Ground and Helicopter Emergency Medical Services Time Tradeoffs Assessed with Geographic Information

Michael J. Widener; Zac Ginsberg; Daniel Schleith; Douglas J. Floccare; Jon Mark Hirshon; Samuel Galvagno

INTRODUCTION: We describe how geographic information systems (GIS) can be used to assess and compare estimated transport time for helicopter and ground emergency medical services. Recent research shows that while the odds of a trauma patient's survival increase with helicopter emergency medical services (HEMS), they may not increase to the extent necessary to make HEMS cost effective. This study offers an analytic tool to objectively quantify the patient travel time advantage that HEMS offers compared to ground emergency medical services (GEMS).

METHODS: Using helicopter dispatch data from the Maryland State Police from 2000–2011, we computed transport time estimates for HEMS and GEMS, compare these results to a reference transport time of 60 min, and use geospatial interpolation to extrapolate the total response times for each mode across the study region.

RESULTS: Mapping the region's trauma incidents and modeling response times, our findings indicate the GIS framework for calculating transportation time tradeoffs is useful in identifying which areas can be better served by HEMS or GEMS.

DISCUSSION: The use of GIS and the analytical methodology described in this study present a method to compare transportation by air and ground in the prehospital setting that accounts for how mode, distance, and road infrastructure impact total transport time. Whether used to generate regional maps in advance or applied real-time, the presented framework provides a tool to identify earlier incident locations that favor HEMS over GEMS transport modes.

KEYWORDS: travel time, emergency medical services, geographic information systems, trauma transport.

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Early reports from the Korean and Vietnam Wars suggested a 2% increase in survival for casualties as the time to definitive care improved from 5 h to 1 h with prompt transport by helicopter to forward-deployed surgical theaters.[9] Based on the results of these wartime experiences, U.S. civilian helicopters were used for the first time in 1970 to transport traumatically injured patients to trauma centers. Today, the use of helicopter emergency medical services (HEMS) for the transportation of trauma patients is commonplace in most developed nations.[7–9]

Helicopters are capable of bringing advanced care to the patient and transporting patients with major trauma significantly faster than ground units; the speed benefit is more pronounced as distance from a trauma center increases. Nevertheless, recent research has questioned which traumatically injured patients derive the greatest benefit from the use of this limited and resource-intensive transportation modality.[9]

While recent work has demonstrated an independent association with improved survival when HEMS is used for adults with major trauma,[1,8,9] the specific elements responsible for improved outcomes remain unclear. In particular, dependable triage guidelines to ensure that the right patient is transported by the right modality to the right destination remain elusive.[5] To date, only a few investigators have attempted to use geographic information systems (GIS) technology to establish service distributions for HEMS,[4,11,17] model ideal locations for helipads,[6,12,15] compare road network versus Euclidean (e.g., straight-line) distance travel for

From the Department of Geography, University of Cincinnati, Cincinnati, OH; and the Department of Trauma and Surgical Critical Care, R. Adams Cowley Shock Trauma Center, the Department of Emergency Medicine, and the Division of Critical Care Medicine, Department of Anesthesiology, University of Maryland School of Medicine, Baltimore, MD.

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Address correspondence to: Michael J. Widener, Department of Geography, University of Cincinnati, P.O. Box 210131, Cincinnati, OH 45221; michael.widener@uc.edu.

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ground emergency medical services (GEMS),[3] and to accurately determine the role of out-of-hospital intervals and mortality for trauma patients.[14] GIS is a powerful, yet underused tool with the potential to elucidate important information about the role of distance and time as these variables relate to HEMS.

The objective of this work was to describe how GIS technology can be used to assess estimated travel time using helicopter dispatch data. The focus of this analysis is to introduce a methodology that facilitates improved accuracy for determining time from point of injury to definitive care. The primary purpose of this work is to present a methodology that may be used in emergency medical services dispatch to allocate HEMS resources for patients in need of time-dependent interventions for severe traumatic injuries. Methods for transferring administrative dispatch data to geospatial data are described, as well as a counterfactual analytical model to compare travel time between GEMS and HEMS.

METHODS

Our analysis compared the estimated travel times of transporting trauma patients via HEMS and GEMS to better understand the time tradeoffs between the two modes. These estimated travel times were computed in a GIS using data on HEMS deployments from the Maryland State Police Aviation Command "Trooper 3" medical evacuation helicopter based at Frederick Municipal Airport in central Maryland. Transports to the Shock Trauma Center (STC) in Baltimore, MD, during January 1, 2000, to January 31, 2011, were analyzed. The data include only scene trauma transports to STC; no interfacility transports were included.

Data

After institutional review board approval was granted by the University of Maryland School of Medicine, helicopter dispatch data were obtained from the Maryland State Police Aviation Command dispatch center (SYSCOM) located at the Maryland Institute for Emergency Medical Services Systems. All data were completely de-identified a priori and only information regarding dispatch times, landing (pick up) sites, and trauma center destination (STC) were available for analysis.

Since the SYSCOM dispatch data are administrative rather than research data, there were many misspellings and inconsistent address formats in the helicopter landing sites (pick up address) attribute of the trauma incident records. A series of computer programming steps were initiated to accurately geocode the majority of available data. First, data were edited by a Python script that corrected common mistakes. For example, the script alters the incorrectly spelled city name of "Lineborough" to the correctly spelled "Lineboro." Similarly, an address identified by cross-streets can be changed from "Main St, Elm St" to "Main St and Elm St." Next, the 3509 records of trauma incidents flown by Trooper 3 were sent to an address locator tool in ArcGIS 10.2 [Environmental Research Systems Institute (Esri), Redlands, CA] using a 2005 road file maintained by Esri and Tele Atlas (Tele Atlas NV, Ghent, Belgium), which accurately geolocated 1464 of the incidents (**Fig. 1**). The remaining 2045 records were programmatically submitted to Google Map's (Google, Mountain View, CA) geocoder, where an additional 1646 incidents were successfully geolocated, for a total of 3120 (88.9%) geolocated records.

Google Map's online geocoder is capable of locating additional incidents using up-to-date street data and Google's advanced algorithms that can interpret misspelled or ambiguous information better than the

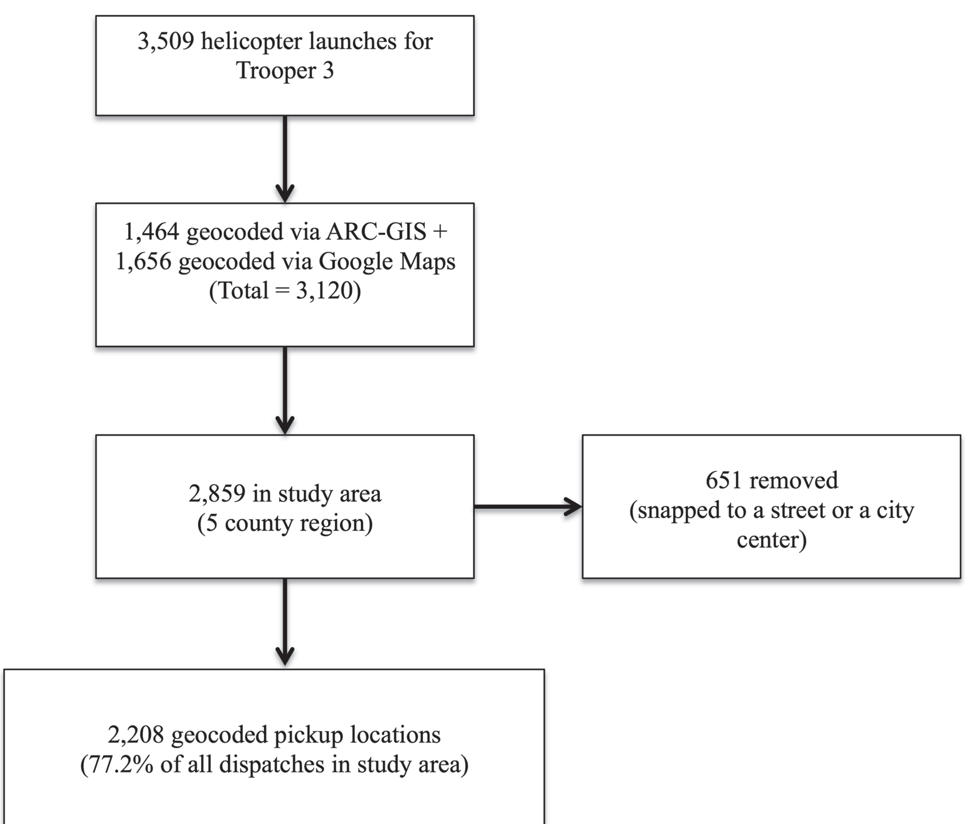

Fig. 1. Study flow diagram using Maryland State Police Aviation Command data for "Trooper 3" medical evacuation helicopter to the Shock Trauma Center (STC) in Baltimore, MD, January 1, 2000, to January 31, 2011.

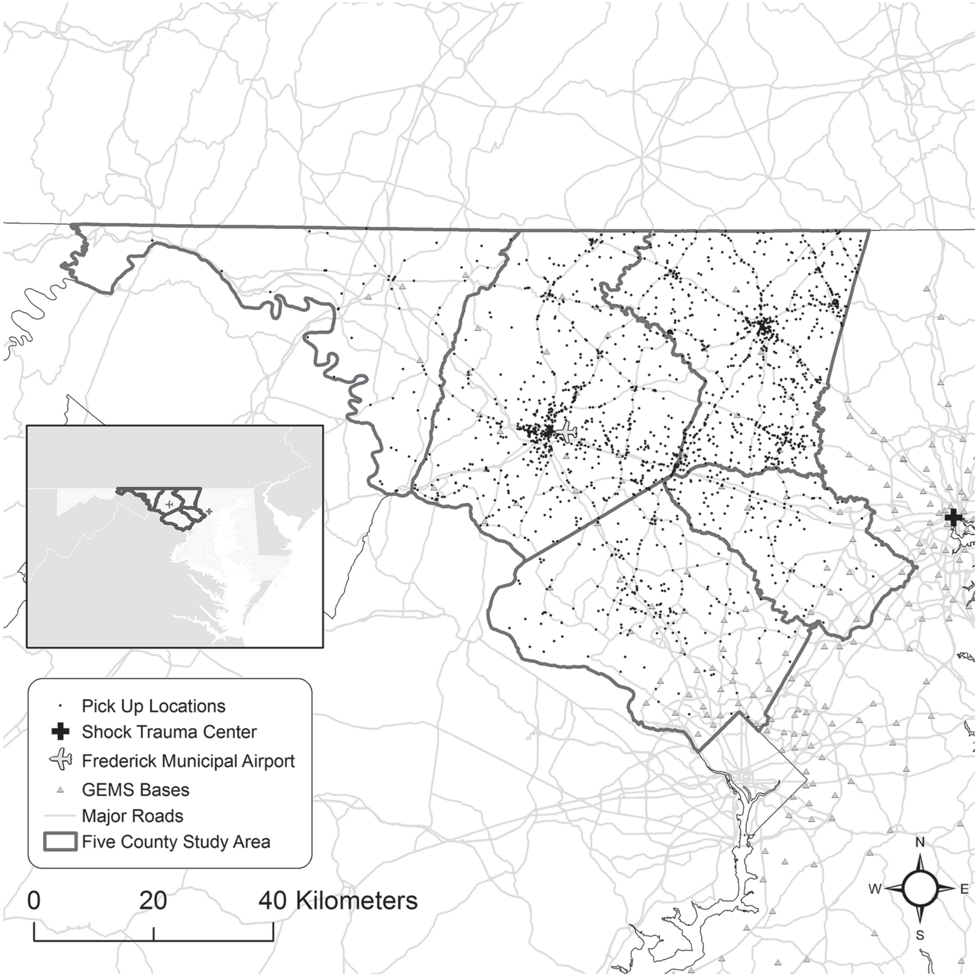

Fig. 2. Helicopter pick-up locations and ambulance stations in Fredrick County and environs, Maryland, January 1, 2000, to January 31, 2011.

reliable, but less flexible ArcGIS address locator tool. However, this flexibility also results in the geolocation of records to more general sites (e.g., the street or city center) when the address or intersection data are unclear. For example, an address with a valid city name and zip code, but an incorrect or indecipherable street address, will be located at the center of the city. Likewise, a record with an incorrect street address number, but with valid street and city data, will be located at the middle of the street in question.

The dataset was further reduced to include only pick up locations within Frederick County and the four neighboring counties of Carroll, Howard, Montgomery, and Washington for a total of 2859 records. Lastly, any records that were geocoded to a general location (e.g., a city center or the middle point of a street) were discarded to ensure that the locations of records are not biased toward the midpoint of roads or city centers for a final dataset of 2208 spatially located records, which made up 77.2% of geolocated records in the five-county study area, and 62.9% of all incidents flown by Trooper 3.

The authors could not find a comprehensive list of all ambulance bases in the state of Maryland. Therefore, using a combination of county emergency medical services government websites, firedepartment.net, and usfiredept.com, local emergency services department websites were identified. Every fire or ambulance station site was then reviewed to determine if their apparatus included an ambulance or medical response capability. If so, they were included and their address recorded. In addition to the records regarding HEMS pick up sites, the addresses of the 341 ambulance bases distributed throughout the state of Maryland, the R. Adams Cowley Shock Trauma Center, and the Frederick Municipal Airport (the base of Trooper 3) were geolocated using ArcGIS's address locator tool. Of these, only 21 of the ambulance bases were not found via the address tool, but were subsequently located through searches on Google Maps and manually geolocated. **Fig. 2** displays the study area and previously referenced data.

Lastly, network calculations were run on the aforementioned 2005 road file maintained by Esri and Tele Atlas. The road data includes speed limit information, making it possible to easily estimate travel time in minutes, given an assumed vehicle speed.

Procedures

Two travel times were computed for each of the 2208 geolocated records in the study area. The first formula (**Eq. 1**) estimates the time required to transport a patient to the STC via GEMS and the second formula (**Eq. 2**) estimates the time required to transport a patient via HEMS.

The GEMS estimate assumes that local authorities are immediately notified about the incident, an ambulance from the closest ambulance base is sent to the incident location, a transition time period transpires where the patient is transferred to the vehicle, and the ambulance drives to the STC in Baltimore. This can be formally represented as follows:

$$T_{total_G} = T_{base_G} + T_{transition_G} + T_{STC_G} \quad \text{Eq. 1}$$

T_{total_G} is the total time in minutes it takes to move a patient to the STC from the site of the incident via ambulance. T_{base_G} is the travel time in minutes from the closest ambulance base to the site of the incident over the road network, where the ambulance is assumed to travel a constant 10 mph over the official speed limit. This time, while not endorsed nationally,[13] is derived based on expert consensus of the authors to provide a realistic estimate of actual ground time. $T_{transition_G}$ is the assumed time it takes to move a patient into the ambulance and prepare them for transport. While there is no industry standard for suggested loading times from ground to GEMS,[2] for this study, this variable was assigned a constant value of 15 min based on a random sample derived from prehospital data available in the STC trauma registry. Finally, T_{STC_G} is the travel time in minutes from the site of the incident to the STC across the road network, with an assumed speed of 10 mph over the posted speed limit. It should be noted that this formula does not account for traffic delays (i.e., rush hour, construction delays, traffic jams).

The HEMS estimates use similar assumptions as the GEMS estimates (e.g., immediate notification of the incident), but incorporates travel times that characterize a helicopter transport. The total time from the site of the incident to the STC via HEMS is calculated as follows:

$$T_{total_H} = T_{base_G} + T_{FMA_H} + T_{transition_H} + T_{STC_H} \qquad \text{Eq. 2}$$

T_{total_H} is the total time in minutes it takes to move a patient to the STC from the site of the incident via helicopter. T_{base_G} is the same as described above and is included because a helicopter is only called onto the scene after first responders determine the case is of a certain level of severity. As it is known that all of the patients in this dataset were transported to the STC by a helicopter departing the Frederick Municipal Airport, T_{FMA_H} is the estimated travel time from the Frederick Municipal Airport to the site of the incident, assuming the helicopter travels in a straight line and at a cruising speed of 225 kph. $T_{transition_H}$ is equal to 20 min and is the assumed time it takes to move a patient into the helicopter and prepare them for transport. This time interval was based on the median transition

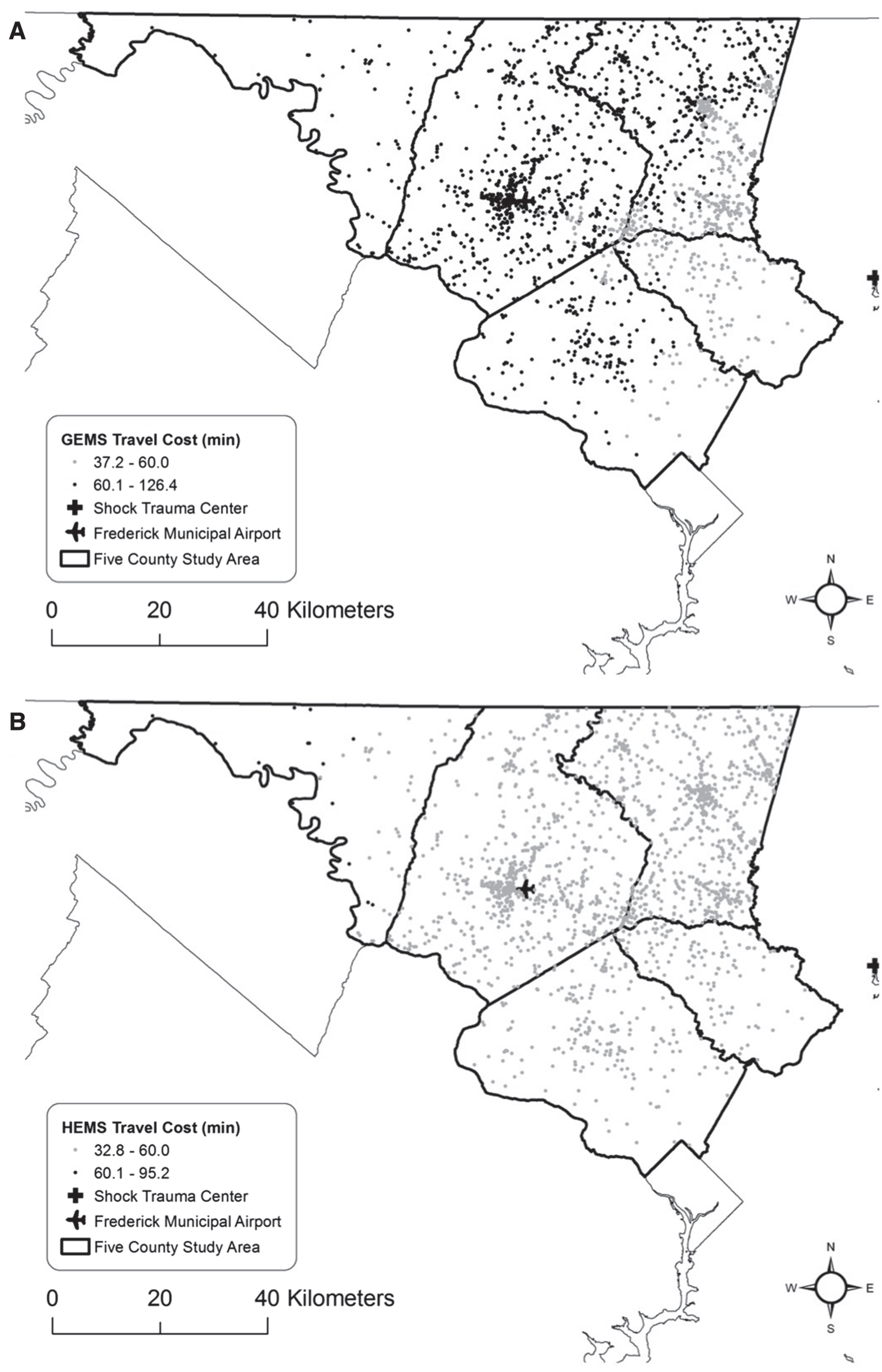

Fig. 3. A) GEMS travel time in minutes and B) HEMS travel time in minutes.

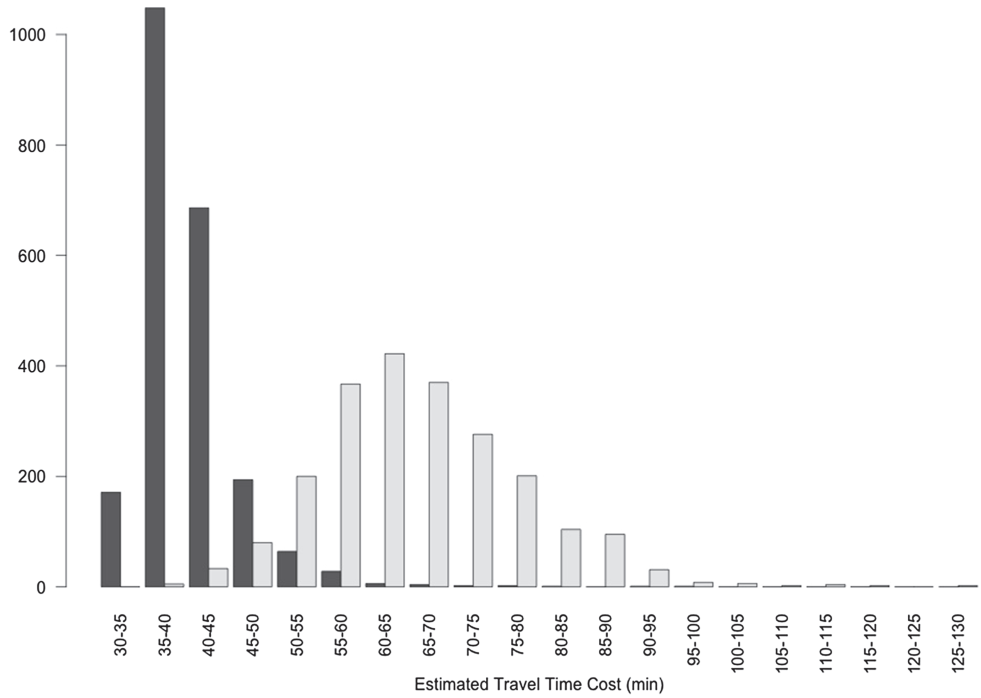

Fig. 4. Histogram of T_{total_G} (light gray) and T_{total_H} (dark gray) travel times in minutes.

times documented in the SYSCOM helicopter dispatch database. Lastly, T_{STC_H} is the estimated travel time from the site of the incident to the STC, assuming a straight-line flight path and a cruising speed of 225 kph.

Eqs. 1 and 2 are calculated and linked to all records in the geocoded dataset. This new information allows for the direct comparison of realistic estimates of both HEMS and GEMS travel times, discussed in depth in the following section.

RESULTS

The estimated travel times are plotted in **Fig. 3**, showing estimated GEMS times and HEMS times in Fig. 3A and Fig. 3B, respectively. For both figures, points are categorized as having an estimated travel time of less than or equal to 60 min, or greater than 60 min. This categorization was chosen so as to indicate where patients would arrive at the STC within the reference time of 60 min (i.e., the “golden hour”).

Fig. 3A shows that the location of 685 of the 2208 trauma incidents, with an estimated GEMS travel time of 60 min or less, were primarily distributed within the three eastern counties, with only 43 in the southeastern portion of Frederick County near a major highway, I-70. Fig. 3B shows the majority of trauma incidents (2191) have a HEMS travel time of less than or equal to 60 min, while the 17 incidents with estimated travel

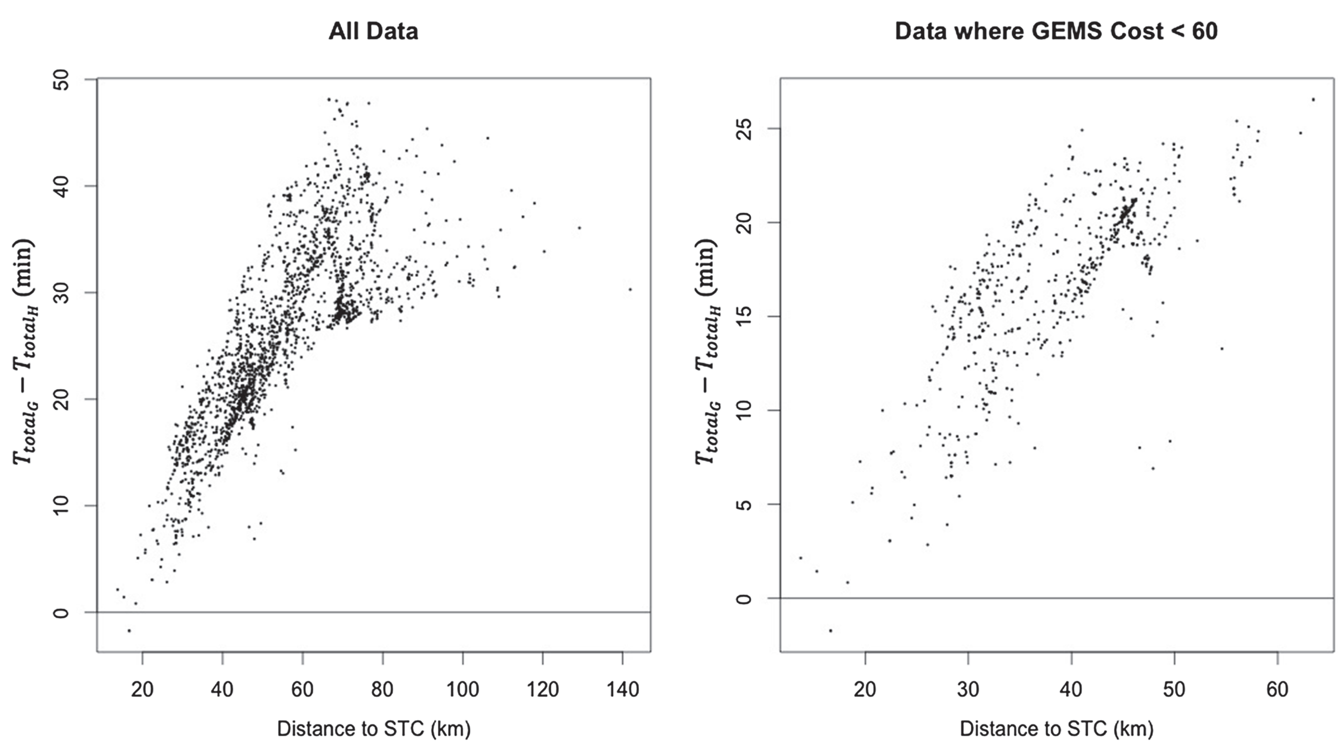

Fig. 5. Differences in estimated travel time between GEMS and HEMS versus distance in kilometers to the STC.

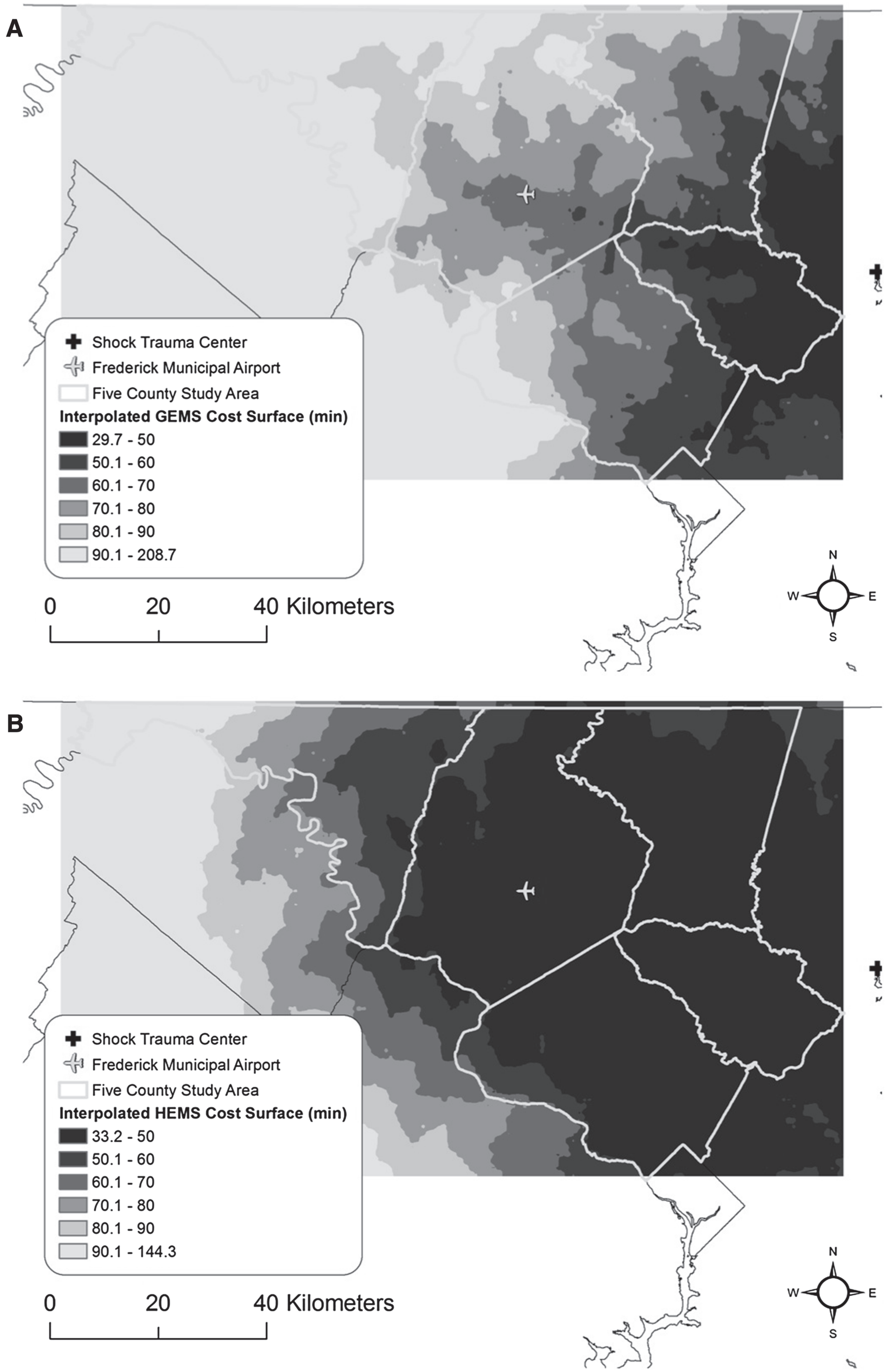

Fig. 6. Maps of the A) T_{total_G} interpolated time surface and B) T_{total_H} interpolated time surface.

times greater than 60 min were mostly distributed in the peripheral, western parts of the study area. The distribution of times for both GEMS and HEMS are summarized in **Fig. 4**. These maps and graph indicate HEMS transport was able to reliably move trauma patients in the study area to the STC within the golden hour.

Fig. 5 plots the difference in travel times versus the Euclidean distance to the STC, where a negative value indicates the estimated T_{total_G} time at an incident location is lower than the corresponding T_{total_H} time. The left plot demonstrates that there were only two incidents where T_{total_G} times are less than T_{total_H} times and an expected positive relationship between distance to the STC and advantage to transport times using HEMS. The right plot only shows the 685 incidents where the estimated T_{total_G} times are less than the 60-min threshold. This plot demonstrates that the maximum benefit acquired from using HEMS over GEMS, in cases where GEMS transport requires an hour or less, is approximately 25 min, and the average time improvement is 16.76 min.

To provide a more thorough analysis of the spatial distribution of travel times across the study area, interpolated surfaces for T_{total_G} and T_{total_H} transport were calculated. Interpolated surfaces are bounded, with continuous surfaces representing the interpolated value of a variable at any location, allowing for a more complete picture of that variable's spatial distribution. To accomplish this in a standardized manner, a rectangular grid of approximately 10,000 points was generated, spaced 1 km apart and with a boundary determined by the latitudinal and longitudinal extent of the five-county study area. Next, the times described in Eqs. 1 and 2 were computed for every point in the grid, resulting in T_{total_G} and T_{total_H} values being calculated at regularly spaced intervals. Finally, inverse distance weighting interpolation[16] was used to compute the continuous interpolated time surfaces for both T_{total_G} and T_{total_H} (**Fig. 6**).

From these surfaces, it is possible to estimate the geography of EMS travel times to the STC in the study area. Fig. 6A shows that only trauma incidents occurring in the eastern most county, directly west of the STC, could be transported via GEMS within 60 min. Incidents occurring in most of central Frederick County can reach the STC in 70 min or more. Fig. 6B shows that trauma incidents that occur in the majority of the study area, with the exception of part of the westernmost county, can reach the STC within the golden hour threshold with HEMS. Finally, **Fig. 7** presents a difference map of the two interpolated time surfaces, where the HEMS interpolated time surface is subtracted from the GEMS interpolated time surface. This results in a continuous surface with positive and negative values, where negative values indicate T_{total_G} times are lower and positive values indicate T_{total_H} times are lower. It should be noted that Fig. 7 depicts responses only from the Trooper 3 helicopter. The Maryland HEMS system has significant cross-coverage from helicopters in neighboring regions.

DISCUSSION

In Maryland, the HEMS system is a publicly funded system that is highly motivated to deliver efficient care that maintains excellent patient outcomes while limiting unnecessary flights and expenditures of public funds. A major goal of HEMS nationally is to neutralize the potential harm of delays to definitive trauma care (i.e., the "tyranny of time and distance"[9]) for patients seriously injured in more remote settings as compared to a patient injured in closer proximity to a trauma center who can be safely transported by GEMS. Applied in real time at the moment of decision-making, GIS-based methodology could accurately determine the time tradeoff between HEMS and GEMS to assist clinicians when selecting the mode of transport to a trauma center. Currently, decisions by clinicians are based upon patient description, reference to dispatch guidelines, and loose estimates of GEMS travel times to definitive care, such as at the Shock Trauma Center. Once the need for transport to STC is determined, providers must weigh the patient's severity with the capacity to tolerate delays using best guess estimates of GEMS and HEMS travel time to the general region, and not a specific incident location. This reliance on ambiguous, and potentially inaccurate, travel time estimates for selecting the most expeditious transport option could result in the overuse of the limited and expensive HEMS option. The use of GIS to estimate a more precise travel time difference between GEMS versus HEMS is intuitive and forthright, and would enable more informed decision making. Ultimately, the methodology described in this study has great potential for use in optimizing triage for HEMS.

The major goal of this work was to describe a methodology that can be refined for use with additional variables to help medical directors, researchers, and policy makers allocate HEMS in an evidence-informed manner. While there are limitations to the data used, the methodology outlined above opens the door to geographic statistical analysis of prehospital air transport usage. In our dataset, it is important to understand that only HEMS dispatch data was used for this study. Hence, the results are predicated on a counterfactual conditional assumption that suggests what might have occurred had the patient been transported by GEMS. The total prehospital time may be influenced more by other variables than transport mode, therefore limiting the conclusions we are able to draw. Several assumptions were used based on mean scene times in the state of Maryland. HEMS dispatch data do not account for excessive extrication time or additional scene time. Some ambulance services included volunteers during the study period, possibly prolonging response time. The Maryland system also includes extensive cross-coverage ability by other HEMS sections; this was not accounted for in this limited proof-of-concept analysis. Incident-specific factors may assess added value to HEMS, skewing the decision toward using HEMS (e.g., removing the most critical patient from the scene, allowing ground crews to remain on

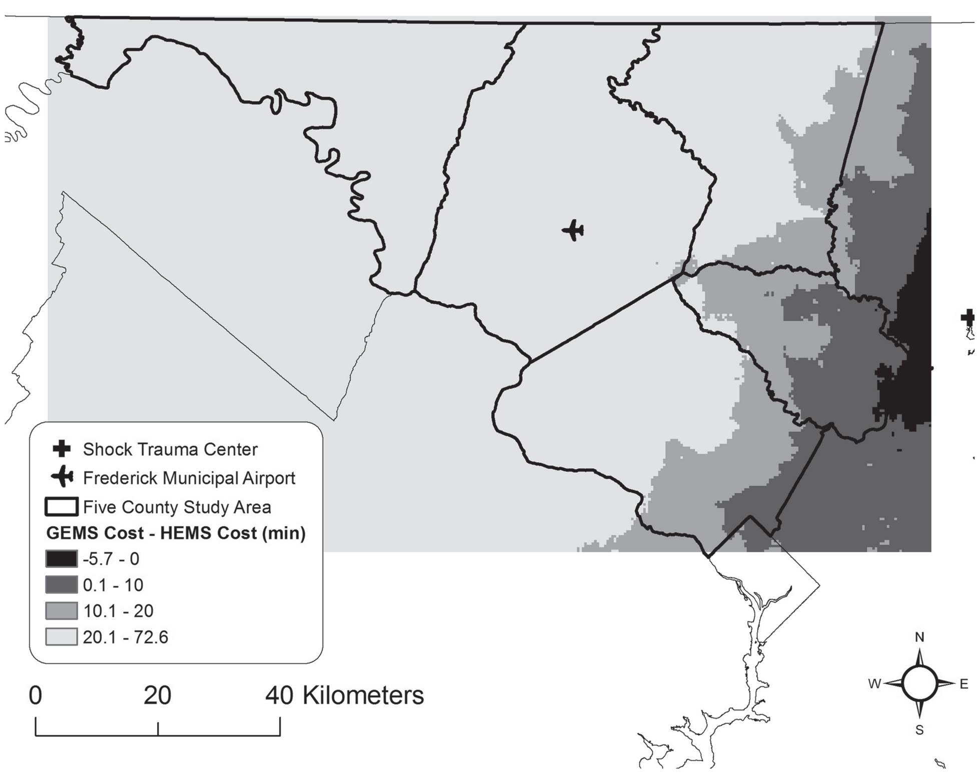

Fig. 7. Difference surface ($T_{total_G} - T_{total_H}$), where negative values indicate a faster transport via GEMS.

scene to continue extrication efforts in the event of multiple injuries). Time to correction of physiological derangements may be critical and this interval may be significantly decreased merely by the arrival of HEMS crews on scene. Road traffic patterns (i.e., construction, rush hour traffic, other ground travel impediments) and weather patterns were not fully accounted for in this analysis, and GEMS times could be longer than estimated.[10] Moreover, the Maryland HEMS system uses seven helicopters, each capable of significant cross coverage. The GIS modeling used to illustrate the methodology assumed coverage of a five-county region by only one helicopter (Trooper 3). Finally, only transports to STC were included. Patients with other types of time-sensitive injuries, including severe burns, pediatric trauma, and hand injuries, are transported to specialty centers in accordance with statewide protocols.

The indications for HEMS transport, including patient severity, cannot be accurately assessed based on these limited data. Future studies are underway to examine the role of injury mechanism, severity, and other patient-related factors in relation to patient outcomes as they relate to prehospital travel time. Notably, the time period of 2000–2011 encompasses several statewide protocol changes, including adoption of CDC dispatch criteria changes as well as a trauma center closure in nearby Washington County. While this falls outside the scope of this paper, the GIS-based methodology may present opportunities to trend usage practice changes over time in response to policy changes, hospital closures, or even regional disasters.

Any HEMS-associated benefit is likely to be some combination of crew expertise, decreased prehospital time, and the fact that HEMS exist as a transportation modality that is highly integrated into an existing trauma system. The use of GIS and the methodology described in this study has great potential for advancing the science of aeromedical critical care by enabling an accurate assessment of how the contribution of time and distance relate to patient outcomes. Using GIS and robust techniques for observational data, the hypothesis that HEMS mediates improved patient outcomes by decreasing the time to arrival at definitive care can be accurately assessed.

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Authors and affiliations: Michael J. Widener, Ph.D., M.S., and Daniel Schleith, M.S., Department of Geography, University of Cincinnati, Cincinnati, OH; and Zac Ginsberg, M.D., MPP, Department of Trauma and Surgical Critical Care, R. Adams Cowley Shock Trauma Center, Douglas J. Floccare, M.D., M.P.H., and Jon Mark Hirshon, M.D., Ph.D., M.P.H., Department of Emergency Medicine, and Samuel Galvagno, D.O., Ph.D., Division of Critical Care Medicine, Department of Anesthesiology, University of Maryland School of Medicine, Baltimore, MD.

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