SPATIAL ACCESS AND LOCAL DEMAND

FOR EMERGENCY MEDICAL SERVICES

IN UTAH

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

Emergency Medical Services form the backbone of the prehospital emergency medical care system in the United States. Prompt treatment and transport to a definitive care facility provide the greatest chance for reduced morbidity and mortality. People's ability to use this public service can be a determinant of their wellbeing, as well as a measure of community disaster preparedness. The objective of this study is to measure spatial access to Emergency Medical Service (EMS) systems, and to quantify local demand for these services. EMS facilities and population location data are mapped across Utah. Spatial access is measured using an enhanced two-step floating catchment area method (E2SFCA) that incorporates both travel time and EMS ground transport capacity. Demand is estimated from the EMS spatial access metric and local population count. Results are evaluated using actual response times and patient death rates. The study finds that the 2SFCA method adequately measures relative access across large areas that encompass multiple service regions. In conclusion, additional improvements and future research potential are discussed.

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The University of Utah deserves substantial credit for offering a wide array of resources that foster impactful, interdisciplinary research. The Geography Department reflects such research efforts, and I extend my thanks to the faculty and graduate students who have enriched my time here. It should be duly noted that foremost among these is Academic Coordinator MaryAnn Golightly. The first person at this institution who I met, MaryAnn's warm encouragement and guidance has kept me on track. Thank you, MaryAnn. My sincere best wishes as you begin a new chapter.

Last but not least, I wish to thank Corinne Haynes and my family for their love and support; it means the world to me.

CHAPTER I

INTRODUCTION

Access to health care is an important determinant of patient wellbeing, particularly in emergency situations that require timely medical intervention (Trunkey, 1983; Cannon et al., 2000; Brodie et al., 2001; Rivers et al., 2001; Mackenzie et al., 2006). The 'golden period' is an important concept that emphasizes the need for speedy, professional treatment and transport to a definitive care facility (Sampalis et al., 1993). Emergency Medical Services (EMS) play a critical role in meeting this threshold by providing initial treatment, stabilizing patients, and transporting them to definitive care facilities. While recent research has measured population access to emergency departments (Carr et al., 2009) and primary care physicians (Wang and Luo, 2005), there is a notable absence of academic literature on the topic of measuring access to EMS across large, continuous areas.

EMS are unique among health care providers for many reasons, including their dual roles as both public safety and medical practitioners, a singular travel model, and the dynamic spatiotemporal capacity of EMS resources. Geographic considerations are a central component of EMS management, and researchers have examined topics such as resource allocation, transportation network analysis, dispatch policy, and performance optimization (Fitzsimmons, 1973; Swoveland et al., 1973; Carr et al., 2006; Chanta et al., 2011; Bandara et al., 2012). While these analyses are critical to the efficacy and operational success of EMS systems, they do not consider spatial access or local demand across multiple service regions.

Spatial access is a product of the accessibility and availability of resources for a population in need (Joseph and Phillips, 1984). In the field of EMS, accessibility and availability determine the relative difference in people's ability to receive medical 911 services across localized areas. An understanding of these relative differences could be used to generate a metric of community wellbeing, offer insight into equity and local disaster preparedness, as well as promote further comparative studies on EMS operations, tactics, and results. Modern-day EMS is a disconnected patchwork of service areas and systems. These systems vary geographically and further study of EMS access and demand across space and time is warranted.

This study addresses the following three research questions: (1) what is the relative spatial access to emergency medical service transport at distinct locations across the state of Utah?, (2) what is the relative potential local demand for emergency medical service transport at distinct locations across the state of Utah?, and (3) how do measurements of spatial access to emergency medical service transport compare with the localized operational performance metrics of response time and patient death rate?

CHAPTER II

LITERATURE REVIEW

The History of Emergency Medical Service Systems

The modern EMS system developed in the 1960s at a time when professional medical opinion, public pressure, and political willpower converged to establish baseline service standards. The call for modernization of treatment procedures, resources, training, and oversight is best encapsulated in the report *Accidental Death and Disability: The Neglected Disease of Modern Society*, published by the National Academy of Sciences in 1966. The report cites accidental injuries as the "leading cause of death in the first half of life's span" and therefore the "nation's most important environmental health problem" (National Academy of Science, 1966, p. 5). The report notes the paucity of prehospital emergency care resources with the statistic that "approximately 50% of the country's ambulance services are provided by 12,000 morticians, mainly because their vehicles can accommodate transportation on litters" (National Academy of Science, 1966, p. 13), and further emphasizes that "…most ambulances used in this country are unsuitable, have incomplete fixed equipment, carry inadequate supplies, and are manned by untrained attendants" (National Academy of Science, 1966, p. 15). The report follows these criticisms with a number of policy recommendations meant to improve EMS systems across the country.

The federal government took notice of these poor conditions –and frequent absences– in prehospital emergency care. The 1966 National Highway Safety Act led to the implementation of standard Emergency Medical Technician (EMT) and paramedic curricula, as well as a regulatory model that state legislatures could choose to adopt. The 1973 EMS Systems Act provided federal block grants and funded EMS feasibility studies. The $300 million invested from this Act between 1973 and 1981 equates to more than $1.5 billion in 2013 dollars (Institute of Medicine, 2007; Merritt, 2014). This legislation also contributed heavily to states' decisions to form EMS offices and establish EMS regions within their jurisdictions (Mears et al., 2011). Once formed, state EMS offices used federal, state, and private grant money to develop EMS systems, write regulations, and enforce these new standards (National Highway Traffic Safety Administration, 1996; Shah, 2006).

The 1980s saw a reduction of federal attention and expenditure in EMS. Since this time, funding has come primarily from patients and local taxpayers. EMS systems are organized and administrated at local and county levels, with regulatory oversight provided by state EMS offices (Institute of Medicine, 2007). One product of state and local control has been disjointed and haphazard development in services across the United States since the 1980s.

As such, EMS providers often operate independently of one another, within bounded administrative areas. These boundaries commonly form the extent of operational knowledge or study area. The National Academy of Sciences notes in the opening remarks of their latest publication on EMS that "the transport of patients to available emergency care facilities is often fragmented and disorganized, and the quality of emergency medical services is highly inconsistent from one town, city, or region to the next" (Institute of Medicine, 2007, p. xiii). Pozner et al. (2004) attribute the fragmentary system of today to a steep reduction in federal funding, and with it the national commitment to EMS.

The Structure of Emergency Medical Services

Today, EMS agencies can be categorized as public, private, or volunteer-run, with either for-profit or nonprofit business models. Government-run EMS agencies can be classified as Fire or non-Fire (Mears et al., 2011). In a fire-based EMS system, the municipal fire department provides EMS resources. Firefighters may be among the cadre of medical personnel, and resources are shared between firefighting and EMS functions. These arrangements are common (Pozner et al., 2004). In a non-Fire system, the EMS agency and fire department operate independently from one another. For the purposes of this study, all state-licensed EMS providers are included, regardless of their organizational structure.

EMS personnel can be categorized into two groups: Emergency Medical Technicians (EMTs) and paramedics. EMTs are further divided into the categories of EMT-Basic, EMT-Intermediate, and EMT-Advanced. Training length, skill level, and scope of practice increase from basic to advanced. Paramedics are senior to EMTs in knowledge level and scope of medical practice. EMS vehicles operated by EMTs are termed Basic Life Support (BLS) units while vehicles with at least one paramedic onboard are termed Advanced Life Support (ALS) units.

ALS units stock a wider selection of medicines and may carry more advanced medical equipment. Despite these enhancements, a number of studies have failed to conclusively demonstrate a positive differential in trauma patient outcomes for those who received ALS instead of BLS (Liberman et al., 2000; Stiell et al., 2008). For this reason, both unit types are weighted equally in this study.

At this time, the federal government has minimal involvement in the management or regulation of EMS. Two advisory councils housed under the National Highway Traffic Safety Administration (NHTSA), the National EMS Advisory Council (NEMSAC) and the Federal Interagency Committee on EMS (FICEMS), compose the extent of this involvement. Nevertheless, their work on the National EMS Information System (NEMSIS) provides a valuable resource for locating and inventorying EMS resources, practices, and outcomes across the United States. Outside of the federal government, the National Association of State EMS Officials (NASEMSO) is the national organization whereby state EMS offices can coordinate activities, share best practices, and gain a broader understanding of trends and advances in EMS policy and procedure.

The latest national review of EMS capabilities was conducted in 2011. This composite study used the NEMSIS database and NASEMSO survey responses from all 56 state and territory EMS offices. The review found the number of EMS vehicles in the United States equated to approximately 3 per 10,000 population across the United States in 2011, while the number of EMS professionals equated to approximately 29 per 10,000 population (Mears, 2011). The national yearly average of EMS emergency activations was calculated at 1,217 per 10,000 population, while the annual number of EMS patient transports provided was approximately 950 per 10,000 (Mears, 2011).

This review also highlights the absence of critical communication and data links. In

2010-2011, only 11 of the 50 state EMS offices self-reported the ability to track EMS dispatch data (Mears, 2011, p. 414) and fewer than 10% of state EMS offices reported being able to communicate directly with local EMS agencies, public safety agencies, or hospitals (Mears, 2011, p. 378). This national review identifies current conditions in EMS across the country. Likewise, a study of spatial access and local demand for EMS is needed for understanding the present-day distribution of capacity and use.

Access to Emergency Medical Services

Five principle components of access are commonly identified: availability, accessibility, accommodation, affordability, and acceptability (Penchansky and Thomas, 1981). Availability is a measure of supply; accessibility is a measure of distance; accommodation is a measure of convenience; affordability is a measure of monetary cost; and acceptability is a measure of client tolerance of the service. Availability and accessibility are the two most frequently cited forms of access in the healthcare field (Joseph and Phillips, 1984; Guagliardo et al., 2004; Shi et al., 2012). These are also the two dimensions examined in this study.

Acceptability is not considered in this study because of the widespread societal use and acceptance of EMS. The impact of affordability on access to EMS and ambulance utilization rates is not well documented, and therefore not included; further research is needed. Accommodation is not considered due to the static nature of this study. Nevertheless, it should be noted that hours of operation, patient-use eligibility, and ambulance in-service frequency are important determinants of access to EMS. Unfortunately, these determinants are not widely reported and therefore, this dimension is excluded.

EMS access is frequently measured as a function of response time —in other words, the time that elapses between EMS dispatch and on-scene arrival. Response times are often used as a key performance indicator, and some EMS provider contracts mandate response time benchmarks (Henderson and Mason, 2004; Fitch, 2005; McLay and Mayorga, 2010). Many researchers from a cross sample of disciplines have studied various aspects of EMS operations with the objective of minimizing the mean ambulance response time in a limited service area (Fitzsimmons, 1973; Swoveland et al., 1973; Ball and Lin, 1993; Brotcorne et al., 2003; Peleg and Pliskin, 2004; Ertugay and Duzgun, 2011). However, this approach fails to consider resource capacity or performance across multiple municipalities. In addition, from a user's perspective, the 911-call-to-scene time —the time between when a caller dials 911 and an ambulance arrives on-scene— is a more relevant metric, as this timeframe better reflects the patient wait time. To better understand the resultant geographic disparities caused by EMS heterogeneity, a broad study on access, local demand, and their relationship with key performance indicators is needed.

CHAPTER III

METHODOLOGY

Computing Spatial Access Ratios Using the Enhanced Two-Step Floating Catchment Area Method

The Two-Step Floating Catchment Area method (2SFCA) considers both travel impedance and capacity, and is a special case of the gravity model (Luo and Wang, 2003). The approach taken in this study relies on applying a version of the 2SFCA to an EMS context. This method uses two geo-located point data sets; one set consists of service providers (EMS agencies) and the other consists of users (the general population). The service provider points correspond to EMS stations while the population points correspond to the cell centers of a raster population dataset. A threshold travel time window is set around each EMS station (k) and the EMS to population ratio is calculated for that space. This ratio is assigned to the station. Next, a threshold is placed around each population location (i) and the sum of ratios for all stations that fall within this catchment is taken. This sum reflects the relative accessibility of the population to the service provider (Cromley and McLafferty, 2012). To capture time-distance decay within a threshold, an enhancement to the original 2SFCA method is made, whereby travel time is weighted on a sliding scale (Luo and Qi, 2009; McGrail and Humphreys, 2009).

EMS capacity is determined by the number of in-service, prestaffed ground ambulances located at each EMS station. Although ambulance count is an imperfect measure of capacity, given that other resources such as manpower may be exhausted more rapidly, ambulances are needed to stabilize and treat patients en route to the hospital. Additionally, ambulance count is a more consistent and readily available metric, and selection of this variable is similar to the practice of using hospital beds to measure capacity at definitive care facilities (Green, 2002; Harper, 2002; Shi et al., 2012).

The enhanced 2SFCA equation used for this study is adapted from Luo and Qi (2009).

$$SPAI_i = \sum_{k \in (t_{i,k} < T)} \frac{S_k W_{k,i}}{\sum_{j \in (t_{k,i} < T)} P_i W_{k,i}}$$

$SPAI_i$ is the spatial access index to EMS at population location i, S_k is the service capacity (i.e., number of transport units) at EMS station k, $W_{k,i}$ is the travel time weight determined by the lapse in travel time from EMS station k to population location i, P_i is the population at location i, and T is the catchment threshold, which is the drive time boundary drawn around each EMS station and population location. Threshold drive time values are set to the 95th and 99th response time percentiles for the overall study area. To remove the edge effect, population and EMS stations are included for 30 miles beyond Utah's borders. Final results are then clipped to the state boundary.

Population centers' spatial access indices are calculated from the enhanced-2SFCA equation above using an ArcGIS extension tool developed by Higgs et al. (2014). Supply and demand points (i.e., EMS stations and population cell centroids, respectively) are relocated to the nearest road segment, up to one mile away. Travel times are then calculated to and from these relocated points along the road network. A radius of one mile is selected because driveways are unlikely to be greater than one mile in length, and off-road travel would significantly increase EMS response time. The author experimented with distances of three miles, one mile, and 1/3 mile, and found the one mile radius produced the best results given the population dataset resolution and response time metric. Travel time weights are assigned using a Gaussian decay bandwidth of 50, which represents a normal distribution path of decay.

The final step is to convert these spatial access indices to spatial access ratios, for the purpose of establishing a robust access measure that withstands sensitivity to the impedance coefficient (Wan et al., 2012). Spatial access ratios are calculated as the ratio between the spatial access index for a population center and the mean spatial access index of all population centers:

$$SPAR_i = \frac{SPAI_i}{\overline{SPAI}}$$

The spatial access ratio serves as a unitless measure of relative access to EMS. Zero indicates there is no access and/or no demand for EMS. A $SPAR_i$ of 1 is twice as accessible as a $SPAR_i$ of 0.5.

Calculating Local Demand with Relative Spatial Access

The estimated local demand for emergency medical service transport can be measured from the spatial distribution of potential patients and the spatial access to EMS transport. This approach has been used by Shi et al. (2012) to measure estimated potential local demand for cancer treatment centers. While the composition of a population is known to impact EMS demand, an absence of quantifiable research combined with data limitations resulted in this study using population totals to tally the number of potential patients. This approach can be represented as:

$$D'_i = \log_{10}(\frac{P_i}{SPAR_i})$$

where D is the estimated local demand at location i, P is the population at location i, and SPAR is the spatial access ratio at location i. $SPAR_i$ is the final access ratio calculated above. Log transformation is used to reign in large residuals. Where appropriate, the local demand equation can be expanded to account for diurnal population flows and/or demographic variables that correspond with a shift in demand for EMS resources.

Validation

The spatial access ratio and local demand metric are intended to provide an assessment of relative EMS coverage and resource distribution. To evaluate the significance of these results, they are aggregated to zip code and county levels and these mean spatial access ratio and local demand values are compared with the local EMS timestamps. This additional step links the research with established EMS outcomes and serves as a validation measure.

The date and time for each applicable segment of an EMS call is recorded, as shown in Figure 1. The National EMS Information System (NEMSIS) data dictionary element is listed as well. This study analyzes 911-call-to-scene time (E05_06 - E05_02; n=300,116), response time (E05_06 - E05_04; n=486,447), and transport time (E05_10 - E05_09; n=198,214). The 911-call-to-scene response times are included for all records 2010 – 2013 that consist of a ground 911 response with a transport unit, and a patient found. Transport times are included for all records 2010 – 2013 where the patient was

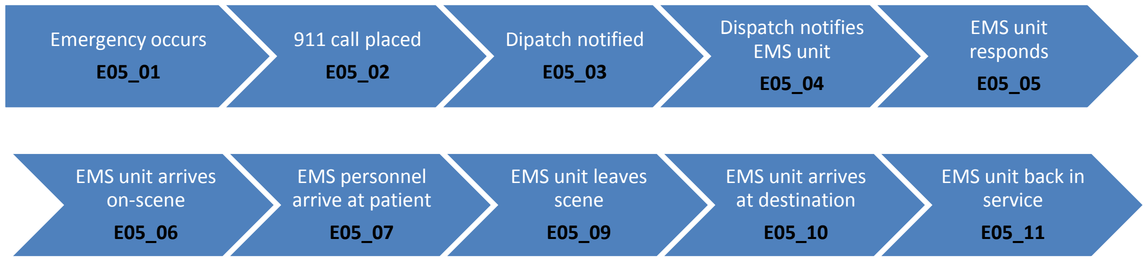

Figure 1. The sequence of a standard EMS call, without patient transfer to ALS.

transported by the ground EMS unit to a definitive care facility. Unfortunately, not every record is complete and times are included when provided.

Some researchers have suggested that patient survivability should be taken into account alongside EMS timestamps as a second key performance indicator (Fitch, 2005; Al-Shaqsi, 2010; McLay and Mayorga, 2010). The method herein assumes that EMTs and paramedics are able to treat life threatening injuries and stabilize patients during transport. This assumption would suggest greater access results in an elevated patient survivability rate, and vice versa.

One challenge to adopting this approach is the segmentation of patient health information by different health organizations along the continuum of care (Schooley, 2009). Disconnect between prehospital and emergency department/hospital IT systems, personnel, and communication channels were cited as cause for concern by the Academy of Sciences in 1966. Disconnect persists today (Institute of Medicine, 2007). As a result, few patient care reports include emergency department and hospital dispositions, thereby hindering efforts to track patient outcomes or evaluate intervention techniques. In contrast, response times are widely chronicled. In this study, 30% of patient care reports (n = 145,279) for patients treated and transported by ground ambulance were successfully linked with disposition data from definitive care facilities. Therefore, where possible, patient death rates are measured and presented alongside response times.

Study Area and Data

This study encompasses the state of Utah (Figure 2), and includes all EMS service regions therein. Utah's land surface encompasses nearly 85,000 square miles. The state's population at the 2010 US Census was 2.78 million, and reached 3 million in 2015, according to Census Bureau estimates. Population and growth are centered along the Wasatch Front in the north-central portion of the state, parallel to the I-15 corridor.

Four datasets are integrated for the purposes of this study. First, the Center for International Earth Science Information Network (CIESIN) Gridded Population of the World, Version 4 (GPWv4), which provides global 30 arc-second population estimates for the year 2010, was used to measure population across the study area. Second, the Utah Bureau of Emergency Medical Services provided basic agency and vehicle licensing information for the purpose of creating a facilities and capacity dataset. Facilities were sited at the station or post of each ground ambulance crew, and capacity was measured as the number of in-service, staffed transport units operated from this location. Fractional capacity values were used for partial and seasonal staffing. To reflect this methodology, the state-supplied dataset required numerous revisions, which were provided independently by each Utah-licensed EMS agency. Third, the Environmental Systems Research Institute (ESRI) 2012 Streetmap product was used to build a network dataset for calculating drive time distances and establishing catchment sizes. Lastly, the Utah Pre-hospital OnLine Active Information Reporting System

Figure 2. Location of Utah.

(POLARIS) —derived from the National EMS Information System (NEMSIS) database structure— was used to access all EMS records from 2010 through 2013. Where possible, the Utah Bureau of Health linked these records with emergency department and hospital patient dispositions. The response times and patient dispositions used to evaluate the spatial access and local demand metrics are derived from this dataset.

CHAPTER IV

RESULTS

Figures 3 and 4 show spatial access ratios at 30 arc-second resolution across Utah. In Figure 3, the drive time catchment is set to the 95th percentile of all EMS response times for 2010 – 2013 (16 minutes). In Figure 4, this catchment size is extended to the 99th percentile (32 minutes). Both figures illustrate the comparatively greater accessibility to EMS in Salt Lake Valley, along the I-15 corridor, and in county seats of government, where staffing needs can be more readily met and where a majority of potential users reside. While residents of Park City, Salt Lake Valley, Provo, Ogden, and other urban-suburban communities of the Wasatch Front reside in close proximity to EMS facilities, the large population dilutes overall availability of these resources and lowers spatial access ratios in these areas. More favorable provider to population ratios in isolated micropolitan cores result in higher spatial access ratios there.

Figure 5 shows logarithmically transformed demand values generated from the population and spatial access ratio at each population location. It shows demand is greatest along the northern I-15 corridor, where population concentrations are highest in the state. Demand is only calculated for places that fall within the catchment threshold (set to the 99th percentile of response times), and therefore have a spatial access ratio greater than zero. As gray regions fall outside this threshold, demand is unknown there.

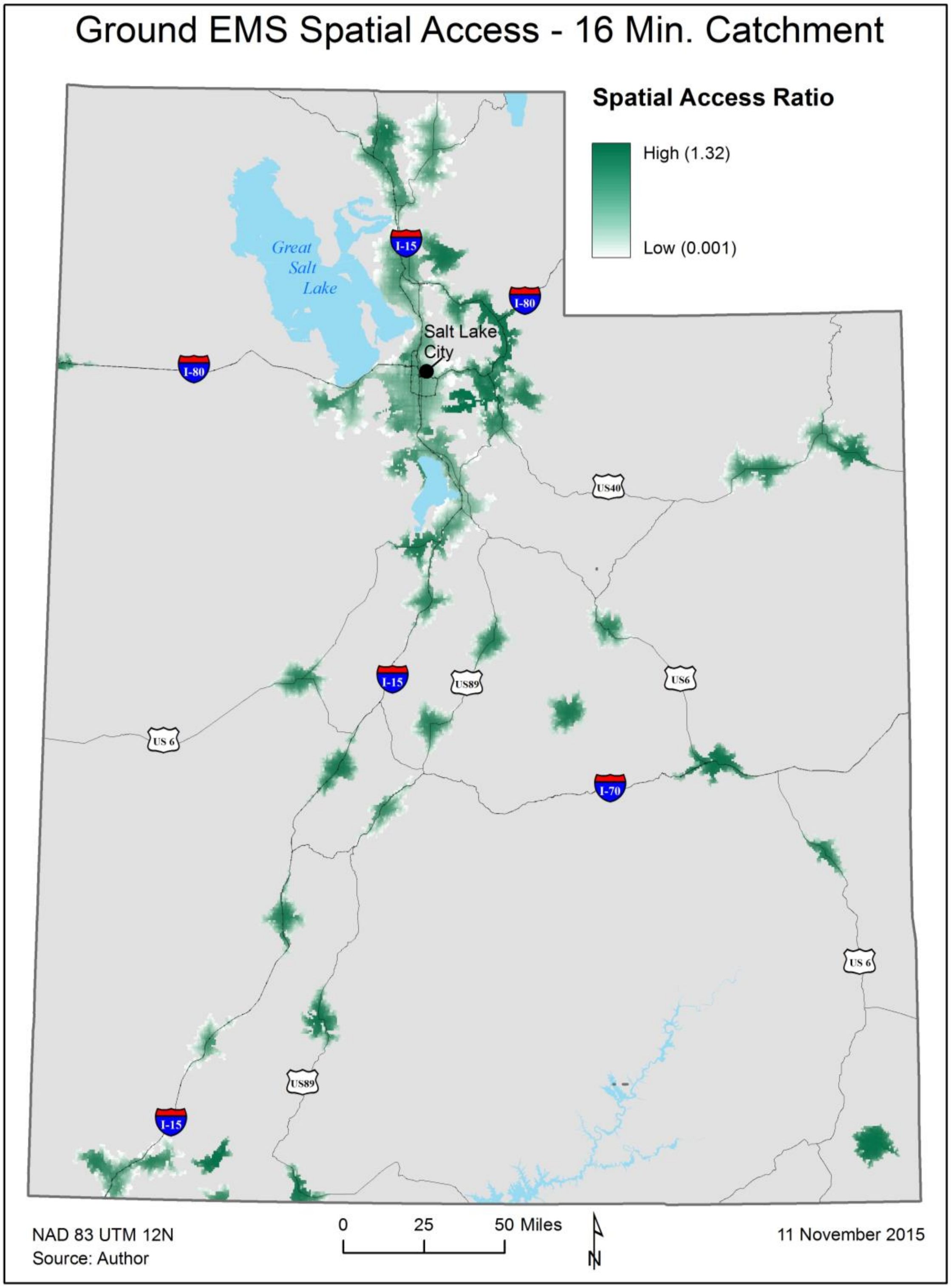

Figure 3. Spatial access for a 16-minute drive time radius with Gaussian decay.

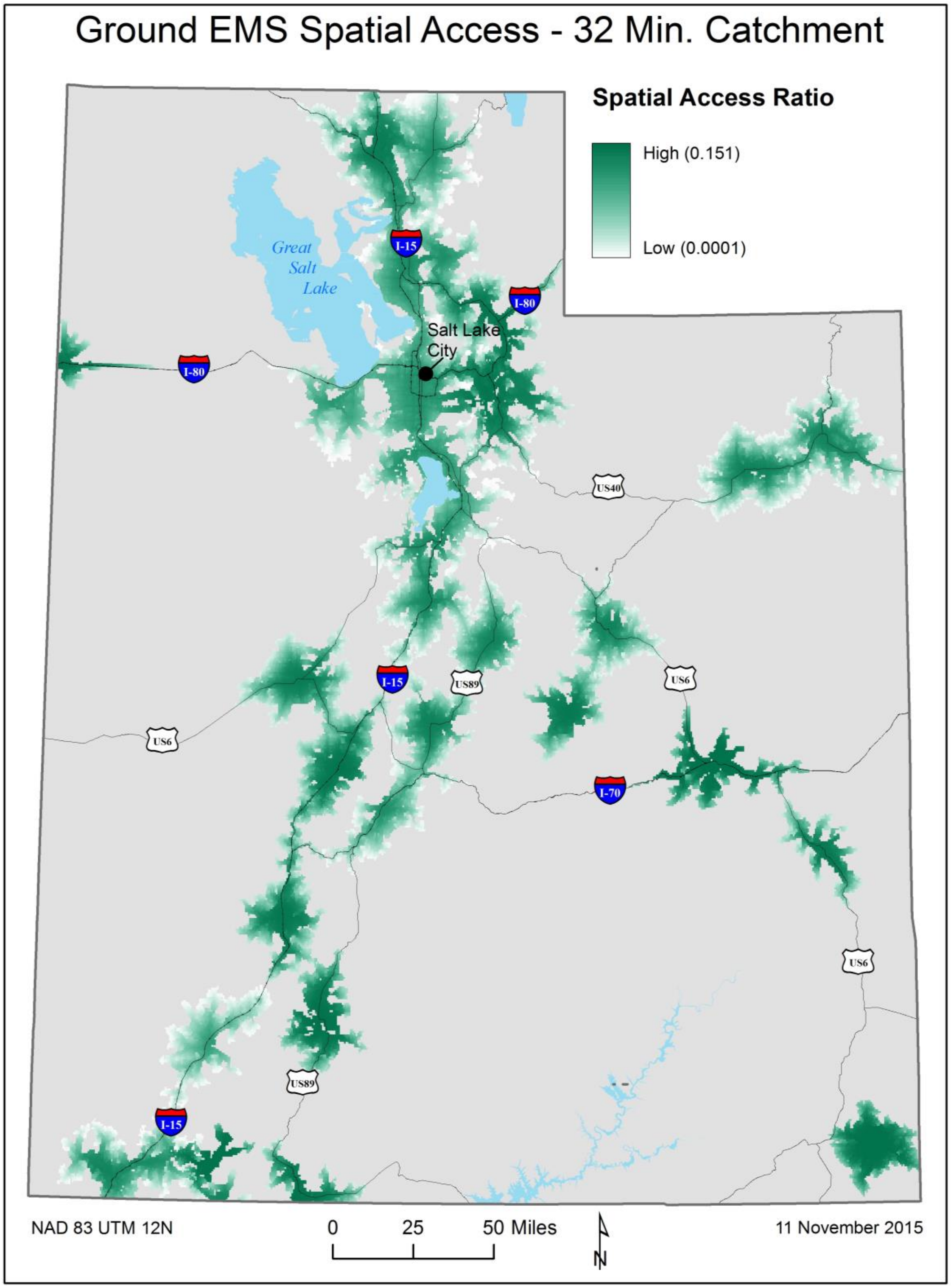

Figure 4. Spatial access for a 32-minute drive time radius with Gaussian decay.

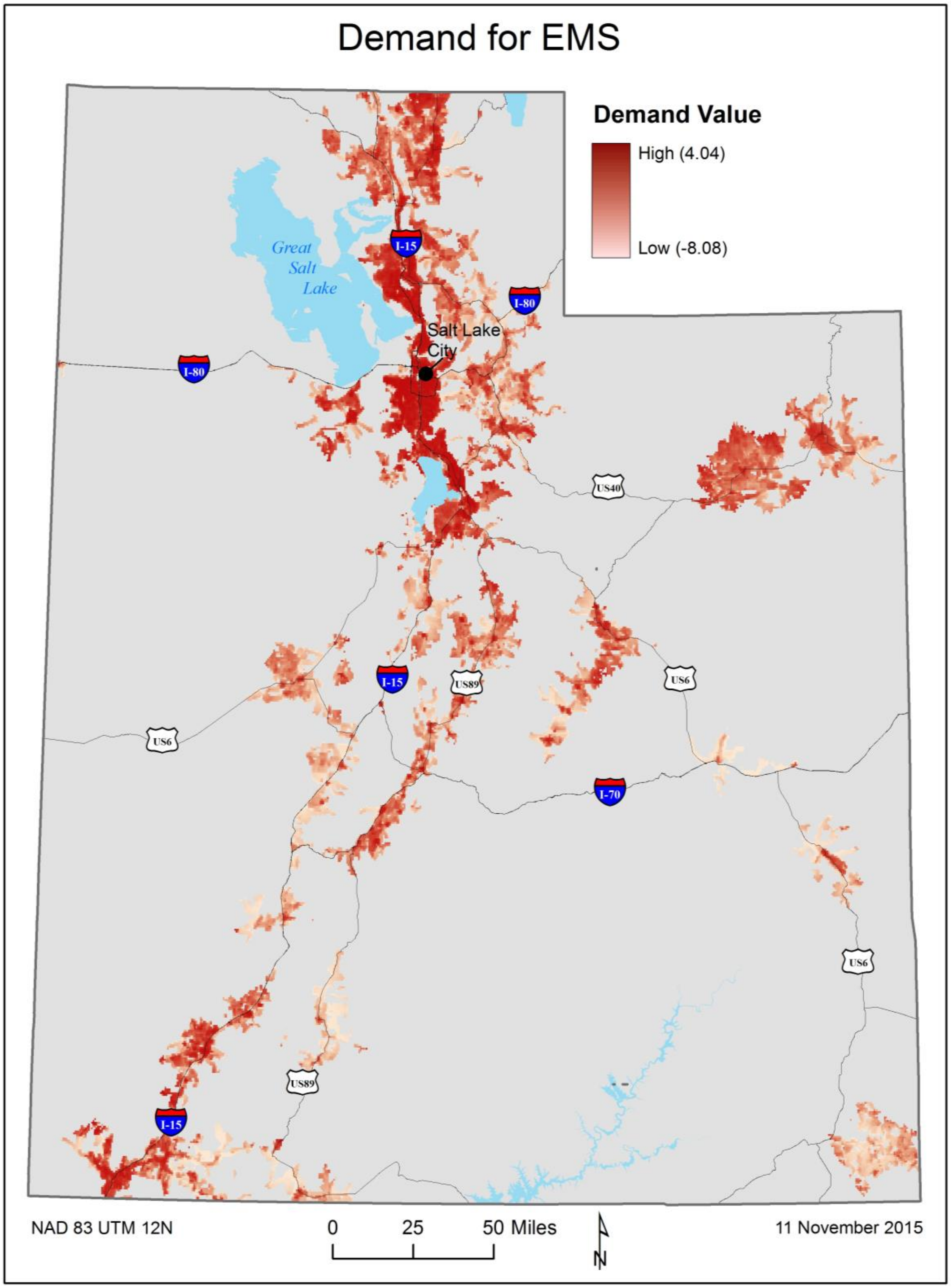

Figure 5. Demand measured using 32-minute drive time spatial access ratios.

Figure 6 shows mean ground ambulance response times by zip code across Utah for years 2010 – 2013. Figure 7 shows the total death rate by county for the same time period. The patient death rate, or total death rate, is calculated by dividing the number of patients who died on scene, during transport, or in definitive care for a given incident region by the total number of patients transported in the same incident region, as reported by the Utah Dept. of Health for years 2010 – 2013. To compare spatial access ratios with response times and patient death rates, mean spatial access ratios are computed for each zip code and county. The resulting Spearman correlation matrices are shown in Figures 8 and 9. Using results from the 99^{th} percentile catchment threshold aggregated to the zip code level, the spatial access ratio (SPAR) variable is negatively correlated with mean response time (rho: -0.57; p: <2.2e-16), mean 911-call-to-scene time (rho: -0.39; p: <3.88e-16), and mean transport time (rho: -0.54; p: <2.2e-16). The SPAR variable is positively correlated with population (rho: 0.51; p: <2.2e-16), and has no correlation with patient death rates either pre- or posttransport. Also of note are the findings that mean 911-call-to-scene, response, and transport times do not have significant correlation with patient death rates.

At the county level, the SPAR variable is negatively correlated with mean response time (rho: -0.55 ; p: 0.002), mean 911-call-to-scene time (rho: -0.49; p: 0.006), and mean transport time (rho: -0.55; p: 0.002). The SPAR variable is positively correlated with population (rho: 0.57; p: 0.001). Of note is the finding that times and death rates are not significantly correlated, and that county population has a strong negative correlation with mean response time (rho: -0.87; p: 7.46e-07), mean 911-call-to-scene-time (rho: -0.88; p: 6.3e-07), and mean transport time (rho: -0.88; p: 3.22e-10).

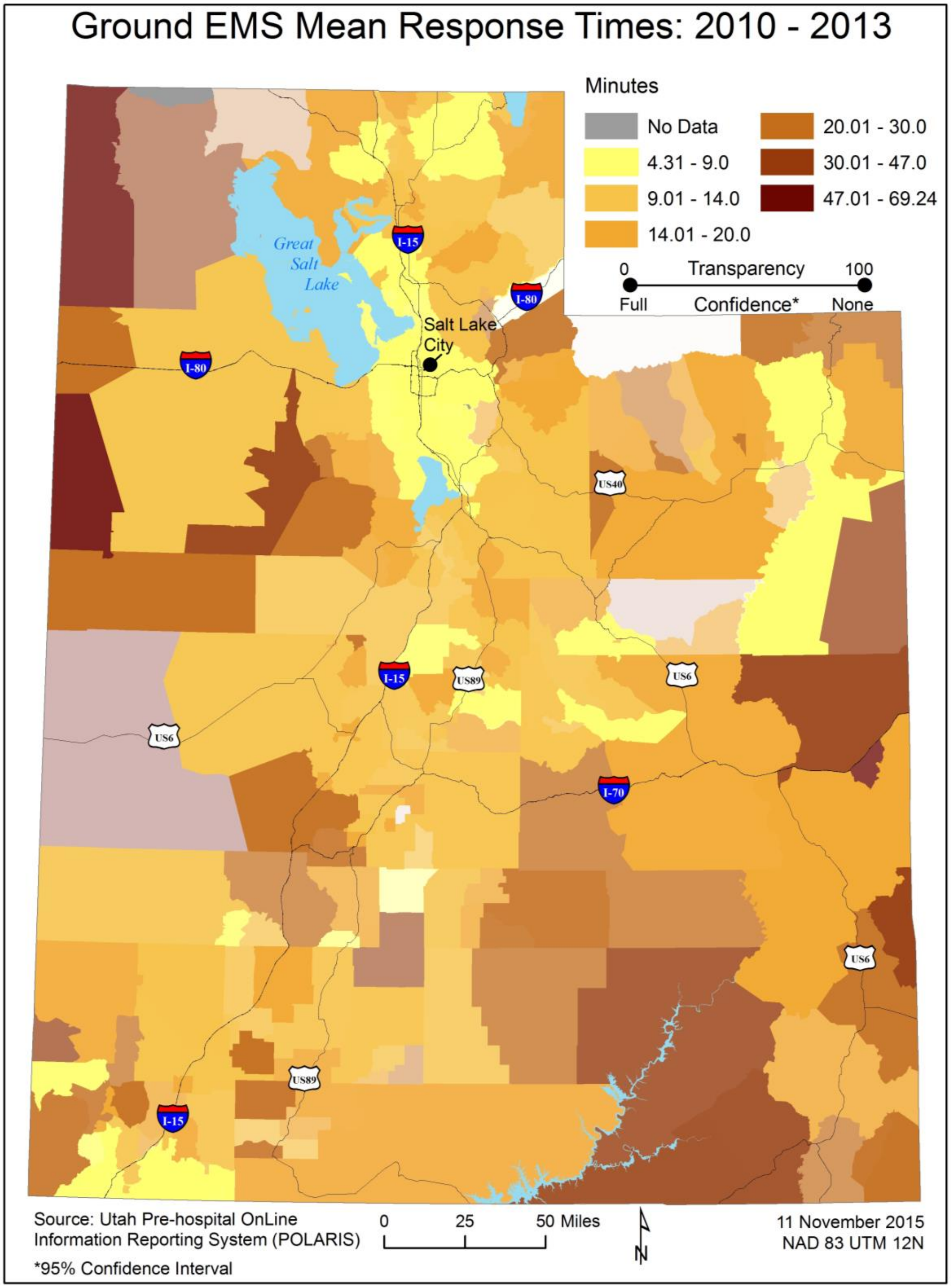

Figure 6. Mean EMS response time by Utah zip code.

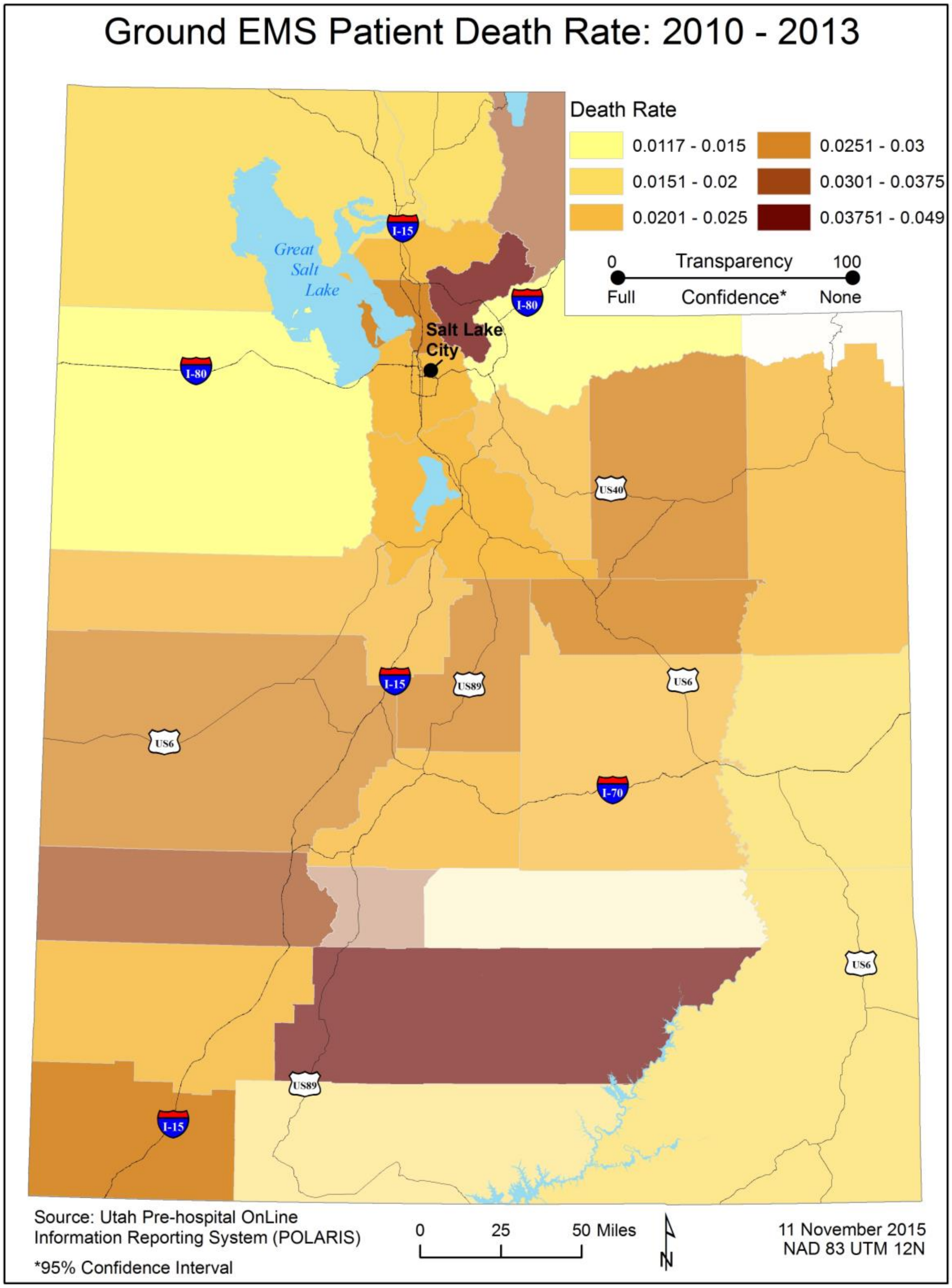

Figure 7. Ratio of deceased patients to treated patients by Utah county.

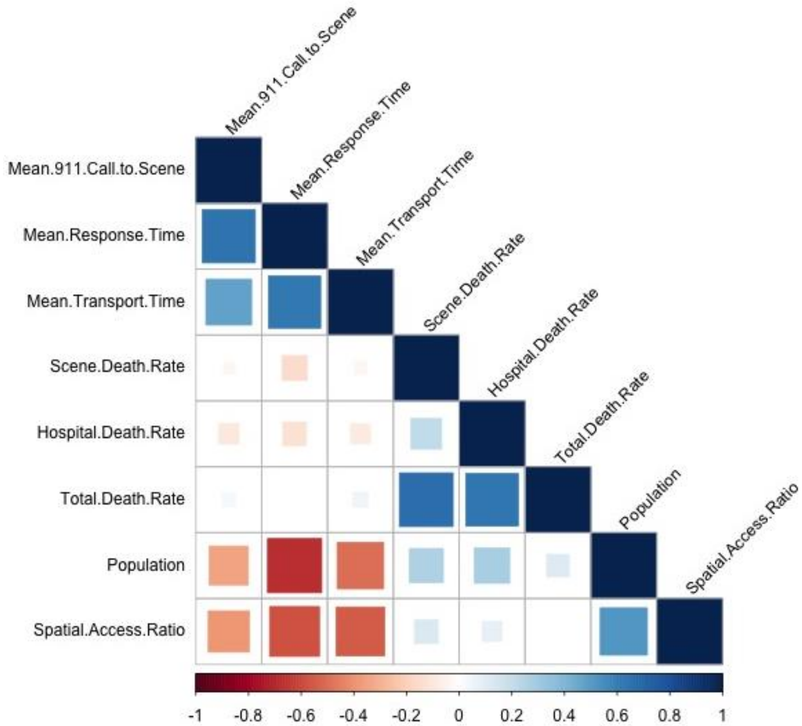

Figure 8. Zip code level correlation, 99th percentile catchment

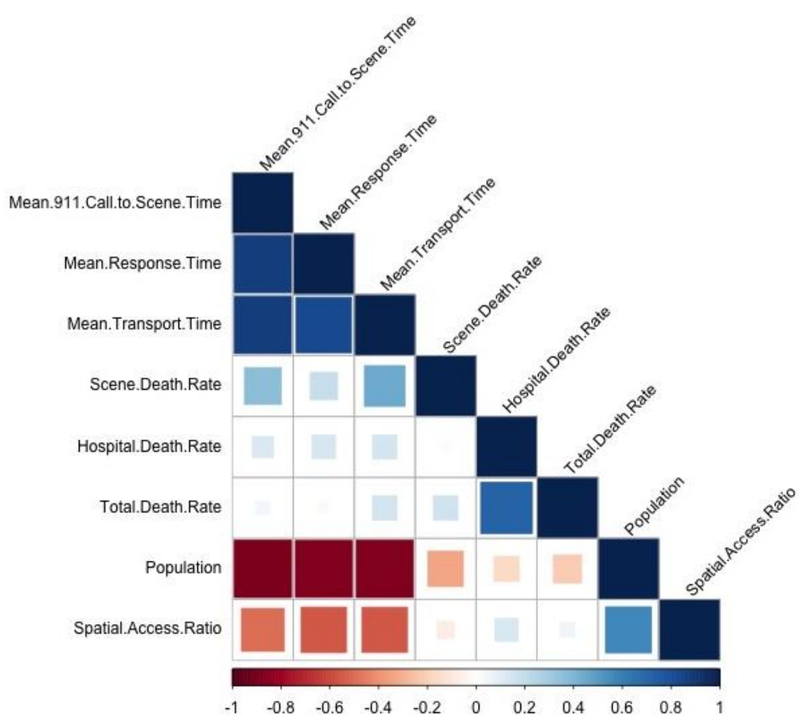

Figure 9. County level correlation, 99th percentile catchment

The analysis of EMS records also afforded the opportunity to measure diurnal, weekly, and yearly fluctuations in demand, as measured by number of dispatches. Figure 10 identifies a pattern of peaks and valleys in demand for emergent care. The value of this information is discussed in the next chapter.

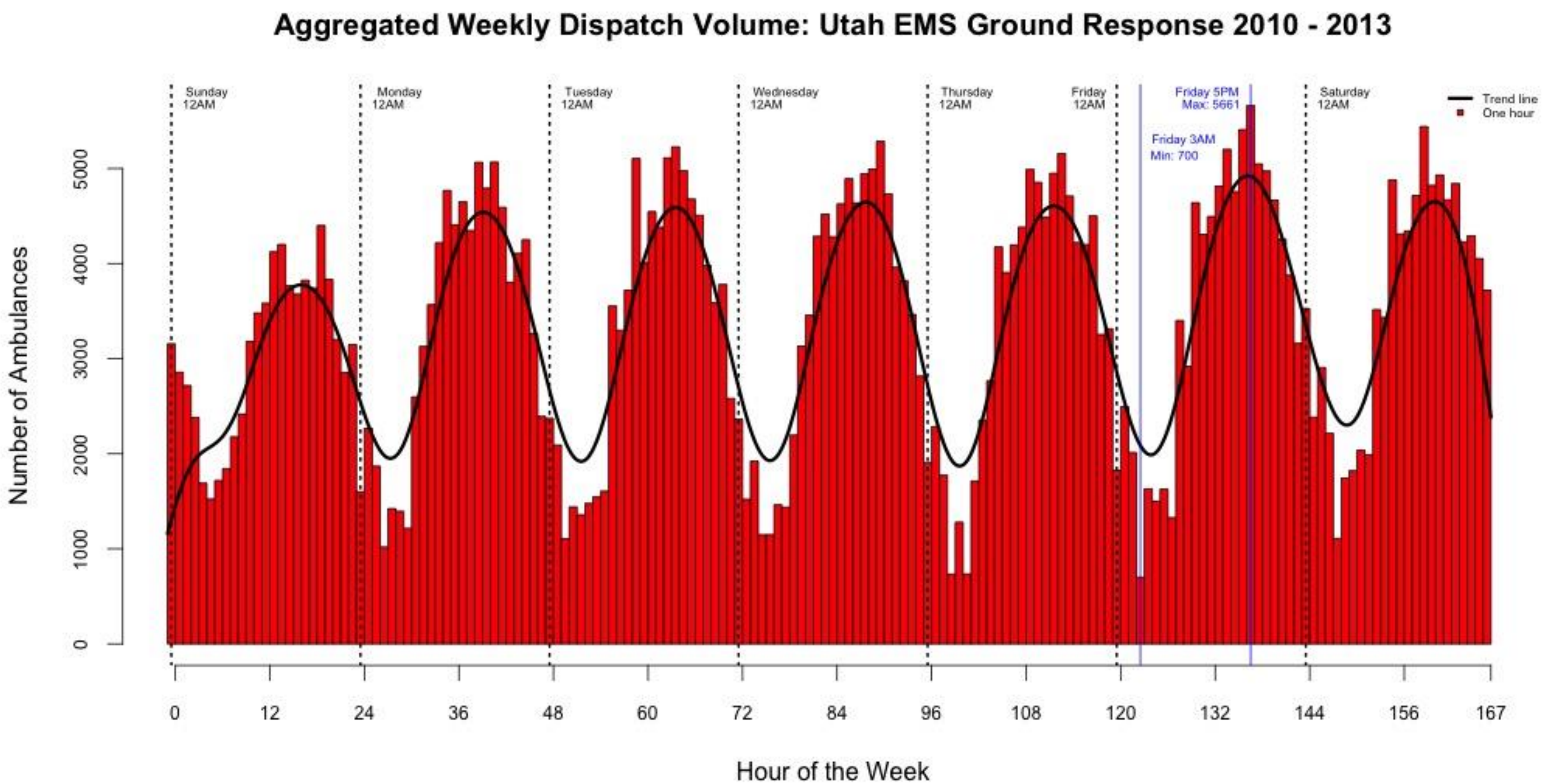

Figure 10. Aggregated hourly volume of ambulance dispatches. The single busiest hour of the week is Friday at 5:00pm.

CHAPTER V

DISCUSSION AND CONCLUSION

This study measures the relative spatial access to, and local demand for, Emergency Medical Service transport across the state of Utah. These findings are then compared with operational time metrics and death rates. This third step tethers the spatial access and local demand values to tangible outcomes, and prompts further inquiry of the spatiotemporal patterns and relationships of these performance indicators and the concept of access.

The first research question, which examines spatial access to EMS across Utah, is answered using Figures 3 and 4. Salt Lake and Utah valleys have the broadest high access to EMS of anywhere in the state. Also notable are the many discontinuous centers of high access scattered about the state. These are local centers of commerce and governance with populations great enough to justify a continually staffed EMS presence, but small enough that provider-to-population ratios are significantly more favorable than the ratios found in Utah's large cities. EMS access extends out from local centers in branches, along high-speed routes. The absence of transient demand in this study, to include tourists, outdoor enthusiasts, and travelers, may contribute to an artificially high EMS access ratio in some places. Nevertheless, these results are useful for establishing a baseline comparison of spatial access to EMS at specific locations across Utah.

The second research question addresses relative local demand for EMS across Utah. Figure 5 shows significant demand for EMS in Salt Lake and Utah valleys, along the northern stretch of the I-15 corridor. While the population and EMS resources are concentrated in this region, demand for EMS remains greatest in this portion of the state. Demand is also outstanding at points East, North, and Southwest, in Vernal, Ogden and Logan, and St. George, respectively. This finding reaffirms conventional knowledge concerning the siting of population and demand, but also raises the prospect of shortages during times of greater demand in the weekly dispatch cycle, as shown in Figure 10. Further research that considers the robustness of backup coverage and EMS system resiliency (i.e., the ability to scale resources to meet demand and maintain established response time goals) would benefit our understanding of these results and whether they reflect levels of community preparedness.

With regard to the third research question, significant correlation is found to exist between spatial access values and operational time metrics, while no correlation is found with regards to spatial access and patient death rates, either pre- or postincident scene. Therefore, this study finds that spatial access ratios do not serve as a direct indicator of patients' chance of survival. This study also found that time intervals and death rates are not correlated. The absence in association between EMS time intervals and mortality is a finding that has precedent (Newgard et al., 2010). Correlation alone may be an inadequate approach for determining the potential relationship between time intervals and survivability. Instead, classification of response times using a threshold has yielded significant correlation with patient survivability (Blackwell and Kaufman, 2002). Therefore, the study of EMS spatial access as it relates to patient outcomes needs further attention.

The methods used in this study enable researchers and medical practitioners alike to better understand the baseline standards, trends, and variance in access and demand across a state or other large area that transcends multiple operational jurisdictions. This process also affords the researcher a unique opportunity to validate outputs, and explore additional variables or alternative approaches for achieving results that reflect common sense, operationally relevant performance indicators.

A number of complimentary analyses can be proposed from this work. For one, this study uses static population data for purposes of measuring access and demand. A study that uses diurnal population flows would improve temporal resolution and illustrate the time-dependent fluctuation of access and demand for EMS, such as those shown in Figure 10. This information could be used to inform staffing needs and shift changes across municipalities. Transition from a static to dynamic model would also prompt a review of irregular demand. Irregular peaks in demand will occur when populations converge for reasons such as sporting events, festivities, or embark on holiday travel. Demand can also be expected to be higher along transportation routes, and particularly interstates. Quantifying the contribution of vehicle traffic to overall EMS demand, and identifying the percentage that is transient vs. local, is a next step in more accurately measuring demand for EMS.

In addition, greater attention could be given to the demographic weights that effect variations in demand for EMS. This study treats populations as homogenous and assumes a linear relationship between population count and EMS demand. Some studies have indicated geriatric patients have greater-than-proportional demand on prehospital emergency services (Rucker et al., 1996; Platts-Mills et al., 2010), and more research is needed to identify the demographic structure of EMS patients relative to the general population. With a better understanding of the demographic variables that impact EMS use, demand measures could be modified to account for these population characteristics.

A third important consideration is the appropriateness of use of EMS –whether ambulance transport is necessary or not given the patient's symptoms. A recent study by L. M. Beillon (2009) finds that EMS patients in rural areas are in serious or critical condition more often than EMS patients in urban settings. Population density was found to correlate with misuse of EMS. The review of patient care reports by qualified health professionals for a given study area and time span could be included for purposes of reviewing the appropriateness of demand.

A fourth area for expanded study lies with the method used for measuring EMS capacity. In-service, staffed, transport unit count -the surrogate variable for EMS capacity used in this study- may not sufficiently capture resource distribution or availability. The varied EMS structures employed across service regions present a unique challenge to effectively assessing capacity. Incorporating personnel skill levels, equipment, and reserve resources would provide a more comprehensive capacity measure. More attention should be given to developing uniform metrics that transcend organizational structures and response protocols, in order to establish comparable baseline readiness evaluations.

Due to the intricacies and nuances characteristic of the EMS system, the results of this particular study should be viewed as steps towards achieving a comprehensive model of access and demand, rather than an end unto itself. Nevertheless, this study presents an important application for access modeling, and offers significant tools for its use by practitioners and evaluators.

APPENDIX

TABLE OF CORRELATION VALUES AND SIGNIFICANCE LEVELS

Table 1. Correlation matrix using the 99th percentile catchment. Zip code results appear in the top-right half and county results are shown in the bottom-left half. Significance level of p <0.05, <0.01, and <0.001 shown using one, two, and three stars, respectively.

	Mean 911-call-to-scene time	Mean response time	Mean transport time	Scene death rate	Hospital death rate	Total death rate	Population	Spatial access ratio
Mean 911-call-to-scene time		0.65***	0.48***	Insig.	Insig.	Insig.	-0.35***	-0.39***
Mean response time	0.88***		0.63***	-0.14*	-0.13*	Insig.	-0.67***	-0.57***
Mean transport time	0.87***	0.82***		Insig.	Insig.	Insig.	-0.50***	-0.54***
Scene death rate	Insig.	Insig.	0.44*		0.22***	0.66***	0.27***	0.13*
Hospital death rate	Insig.	Insig.	Insig.	Insig.		0.63***	0.29***	Insig.
Total death rate	Insig.	Insig.	Insig.	Insig.	0.71***		0.12*	Insig.
Population	-0.88***	-0.87***	-0.88***	Insig.	Insig.	Insig.		0.51***
Spatial access ratio	-0.49**	-0.55**	-0.55**	Insig.	Insig.	Insig.	0.57**	

REFERENCES

Al-Shaqsi, S., 2010. Models of International Emergency Medical Service (EMS) Systems. Oman Medical Journal 25(4), 320.

Ball, M., Lin, F., 1993. Reliability Model Applied to Emergency Service Vehicle Location. Operations Research 41(1), 18-36.

Bandara, D., Mayorga, M., McLay, L., 2012. Optimal Dispatching Strategies for Emergency Vehicles to Increase Patient Survivability. International Journal of Operational Research 15(2), 195-214.

Bellion, L. M., Suserud, B., Karlberg, I., Herlitz, J., 2009. Does Ambulance Use Differ Between Geographic Areas? A Survey of Ambulance use in Sparsely and Densely Populated Areas. American Journal of Emergency Medicine 27, 202-211.

Blackwell, T.H., Kaufman, J.S., 2002. Response Time Effectiveness:Comparison of Response Time and Survival in an Urban Emergency Medical Services System. Academic Emergency Medicine 9(4), 288-295.

Brodie, B. et al., 2001. Importance of Time to Reperfusion on Outcomes with Primary Coronary Angioplasty for Acute Myocardial Infarction. American Journal of Cardiology 88(10), 1085-1090.

Brotcorne, L., Laporte, G., Semet, F., 2003. Ambulance Location and Relocation Models. European Journal of Operational Research 147(3), 451-463.

Cannon, C. et al., 2000. Relationship of Symptom Onset to Balloon Time and Door to Balloon Time with Mortality in Patients Undergoing Angioplasty for Acute Myocardial Infarction. Journal of the American Medical Association 283(22), 2941-2947.

Carr, B. et al., 2006. A Meta-Analysis of Prehospital Care Times for Trauma. Prehospital Emergency Care 10(2), 198-206.

Carr, B. et al., 2009. Access to Emergency Care in the United States. Annals of Emergency Medicine 54(2), 261-269.

Center for International Earth Science Information Network - CIESIN - Columbia University, 2014. Gridded Population of the World, Version 4 (GPWv4), Preliminary Release 2 (2010). Palisades, NY. http://www.ciesin.columbia.edu/data/gpw-v4.

Chanta, S., Mayorgia, M., McLay, L., 2011. Improving Emergency Services in Rural Areas: A Bi-Objective Covering Location Model for EMS Systems. Annals of Operations Research 221(1), 133-159.

Cromley, E., McLafferty, S., 2012. GIS and Public Health. Guilford Press, New York.

Ertugay, K., Duzgun, S., 2011. GIS-based Stochastic Modeling of Physical Accessibility Using GPS-based Floating Car Data and Monte Carlo Simulation. International Journal of Geographical Information Science 25(9), 1491-1506.

Fitch, J., 2005. Response Times: Myths, Measures, and Management. Journal of Emergency Medical Services 30(9), 47.

Fitzsimmons, F., 1973. A Methodology for Emergency Ambulance Deployment. Management Science 19(6), 627-636.

Green, L., 2002. How Many Hospital Beds? The Journal of Health Care Organization, Provision, and Financing 39(4), 400-412.

Guagliardo, M. et al., 2004. Physician Accessibility: An Urban Case Study of Pediatric Providers. Health & Place 10(3), 273-283.

Harper, P., 2002. A Framework for Operational Modeling of Hospital Resources. Health Care Management Science 5(3), 165-173.

Henderson, S., Mason, A., 2004. Ambulance Service Planning: Simulation and Data Visualisation. Operations Research and Health Care 70, 77-102.

Higgs, G., Fry, R., Langford, M., 2014. USWFCA: An ArcGIS Add-In Tool To Compute Enhanced Two-Step Floating Catchment Area Accessibility Scores. University of South Wales.

Institute of Medicine, Committee on the Future of Emergency Care in the US Health System, 2006. Emergency Medical Services: At the Crossroads. National Academies Press. Washington, DC.

Joseph, A., Phillips, D., 1984. Accessibility and Utilization: Geographical Perspectives on Health Care Delivery. Happer & Row Publishers, New York, 214pp.

Liberman, M., Mulder, D., Sampalis, J., 2000. Advanced or Basic Life Support for Trauma: Meta-Analysis and Critical Review of the Literature. Journal of Trauma-Injury, Infection, and Critical Care 49(4), 584-599.

Luo, W., Qi, Y., 2009. An Enhanced Two-Step Floating Catchment Area (E2SFCA) Method for Measuring Spatial Accessibility to Primary Care Physicians. Health & Place 15(4), 1100-1107.

Luo, W., Wang, F., 2003. Measures of Spatial Accessibility to Health Care in a GIS Environment: Synthesis and a Case Study in the Chicago Region. Environment and Planning B 30(6), 865-884.

Mackenzie, E. et al., 2006. A National Evaluation of the Effect of Trauma Center Care on Mortality. The New England Journal of Medicine 354(4), 366-378.

McGrail, M., Humphreys, J., 2009. Measuring Spatial Accessibility to Primary Care in Rural Areas: Improving the Effectiveness of the Two Step Floating Catchment Area Method. Applied Geography 29(4), 533-541.

McLay, L., Mayorga, M., 2010. Evaluating Emergency Medical Service Performance Measures. Health Care Management Science 13(2), 124-136.

Mears, G. et al., 2011. National EMS Assessment. Federal Interagency Committee on Emergency Medical Services, US Department of Transportation, National Highway Traffic Safety Administration, DOT HS, Washington, DC.

Merritt, A., 2014. The Rise of Emergency Medicine in the Sixties: Paving a New Entrance to the House of Medicine. Journal of the History of Medicine and Allied Sciences 69(2), 251-293.

National Academy of Science. National Research Center: Accidental Death and Disability: The Neglected Disease of Modern Society. Washington, DC: National Academy Press, 1966.

National Highway Traffic Safety Administration, Department of Transportation, 1996. Emergency Medical Services Agenda for the Future. Washington, DC.

Newgard, C. et al., 2010. Emergency Medical Services Intervals and Survival in Trauma: Assessment of the "Golden Hour" in a North American Prospective Cohort. Annals of Emergency Medicine 55(3), 235-246.

Peleg, K., Pliskin, J., 2004. A Geogrphic Information System Simulation Model of EMS: Reducing Ambulance Response Time. American Journal of Emergency Medicine 22(3), 164-170.

Penchansky, R., Thomas, J., 1981. The Concept of Access: Definition and Relationship to Consumer Satisfaction. Medical Care 19(2), 127-140.

Platts-Mills, T. et al., 2010. Emergency Medical Services Use by the Elderly: Analysis of a Statewide Database. Prehospital Emergency Care 14(3), 329-333.

Pozner, C. et al., 2004. International EMS Systems: The United States: Past, Present, and Future. Resuscitation 60(3), 239-244.

Rivers, E. et al., 2001. Early Goal Directed Therapy in the Treatment of Severe Sepsis and Septic Shock. The New England Journal of Medicine 345(19), 1368-1377.

Rucker, D. et al., 1996. Patient-Specific Predictors of Ambulance Use. Annals of Emergency Medicine 29(4), 484-490.

Sampalis, J. et al., 1993. Impact of On-Site Care, Prehospital Time, and Level of In-Hospital Care on Survival in Severely Injured Patients. The Journal of Trauma 34(2), 252-261.

Schooley, B., 2009. Integrated Patient Health Information Systems to Improve Traffic Crash Emergency Response and Treatment. System Sciences, 2009. HICSS'09. 42nd Hawaii International Conference on System Science, IEEE, 1-10.

Shah, M., 2006. The Formation of the Emergency Medical Services System. American Journal of Public Health 96(3), 414.

Shi, X. et al., 2012. Spatial Access and Local Demand for Major Cancer Care Facilities in the United States. Annals of the Association of American Geographers 102(5), 1125-1134.

Stiell, I. et al., 2008. The OPALS Major Trauma Study: Impact of Advanced Life-Support on Survival and Morbidity. Canadian Medical Association Journal 178(9), 1141-1152.

Swoveland, C. et al., 1973. Ambulance Location: A Probabilistic Enumeration Approach. Management Science 20(4), 686-698.

Trunkey, D., 1983. Trauma. Scientific American 249(2), 28-35.

Wan, N. et al., 2012. A Relative Spatial Access Assessment Approach for Analyzing Potential Spatial Access to Colorectal Cancer Services in Texas. Applied Geography 32(2), 291-299.

Wang, F., Luo, W., 2005. Assessing Spatial and Nonspatial Factors for Healthcare Access: Towards an Integrated Approach Defining Health Professional Shortage Areas. Health and Place 11(2), 131-146.