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Redefining trauma deserts: novel technique to accurately map prehospital transport time

Leah C Tatebe ,[1] Vanessa P Ho ,[2,3] Heena P Santry,[4] Ken Tatebe[5]

[1]Department of Surgery, Northwestern University Feinberg School of Medicine, Chicago, Illinois, USA
[2]Department of Surgery, Case Western Reserve University School of Medicine, Cleveland, Ohio, USA
[3]Department of Population and Quantitative Health Sciences, Case Western Reserve University, Cleveland, Ohio, USA
[4]Department of Surgery, Kettering Hospital, Columbus, Ohio, USA
[5]Department of Radiation Oncology, Rush University Medical Center, Chicago, Illinois, USA

Correspondence to
Dr Leah C Tatebe; leah.tatebe@northwestern.edu

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ABSTRACT

Background Prehospital transport time has been directly related to mortality for hemorrhaging trauma patients. 'Trauma deserts' were previously defined as being outside of a 5-mile radial distance of an urban trauma center. We postulated that the true 'desert' should be based on transport time rather than transport distance.

Methods Using the Chicagoland area that was used to describe 'trauma deserts,' a sequential process to query a commercial travel optimization product to map transport times over coordinates that covered the entire urban area at a particular time of day. This produces a heat map representing prehospital transport times. Travel times were then limited to 15 minutes to represent a temporally based map of transport capabilities. This was repeated during high and low traffic times and for centers across the city.

Results We demonstrated that the temporally based map for transport to a trauma center in an urban center differs significantly from the radial distance to the trauma center. Primary effects were proximity to highways and the downtown area. Transportation to centers were significantly different when time was considered instead of distance (p<0.001). We were further able to map variations in traffic patterns and thus transport times by time of day. The truly 'closest' trauma center by time changed based on time of day and was not always the closest hospital by distance.

Discussion As the crow flies is not how the ambulance drives. This novel technique of dynamically mapping transport times can be used to create accurate trauma deserts in an urban setting with multiple trauma centers. Further, this technique can be used to quantify the potential benefit or detriment of adding or removing firehouses or trauma centers.

BACKGROUND

For critically injured patients, rapid transport to appropriate trauma care is imperative. This 'golden hour' concept remains the cornerstone of the ordered trauma system in the USA.[1] Trauma systems offer specialized care and expertise for the injured patient and are widely accepted as an effective strategy to reduce mortality and improve outcomes.[2–4] While the concept of rapid transport remains a central dogma in trauma care, specific aspects of how to optimize and operationalize prehospital transport to maximize access to trauma centers remain in flux.

Key to these discussions are 'trauma deserts' or areas that lack timely access to trauma care. Trauma deserts were first described by Crandall *et al*, who studied the effects of patients with gunshot wounds in the Chicagoland area and found that being shot more than 5 miles from a trauma center was associated with an increased risk of death (OR 1.23, 95% CI 1.02 to 1.47, p=0.03).[5] Further supporting this concept, studies have shown that increasing distance to a trauma center in the metropolitan area surrounding Detroit is associated with increasing mortality after penetrating trauma.[6] Trauma deserts further were postulated as a possible underlying mechanism contributing to disparate racial and ethnic outcomes in trauma care, where urban trauma deserts are more likely to be found in areas with higher populations of minority residents.[7] Effective trauma transport must not only be rapid but also reach the right destination. A recent study suggested that geographically informed triage has the potential to inform prehospital transport to improve outcomes.[8]

Although trauma deserts were defined using 'as the crow flies' radial distance, urban traffic patterns can drastically affect the amount of time taken to move even small distances. The appropriate destination may not always be one which is geographically closest. Therefore, we sought to apply more rigorous geographical information system modeling to the previously described Chicagoland area. We hypothesized that this method could be used to create temporally defined trauma deserts maps and inform high-traffic transport time changes based on time of day.

METHODS

No specific EQUATOR network guideline was applicable for this descriptive technique analysis. We created a matrix of latitude and longitude boundaries of the County of Cook from publicly available mapping information. Adjustments were made for the border of the lake as attempts to determine transport times over bodies of water resulted in errors. The coordinates of the target location were set. Using code adapted from the Google Maps application programming interface (API), transport times at a given date and time were then calculated in an iterative fashion through the grid of coordinates to the target location. Distance traveled was also exported for each calculation, and from this, the average speed for the transport was extrapolated. The transport times could then be filtered for maximum time to exclude all coordinates for which transport time was greater than the set cut-off. The final dataset of starting latitude, starting longitude, travel time, distance, and speed was exported into a comma-separated values file for processing. Median

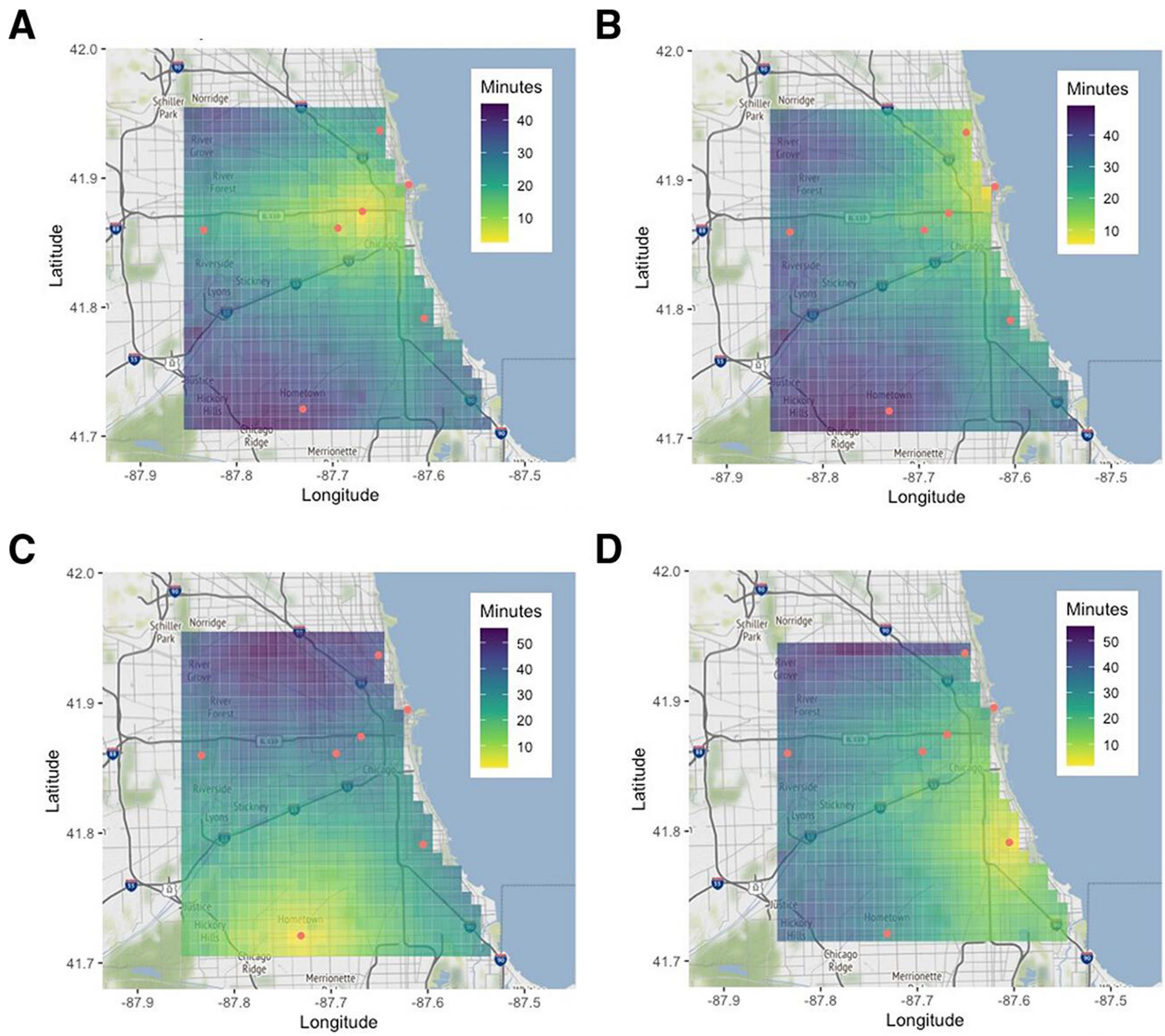

Figure 1 Transport times in minutes to four representative level 1 trauma centers (A–D). Red circles represent all level 1 trauma centers in the Chicagoland area.

and IQR were calculated for the continuous variables of time traveled in minutes and speed in miles per hour. Normality for these datasets were confirmed with the Shapiro-Wilk test, and comparisons were made with Student's t-test with a significance threshold of $p<0.05$.

All graphical representations were created using R V.3.5.1 of R Core Team (R Foundation for Statistical Computing, Vienna, Austria). Packages used included devtools, tidyverse, maps, ggthemes, albersusa, viridis, ggmap, ggplot2, Hmisc, pracma, deldir, interp, and akima. The graphic output file could then be displayed as a heatmap overlay demonstrating the transport time from that location to the target location. After applying a time cut-off, additional target locations could be also be overlayed to demonstrate each target locations temporally defined radius. For the graphics shown here, the timestamp was Friday, July 1, 2022 at 08:00; the target location was selected as one of several level 1 trauma centers; and the transport time cut-off used was 15 minutes.

RESULTS

Figure 1 shows the transport times in minutes to four representative level 1 trauma centers in the Chicagoland area. One can see how the transport times to the centers in Figure 1A,B improve along highways. The transport times to the center in Figure 1c is more uniform as it is not near a highway. The substantial impact of downtown location on transport times is clear when comparing times in Figure 1B,1C. Table 1 shows the transportation characteristics for transports within 5 miles of distances traveled for the three trauma centers for which the 5-mile cut-off was completely within our coordinate range. Comparing the trauma centers, we found that there was a significant change in the time it took to travel within the 5-mile distance ($p<0.001$).

Figure 2 demonstrates how a 15 minute transport time cut-off between several trauma centers map with each other. Again, the areas can be seen elongating along the highways and contracting

Table 1 Median and IQR for time in minutes and speed in miles per hour for locations within 5 miles traveled

Transport within 5 miles	Time (minutes), median (IQR)	Speed (mph), median (IQR)	P value
Center 1	31 (25–38)	14 (12–16)	Reference
Center 2	29 (19–36)	16 (16–17)	<0.001
Center 3	25 (20–32)	15 (13–16)	<0.001

Statistical comparison was performed using Student's t-test.

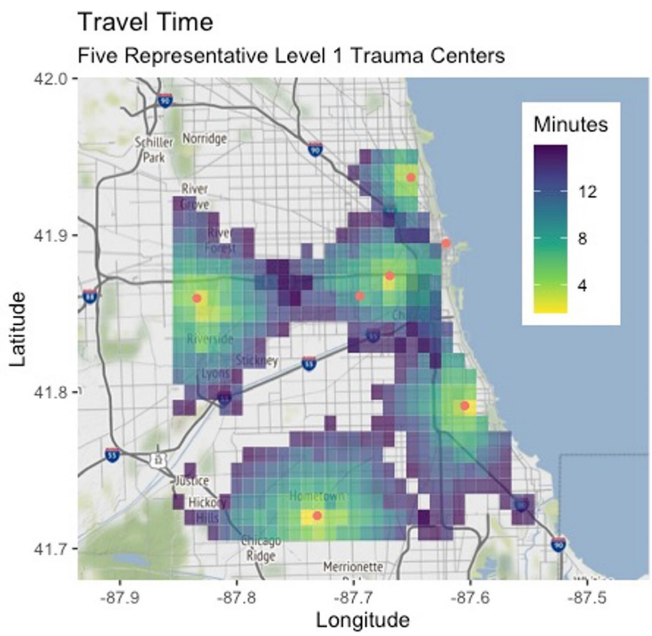

Figure 2 Transportation time to five level 1 trauma centers by location in the city. Time cut-off set at 15 minutes. Red circles represent all level 1 trauma centers in the Chicagoland area.

as the downtown area is approached. In the overlap between catchment areas between trauma centers, there are locations where it appears to be faster to transport to the more geographically distant trauma center. Along this border, the difference in transport time is a median of 1.9 min (IQR 1.1 to 2.4 min, maximum 5.6 minutes). This difference was diminished during low traffic times (overnight hours).

DISCUSSION

Our analysis demonstrates that a map grounded in publicly available dynamic transportation data within an urban center can lead to a significantly different conceptualization of 'access' to timely trauma care than a static radial distance to a trauma center. Interestingly, our data also suggest that traffic patterns can change whether a ground transport crew can truly access the nearest trauma center in a timely fashion, as there are a few exceptions where the geographically closest trauma center was not the center which could be reached the fastest by prehospital personnel. We demonstrated that the temporally based map for transport to a trauma center in an urban center differs significantly from the radial distance to the trauma center. We were further able to map variations in traffic patterns and thus transport times by time of day. In our analysis, the 'closest' trauma center by driving time changed based on time of day and was not always the closest hospital by distance.

The optimal transport time for trauma patients remains an area of debate. For patients with severe injuries or acute bleeding, a short distance to the trauma center has been shown to be advantageous.[5 6 8–10] However, in these studies, the absolute distance to the trauma center was used as a proxy for rapid transport. With modern technology and accurate traffic data, we can and should improve on these estimations. Other important factors include the amount of time between a local fire house or Emergency Medical Services (EMS) dispatch location to the location of the patient, scene safety, and the amount of time spent at the scene. Destination selection is also key.[8] Many studies have examined ways to decrease the number of minutes between injury and arrival to the hospital, including 'scoop and run' to decrease scene time,[11–13] and use of helicopters for patients outside a timely ground transport radius.[9] A recent scoping review of ambulance dispatch algorithms suggested that there are opportunities for improvement in dispatch strategies to standardize outcomes and develop intelligent dispatch systems.[14] Thoughtful integration of dynamic time-sensitive geolocation algorithms may provide an innovative strategy to reduce patient prehospital times by meaningful minutes.

These data may also have wider potential for application than just the individual patient's transport. A variety of factors contribute to the amount of time between a patient's injury and arrival to a trauma center; many are geographically relevant. The methods described can be used for local resource allocation, staffing considerations, and dispatch planning. If a new firehouse is to be built which will be dispatching EMS personnel, identifying geographical locations which are not currently easily accessed by existing dispatch locations or locations that are less likely to be affected by heavy traffic could be considered. These methods could be used in real time to change triage destinations, depending on local or expected traffic patterns. Historical data for similar traffic strategies can be used to estimate accurate transport times to account for weather changes and seasonal variation, and road closures or temporary heavy traffic times due to local events (eg, a sporting event or concert).

Trauma center access should be carefully and deliberately maintained, and considerations differ for urban than rural trauma. In 2005, it was estimated that nearly 70% of US residents had access to a level 1 or 2 trauma center within 45 minutes by ground transport or helicopter, which increased to 84% when the parameter was increased to 60 minutes.[15] A more recent study estimated that 80% of the US population had access to a trauma center (of any level), defined as 30-minute ground transport times.[16] Many of these studies suggest that lack of trauma access is an issue mostly in rural America.[15 17] Urban centers have different issues affecting access to trauma care. One study of three major cities, including Chicago, Los Angeles, and New York, examined access to trauma care (here defined as within 8 km) and found that, even in major urban centers, access to trauma care varied such that black majority census tracts had lower relative access to trauma. Distance from a trauma center may be potentiating disparities in trauma; a study examining trauma care in Maryland found that patients with highest odds of death were injured in communities with higher median age, lower per capita income, or locations farthest from trauma centers. Unfortunately, opening more trauma centers may not be the answer. Although the absolute number of trauma centers is increasing in the USA, it is unclear whether these hospitals provide new access to previously underserved populations.[16] We suggest that dynamic models of considering geographical parameters can be used to plan and improve urban access to trauma care.

Our study examined the estimated driving time between the potential geographical sites of injury and the trauma centers in the Chicagoland area. The methodology is an innovative application, but it has several limitations. The primary limitation is that the times calculated are based on civilian driving rules. One would anticipate the ambulance transport with 'lights and sirens' would be faster than for the general public. A prior study demonstrated this difference to be 3–5 minutes.[18] The cut-off presented of 15 minutes assumes covering the previously used 5 miles at 20 mph. If an ambulance was traveling on average at 30 mph (10 mph over the general public), this would scale down to approximately 10-minute transport time. The details of transport within overlapping catchment areas may not be as significant as a result. Second, the Google Maps API requires a timestamp for a predictive model that must be in the future. One cannot retrospectively look back to see what actual transport times were. If one wanted can approximate the effect of a large sporting event, for example, it would be best examined in real time, running the algorithm just a few minutes in the future. Finally, this is only a proof-of-concept analysis of one city and only considering urban ground transport. If one wanted to use this model for one's own city, external validation should be performed using transport times from different regions. Actual transport times from the Chicagoland area were not available for comparison. Other dynamic mapping applications exist, but advantages of API include its accessibility and regular updates.[19]

Dynamic mapping technology has improved drastically and should be leveraged for optimal trauma system planning. Trauma care for the critically ill is a race against the clock. It is the 'golden hour' not the 'golden mile'. This methodology identified areas within an urban center where the shortest transport time to a trauma center did not correlate with the closest center. As such, future evaluations of trauma deserts should use transport time over radial distance.

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ORCID iDs
Leah C Tatebe http://orcid.org/0000-0003-0401-3813
Vanessa P Ho http://orcid.org/0000-0002-6113-2555

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