TRAUMA DESERTS

A Geospatial Analysis of Trauma Center Accessibility in the Inland Empire

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[*Link to Google Slides Presentation*]

ABSTRACT

Trauma care centers exist with the intended purpose of providing timely and quality care to prevent injuries, minimize death, and provide quality of care to trauma related injuries. To do this effectively, timely accessibility to trauma centers is critical. Receiving trauma care within an hour can be the difference between life and death. With over 4.2 million residents, the Inland Empire is home to two of the largest counties in California. In accordance with the California Statewide Trauma System Planning Committee (STAC), we analyze trauma center accessibility for residents of San Bernardino and Riverside counties. Due to its growing population and vast size, our analysis is critical to ensure trauma care accessibility in the expanding region. Using various Network Analyst Models, our findings indicated that nearly 12.8% of the population within the Inland Empire lives an hour or more away from a trauma center, substantially increasing the risk of fatality. Using a Location Allocation Network Analyst model, we identified St. Mary Medical Center in Apple Valley, the Barstow Community Hospital in Barstow, and the Hi-Desert Medical Center in Joshua Tree to be the most ideal candidates to receive funding for upgrading their hospital facilities into top tier trauma centers. This is expected to significantly reduce the mortality rates for those who experience a traumatic injury within the region by increasing trauma center accessibility and reducing health disparities in the region.

OBJECTIVE

Our objective is to locate trauma center and hospital locations within the Inland Empire in order to conduct a geospatial analysis that assesses trauma center accessibility using Geographic Information System (GIS) Network Analyst models. Using these GIS models allow us to identify Trauma Deserts, or regions lacking suitable access to trauma center facilities. Additionally, we will identify hospitals within the region that would be prime candidates for additional grants and funding that allow for the hospital to be upgraded into a top tier trauma center location. This analysis allows us to ultimately provide policy suggestions to regional policy makers and healthcare providers to develop and expand trauma center accessibility within the Inland Empire.

BACKGROUND

ACCESSIBILITY OF TRAUMA CENTERS

Having access to health care is essential for the safety and well being of any society. Having access to a trauma center after suffering a traumatic injury could mean the difference between life and death. Recent studies have shown that trauma center geographic distributions vary widely across states. Large cities have more access to trauma centers, however, this often means trauma centers are clustered within a smaller geographic space, leading to inefficiencies related to costs of maintenance. Other areas of the country see a smaller share of these centers. This is especially evident for rural residents where trauma centers are not readily accessible. Previous research has shown that while the need for trauma centers has increased the acceleration of trauma center closures has persisted, resulting in longer distances and driving times for vulnerable populations to travel (Hsia & Shen, 2011). Even as the need for centers has been recognized, the high costs associated with operations has led to mass trauma center closures. Hsia and Shen conducted research that documented 339 trauma centers closures out of the 1,125 that existed between 1990 and 2005 (Hsia & Shen, 2011). This is despite the fact that the United State's Healthy People 2020 Initiative declared that "increasing access to trauma center care" was a goal. Between 1999 and 2006, the number of trauma incidents overall decreased slightly but the severity of these incidents went up in California (Hsia et al. 2008).

TRAUMA CENTER DISTANCE AND FATALITY RATES

It has been well documented that access to a trauma center greatly improves the chances of survival after experiencing a traumatic injury. A study conducted in 2016 by a team of medical professionals at the University of Pittsburgh found that fatality rates were spatially autocorrelated by a Morian's I factor of 0.35 (Horst et al., 2017). Meaning more densely populated areas with relatively quick and easy access to a trauma center saw lower rates of fatality than areas that are more widely dispersed with longer trauma center travel distances.

In a follow-up study conducted in 2018, the researchers discovered that motor vehicle collision fatalities increased by a factor of 0.141 for every 10 miles traveled to the nearest trauma resource system (Brown et al., 2018). This means that for every 10 miles traveled, the odds of survival drops by approximately 14%. The odds of survival drop even further when time is factored into the model. According to Brown and his team, those who are 45-60 minutes away from a trauma center saw their chances of survival drop by 13%. Those who were more than 60 minutes away from a trauma center saw their odds of survival drop by 23% after a motor vehicle collision.

Jarman et al. (2018) mapped areas in the United States that were at higher risk of trauma mortality and also found that the fatality rate was highest in rural areas where trauma centers are less accessible. Additionally, older populations face high risks when faced with trauma related incidents. Despite the increased likelihood of trauma care needed for all age groups, Flottemesch et al. found that between 2009 and 2012 the largest increase was among those over 84 years of age. Yet, access to trauma care was less likely for those over 45 years of age. This presents a unique challenge for the currently aging populations that tend to live in more isolated and private areas.

RACE AND SOCIOECONOMIC STATUS

These results above are then shown to be more fatal by communities with a lower socio-economic status (SES). Race and SES also had a major effect on geo-spatial access to trauma center resources. Over time, because of increased costs of operating trauma resource centers, vulnerable populations, “specifically the socio-economically disadvantaged, racial and ethnic minorities, and rural communities,” saw a decrease in the number of available trauma centers in their area, increasing travel times and subsequently increasing fatalities (Hsia and Shen, 2011). A 2011 analysis of urban and rural communities, Hsia and Shen calculated that more than 38.4 million people “do not have access to trauma care within 1 hour of driving time” (Hsia and Shen, 2011). In the same study, Hsia and Shen found that in the past two decades, the disparities in health indicators like mortality from traumatic injuries have worsened for Black, Latino/a, and low-income groups (2011).

LITERATURE REVIEW

Determining accessibility through the use of geo-spatial network analyst models is common in both academic and professional studies. This is especially true in the local municipal settings to determine accessibility to emergency services, utilities, or parks. In a study similar to our own, Comber, Brunsdon and Green (2008) used the Network Analyst Model in ArcGIS (Esri, Redlands, CA) and socio-economic data to assess differences in access to greenspace among religious and ethnic groups. They found that the distribution of greenspace in the United

Kingdom resulted in inequitable access and recommended that new developments should include increased access to greenspaces in certain areas.

Lawson et al. (2013) used the Origin-Destination Cost Matrix tool in the ArcGIS Network Analyst toolbox in order to examine spatial access to trauma centers in Canada by people in accidents that were hospitalized or died. Their research indicated that traumas that resulted in death were found to have poorer spatial access to trauma center care. Meaning, those who died typically lived in a region with limited and untimely access to a trauma center.

A study by Hsia and Shen (2011) used a different method of calculating trauma center access but drew a similar conclusion. Instead of using network analyst tools to calculate the Manhattan distance using surface streets, the researchers measured the straight-line euclidian distance between a trauma center and the population center of a zip code block and converted the distance into a drive time to better accommodate air ambulance access. However, using zip code blocks results in a much lower resolution than the use of census block data. This method also assumes that all people within a particular zip code block will have equal drive times and distances to travel in the event of an emergency. An individual living at one end of a zip code may find it quicker to access an entirely different trauma center than someone geo-spatially located at the opposite end of tract, making this study less accurate than using a network analysis model. Additionally, weather conditions may affect air ambulance access.

A study conducted by Carr (2017) used the ESRI ArcGIS Network Analyst model to calculate disparities in trauma care access in the United States as a whole. Instead of using zip code blocks Carr opted instead for using individual centroids of census blocks to maximize accuracy and spatial resolution.

Yerramilli and Fonseca (2014) used these network analyst models to geo-spatially map access to health care services in Mississippi. Finally, Horst et al. (2017) used the same network analysis tools to determine optimal locations for the construction of new trauma centers in Pennsylvania.

METHODOLOGY & DATA

DATA

Data was collected from various sources including the United States Census Bureau, Esri, The Southern California Association of Governments, the University of California Riverside (UCR) Center for Geospatial Sciences, and the American Hospital Association. Hospital and trauma center location data was retrieved from previous projects conducted by the UCR Center for Geospatial Sciences and the American Hospital Association. This data included geospatial location data for 6,239 hospital and 1,709 trauma center locations across the continental United States, Hawaii, Alaska, and U.S. territories. The GIS shapefile used for the analysis was retrieved from the Southern California Association of Governments (SCAG) GIS Open Data Portal online. The shape file provided by SCAG contained polygons that were broken down by block groups, which is the highest resolution data available from the United States Census Bureau. Population data was sourced from the United States Census Bureau. This data included population statistics by race gathered through 2010 census efforts. The dataset also included projected population totals for 2018. Additionally, block groups were labeled using Federal Information Processing Standards (FIPS) codes and geospatial projection data. Finally, the North American Street Map Data (Esri, Redlands, CA) was used to construct our maps. This provided us with information including city, highway, lake, lake, river, and park data - to name a few. The most important part of this dataset was the street network data. This data set included information such as speed limits, toll roads, one way streets, which streets were private access only and more. This allowed for an accurate measurement of time and distance when running network analyst models. Avoiding segments of unusable streets greatly helps in developing a more accurate estimate of travel times.

METHODOLOGY

The analysis for this study was conducted using ArcMap 10.7.1 software by Esri. All data frames were geospatially mapped using the "NAD 1983 StatePlane California VI FIPS 0406 (US Feet)" coordinate system. While both San Bernardino and Riverside counties are located in different state plane coordinate systems, the majority of the population was located near or within the northern boundary of the California VI coordinate plane north of Riverside county. All additional layers added into the system were automatically converted to this coordinate system for uniformity. Thematic Group Layers by Esri were included as a basemap for a global reference of city and topographic data.

The shapefiles that included polygons for all block groups within the Southern California Association of Governments (SCAG) were added to the map. The polygons labelled with the county code 065 (for Riverside County) and 071 (for San Bernardino County) were selected using the selection query and extracted into their own layer for easy identification and analysis. To visually represent population densities, total population data within each polygon was symbolized in quantities using graduated colors and Jenks Natural Breaks in the dataset. Data containing all hospital and trauma center locations were also added to the map (2014 American Hospital Association). Using the Select by Location tool, we were able to use the Inland Empire

Census Blocks as our source layer to identify trauma centers and hospital facilities within the Inland Empire and 100 miles from the county borders. The identified locations were then extracted and added as their own easily identifiable layer.

Using these new points, a Network Service Area model was used to identify the geographic area both trauma centers and hospitals serviced. All of these models were run by calculating either distance or time traveled to a facility from a demand point. U-turns at junctions and one way streets were allowed for use, however these analyses were restricted from using guard controlled entryways, keyed access entry ways, limited access roads, passenger fairies, toll roads, vehicular ferries and non-reroutable segments. Rather than using a direct Euclidian measurement, our street network data allowed us to calculate a far more accurate analysis similar to that of a Manhattan measurement.

A total of 4 solutions were run of this kind of analysis. The first two were to calculate the Trauma Center Service Area and Hospital Service Areas by time in minutes. This time impedance was broken up into 15, 30, 45, and 60 minute intervals. New color coded polygons were then generated and merged at these break value intervals. The other two service area models used distance as the impedance method and were broken up into 5, 10, 20, and 50 mile intervals. The results of these models were then spatially joined to the census block layers for easy identification and analysis.

Finally, in order to identify the optimal location for the construction of a new trauma facility, we ran a New Location-Allocation model on the existing data. The analysis settings were set to the same settings as before, however, we used the 60 minute critical time windows as our impedance metric. The system located 3 new potential hospitals that can be converted into trauma facilities to maximize coverage. We wanted to ensure that we were expanding accessibility to as many people as possible by giving block groups with denser populations greater weight in the analysis.

FINDINGS AND POLICY IMPACT

FINDINGS

Population. Of the 83,891 census blocks that were analyzed, 2010 census data, collected by the US Census Bureau, showed that the Inland Empire has a total population of roughly 4,224,851. Of that population, 2.2 million live in Riverside County while 2.0 million live in San Bernardino County. Of this population, Non-White Hispanics makeup approximately 47.25% of the population, while 36.61% of the population is White, and 7.14% Black. While these populations are roughly split evenly between both counties, most of the population lives in the south-western part of the region with four distinct population clusters. These population clusters are identified by red circles in Figure 1 below. The two largest clusters are located in south-west San Bernardino County/Western Riverside county and in central Riverside County. However, the focus of this analysis will be of the two smaller clusters (labeled A and B) in San Bernardino County. This is because, as our analysis will show, these population dense regions face higher disparities in regards to trauma center access and are located further inland than the other two highly populated areas. This is also because of the existing mountain range bisecting San Bernardino county. Access to area A is also limited as often a single interstate highway cutting through the mountain is the only way to gain access to the area. The same is true for Area B that encompasses most of the Joshua Tree region.

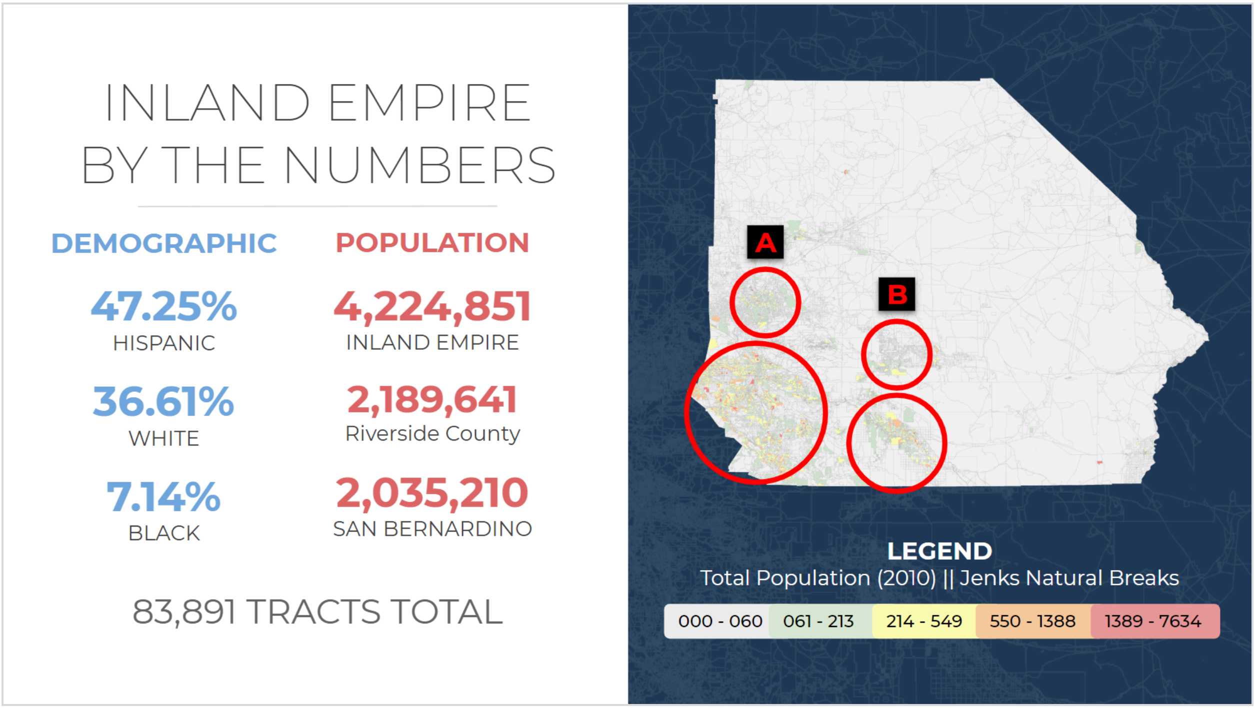

Figure 1 Inland Empire by the Numbers. This image depicts population densities in the Inland Empire. Four population dense areas are identified with red circles.

Disparities. When calculating the Trauma Center Service Area by distance [Appendix, Figure A and Appendix, Figure B], we find that approximately 10.1% of the population, around 426,664 individuals, do not have access to a trauma center within a 50 mile travel distance. Of those who live within the service area, approximately 518,000 live within 0-5 miles of a trauma center, 864,000 are within a 5-10 mile range, 1.44 million live within a 10-20 mile range, and 974,000 live within a 20-50 mile range. The densely populated clusters labeled A and B in Figure 1 are partially within the 50 mile range but are mostly left out. These statistics become more stark when the trauma center service area is calculated by time in minutes [Appendix, Figure C and Appendix, Figure D]. Using these metrics, the population that does not have access to a trauma center within 60 minutes jumps to 12.8%, or approximately 541,516 people. Of those within the service area 1.15 million live between 0-15 minutes from a trauma center, 1.29 million live within a 15-30 minute range, 1.07 million live within a 30-45 minute range, and 170,000 live within a 45-60 minute range.

Race. This becomes more worrisome when race is taken into account. Of the 4.22 million people living in the Inland Empire, 11% of the Hispanic population (219,622 people) lives outside of the critical 60 minute survival window. That number jumps to 15.44% for White populations (238,812 people), 15.97% for Black populations (48,161 people), 5.4% for Asian populations (13,610 people) and 21.44% for Native American populations (4,170 people). While the total population of Native Americans in the Inland Empire is relatively low in the Inland Empire, they face the largest disparities in regards to trauma center access followed by Black and White populations.

Facility Location and Allocation. After trauma centers and hospitals within a 100 mile radius of the Inland Empire were identified, the region was left with 41 trauma centers and 271 hospital locations. Of these remaining locations, only 5 trauma centers operated within the Inland Empire and 5 were located in a different state while the remaining facilities operated in Los Angeles, Orange, Imperial and San Diego counties. These counties, however, covered a majority of the southern region. Fortunately, all of the trauma centers located within the Inland Empire were designated as Level 1 or Level 2 trauma centers, which are the highest trauma center rankings. Of the 271 hospitals identified within 100 miles of the Inland Empire, 43 operated within the region while the rest were located outside San Bernardino and Riverside counties.

After a New-Location Allocation analysis was run [Appendix, Figure E], ArcMap determined that the most optimal location for the creation of a new trauma center would be facility 111, or the St. Mary Medical Center in Apple Valley. This was followed by facility 297, or the Hi-Desert Medical Center in Joshua Tree. Finally, it suggested facility 135, or the Barstow community Hospital in Barstow. All three of these locations are located within the areas of interest labeled A and B in Figure 1.

POLICY IMPACT & SUGGESTIONS

The results of our study suggest that the Inland Empire would benefit from building and expanding particular hospitals into trauma centers including the St. Mary Medical Center, the Barstow Community Hospital, and the Hi-Desert Medical Center [Table 1]. Our primary suggestion would be to expand trauma center services to the St. Mary Medical Center in Apple Valley, California. This new location alone would increase trauma center accessibility by 8.9% and include 378,121 new patients. This is more than the total new population covered by the second and third recommended combined. The second recommended location is the Hi-Desert Medical Center in Joshua Tree, California. Converting this facility to a trauma center would increase accessibility by 1.6% and add 5,909 new patients. The final suggested location is at the Barstow Community Hospital in Barstow, California. Converting this facility into a trauma center will increase trauma center accessibility by 0.9% and expand coverage to 36,414 new patients. Yet, we would strongly encourage that the Saint Mary Medical Center be the primary candidate for expansion. In the unlikely event that all three all three candidates are converted into trauma centers, we would expect to see inaccessibility drop to 1.4% (an 89% increase). This means Inland Empire trauma patient coverage would then be at 97.6%. Expanding these hospitals also has a positive effect in reducing disparities by race. For Hispanic populations the percentage of the population without access to a trauma center drops from 11% to 7.85%. The effect is greater for White populations as inaccess drops from 15.44% to 10.38%, Black population inaccessibility drops from 15.97% to 12.35% and Asian population inaccessibility drops from 5.4% to 4.12%. Unfortunately, Native American populations do not stand to benefit greatly from any of these changes and we would encourage a needs assessment to be conducted for Native American populations and assess what steps can be taken to make sure the community gets the assistance it needs in developing community health and trauma center accessibility.

Selected Facilities	Location 111 St. Mary Medical Center	Location 297 Hi-Desert Medical Center	Location 135 Barstow Community Hospital
Facility Location	Apple Valley, CA	Joshua Tree, CA	Barstow, CA
New Block Groups	13,255	5,909	2,460
New Patient Coverage	**378,121 (8.9%)**	**66,946 (1.6%)**	**36,414 (0.9%)**

Table 1 Trauma Center Allocation Results Results from the New-Location Allocation model are shown. The percentage of New Patient coverage is relative to the total population of the Inland Empire.

LIMITATIONS

Although GIS offers an accurate and objective way to assess the need of trauma centers in various communities, our study was conducted with several limitations. First, the data we assessed is retrospective in nature. We conducted our studying using data from 2014 as well as census data ranging back to 2010 due to data availability. While we had access to projected 2018 census data we preferred to use data with more concrete conumbers rather than estimates. Either way, because both years are 4 years away from 2014, either would have been a good way to conduct an analysis with the 2014 hospital and trauma center data. Upon closer examination, there has been little to no change in the hospital and trauma center locations between 2014 and

2020, particularly in the Inland Empire, meaning our maps are accurate, although not reflective of current populations. While trauma center and hospital locations remained the same, population growth within the Inland Empire, and California as a whole, within the last decade will greatly affect our calculated disparity rates. We can expect those disparities are in fact greater than the analysis we conducted. We hope that this analysis can be conducted again once the 2020 census has been completed.

Second, the scope of our examination is limited to ground transportation. The use of air ambulances is popular however, because previous studies have concluded that driving times to trauma centers are associated with death risks, so we decided to focus on this aspect of trauma center accessibility. We also took into consideration the fact that severe weather patterns can affect the availability of air ambulance use. This means that, depending on weather conditions, it may be safer to access a hospital or trauma center using ground transportation instead of air transportation.

Finally, our analysis does not account for capacity. While a center might be able to service a region from a geospatial perspective, this study did not look into how well a new trauma center would be able to handle a large number of traumatic incidents. This study would also require a comprehensive cost benefit analysis that looks at regional economies and their ability to maintain a top tier trauma center facility. While we strongly recommend the building of a trauma center at the St. Mary Medical Center in Apple Valley, evaluating the financial feasibility of a trauma center expansion was beyond the scope of our study.

CONCLUSION

Our study analyzing trauma care accessibility focuses on Riverside and San Bernardino counties. Home to over 4.2 million residents, the Inland Empire is a vast region made up of many suburban and rural communities. While the western Riverside region benefits from a higher concentration of hospitals, the persistence of trauma center inaccessibility remains, resulting in mass trauma deserts. These trauma deserts are more widely seen further inland into the region. Communities north of the San Bernardino mountain region have less accessibility to these life saving services and facilities. Our findings shed light on a significant portion of the population that does not have access to trauma care services within a critical 60 minute travel time. Our model suggested trauma center additions to three hospital locations, however, due to the high costs of operating trauma centers, stakeholders and healthcare policy makers should consider the impact that each new trauma center can have on the surrounding populations, especially areas with higher concentrations of older populations and racial and ethnic minorities.

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APPENDIX

FIGURE A

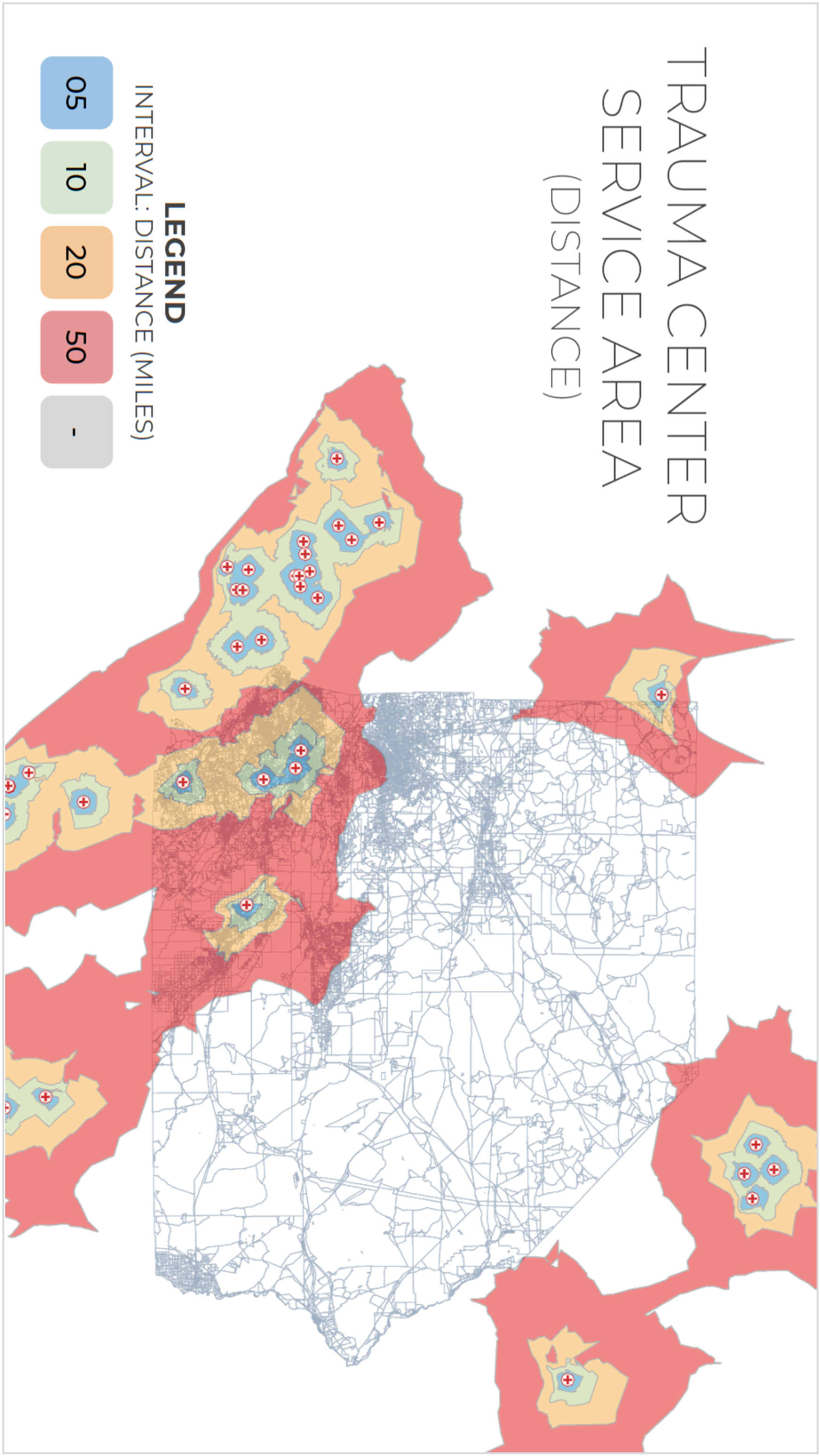


FIGURE B

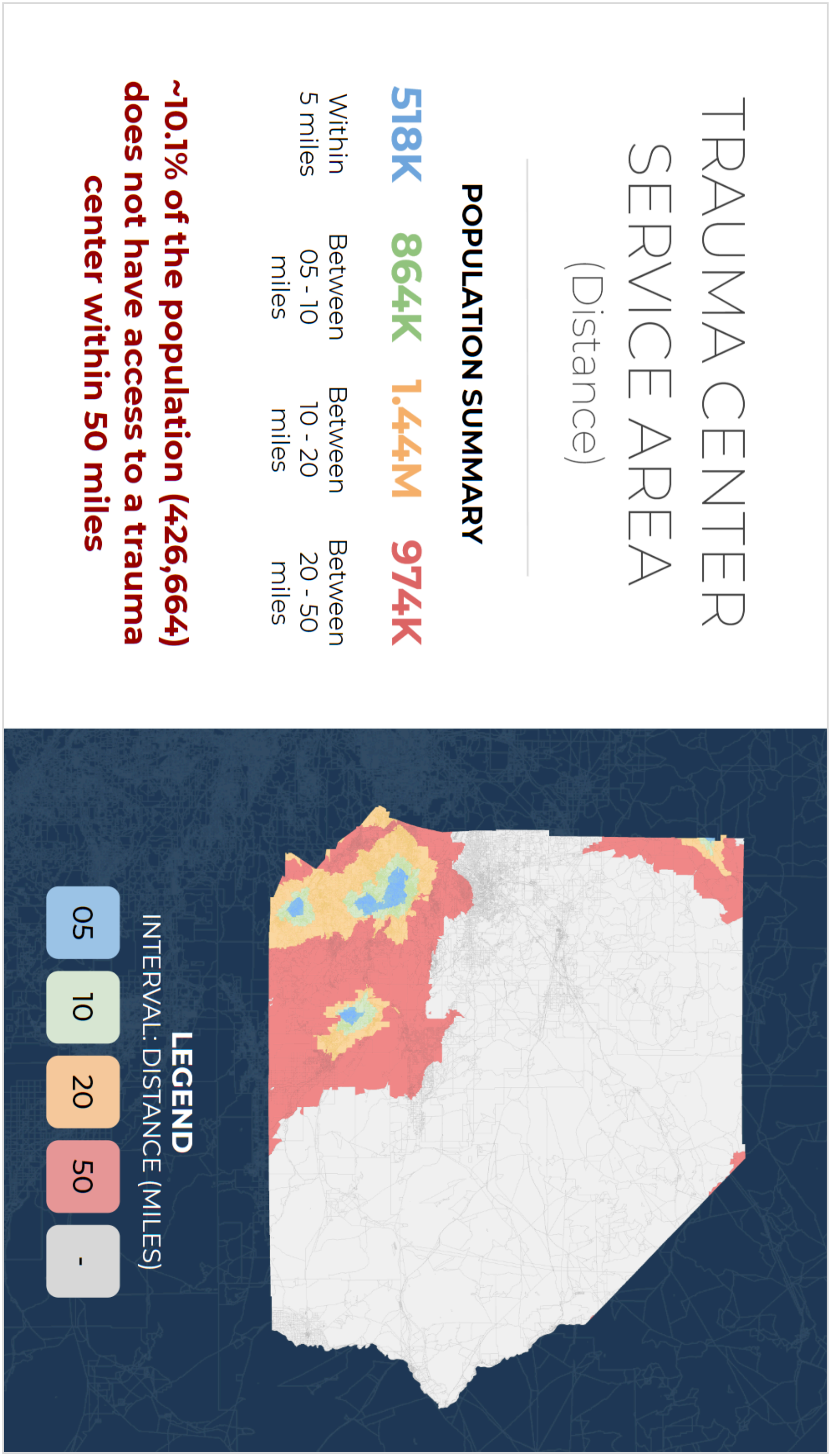

TRAUMA CENTER SERVICE AREA
(Distance)
POPULATION SUMMARY
518K
Within 5 miles
864K
Between 05 - 10 miles
1.4M
Between 10 - 20 miles
974K
Between 20 - 50 miles
~10.1% of the population (426,664) does not have access to a trauma center within 50 miles
LEGEND
INTERVAL: DISTANCE (MILES)
05
10
20
50
-

FIGURE C

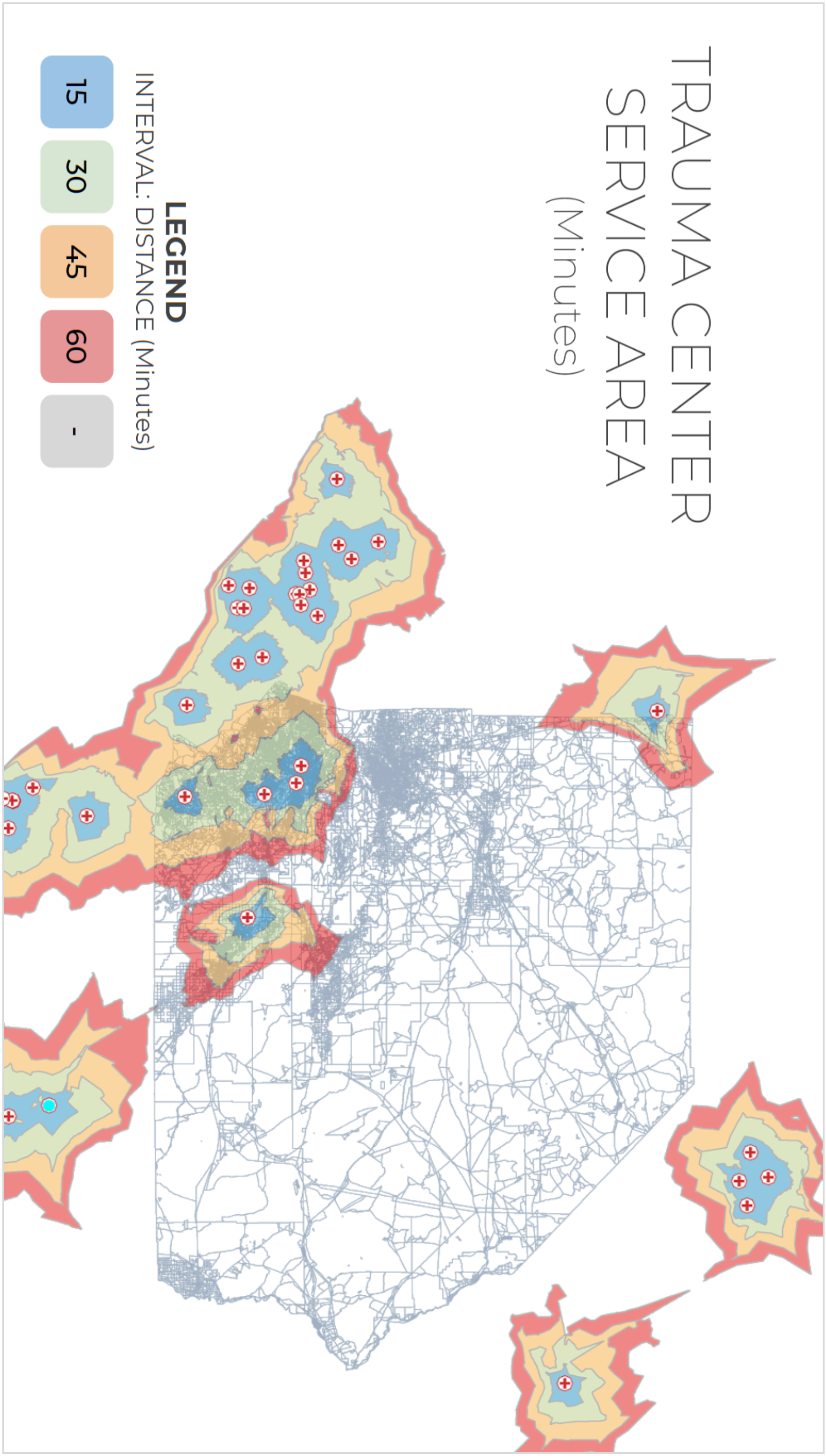

TRAUMA CENTER
SERVICE AREA
(Minutes)
LEGEND
INTERVAL: DISTANCE (Minutes)
15
30
45
60
-

FIGURE D

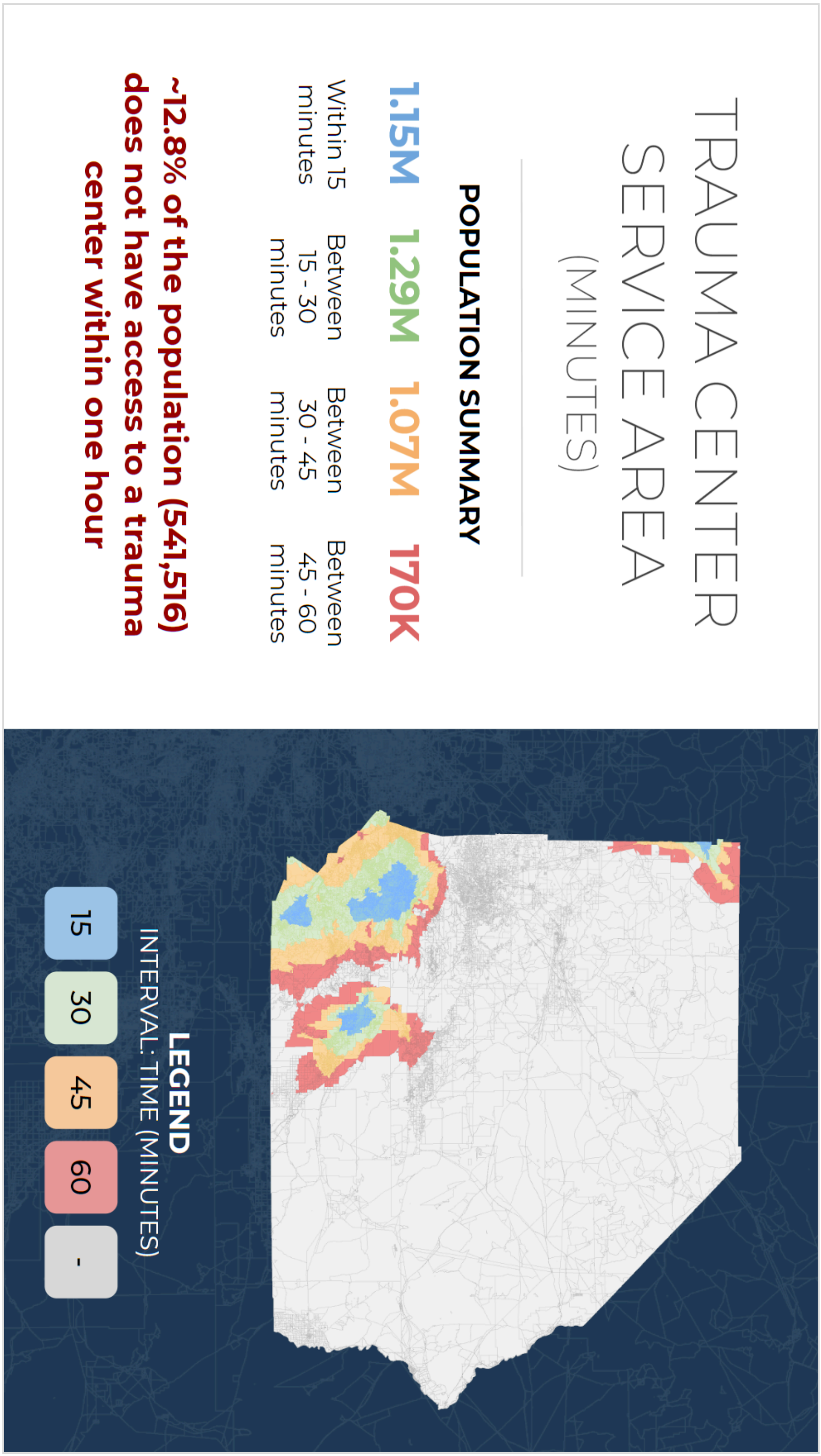
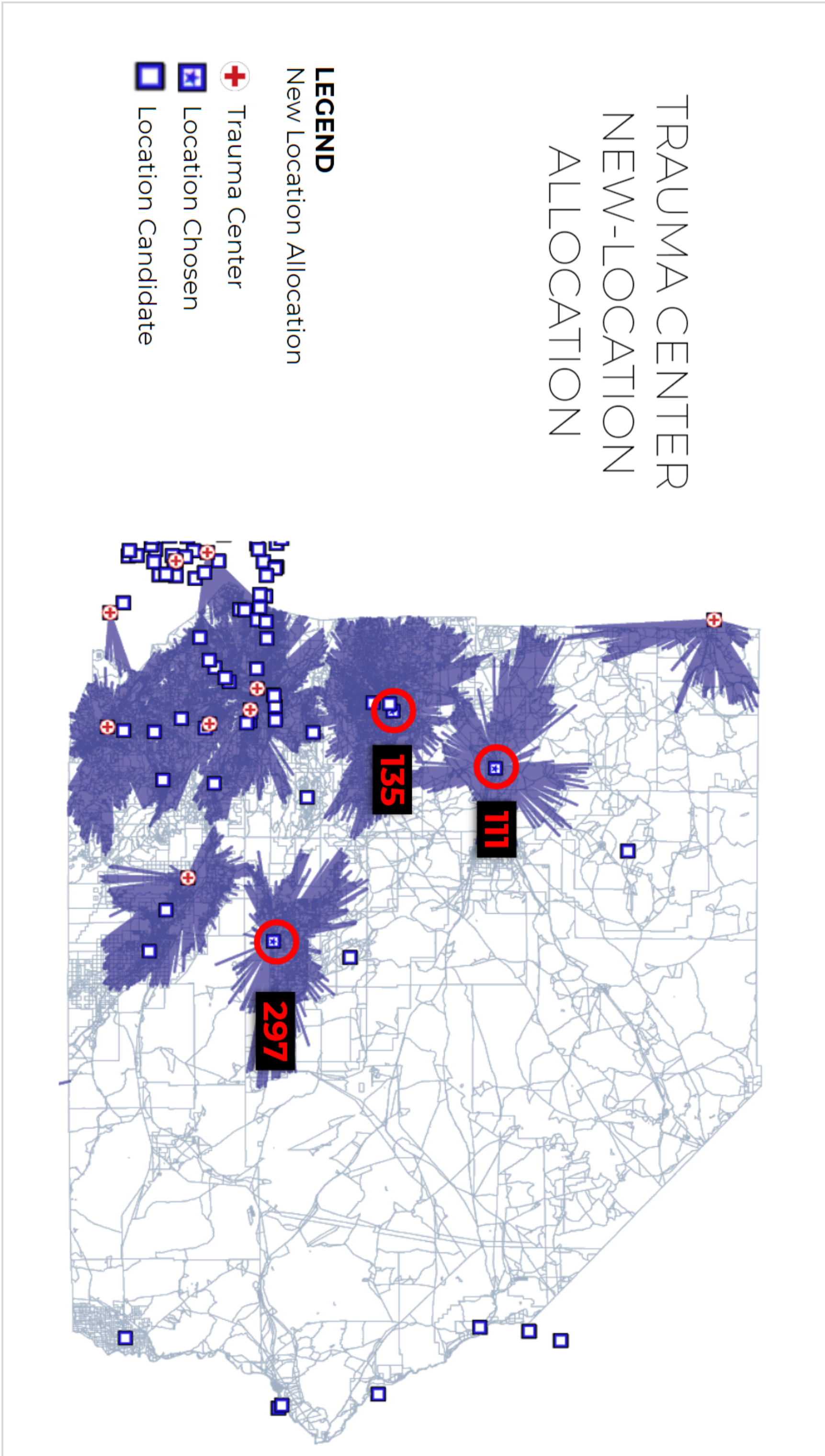

TRAUMA CENTER
SERVICE AREA
(MINUTES)
POPULATION SUMMARY
1.15M
Within 15 minutes
1.29M
Between 15 - 30 minutes
1.07M
Between 30 - 45 minutes
170K
Between 45 - 60 minutes
~12.8% of the population (541,516) does not have access to a trauma center within one hour
LEGEND
INTERVAL: TIME (MINUTES)
15
30
45
60
-

FIGURE E


TRAUMA CENTER
NEW-LOCATION
ALLOCATION
LEGEND
New Location Allocation
Trauma Center
Location Chosen
Location Candidate
135
111
297