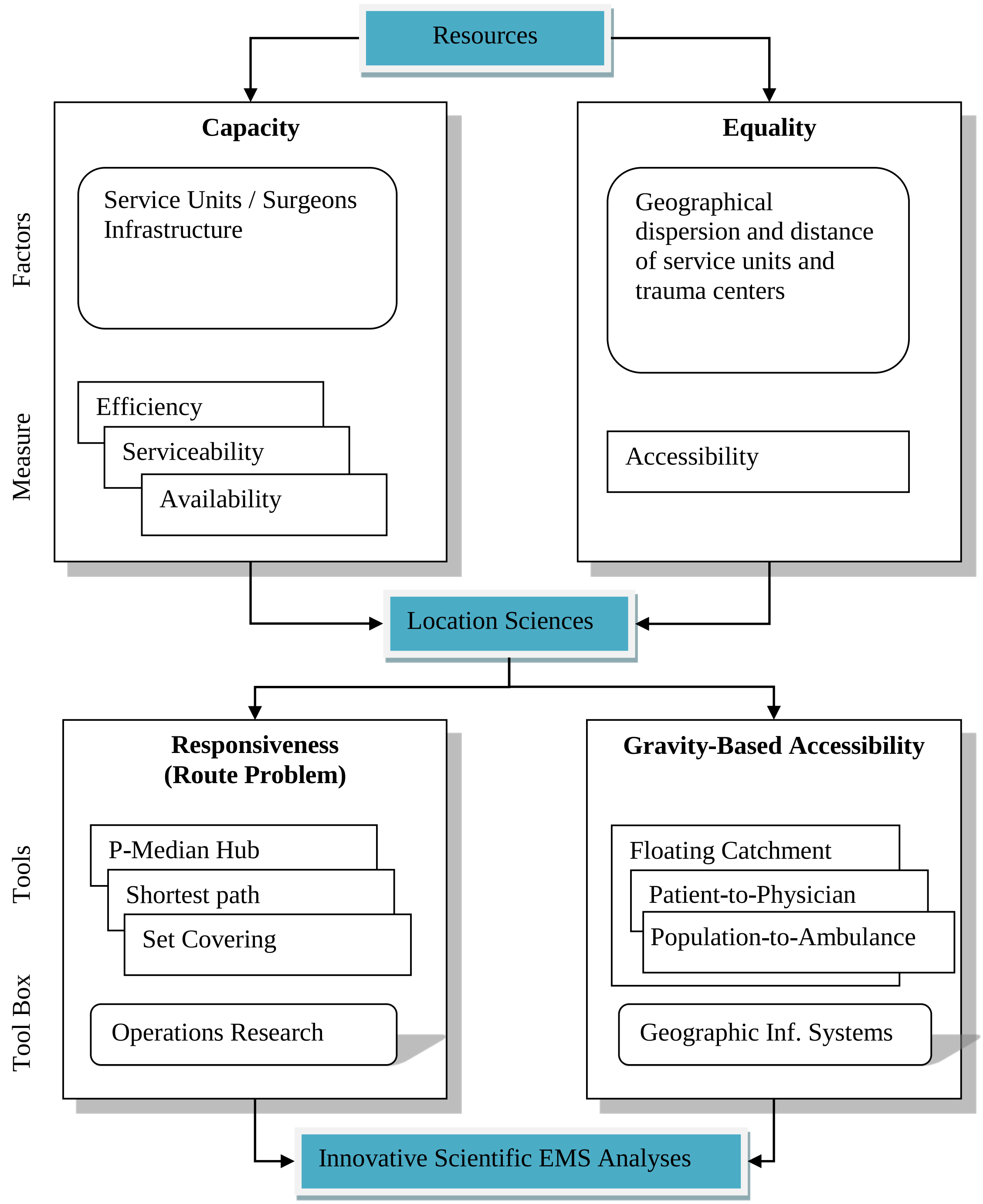


Figure 2 Taxonomy of literature review in emergency response practice.

To analyze the capacity and equity problems, location sciences are related to (i) the location decisions to facilitate quick response and increase the accessibility to areas of dense population and (ii) geographical accessibility considering the distance and service ratio. Operations research techniques are applied to decisions related to service unit locations (e.g. ambulance, 911, and trauma centers) and the number of units available to serve the population in the catchment areas. In particular, location analysis is applied to route problems to facilitate rapid response considering the location of ambulance service units and the demand points of incidents and traumas.

Routing problems are a special form of location problems because they consider the actual travel distance and travel speed or impedance between locations rather than Euclidean straight lines. Routing is influenced by the sensitivity of the impedance factors (Christie and Fone 2003). For the overall route from ambulance service units to trauma centers via demand points of trauma are also a special form of hub-location problem (Radke and Mu 2000) with Dijkstra's shortest path algorithm (Luo and Wang 2003).

Accessibility of emergency medical services has been studied by patient-to-physician or population-to-ambulance ratio in various geographical regions (Jenkins and Campbell 1996). The models were advanced with a gravity model to explain the distance and transportation infrastructure between demand points and service units or trauma centers (Parker and Campbell 1998; McGrail and Humphreys 2009; Knox 1979). Facilities and demand are allocated to the closest service points by point-to-point routing with the shortest Euclidean distance, which is straight. A point-polygon class maps provide unconstrained allocation models without any line directions. Regarding capacity of the service supply, weighted Voronoi point-polygon class maps can be used to measure impact the demand region (Radke and Mu 2000).

The current EMS ambulance service area boundaries in North Dakota are determined by Voronoi point-polygon class maps. This method is developed by applying set-covering problems implemented in Geographic Information Systems (GIS). For example, the Voronoi point-polygon class map is modified by the fastest path distance with speed impedance (Luo and Wang 2003). The accessibility strategies would be incorporated in consideration of a local transportation plan (Langford and Higgs 2006). A two-step floating catchment area (2SFCA) enhanced the measure of accessibility based on and introduced by Radke and Mu (2000), Luo and Wang (2003), and Langford and Higgs (2006).

Policy and Regulation

Because of the complexity of the definitions based on the geographical, environmental, and socio-demographic characteristics, accessibility is commonly used to determine the allocation and distribution of resources. The basic idea of equality is that everybody should be considered to be safe and should have access to the same resources and service. McGrail and Humphreys (2009) measured the spatial accessibility to improve primary care equality in rural areas. In their model, a two-step floating catchment area method is used to measure the accessibility to primary care (e.g. emergency and hospital-based care). Two components of availability and proximity are measured for the accessibility by Luo and Wang (2003) and McGrail and Humphreys (2009). The nearest service location, based on distance, ignores availability and travel impedance such as congestion and construction. The travel time, which includes the travel impedance, would determine the service route and dispatched units for service to meet the demand because the nearest service may not provide the most rapid service in high-service-density areas. The drawback of population-to-service ratio is that the service region is fixed. Service regions would vary based on nearest service point regardless of capacity at individual service points.

Felder and Brinkmann (2002) compared equal accessibility with uniform response time to a maximal admissible response time for ambulances. They developed the capita-per-cost model to evaluate various policy scenarios to identify the equity-efficiency trade-off in providing EMS. In other words, the trade-off between budget constraints and equal access is demonstrated for the maximal response time and the minimal average response time. The study found that a shorter response time is required in the populated areas, which means that it is reasonable to allocate more resources in urban areas.

Accessibility in Respect of Equality

Luo and Wang (2003) defined the service area of physicians by travel time considering physician availability. Joseph and Phillips (1984) used a spatial decomposition method, the two-step floating catchment area (2SFCA), in GIS using travel time instead of straight-line distances. In step one, the populations are counted for each service location within a threshold travel time (e.g. 30 minutes) and then used to calculate a physician-to-population ratio. In the step two, the total service capability is counted for each service location within a threshold travel time (e.g. 30 minutes) and then calculated the physician-to-population ratio, which is a measure of accessibility. However, the border areas show higher accessibility than other areas even if the service areas are far from the service locations. A gravity-based model with a decay-distance function is applied to compare to the two-step FCA. The model is not a competitive model, which means that the gravity-based model is measured for the residential areas located in the catchment area (e.g. 30 minutes) to supplement the two-step FCA method. The drawback of the two-step FCA can be corrected by the distance-decay function. The gravity-based method and floating catchment area are compared for accessibility measurement in the study. The gravity-based model is continuous and the FCA method is dichotomous. The gravity model is less intuitive and computational, while FCA method uses an intuitive threshold travel time. The gravity model overemphasizes the decay function leading to results that are heavily, spatially smoothed. It is assumed that the populations are car-owners. The population was explained by socioeconomic status, ethnicities, and income level. The two-step FCA method is easier and simpler to use and interpret. The paper used the two-step FCA method to improve the designation of health shortage area.

Representation of Population

Population was collected in zip code polygons from the U.S. Census Bureau (2010). The population data is represented as a centroid in the type of points or polygon.

Location problems and accessibility of medical care systems used a discrete demand point for zip code polygon centroids based on the continuous areas of zip code. This approach has drawbacks related to the geographical bias between centers of the areas and border areas, but is the best available unit of study that could be identified in existing geospatial data sources.

Langford and Higgs (2006) investigated the influence of spatial representation models of the population. They summarized three alternatives to represent the population: (i) a population-weighted single representative point of centroid in zip code areas, (ii) a uniformly distributed proportional method in a zone, and (iii) a dasymetric model in census zones. The first method is self-explanatory. The second approach has limitations in rural areas, in which the population is concentrated in certain areas, while it fairly represents the urban area. The last method provides a realistic distribution in fringe areas in rural and urban areas. In spite of the advantages of the dasymetric maps, the implementation is challenge because there is a lack of standardized methods such as three-tier classification, binary dasymetric methods, and remote sensing for the binary methods to identify residential areas (Langford and Higgs 2006).

Consequently, we generate random points to mimic the residential houses in each zip code area. The random points are generated by the number of houses surveyed by the U.S. Census Bureau in 2000. In the absence of private data, measures are calculated on random points within a zip code area. In our study, we use the second modified method. Instead of using evenly distributed population, we used random spatial point technique. The rationales for the method are that:

- We have less clear information about locations of houses in maps. Even if the bias remains between random points and actual residential locations, the bias is smaller than the use of the zip centroid.
- The randomly distributed population represents the fringe of the rural and urban areas.
- Emergencies can happen anywhere, including on trails and unmapped gravel roads.

CASE STUDY

We measure the current practices for the EMS response in the study region. By understanding and analyzing current EMS practices, potential investments and policy changes can be analyzed based on a closed loop process (Figure 3).

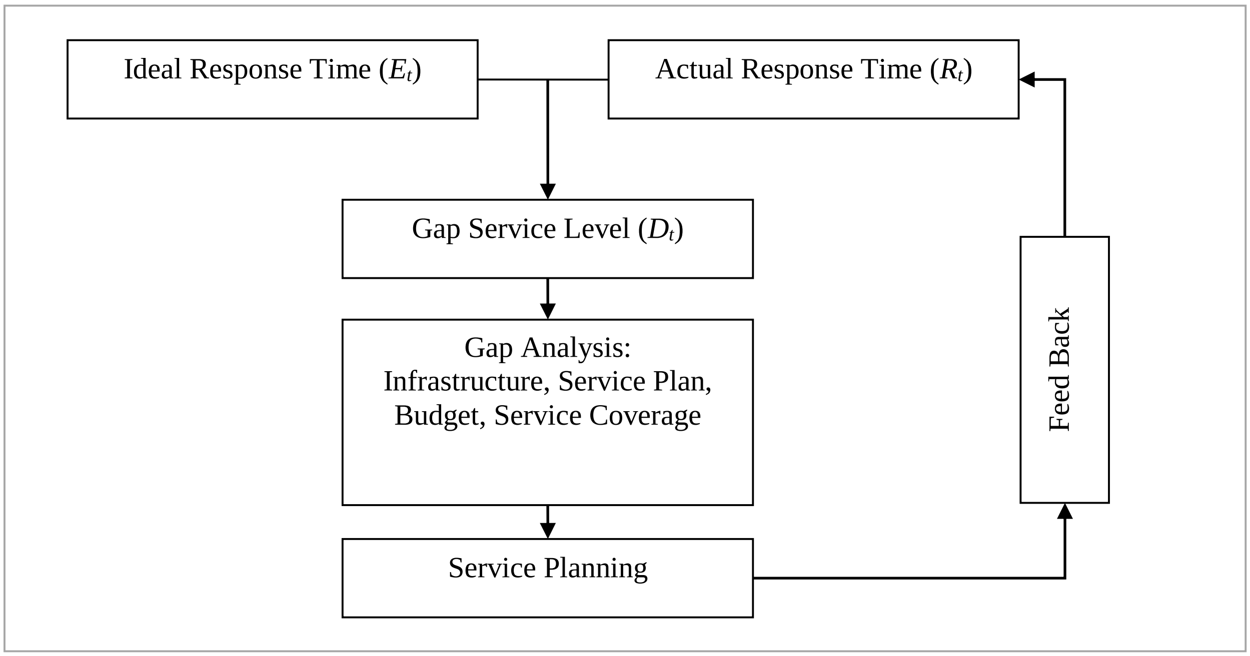


Figure 3 Closed loop process for service planning.

Study Region

The Williston Basin in North Dakota was selected because we hypothesize that the rural area has had recent changes in its need for EMS services due to unprecedented oil exploration and development there (Figure 4). In addition, the area includes two parts of a national park and Lake Sakakawea along the Missouri river, which are popular national and local recreational destinations. This study investigates accessibility and service quality for counties in the Williston Basin area. In the study area, three advanced life support (ALS) and 25 basic life support (BLS) ambulances are active (NDDOH 2010). Ambulances use model-designated service areas based on the smallest available study unit, zip code. The zip code boundaries may not align with current service area boundaries. Among the ambulance services, two - Sydney and Fairview - are from Montana and cross the state border to provide service.

Within or adjacent to the region, are one Level II trauma center at Minot and four Level IV trauma centers in Williston, Dickinson, Garrison, and Hazen. These five trauma centers are located in population centers. Three Level V trauma center are scattered between the Level II and Level IV trauma centers. Crosby has a center without a trauma designation. In addition, the seven trauma centers bordering the study region are included because it is assumed that these facilities would provide services to the region because of their proximity.

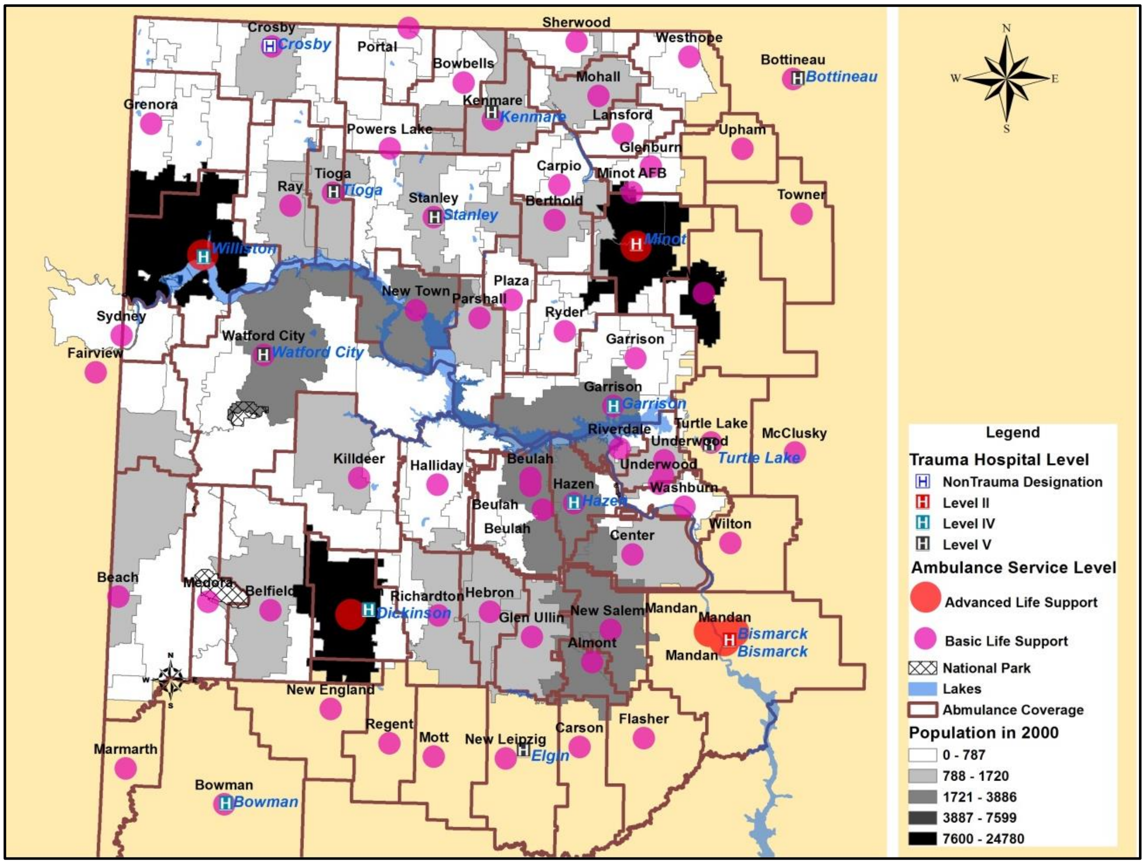


Figure 4 Study region and service locations.

Modeling exercises in this study are based on existing data. When it comes to the transportation infrastructure in the region, the primary and secondary roads defined by TIGER files include 2,487 miles (Table 1). The mile length of both the primary and secondary roads show just 5.3% of the total road miles in the region. These roads are defined as divided and limited-access highways such as interstate highways for the primary roads and U.S., state, and major county roads with one or more lanes of traffic in each direction for the secondary roads. In addition, 40,358 miles were defined as the local neighborhood roads, rural roads, and city edges roads including scenic park roads in the region. This portion of the total roads in the regions is 85.2%. These roads would constrain the driving maneuvers and speed for dispatched ambulances. Unpaved roads classified as vehicular four-wheel drive (4WD), total of 4,489 miles and 9.5% of the total road miles in the region.

Table 1: Tiger® road miles by classification

Classification	S1100 and S1200	S1400	S1500	Others	Total
Miles	2,487	40,358	4,489	35	47,369
Ratio	5.25%	85.19%	9.47%	0.09%	100.00%

In addition to the road infrastructure, the social impacts of the oil industry boom in the Williston Basin have a major impact on emergency medical services. Because of the limited transportation capacity for transferring oil from Williston to refineries in Wyoming and Mandan, ND, the trucking and railroad industries are being used to move oil, causing heavy traffic in the region (DMR News 2007, Donovan 2010). Increased traffic from hauling oil drilling equipment and oil tanks will delay ambulance responses time and increase the number of traffic accidents on roads.

For the purpose of monitoring the quality of emergency medical services, ND-DOH provides an ambulance dispatch reporting service to collect information on incidents of service delays of more than 30 minutes. On the website, citizens can report the type of incidents, and response delay and dispatch, and en route time of an ambulance service dispatched (Figure 5). This delay contributes to the impedance function for the overall response time depending on truck traffic densities along ambulance routes.

Figure 5 A screenshot of ambulance dispatch report of North Dakota.

Data Preparation

An initial step in the analysis is to define the transportation network and the spatial metrics. The supply and demand will be modeled in alternate scenarios within these routing and spatial contexts. The ambulance services and EMS depend on the capability of vehicle. The speed of ambulance service is assumed homogeneous on road classes. Depending on the road conditions and capacity, the response time varies even though an ambulance has priority travel in traffic. Maximum speeds on major roads and county roads, from the ND GIS Hub, are based on the road classification (Table 2). Depending on the speed limit on road classification, results of travel response time will be changed.

Table 2 Tiger® road classification and the assumed maximum speed of ambulances

Class	S1100	S1200	S1400	S1500	S1630 – 1640	S1750-1780
	Interstate	U.S and State	Rural and City	Unpaved		
Average Speed (MPH)	75	65	55	30	25	10

The U.S. Census figures were used to measure the population coverage by ambulance services and trauma centers. Most of EMS accessibility research uses the centroid of zip codes as continuous demand areas, while ND Ambulance Response Area Map Book (2009) uses Public Land Survey System (PLSS) sections and townships for coverage. PLSS sections themselves do not include population data and crash information, so we used geospatial random points in the study area. For the holistic approach, the random points were generated in zip code areas for traumas and public emergency services and on highways in an experiment to model rather unpredictable highway crashes. The detailed methods to generate random points are as follows:

- Trauma random points: one trauma point is generated to represent 10 persons based on 2000 Census Bureau population data in a zip code. It does not represent the square miles of area. For example, the population in 2,000 of zip code 58662 area was 358, thereby generating 36 random points. A total of 9,600 points were generated in the study region.
- Highway incident random points: 4,356 random points were generated on the highways including interstate, U.S., and state highways. Five random points were generated on a road segment separated by a minimum distance of 50 feet.

Ambulance locations and trauma centers-related GIS shapefiles are provided from NDDOH and the linked to the up-to-date ambulance contracts and trauma designation in the regions. The service locations are not exactly located on the roads network, thereby the connectivity between the location points and the road lines were based on the nearest networks in GIS to estimate origin and destination (O-D) travel time/distance matrix.

Estimating response time (E_t)

This paper uses a holistic approach in the study region in order to estimate the minimal response time. To measure the current practices, two methods are used: 1) the shortest path between the random demand points and ambulance locations for matching services, and 2) data-driven analysis based on the random demand points on highways and in zip code areas and response records from the state authority. The shortest path between demand points and services are created by using *closest facility* module in ArcView® 9.3. Table 3 shows a descriptive summary of the ideal shortest response time from ambulance locations to accidents in minutes. The results do not consider the call response time or dispatching time.

Results

The ideal shortest response time from ambulance to crash and trauma centers are summarized in Table 3. In the table, each attributes of minutes, miles, minutes per mile, and mile per hour are independently collected from 12055 samples. In other words, the minimal travel speed, *miles per hour*, is not calculated from the minimum travel time, *minutes*, and the shortest travel distance, *miles*, but queried from all response's travel speed. The longest estimated response time was 54.83 minutes along 53.44 miles, resulting in 1.65 minutes per mile response time, while the average response time was 12 minutes along 12 miles resulting in 1 minute per mile (Table 3).

Table 3 Ideal shortest response time from ambulance to crash and trauma (in minutes)

	Minimum	Maximum	Average	Median	Standard Deviation	Variability	Sample Size
Minutes	0.04	54.83	12.04	11.15	7.83	61.34	12,055
Miles	0.04	53.44	11.96	11.13	7.71	59.49	
Minutes/mile	0.81	1.65	1.01	1.00	0.08	0.01	
Speed (mile per hour)	36.33	73.80	59.90	60.07	4.88	23.82	

The response time under 10 minutes, which is the federal recommendation, was found in less than half the cases, 44.5%. Overall presentation shows a right-skewed distribution of the response times (Figure 6). The traumas in Killdeer area have the longest response times at more than 50 minutes (Figure 7). Based on the Division of Emergency Medical Service and Trauma recommendations (2008), urban ambulance services must respond and arrive on scene within 9 minutes for 90% of all cases. The rural and transportation corridor ambulances must arrive on the scene within 10 minutes or less 90% of the time and the overall response time should be within in 20 minutes 90% of the time. Frontier ambulance services were recommended to respond within 10 minutes or less 90% of the time with an overall response time of less than 30 minutes 90% of the time.

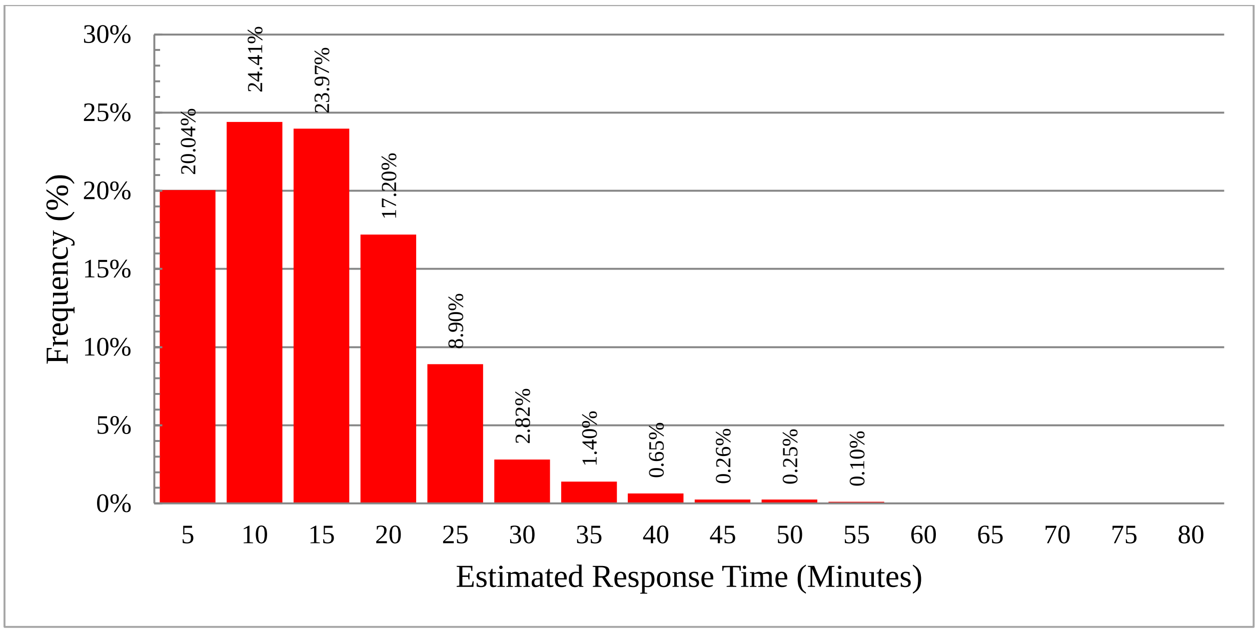


Figure 6 Frequency graph of response time – ambulance to crash/trauma scene

In Figure 7, several findings are

- All crashes in the region are covered by ambulances in the same region, including Sydney and Fairview in Montana,
- A couple of crashes around Sydney, MT, were covered by the ambulance service in Sydney with the ambulance service crossing the state border, and
- The national parks and lake regions are characterized by longer response times due to more remote locations and limited road networks.

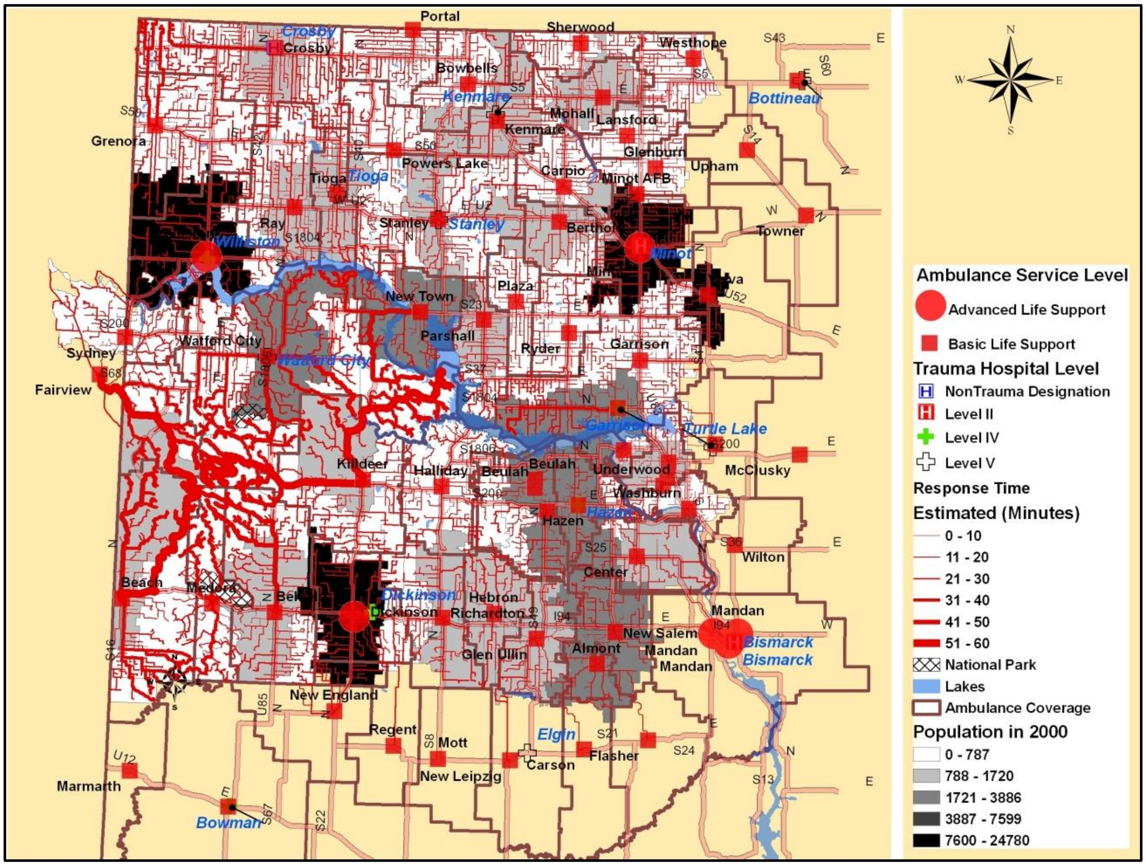


Figure 7 Ideal closest facilities from ambulances to highway accidents (2005-2007)

Table 4 indicates that the accidents are distributed everywhere across the region. The longest response time from an accident location to the closest trauma center was 78.1 minutes. This time would go beyond the ‘golden hour.’ The average response travel time from accidents to trauma centers was 25.1 minutes along 26.5 miles resulting in 1.05 minutes per mile response time, which is an estimated travel speed of 62.9 miles/hour. Trauma centers are closely located along the major roads. As expected, when traumas occurred far from the major roads the response time from incidents to the trauma centers is long.

Table 4 Ideal shortest response time from crash to trauma center (in minutes)

	Minimum	Maximum	Average	Median	Standard Deviation	Variability	Sample Size
Minutes	0.04	78.10	25.09	23.98	13.52	182.75	12,055
Miles	0.03	87.33	26.46	24.94	14.70	216.23	
Minutes/mile	0.72	1.24	1.05	1.05	0.08	0.01	
Speed (mile per hour)	43.41	74.31	62.82	62.80	4.92	24.24	

The travel response time is distributed within 55 minutes for 95.6% of the all crash sites. The distribution of the frequency of the travel time (Figure 8) seems similar to a normal distribution centered at 25 and 30 minute intervals.

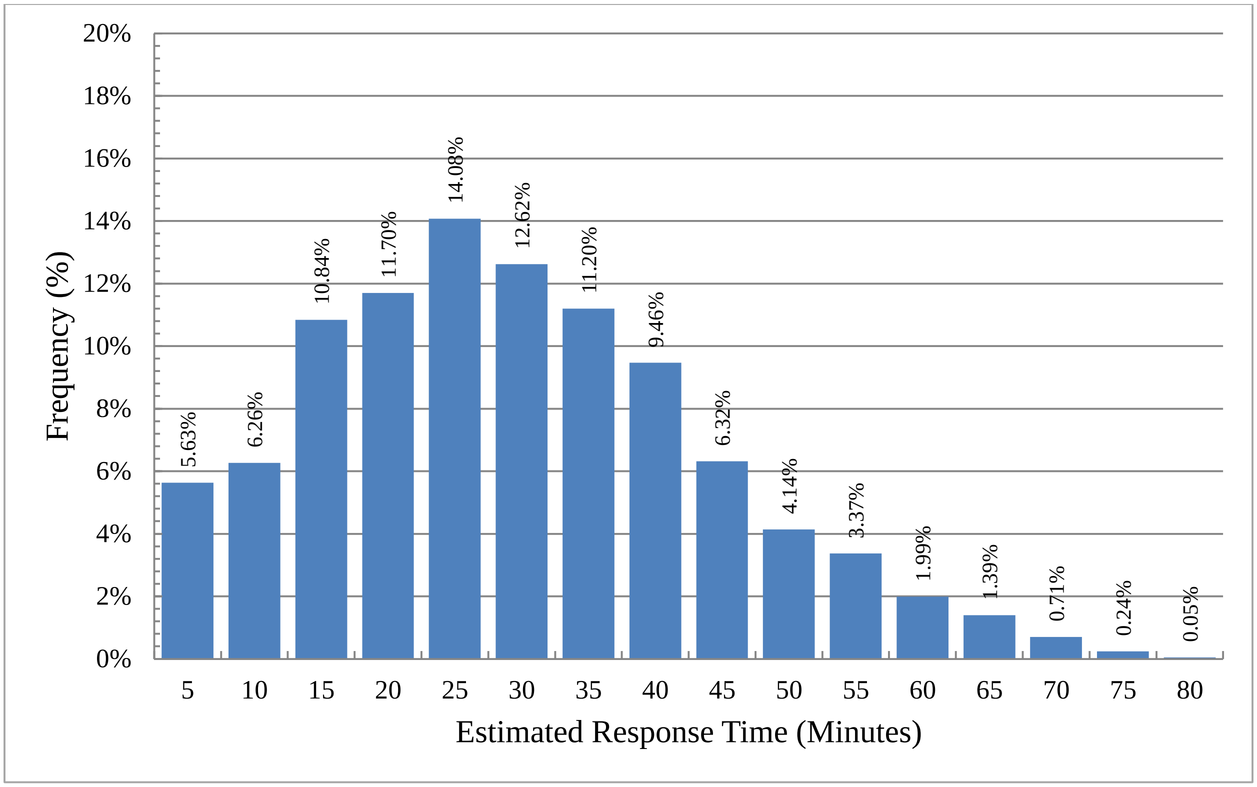


Figure 8 Frequency graph of response time – crash/trauma scene to trauma center

In Figure 9, several findings are:

- Accidents in densely populated areas are characterized by shorter response time to reach trauma centers.
- Random traumas and highway crashes along Montana border seem to be under-served as indicated by slow response time.
- Random incidents along Lake Sakakawea also have longer response time.

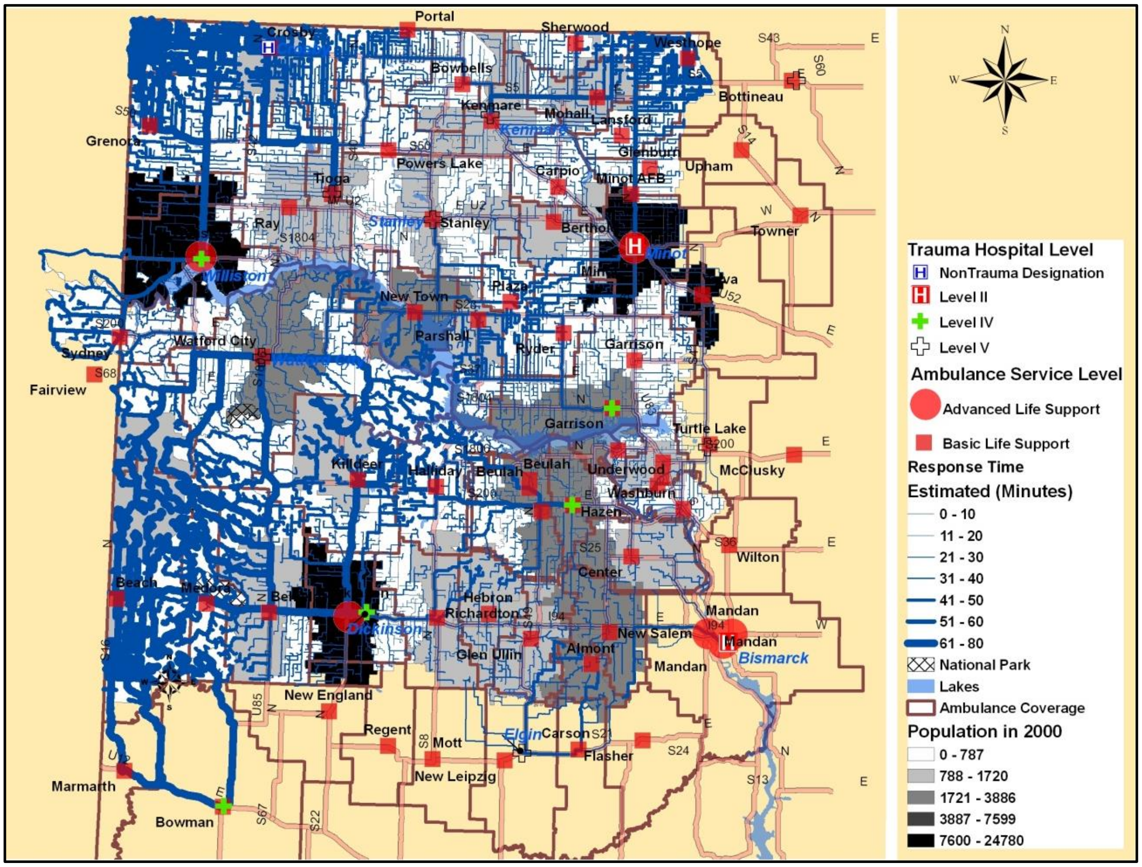


Figure 9 Ideal closest facilities from highway accidents to trauma centers.

Estimating the practical response time (*R_t*)

The practical response time, which is currently practiced by the service units, is estimated by the average user response time (AURT). The AURT is as follows:

Average User Response Time (AURT) = Average Set-up time + Average Travel Time
The function of AURT is decomposed into several detailed components to evaluate the practices, (1),

$$\overline{R}_j = \frac{\sum_{i\in I}\sum_{j\in J}\left(c_i + t_{ij}\right)}{n(I)\cdot n(J)} + \frac{\sum_{j\in J}\sum_{k\in K}\left(s_j + t_{jk}\right)}{n(J)\cdot n(K)} \qquad (1)$$

where I = set of ambulance location(s), i
J = set of incidents j covered by an ambulance location i
K = set of trauma centers k destined by an ambulance i
c_i = dispatch or preparation time at ambulance location i after call has been received by ambulance provider
t_{ij} = travel time from ambulance location i to incident site j
s_j = set-up time (i.e. treatment and loading) at incident site j
t_{jk} = travel time from incidnet site j to a trauma center k
$\overline{R}_j$ = average user response time for an incident j

However, trauma records do not show set-up time at incident site, so set-up is assumed to be included in travel time t_{jk}.

Iannoni, Morabito and Saydam (2009) considered set-up time as a fraction of dispatches from ambulance location to crash scene. However, we consider set-up time (c_i) at ambulance locations as seperate component including service calling time from call center to driver/respondent adding to dispatching time from the location. The AUST does not include queuing time as queuing is not allowed for the emergency cases (Iannoni, Morabito and Saydam 2009). In addition, multiple crashes occur rarely in the rural study areas. In conjunction with these assumptions, we assume that back-up service coverage is not allowed. The primary ambulance service locations each cover crashes in their coverage area. Travel time is measured as t_{ij}, from an ambulance location (i) to a crash site (j), and as t_{jk}, from the crash site (j) to a trauma center (k).

To measure the current practice, we separated valid records in the DEMST trauma data into two components (Figure 10): (1) dispatching, which is the transportation activity to crash (or trauma) scene after event notification is received, and (2) delivery, which is the transportation activity from crash (or trauma) site to trauma center(s). Time conflict data, where the arrival time is earlier than the depart time, and where time observations missing were deleted. The remaining 1,294[1] records were analyzed. The average response time was 16 minutes between notification time and arrival time at the demand point. Results show that 64.7% of the total demand-based crashes were served within 15 minutes, and 97.4% of the all crashes were served within 60 minutes (Figure 11).

[1] From the original file, 585 records were excluded: 2 of wrong data, 114 of blank time information, and 469 of unknown and N/A codes.

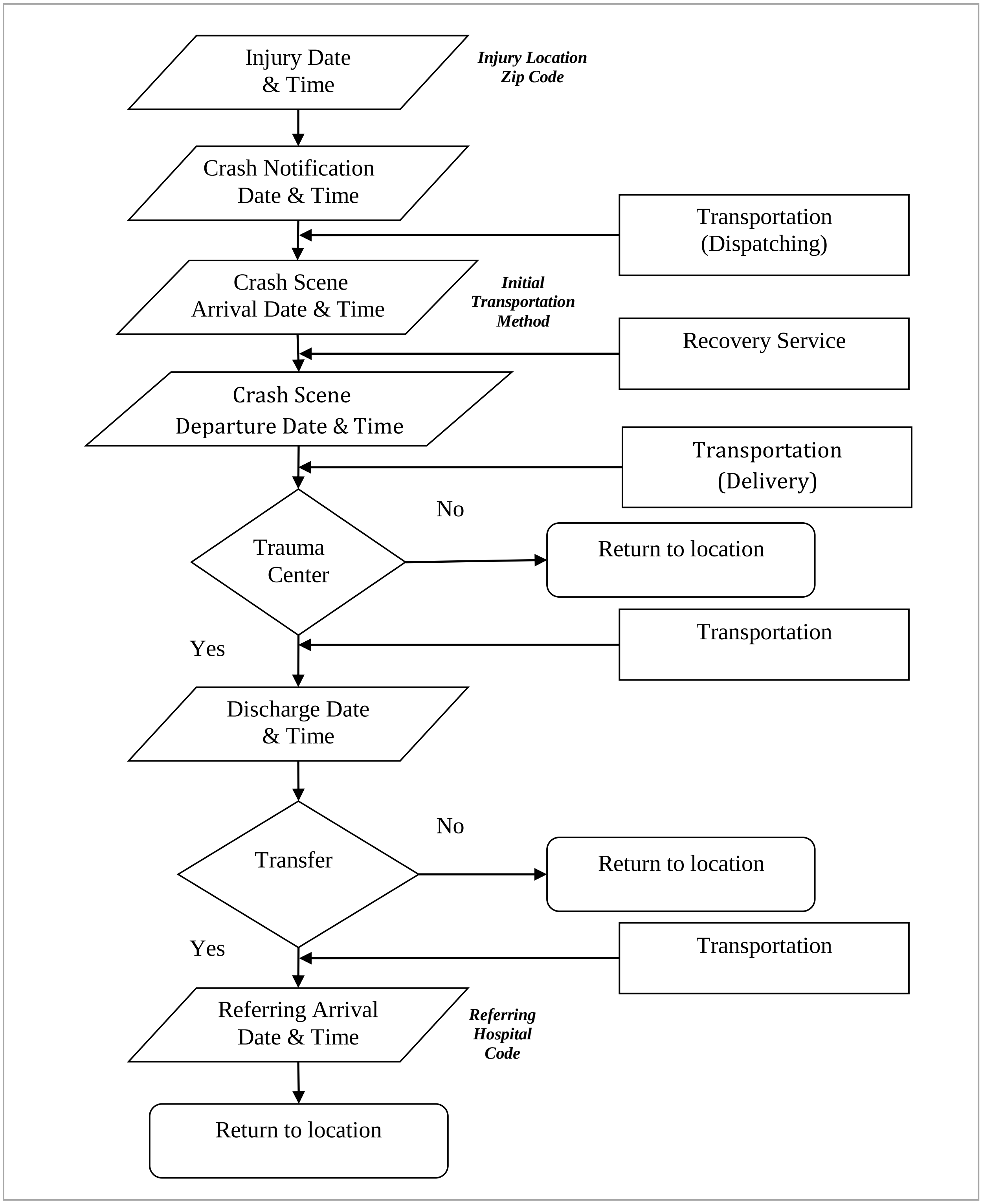


Figure 10 Events and attributes of the trauma records.

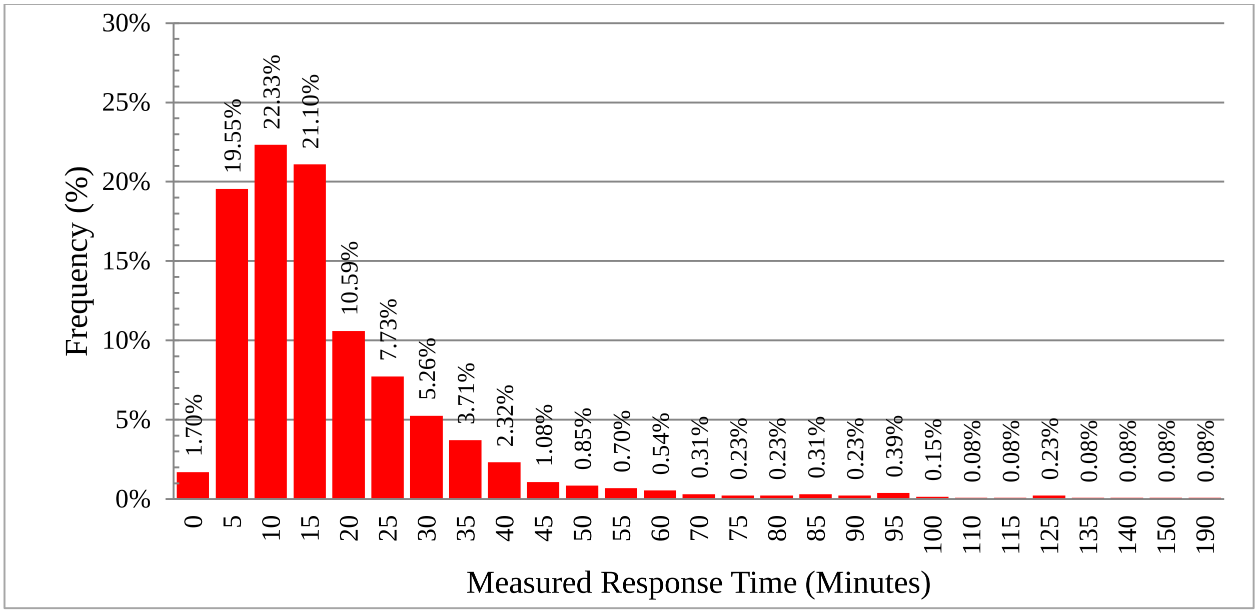
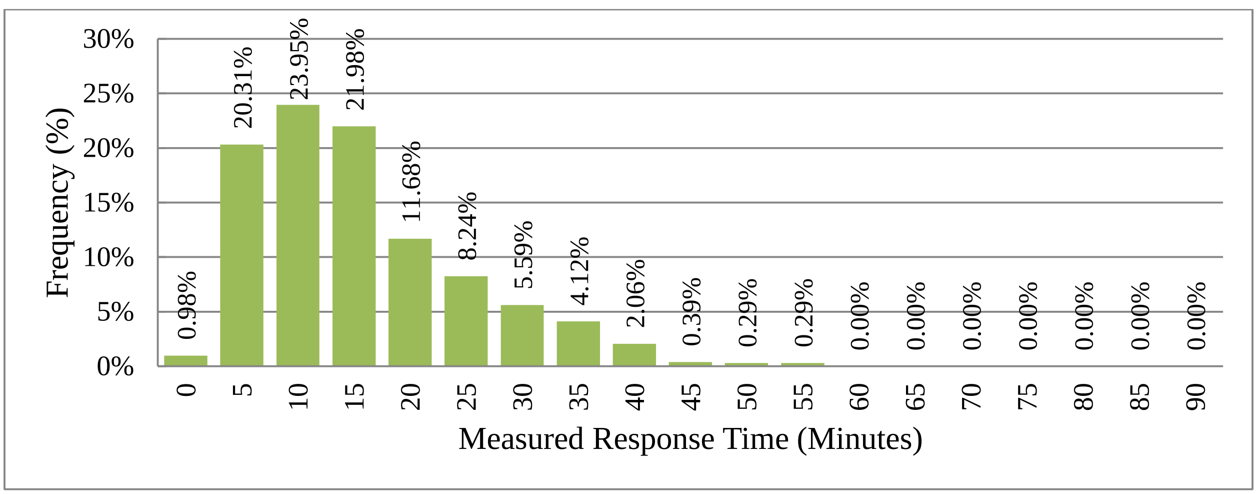


Figure 11 Measured response time from ambulance locations to demand points.

For the hospital delivery analysis, we trimmed the original datasets by cutting out the error-like data such as blank, earlier arrival time than the departure time, and excessively long delivery times over five hours. The time is computed based on non-hospital transfers. Therefore, the quality data set includes 1,019 records to be analyzed. The average delivery time from the incident locations to the hospitals was 13.8 minutes. Note that the delivery time excludes the service time for victims at the incident locations. In other words, the delivery time only includes the transportation time on roads to a hospital. For all services, transportation from incident to hospitals was completed within 30 minutes 92.7% of the time and within 60 minutes 99.9% of the time.



Note: Services only within 90 minutes were displayed in the above graph for a convenience.

Figure 12 Measured response time from demand points to hospitals.

Differences between ideal response and practices (Dt)

The difference between the ideal response time and the practical response time is measured for the gap analysis. Suppose that the gap is $D_t = E_t - R_t$. When the gap D_t is bigger than 0, the current operations of the ambulance service must be examined in order to find critical points for improvement. On the contrary, if the gap D_t is smaller than 0, the ambulance service is providing better service than expected. The case study examines services once the set-up time is removed. Thus, our hypothesis for the response time between locations to accident locations is

H_0: $D_t^{ambulance} = 0$ between ambulance locations and demand points

H_a: $D_t^{ambulance} \neq 0$ between ambulance locations and demand points

A one factor analysis of variance test was conducted based on the 95% confident interval. The P-value of the ANOVA test is smaller than 0.05, so we reject the null hypothesis at 95% confidence. By the ANOVA results, the measured average response time is significantly different from the estimated shortest response time ($F = 103.11$, $P \leq 0.001$, $n=13{,}338$). The estimated response time is smaller than the statewide measured response time by 2.5 minutes, suggesting efficiency may be gained by re-evaluating asset positions and response practices.

We also test the hypothesis of the response time from accidents/trauma locations to hospitals. The null hypothesis is as follows:

H_0: $D_t^{traumacenter} = 0$ between demand points and hospitals

H_a: $D_t^{traumacenter} \neq 0$ between demand points and hospitals

A one factor analysis of variance test was conducted based on the 95% confident interval. The P-value is small enough to reject our null hypothesis ($F=151.38$, $P \leq 0.001$, $n=13{,}283$). Thus, the average delivery time of about 26.9 minutes in the Williston basin area is significantly longer than the statewide average delivery time of about 21.4 minutes by 5.4 minutes.

Transportation Preparedness

While practices of the present ambulance services are indicated in the response time to the demands, transportation preparedness presents response time while taking into account the transportation infrastructure that must be travelled to connect to the traumas. In doing so, transportation preparedness is measured in the miles per hour. In this research, the transportation preparedness is measured between the ambulance location and crash/trauma and between the crash/trauma and trauma centers. The measured response time shows the speed of the response to the demand call. However, it does not mean fast response without regard to distance. For example, if the ambulance responded in 10 minutes to a demand point only 1 mile away, it would not be considered a quick response by the clients. Thus, we measure emergency transportation preparedness in miles per hour.

Firstly, to find the historical crashes, we use probabilistic matching to merge historical crash and trauma data. The rough data sets were cleaned by removing the crashes which are out of the geographical scope (Williston Basin) and which used air transportation such as a helicopter. After joining the ambulance services by location license information, the ambulance services beyond the Williston Basin were removed. Ambulance dispatching time was computed by subtracting notification time from arrival time at the crash location. When the miles per hour (MPH) was more than 100, the data was removed from the analysis as an invalid observation.

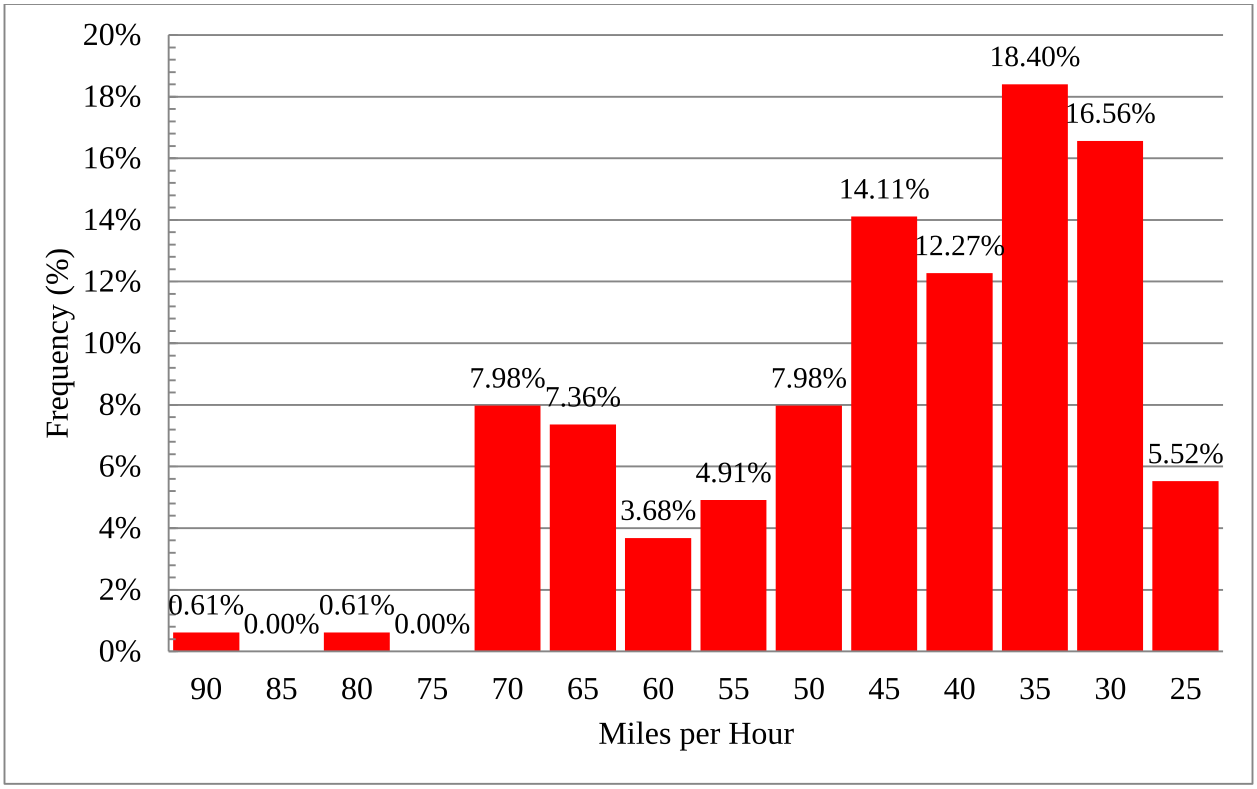


Figure 13 Miles per hour (MPH) information between crash notification and the arrival at the crashes.

From Figure 13, less than 1% drove at speeds of about 90 MPH, while most of the responses were recorded at less than 70 MPH. The average mile per hour for crash responses in the region was 42.7 MPH. Results indicate the slowest response was at 19.6 MPH. In general, the response time in miles per hour shows that the service is relatively slower than the ideal response time of 59.9 MPH between a service unit and trauma location (Table 3). The slow response time in terms of miles per hour are presumed to be a result of volunteer emergency services, lower service-levels, and natural barriers in the region. Transportation infrastructure characteristics, road classification and assumed maximum road speed of ambulances, used in this analysis are determined by using Table 2.

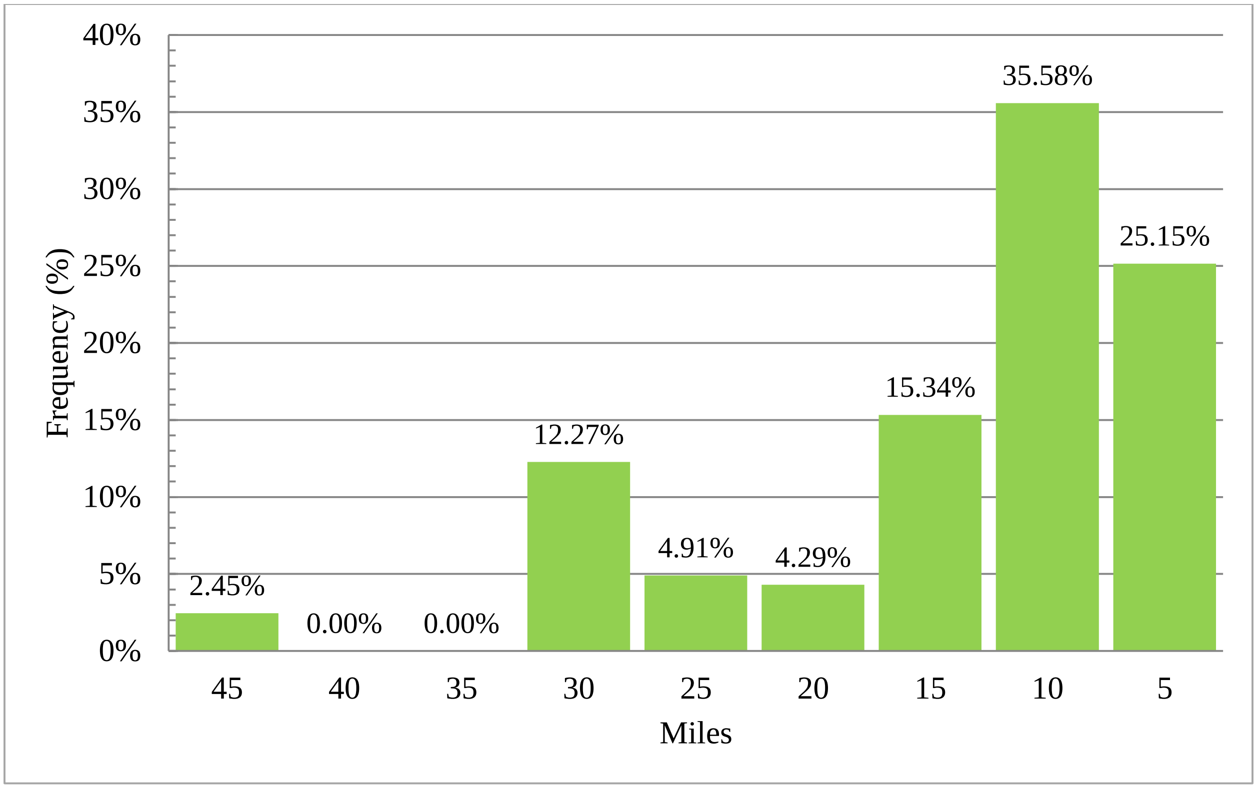


Figure 14 Distance traveled by ambulance service to crash or trauma scene.

Figure 14 presents the number of miles traveled by ambulance service providers. The average miles traveled for crash responses in the region was 11.9 miles. The longest travel distance was 41.4 miles, resulting in 0.92 minutes per mile response time, while the shortest travel distance was 1.3 miles, resulting in 2.86 minute per mile response time.

Trauma centers do not have a key column to match to the trauma transaction file which would indicate the time it takes the ambulances to delivered victims from crash location. Thus, the analysis for the transportation preparedness between crashes on roads and trauma centers are not conducted.

CONCLUSIONS

In this study, we estimated the travel response time between the ambulance locations and the demand points and between the demand points and the hospitals. The estimation was conducted in Geographic Information Systems (GIS) by utilizing the shortest path algorithm. The demand points were randomly generated to represent the holistic approach in the study region, Williston Basin. In addition, the current practices for the ambulance responses to demands were measured based on the historical data of trauma. Then, we compared the two different results to measure the performance.

A single factor analysis of variance test was conducted with the two groups. From the average comparison, we found that the average response time in the study region is expected to be better than the statewide response time between the ambulance locations and demand points. However, the estimated delivery time between demand points and hospitals was longer than the statewide, measured delivery time.

This study is limited for several reasons. First, the historical data shows a wide range of dispersion, showing high variance. The outliers of the data should be carefully investigated. Second, the historical data is based on the statewide region, which includes some data from outside of the study region.

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APPENDIX 1. TOP 10 SERVICE PROVIDERS

By Total Number of Dispatching

License Number	Service Provider	Total Number of Incidents	Dispatching Time (minutes)				
			Average	Standard Deviation	Minimum	Maximum	Median
12	Metro Area Ambulance Service Inc. - Bismarck	160	13.38	18.72	1	150	8
150	Jamestown Area Ambulance	75	10.52	8.12	0	30	7
35	F-M Ambulance Service, Inc.	74	8.36	8.47	0	53	5
88	Community Ambulance Svs. Inc. - Minot	65	13.11	23.13	0	131	7
48	Altru Health System Ambulance Service	60	8.70	6.70	0	25	5
41	Standing Rock Ambulance Service	52	16.33	9.04	2	37	13
131	Williston Ambulance Service	48	12.27	8.48	0	40	11
602	Merit Care LifeFlight	43	44.47	26.49	8	112	37
702	Unknown	40	13.63	8.69	1	32	12
29	Dickinson Area Ambulance Service, Inc.	40	13.80	8.41	3	34	11

By Total Number of Delivery

License Number	Service Provider	Total Number of Incidents	Delivery Time (minutes)				
			Average	Standard Deviation	Minimum	Maximum	Median
12	Metro Area Ambulance Service Inc. - Bismarck	151	10.44	7.23	1	39	8
35	F-M Ambulance Service, Inc.	73	8.36	8.53	0	53	5
150	Jamestown Area Ambulance	62	10.55	7.87	0	30	7
48	Altru Health System Ambulance Service	58	8.83	6.78	0	25	6
88	Community Ambulance Svs. Inc. - Minot	58	8.03	6.65	0	38	7
41	Standing Rock Ambulance Service	40	18.15	8.98	7	37	15
131	Williston Ambulance Service	36	11.47	7.26	0	28	10
28	Lake Region Ambulance Service	35	11.57	8.43	0	32	11
702	Unknown	30	13.17	8.75	3	32	11
602	Merit Care Life Flight	27	28.59	10.98	8	54	29

APPENDIX 2-A. TRAVEL DISTANCE BY SERVICE PROVIDERS,

(Use as Example Only Due to Limited Sample Size)

License Number	Service Provider	Total Number of Incidents	Travel Distance (miles)				
			Average	Standard Deviation	Minimum	Maximum	Median
4	Community Ambulance Service Inc.	10	8.26	2.40	7.20	14.39	7.20
5	Belfield Ambulance Service Inc.	1	6.01	N/A	6.01	6.01	6.01
6	Berthold Ambulance Service Inc.	1	13.39	N/A	13.39	13.39	13.39
29	Dickinson Area Ambulance Service, Inc.	16	9.24	6.81	1.63	23.14	9.57
44	Glen Ullin Area Ambulance Service	6	8.08	0.56	7.72	8.80	7.72
84	Billings County Ambulance Service	3	7.53	0.82	6.58	8.00	8.00
88	Community Ambulance Service, Inc.	35	9.26	12.37	1.40	41.35	4.08
89	Lansford Substation, Mohall Ambulance Service, and Tolley Substation	6	11.40	0.00	11.40	11.40	11.40
96	New Salem Ambulance Service	8	11.35	8.63	5.51	25.27	7.32
107	Ray Community Ambulance District	1	9.28	N/A	9.28	9.28	9.28
109	Richardton-Taylor Ambulance Service	6	19.41	1.42	17.57	20.32	20.32
116	Stanley Ambulance Service	15	10.00	6.22	1.30	21.95	10.47
118	Tioga Ambulance Service	5	4.19	0.00	4.19	4.19	4.19
128	Washburn Volunteer Ambulance Service	12	8.39	0.00	8.39	8.39	8.39
129	McKenzie County Ambulance Service	29	22.86	8.33	9.77	29.22	28.16
131	Williston Ambulance Service	9	8.92	5.02	4.09	19.50	7.44
	Total	163	11.93	9.38	1.30	41.35	8.52

APPENDIX 2-B. TRAVEL TIME BY SERVICE PROVIDERS

(Use as Example Only Due to Limited Sample Size)

License Number	Service Provider	Total Number of Incidents	Travel Time (minutes)				
			Average	Standard Deviation	Minimum	Maximum	Median
4	Community Ambulance Service Inc.	10	14.30	0.48	14.00	15.00	14.00
5	Belfield Ambulance Service Inc.	1	14.00	N/A	14.00	14.00	14.00
6	Berthold Ambulance Service Inc.	1	20.00	N/A	20.00	20.00	20.00
29	Dickinson Area Ambulance Service, Inc.	16	11.38	7.56	4.00	28.00	12.00
44	Glen Ullin Area Ambulance Service	6	17.00	0.00	17.00	17.00	17.00
84	Billings County Ambulance Service	3	13.33	1.15	12.00	14.00	14.00
88	Community Ambulance Service, Inc.	35	11.40	10.26	4.00	38.00	8.00
89	Lansford Substation, Mohall Ambulance Service, and Tolley Substation	6	19.50	4.93	15.00	24.00	19.50
96	New Salem Ambulance Service	8	16.50	6.72	11.00	27.00	13.00
107	Ray Community Ambulance District	1	14.00	N/A	14.00	14.00	14.00
109	Richardton-Taylor Ambulance Service	6	18.00	0.00	18.00	18.00	18.00
116	Stanley Ambulance Service	15	17.47	15.60	2.00	54.00	13.00
118	Tioga Ambulance Service	5	7.00	0.00	7.00	7.00	7.00
128	Washburn Volunteer Ambulance Service	12	15.00	0.00	15.00	15.00	15.00
129	McKenzie County Ambulance Service	29	27.86	11.11	12.00	40.00	27.00
131	Williston Ambulance Service	9	10.56	3.47	6.00	19.00	10.00
	Total	163	16.26	10.51	2.00	54.00	14.00

APPENDIX 2-C. POTENTIAL PERFORMANCE MEASURES,

(Use as Example Only Due to Limited Sample Size)

License Number	Service Provider	Total Number of Incidents	Average Travel Distance (miles)	Average Travel Time (minutes)	Average Response Performance (minutes/mile)
4	Community Ambulance Service Inc.	10	8.26	14.30	1.82
5	Belfield Ambulance Service Inc.	1	6.01	14.00	2.33
6	Berthold Ambulance Service Inc.	1	13.39	20.00	1.49
29	Dickinson Area Ambulance Service, Inc.	16	9.24	11.38	1.56
44	Glen Ullin Area Ambulance Service	6	8.08	17.00	2.11
84	Billings County Ambulance Service	3	7.53	13.33	1.77
88	Community Ambulance Service, Inc.	35	9.26	11.40	1.81
89	Lansford Substation, Mohall Ambulance Service, and Tolley Substation	6	11.40	19.50	1.71
96	New Salem Ambulance Service	8	11.35	16.50	1.75
107	Ray Community Ambulance District	1	9.28	14.00	1.51
109	Richardton-Taylor Ambulance Service	6	19.41	18.00	0.93
116	Stanley Ambulance Service	15	10.00	17.47	1.61
118	Tioga Ambulance Service	5	4.19	7.00	1.67
128	Washburn Volunteer Ambulance Service	12	8.39	15.00	1.79
129	McKenzie County Ambulance Service	29	22.86	27.86	1.23
131	Williston Ambulance Service	9	8.92	10.56	1.34
	Total	163	11.93	16.26	1.60

APPENDIX 3. TRAVEL TIME PER MILE FROM AMBULANCE TO ACCIDENT BASED ON THE SHORTEST TRAVEL TIME PATH

Ambulance	Min	Max	Average	Standard Deviation	Variability
2	0.923722594	1.2646185	1.003619199	0.065917472	0.004345113
3	0.875996202	1.210624134	1.011494124	0.079594473	0.00633528
4	0.884595259	1.2860499	1.024552569	0.083860633	0.007032606
5	0.929177514	1.419237467	1.089285923	0.095092304	0.009042546
6	0.813005724	1.124651161	0.927819887	0.081855643	0.006700346
7	1.090909091	1.090909091	1.090909091	-	-
8	0.838743491	1.189533807	0.941256443	0.103006866	0.010610414
9	1.083729792	1.084810419	1.084463901	0.000462882	2.1426E-07
10	0.932105109	1.156955964	1.054727478	0.07043744	0.004961433
12	0.861881692	1.323070755	1.053340067	0.105682533	0.011168798
14	0.872967557	1.108304017	1.029824267	0.135841905	0.018453023
15	0.923076923	1.390863115	1.009177055	0.070575558	0.004980909
16	0.918362014	1.172356286	1.075668254	0.052280743	0.002733276
17	0.926040079	1.385039481	1.008572425	0.084638559	0.007163686
18	0.854905266	1.180125795	0.987793362	0.084250628	0.007098168
19	0.897760181	1.201262738	0.994119009	0.061037471	0.003725573
20	1.088176589	1.088244387	1.088210488	4.79405E-05	2.29829E-09
21	0.822318712	1.105551844	0.951818351	0.075031435	0.005629716
22	0.923076923	1.150039161	0.982715704	0.055564713	0.003087437
25	0.826768201	1.271206856	0.974320507	0.078784968	0.006207071
26	0.821232576	1.162252104	0.950604659	0.073778875	0.005443322
27	1.090909091	1.235924409	1.105335301	0.034333732	0.001178805
28	0.900997307	1.090909091	0.969403075	0.040271707	0.00162181
29	0.923872726	1.090909091	1.029129225	0.061235019	0.003749728
30	0.924283141	1.102532014	0.989239557	0.051521987	0.002654515
32	0.905728091	1.344832304	1.014246659	0.063765505	0.00406604
33	0.863225534	1.298698233	0.981222873	0.063817562	0.004072681
34	0.930419186	1.604744132	1.111749458	0.104127877	0.010842615
35	0.924112041	1.090909091	1.02617515	0.055678318	0.003100075
36	0.92465172	1.320815616	1.038904346	0.090655531	0.008218425
37	0.928385786	1.396122549	1.022531104	0.066925087	0.004478967
38	1.023382079	1.384823341	1.107003948	0.057822123	0.003343398
39	0.924063287	1.122277042	0.991541049	0.054432367	0.002962883
40	0.923076923	1.196231376	0.986140398	0.065151728	0.004244748
41	0.923830089	1.597709685	1.001808311	0.10449813	0.010919859
42	0.879846667	1.185912984	0.98320449	0.061818233	0.003821494
44	0.925928156	1.651647979	1.018328768	0.099679902	0.009936083
45	0.990219686	1.411671156	1.110836636	0.064759823	0.004193835
46	0.933082567	1.402994991	1.061994069	0.071279671	0.005080791
47	0.927370118	1.226152454	1.049927212	0.058433955	0.003414527
48	1.059119863	1.465561336	1.10508946	0.0504753	0.002547756
49	0.927597256	1.136523642	0.986188713	0.048589727	0.002360962
50	0.924091809	1.238929281	1.006036297	0.066629127	0.004439441
51	0.923258124	1.611080942	1.052516138	0.120627353	0.014550958
53	0.915007399	1.199093245	1.008776657	0.074630978	0.005569783
54	1.021250226	1.084614867	1.060754761	0.026219573	0.000687466
55	0.925000118	1.19956719	0.993227239	0.052431696	0.002749083

Ambulance	Min	Max	Average	Standard Deviation	Variability
57	1.086931274	1.086931274	1.086931274	-	-
58	0.896502939	1.382872835	0.991526853	0.068949156	0.004753986
59	0.892197827	1.172975888	1.064148479	0.050193512	0.002519389
60	0.926423314	1.408592792	1.033936773	0.093462435	0.008735227
61	1.090909091	1.391114309	1.119424326	0.08295903	0.006882201
63	0.974583668	1.214173282	1.074520834	0.047744549	0.002279542
64	0.984288231	1.225654321	1.08997072	0.05291102	0.002799576
65	1.043180103	1.25355122	1.11709379	0.047868372	0.002291381
66	0.92401096	1.309859887	1.016841137	0.064661296	0.004181083
67	0.924502526	1.262760997	1.014135932	0.065466398	0.004285849
Grand Total	0.813005724	1.651647979	1.008504951	0.084394323	0.007122402

APPENDIX 4. TRAVEL TIME PER MILE FROM ACCIDENT TO TRAUMA CENTER BASED ON THE SHORTEST TRAVEL TIME PATH

Trauma Center	Min	Max	Average	Standard Deviation	Variability
1	0.86841728	1.157318104	0.961159467	0.058840237	0.003462174
2	0.923646082	1.382087664	0.986720687	0.06265671	0.003925863
3	0.920220402	1.147978059	0.998334148	0.058348384	0.003404534
4	0.861671707	1.298781756	0.976359071	0.053155062	0.002825461
5	0.882606965	1.251164714	0.974256467	0.058662378	0.003441275
7	0.926677869	1.134516764	0.972966648	0.041432018	0.001716612
8	0.901963394	1.344671775	1.003128512	0.060996178	0.003720534
9	0.917960162	1.090909091	0.966465269	0.037045524	0.001372371
10	0.923159433	1.263515788	0.984406204	0.059135733	0.003497035
11	0.995459649	1.119553667	1.041948045	0.043169344	0.001863592
12	0.926383316	1.363225821	1.001902053	0.06588075	0.004340273
13	0.807389585	1.039194672	0.834154455	0.047224448	0.002230148
14	0.916054098	1.159171866	0.966994874	0.043786729	0.001917278
16	0.809338596	1.180608546	0.906364689	0.089252847	0.007966071
Grand Total	0.807389585	1.382087664	0.960897371	0.074652472	0.005572992

APPENDIX 5. RESPONSE TIME FROM AMBULANCE LOCATION TO ACCIDENT BASED ON THE HISTORICAL RESPONSE RECORDS

Minutes	Count	Frequency	Cumulative Frequency
0	22	1.70%	1.70%
5	253	19.55%	21.25%
10	289	22.33%	43.59%
15	273	21.10%	64.68%
20	137	10.59%	75.27%
25	100	7.73%	83.00%
30	68	5.26%	88.25%
35	48	3.71%	91.96%
40	30	2.32%	94.28%
45	14	1.08%	95.36%
50	11	0.85%	96.21%
55	9	0.70%	96.91%
60	7	0.54%	97.45%
70	4	0.31%	97.76%
75	3	0.23%	97.99%
80	3	0.23%	98.22%
85	4	0.31%	98.53%
90	3	0.23%	98.76%
95	5	0.39%	99.15%
100	2	0.15%	99.30%
110	1	0.08%	99.38%
115	1	0.08%	99.46%
125	3	0.23%	99.69%
135	1	0.08%	99.77%
140	1	0.08%	99.85%
150	1	0.08%	99.92%
190	1	0.08%	100.00%
Total	1294	100.00%	

APPENDIX 6. RESPONSE TIME FROM ACCIDENT LOCATION TO HOSPITAL BASED ON THE HISTORICAL RESPONSE RECORDS

Minutes	Count	Frequency	Cum. Frequency
0	10	0.98%	0.98%
5	207	20.31%	21.30%
10	244	23.95%	45.24%
15	224	21.98%	67.22%
20	119	11.68%	78.90%
25	84	8.24%	87.14%
30	57	5.59%	92.74%
35	42	4.12%	96.86%
40	21	2.06%	98.92%
45	4	0.39%	99.31%
50	3	0.29%	99.61%
55	3	0.29%	99.90%
60	0	0.00%	99.90%
65	0	0.00%	99.90%
70	0	0.00%	99.90%
75	0	0.00%	99.90%
80	0	0.00%	99.90%
85	0	0.00%	99.90%
90	0	0.00%	99.90%
95	0	0.00%	99.90%
100	0	0.00%	99.90%
105	0	0.00%	99.90%
110	0	0.00%	99.90%
115	0	0.00%	99.90%
120	0	0.00%	99.90%
125	1	0.10%	100.00%
130	0	0.00%	100.00%
135	0	0.00%	100.00%
140	0	0.00%	100.00%
145	0	0.00%	100.00%
150	0	0.00%	100.00%
155	0	0.00%	100.00%
160	0	0.00%	100.00%
165	0	0.00%	100.00%
170	0	0.00%	100.00%
175	0	0.00%	100.00%
185	0	0.00%	100.00%
190	0	0.00%	100.00%
200	0	0.00%	100.00%
205	0	0.00%	100.00%
210	0	0.00%	100.00%
	Total: 1019	100.00%	