Development of a trauma system and optimal placement of trauma centers using geospatial mapping

Michael A. Horst, PhD, Shreya Jammula, Brian W. Gross, Eric H. Bradburn, DO, MS, Alan D. Cook, MD, Juliet Altenburg, MSN, Madison Morgan, Danielle Von Nieda, *and* **Frederick B. Rogers, MD, MS**, *Lancaster, Pennsylvania*

BACKGROUND: The care of patients at individual trauma *centers* (TCs) has been carefully optimized, but not the placement of TCs within the trauma *systems*. We sought to objectively determine the optimal placement of trauma centers in Pennsylvania using geospatial mapping.

METHODS: We used the Pennsylvania Trauma Systems Foundation (PTSF) and Pennsylvania Health Care Cost Containment Council (PHC4) registries for adult (age ≥15) trauma between 2003 and 2015 (n = 377,540 and n = 255,263). TCs and zip codes outside of PA were included to account for edge effects with trauma cases aggregated to the Zip Code Tabulation Area centroid of residence. Model assumptions included no previous TCs (clean slate); travel time intervals of 45, 60, 90, and 120 minutes; TC capacity based on trauma cases per bed size; and candidate hospitals ≥200 beds. We used Network Analyst Location-Allocation function in ArcGIS Desktop to generate models optimally placing 1 to 27 TCs (27 current PA TCs) and assessed model outcomes.

RESULTS: At a travel time of 60 minutes and 27 sites, optimally placed models for PTSF and PHC4 covered 95.6% and 96.8% of trauma cases in comparison with the existing network reaching 92.3% or 90.6% of trauma cases based on PTSF or PHC4 inclusion. When controlled for existing coverage, the optimal numbers of TCs for PTSF and PHC4 were determined to be 22 and 16, respectively.

CONCLUSIONS: The clean slate model clearly demonstrates that the optimal trauma system for the state of Pennsylvania differs significantly from the existing system. Geospatial mapping should be considered as a tool for informed decision-making when organizing a statewide trauma system. (*J Trauma Acute Care Surg.* 2018;84: 441–448. Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Epidemiological study/Care management, level III.

KEY WORDS: Trauma center; non-trauma center; geospatial mapping; geospatial analysis.

The concept of the *golden hour* is axiomatic in the trauma arena—the sooner a patient presents for treatment after traumatic injury, the better the outcome. Two variables are critical to maximize favorable outcomes: access to appropriate level of care and duration of transport to care. In any trauma system, both of these variables should be optimized to ensure the best possible outcome. Although appropriate levels of patient care at individual trauma *centers* (TCs) has been the focus of intensive process improvement, the placement of TCs within the trauma *system* (TS) is yet to be studied empirically. As communities evolve, TCs are being established without consideration of the impact on the overarching trauma system. Tepas et al. reported on the inefficiency and high costs associated with expansion of trauma systems before conduct of adequate needs assessment.[1]

The tremendous improvements in patient outcomes after establishment of trauma systems is evidenced by the decreased mortality rates observed[2–4] after consolidation of trauma systems in Illinois[5,6] and Florida.[2] A comparison of patient outcomes in Oregon and Washington pre- and postimplementation of a formal trauma network in Oregon revealed statistically significant improvement in risk-adjusted odds of death solely after establishment of the trauma system in Oregon.[7] A national study analyzed the effectiveness of regional trauma systems in 22 states and reported a 9% lower crude injury mortality rate in comparison with states without an existing trauma system.[8] Although the benefits of an organized trauma system are readily apparent, there is still room for improvement. Many people do not have suitable access to a trauma center, which can result in undertriaging of care. In Chicago, despite the existence of multiple Level I TCs, there exist pockets of "trauma deserts" that experience worse outcomes secondary to increased transport time to definitive care. In particular, gunshot wound victims were shown to have a higher mortality when shot more than 5 miles away from a trauma center.[9] Treatment of critically injured patients at hospitals without trauma center designations has been associated with increased mortality. A national study conducted by MacKenzie et al. demonstrated a 25% lower risk of mortality for patients treated at trauma centers versus those treated at non-trauma centers.[10]

Submitted: September 1, 2017, Revised: November 30, 2017, Accepted: December 10, 2017, Published online: December 28, 2017.

From the Trauma Services (M.A.H., S.J., B.W.G., E.H.B., M.M., D.V.N., F.B.R.), Penn Medicine Lancaster General Health, Lancaster, PA; Trauma Research Program (A.D.C.), Chandler Regional Medical Center, Chandler, AZ; and Pennsylvania Trauma Systems Foundation (J.A.), Camp Hill, PA

Address for reprints: Frederick B. Rogers, MD, MS, FACS, Trauma Services, Penn Medicine Lancaster General Health, 555 N. Duke St., Lancaster, PA 17602; email: frogers2@lghealth.org.

This study was presented at the 76th Annual Meeting of the American Association for the Surgery of Trauma and Clinical Congress of Acute Care Surgery from September 13 to 16, 2017 in Baltimore, Maryland.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

DOI: 10.1097/TA.0000000000001782

The aim of this study was to objectively determine the optimal placement of TCs in the state of Pennsylvania. Use of geographic information systems (GIS) has been previously identified as a valuable resource to link associations between geographic regions and injury occurrence and can be used to inform decisions on further expansion of trauma systems.[11] An in-depth geospatial analysis conducted in Canada helped determine the overall trauma coverage as well as recognize existence of disparities in access to adequate trauma care among provinces.[12] Emerson et al. conducted a similar analysis in Scotland to evaluate access to critical care services via ground and air transportation methods.[13] On the premise of a clean slate (i.e., assuming the current trauma network does not exist), locations of TCs were deemed "optimal" if placement resulted in improved trauma coverage or if existing trauma coverage could be matched with fewer TCs than currently exist in the trauma system. Geospatial mapping was hypothesized to be an effective means of determining placement of trauma centers to improve trauma coverage with the same number of trauma centers or fewer than currently exist.

METHODS

Retrospective data from the Pennsylvania Trauma Systems Foundation (PTSF) and Pennsylvania Health Care Cost Containment Council (PHC4) were collected for all adult (age ≥15) trauma patients from 2003 to 2015. The PTSF dataset is published by the Pennsylvania Trauma Outcome Study (PTOS), a state trauma-specific archive of data on all patients meeting one or more of the following criteria: intensive care unit (ICU)/step-down unit admission, death on arrival, trauma fatality, hospital stay >48 hours or hospital stay between 36 and 48 hours with an Injury Severity Score (ISS) ≥9, and admitted transfer in/transfer out. Thirty eight hospitals (Levels I–IV) submitted data to the PTSF registry during the study period and were included in the analysis. The PHC4 (an independent state agency formed to study and address healthcare costs) dataset includes all hospital inpatient admissions within the state of Pennsylvania and is primarily an administrative dataset with limited pertinent patient information. Trauma patients were identified using ICD-9 codes ranging from 800 to 959 and an ISS >9. A prediction model (ICISS)[14] was applied to the ICD-9 scores to generate an analogous ISS value using an algorithm operationalized for Stata statistical software by Clark et al.[15] Patients in the PHC4 database were included if their ISS values were greater than 9. Both datasets are de-identified and do not contain any patient-identifying information (see Supplemental Digital Content 1 for more details regarding the two datasets, http://links.lww.com/TA/B67). The two datasets were used in this analysis to demonstrate the applicability of this methodology with diverse quality of data, in recognition that not all states or geographic regions have meticulous trauma-specific registries or detailed inpatient admission records.

Trauma patients were allocated to the zip code area of residence as a surrogate for location of injury, analogous to techniques used in other geospatial studies concerning trauma outcomes.[16–20] To account for boundary effects (patients seeking trauma care across state lines), we developed quantitative and qualitative decision criteria for inclusion of zip codes outside the state (see Supplemental Digital Content 1 for a more detailed explanation of calculation of these areas, http://links.lww.com/TA/B67). Demographic information pertaining to hospital type, location, and bed size were obtained from the PA Department of Health.[21] Information from the state departments of transportation of PA and neighboring states was used to establish major roads and highways with speed limits to determine travel times. Basic census demographics and TIGER zip code tabulation area shapefiles were downloaded from the US Census Bureau.[22] Information on TCs outside of PA was obtained from the 2015 Trauma Information Exchange Program of the American Trauma Society.

Geospatial Analysis

The goal of the model was to identify optimal locations for Levels I/II adult TCs assuming current TCs did not exist and compare with the existing locations of Level I/II TCs and coverage. Level I and II trauma centers were the subject of this study as they provide definitive trauma care. General hospitals with ≥200 licensed beds were considered as candidate TCs. This threshold was chosen on the supposition that hospitals smaller than 200 beds were unlikely to support the demands of a Level I/II TC. Moreover, the smallest level II TC in the state has 245 beds, and given the reality of primarily small hospitals serving rural areas, 200 was chosen as the minimum bed size for candidate TCs as the most realistic and attainable goal (see Supplemental Digital Content 1 for more details regarding considerations for minimum capacity and volume in selection of candidate TCs, http://links.lww.com/TA/B67).

The Network Analyst Location-Allocation function in ArcGIS Desktop 10.5.1 (ESRI, Redlands, CA) was used to generate the geospatial models. The number of TCs selected ranged from 1 to 27 sites as there were 27 adult level I/II TCs in PA at the time of this study. A 60-minute travel time to TC from zip code centroid was the primary endpoint of the study. This analysis was conducted separately for the PTSF and PHC4 datasets (see Supplemental Digital Content 1 for additional analyses using 45-, 90-, and 120-minute travel time endpoints in addition to details regarding the specific algorithm used in this study, http://links.lww.com/TA/B67).

Maps were produced to provide a visual representation of the TCs selected along with the 60-minute travel time radius around each TC. The level of agreement between the TCs selected using the PTSF and PHC4 databases was calculated for each of the four travel times and number of selected TCs. This was done to assess the potential biases in the selection of TCs using the PTSF (solely trauma cases from the existing trauma network) versus PHC4 (a population-based database). We also used GeoDa 1.8.16.4 for geospatial analyses, Stata 15.0 (Stata Corp., College Station, TX) for data preparation and statistical analyses, and R 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria) for data preparation and geocoding. This study was reviewed and approved by the Lancaster General/Penn Medicine Institutional Review Board.

RESULTS

The PTSF database contained 377,540 adult (age ≥15) traumas and the PHC4 database contained 255,263 adult (age

TABLE 1. Study Population Demographics

	PTSF	PHC4 (ISS > 9)
Hospitals	38	185
Study population (n)	377,540	255,263
Gender		
Female	147,867 (39.2%)	106,611 (41.8%)
Male	229,615 (60.8%)	148,300 (58.1%)
Age		
15–24	60,891 (16.1%)	31,858 (12.5%)
25–34	45,059 (11.9%)	23,839 (9.3%)
35–44	43,204 (11.5%)	23,310 (9.1%)
45–54	51,555 (13.7%)	30,102 (11.8%)
55–64	45,435 (12.0%)	28,864 (11.3%)
65–74	38,133 (10.1%)	28,211 (11.1%)
75–84	50,636 (13.4%)	46,019 (18.0%)
85+	42,563 (11.3%)	43,059 (16.9%)
In hospital mortality*	19,664 (5.2%)	14,251 (5.6%)
ISS		
10–16	83,410 (48.2%)**	134,829 (52.8%)
17–25	55,671 (32.2%)**	85,830 (33.6%)
≥26	33,941 (19.6%)**	34,604 (13.6%)

*Reported mortality rates are unadjusted.
**Denominator includes only PTSF cases with ISS >9.

≥15) traumas with ISS >9 for the calendar years of 2003–2015. Characteristics of the cohort are presented in Table 1. The existing network of 27 TCs was within the 60-minute travel time threshold 92.3% of the time (Table 2). Optimally placing the existing 27 TCs using the clean slate approach for the PTSF database resulted in improved travel time for 95.6% of cases. To maintain the current 92.3% coverage for 60-minute travel time, the clean slate model reduced the number of centers from 27 to 22.

Similarly, with the PHC4 database, the existing network of 27 TCs was within the 60-minute travel time threshold for 90.6% of the cases (Table 2). Placing the existing 27 TCs in the PHC4 database using the clean slate model improved coverage to 96.8%. To maintain the current 90.6% of trauma patients arriving at TCs within 60 minutes, only 16 TCs would be required. Results of existing network coverages and clean slate models for travel time intervals of 45, 90, and 120 minutes for both PTSF and PHC4 databases are presented in the supplementary material (see Supplemental Table 3, http://links.lww.com/TA/B67).

Figure 1A shows the existing TCs (27) within the study area boundaries, population density (per square mile) for each zip code area and the NTCs (candidate sites) by bed size ≥200 beds or <200 beds. The existing TCs in the study area along with the 60-minute travel time zones (PA TCs only) are shown in Figure 1B. Figures 2A and 2B show the clean slate model where 27 sites are selected, which matches the total number of existing sites, for both the PTSF and PHC4 databases. Selected TCs (represented in orange and blue) have a 60-minute travel time and points are included for candidate sites that were not selected (grey circles). Out of the 27 TCs, it should be noted that the same 19 (70.4%) were selected in both database analyses, but the other 8 TCs selected varied between the PTSF and PHC4 databases.

Figures 2C and 2D show clean slate models matched for existing travel time coverage (92.3% for PTSF, 90.6% for PHC4) with 22 selected sites in PTSF and 16 selected TCs in PHC4. Similar to the previous set of models, the optimal locations selected for the TCs were not identical between the two datasets. When more than 10 candidate hospitals were included in the model, approximately 70% of the hospitals selected in both database models are the same (Fig. 3). Thus, the choice of database used to generate the models resulted in discordant TC selection for 30% of the candidate hospitals because of the differing geospatial distribution and trauma case volumes.

DISCUSSION

The results of this study suggest that optimal placement of trauma centers can be determined to maximize access to the most number of patients using geospatial analysis. The optimally placed trauma network with 27 TCs was determined on average to provide a 4.75% increase in coverage compared with the existing network when assessed for travel time of 60 minutes. In addition, maintaining the existing transit time coverage required fewer TCs with PTSF requiring 5 and PHC4 requiring 11 fewer centers. Not only do the numbers of TCs needed vary based on the database but so do the specific locations as seen in Figure 2. As Figure 3 explicitly demonstrates, there is ~70% concordance between the two datasets regarding the TCs selected once the number of TCs selected exceeds 10. The reason for differing sets of optimal TCs chosen could be explained by the different underlying populations represented by the two datasets: the PTSF registry focuses solely on trauma cases at designated TCs whereas PHC4 is inclusive of all trauma cases in the state. Therefore, the

TABLE 2. Comparison of Existing and Optimal TC Coverage for 60-Minute Travel Time Based on Trauma Volume

	PTSF		PHC4	
	No. of TCs	Trauma cases within travel time from zip code centroid to TC	No. of TCs	Trauma cases within travel time from zip code centroid to TC
Existing network (27 TCs)				
60 minutes	27	92.3%	27	90.6%
Clean slate (optimally placing the existing 27 TCs)				
60 minutes	27	95.6%	27	96.8%
Clean slate (matching % trauma cases)				
60 minutes	22	93.2%	16	90.7%

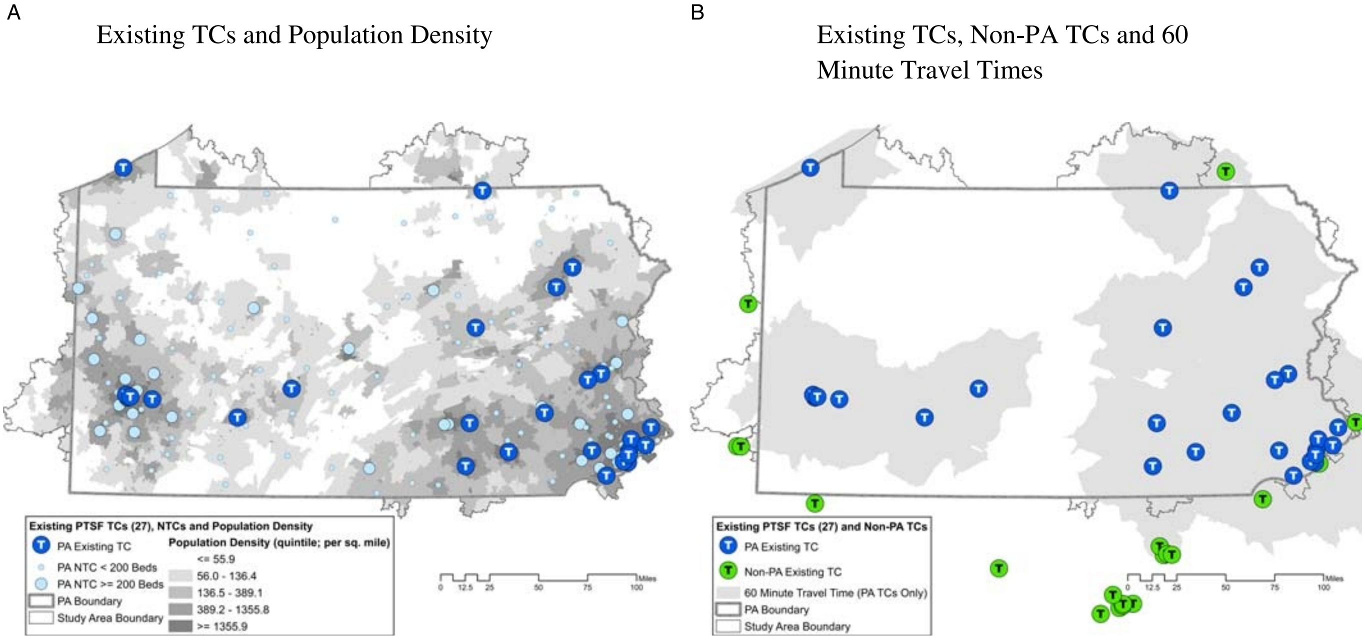

Figure 1. Maps of existing PA TCs, population density, 60-minute travel times to existing TCs, and candidate hospitals.

footprints of the models vary as the PHC4 dataset aims to address the omission of portions of the true trauma population undertriaged to non-TCs that is not captured in the PTSF database. Indeed, the authors' inclusion of the PHC4 database was also based on the hypothesis that the PTSF database was inherently biased to the existing trauma system framework. The lack of complete agreement between the two databases serves to highlight the importance in the use of the PHC4 database along with the PTSF database for objective determination of TC location to best maximize available resources to serve the population needs.

It has been demonstrated multiple times that patient outcomes are significantly improved with the institution of statewide trauma systems.[3–8,10] Focusing resources on a macro level to improve the entire state trauma *system* rather than allowing the ambitions of individual hospitals to dictate trauma care is vital. Articles on the benefits of organized trauma systems are a common fixture in the medical literature, but few studies have sought to analyze *how* to strategically organize the system geographically to derive maximal benefit. Geospatial mapping has previously been employed to determine additional locations of TCs in Pennsylvania[23] and across Canada.[12] This study used the same technique without imposing any geographic constraints relating to existing trauma centers.

Rural areas are at a disadvantage in our existing trauma paradigm given the saturation of TCs in urban locales and the tendency for major TCs to be based in university hospitals. This methodology, especially the use of the PHC4 dataset, accounts for existing undertriage when determining theoretical locations of TCs to provide more comprehensive care. GIS is a major technologic advance ideally suited to tailor an organized trauma system for a particular region based on true need and not the political and financial motivations of specific hospitals. Not all states enjoy access to multiple statewide registries with detailed information on trauma patient admissions. However, it is not necessary to possess such datasets to employ geospatial mapping as optimal locations can still be approximated. Indeed, the purpose of using both datasets was to demonstrate this technology can still be employed to inform decisions regarding trauma system design. Even in the absence of formal statewide trauma registries, by applying a set of assumptions regarding volume of trauma per population in a zip code area (or other defined geographic area), geospatial representations can be generated and models adapted to ameliorate disparities in trauma volume in metropolitan versus more rural regions.

Alternative methods for optimal trauma system derivation exist. The GEOS study in Scotland applied a combined mathematical modeling approach and GIS to calculate travel times from injury locations to hospital sites to generate a series of trauma system configurations with varying combinations of major TCs, trauma units, and local emergency hospitals.[24] The study emphasizes "multi-objective optimization" by using Non-dominant Sorting Genetic Algorithm II to select an ideal configuration of trauma system based on access times, volume requirements, and mode of transportation.[24] The Needs Based Assessment of Trauma Systems (NBATS) tool, developed by the American College of Surgeons (ACS), is another option that assesses the need of TCs in a geographical area.[25] Points are determined based on population, transport times, number of severely injured patients (ISS >15) treated at TCs versus non-TCs, and presence of existing Level I/II/III TCs. This scoring system estimates the need for TCs in a given area. Although both of these methods are promising, each method has drawbacks, limiting their ability to configure an ideal trauma system in PA. The multiobjective optimization model in the GEOS study includes an initial phase of triage data collection, which is conducted through a single nationwide ambulance service.[24] Although this is a significant strength of the GEOS study, this would not be feasible in PA given the regional variations in emergency medical services. In addition, the GEOS group

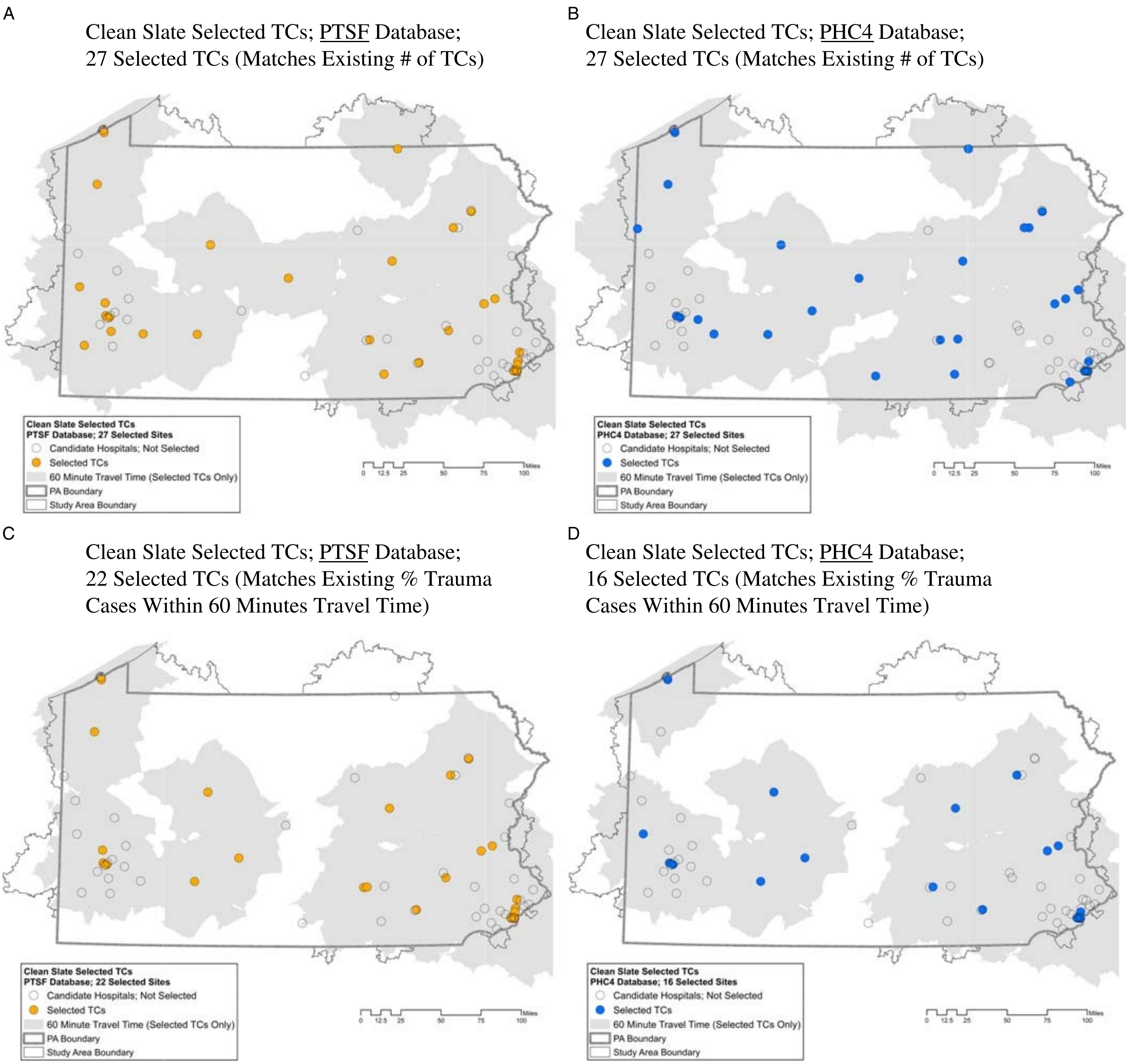

Figure 2. Selected clean slate model results for 60-minute travel time.

acknowledged a network analysis (such as is presented in this paper) is required to determine optimal TC locations.[26] Conversely, the NBATS tool provides information regarding the optimal number of TCs needed, but offers no geographic information for placement of these TCs. In addition, ACS has acknowledged that the NBATS tool is in the initial phase of development and is not based on any clear evidence but rather the result of expert group recommendations.[25]

This investigation is not without its limitations. The injury data collected from PTSF retrospectively was a potential source of bias as the analysis was specific to trauma populations at accredited trauma centers and did not account for patients who were treated at non-trauma hospitals. Therefore, trauma volume would factitiously appear higher in proximity to existing TCs. The trauma volume in the PHC4 dataset was lower than in the PTSF dataset. It was necessary, however, to impose a minimum ISS cutoff to ensure the PHC4 cohort approximated the PTSF for this analysis. The lower trauma volume in the PHC4 registry could have artificially reduced the number of optimal TCs needed to match existing coverage within the specified travel time ranges. Another limitation was the use of patient residence zip codes rather than the site of trauma, which could bias the results of this study. Our models only considered ground transportation and did not account for helicopter transport. In the future, adjustments to the model can be considered to include other means of transportation.

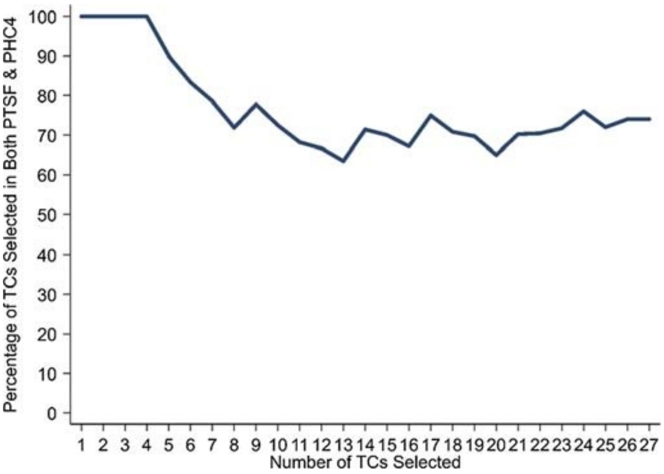

Figure 3. Percentage of selected TCs in agreement in models from both PTSF and PHC4 databases by number of TCs selected.

This study only sought to determine the optimal locations for level I/II TCs in PA given their equivalent capacity to provide definitive care without accounting for Level III/IV TCs. A multilevel spatial model to incorporate the contributions of Level III/IV centers is beyond the scope of this study, but the authors fully acknowledge the importance of Level III/IV centers and the vital role they play in the state trauma system especially in rural communities where access to TCs may be limited. Finally, the clean slate method is not an entirely realistic approach for states with existing trauma systems, such as Pennsylvania. This method may be best suited for states without organized trauma systems where the ideal geographic locations of TCs are yet to be determined.

CONCLUSIONS

The optimal trauma system for the state of Pennsylvania differs significantly from the existing system when priority is given to arrival at TC within the golden hour. Geospatial mapping should be considered as a tool for informed decision-making when organizing a statewide trauma system. Multilevel spatial models for all levels of trauma care warrant further exploration to ensure optimum access to the appropriate level of trauma care.

AUTHORSHIP

M.A.H.: study design, data collection, data analysis, article preparation. S.J.: study design, data analysis, article preparation, editorial oversight. B.W.G.: study design, data analysis, article preparation. E.H.B.: data analysis, editorial oversight. A.D.C.: study design, data analysis, editorial oversight. J.A.: data collection. M.M.: article preparation. D.V.N.: manuscript preparation. F.B.R.: study design, data analysis, editorial oversight.

DISCLOSURE

Conflicts of Interest and Source of Funding: The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article. This study was funded in part by a grant from the Louise von Hess Medical Research Institute.

REFERENCES

1. Tepas JJ 3rd, Kerwin AJ, Ra JH. Unregulated proliferation of trauma centers undermines cost efficiency of population-based injury control. *J Trauma Acute Care Surg*. 2014;76(3):576–581.
2. Waters JM, Wells CH. The effects of a modern emergency medical care system in reducing automobile crash deaths. *J Trauma*. 1973;13:645–647.
3. Mullner R, Goldberg J. Toward an outcome-oriented medical geography: an evaluation of the Illinois trauma/emergency medical services system. *Soc Sci Med*. 1978;12:103–110.
4. Mullins RJ, Veum-Stone J, Hedges JR, Zimmer-Gembeck MJ, Mann NC, Southard PA, Helfand M, Gaines JA, Trunkey DD. Influence of a statewide trauma system on location of hospitalization and outcome of injured patients. *J Trauma*. 1996;40(4):536–545.
5. Boyd DR, Dunea MM, Flashner BA. The Illinois plan for a statewide system of trauma centers. *J Trauma*. 1973;13:24–31.
6. Boyd DR. A symposium on The Illinois Trauma Program: a systems approach to the care of the critically injured. Introduction: a controlled systems approach to trauma patient care. *J Trauma*. 1973;13:275–276.
7. Mullins RJ, Mann NC, Hedges JR, Worrall W, Jurkovich GJ. Preferential benefit of implementation of a statewide trauma system in one of two adjacent states. *J Trauma*. 1998;44(4):609–616.
8. Nathens AB, Jurkovich GJ, Rivara FP, Maier RV. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. *J Trauma*. 2000;48(1):25–30.
9. Crandall M, Sharp D, Unger E, Straus D, Brasel K, Hsia R, Esposito T. Trauma deserts: distance from a trauma center, transport times, and mortality from gunshot wounds in Chicago. *Am J Public Health*. 2013;103(6):1103–1109.
10. MacKenzie EJ, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, Salkever DS, Scharfstein DO. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354(4):366–378.
11. Crandall M, Zarzaur B, Tinkoff G. American Association for the Surgery of Trauma Prevention Committee topical overview: National Trauma Data Bank, geographic information systems, and teaching injury prevention. *Am J Surg*. 2013;206(5):709–713.
12. Lawson FL, Schuurman N, Oliver L, Nathens AB. Evaluating potential spatial access to trauma center care by severely injured patients. *Health Place*. 2013;19:131–137.
13. Emerson P, Dodds N, Green DR, Jansen JO. Geographical access to critical care services in Scotland. *JICS*. 2017;1751143717714948.
14. Osler T, Rutledge R, Deis J, Bedrick E. ICISS: an International Classification of Disease-9 based injury severity score. *J Trauma*. 1996;41(3):380–386.
15. Clark D, Osler T, Hahn D. 2009. "ICDPIC: Stata module to provide methods for translating International Classification of Diseases (Ninth Revision) diagnosis codes into standard injury categories and/or scores," Statistical Software Components S457028, Boston College Department of Economics, revised 29 Oct 2010. Accessed via https://ideas.repec.org/c/boc/bocode/s457028.html on 27 July, 2017.
16. Ashley DW, Pracht EE, Medeiros RS, Atkins EV, NeSmith EG, Johns TJ, Nicholas JM. An analysis of the effectiveness of a state trauma system: treatment at designated trauma centers is associated with an increased probability of survival. *J Trauma Acute Care Surg*. 2015;78(4):706–712.
17. Ciesla DJ, Pracht EE, Cha JY, Langland-Orban B. Geographic distribution of severely injured patients: implications for trauma system development. *J Trauma Acute Care Surg*. 2012;73(3):618–624.
18. Durham R, Pracht E, Orban B, Lottenburg L, Tepas J, Flint L. Evaluation of a mature trauma system. *Ann Surg*. 2006;243(6):775–783.
19. Hsia RY, Wang E, Torres H, Saynina O, Wise P, Perez-Stable EJ, Auerbach A. Disparities in trauma center access despite increasing utilization: data from California, 1999–2006. *J Trauma*. 2010;68(1):217–224.
20. Wang NE, Saynina O, Vogel LD, Newgard CD, Bhattacharya J, Phibbs CS. The effect of trauma center care on pediatric injury mortality in California, 1999 to 2011. *J Trauma Acute Care Surg*. 2013;75(4):704–716.
21. Hospital Reports. PA Department of Health. 2016. Accessed via http://www.statistics.health.pa.gov/HealthStatistics/HealthFacilities/HospitalReports/Pages/HospitalReports.aspx#.V9HFlaPD-Uk on 27 July, 2017.
22. TIGER/Line Shapefiles and TIGER/Line Files. United States Census Bureau. Accessed via https://www.census.gov/geo/maps-data/data/tiger-line.html on 27 July, 2017.
23. Horst MA, Rogers RB, Gross BW, Cook AD, Osler TM, Bradburn EH. A novel approach to optimal placement of new trauma centers within an existing trauma system using geospatial mapping. *J Trauma Acute Care Surg*. 2017;83(4):705–710.

24. Jansen JO, Campbell MK. The GEOS study: designing a geospatially optimised trauma system for Scotland. *Surgeon*. 2014;12(2):61–63.
25. Needs Based Assessment of Trauma Systems. American College of Surgeons. Accessed via https://www.facs.org/quality-programs/trauma/tscp/nbats on 8 November, 2017.
26. Jansen JO, Morrison JJ, Wang H, He S, Lawrenson R, Campbell MK, Green DR. Feasibility and utility of population-level geospatial injury profiling: prospective, national cohort study. *J Trauma Acute Care Surg*. 2015;78(5):962–969.

DISCUSSION

Dr. Ronald M. Stewart (San Antonio, Texas): Thank you. This is another well-written and interesting trauma system manuscript from Pennsylvania. The question the authors seek to answer is relevant and important to needs-based assessment of trauma systems across the globe.

As we have just heard, the geospatial model demonstrated that a trauma system could possibly achieve equivalent or improved trauma system coverage with fewer trauma centers if they were optimally placed.

The authors clearly acknowledge some significant limitations with the data and datasets. Some of these relate to the data themselves; and some of these limitations relate to the assumptions used in the models.

Nonetheless, this is an interesting and probably more objective model to frame the issue of optimal trauma center location and number.

I have three questions and a comment. Why were the time intervals of 45, 60, 90, and 120 minutes selected?

It seems to me from a clinical point of view 15 minutes, 30 minutes, 60 minutes and 120 minutes might be more relevant as most critically-injured patients probably don't have a golden hour and once a center gets beyond an hour it may not make a difference whether it's 90 or 120 minutes. Did you analyze any of the shorter time periods? If so, what did those analyses show?

I have a pretty good eye for global visual assessment, and whenever I look at the maps it seems to me that the idealized geospatial model predicted a need for fewer trauma centers in more densely populated urban/suburban areas.

So, first, do you think my gestalt assessment is accurate? From your vantage I'm sure you have data on this.

Those urban areas tend to have more traffic congestion and a greater frequency of penetrating trauma which may require greater and more expeditious operative care. Does your model address these factors?

My last question is why did you exclude Level IIIs from the model? It seems to me as if these centers can and do provide definitive care for a number of injuries and may be more cost-effective and actually have less negative volume impact on Level I trauma centers.

Lastly, a comment, the geospatial process is quite interesting and it provides another less-subjective tool for needs-based assessment of trauma systems. But at least from my vantage, because of the assumptions and potential gaps in the data, this type of tool likely provides only a general, broad, supplementary guide as to the number and location of trauma centers.

I would be interested in the authors' assessment of where and how this tool could be optimally employed outside Pennsylvania.

I thank the authors and the AAST Program Committee for the privilege of reviewing and discussing this manuscript. Thank you very much.

David J. Ciesla (Tampa, Florida): I think this is a great paper.

I think what you guys did is you showed that you could come up with a tool that objectively measures the colocation of the population of interest and your resources.

And I think that's what is missing from what we have in the NBATS version. What you showed is that you could do it with pretty available data, pretty much free software.

And so I just have a couple of questions.

The first, I got so excited about looking at these maps I might have missed the part in your methods but how did you define the trauma patient?

And the reason I ask that is because all of us in the room know that the spectrum is huge and a lot of the people we take care of could reasonably expect to be taken care of in community hospitals.

So if your 2.2 discharges per bed includes 2.2 minor-injured patients, maybe you're over-estimating the number of centers that you could have and being more inclusive of the system you could expect those patients to be taken care of at lower-level centers.

The second question is, where did that 2.2 discharges per bed come from because that seems like a pretty small number to me, especially if you're not talking about severely-injured patients?

And then the last thing I wanted to ask was – I wrote it on my hand – you used patient ZIP code which is a really, it's a good way to do it because this is the actual population you are looking for and if you get it from a publicly available set like your statewide discharge dataset it give you kind of right, you focus right in on that population but with a few assumptions.

Can you just extrapolate this to the general population? Like we know what the injury rate is and we know what the severe injury rate is and by taking that couldn't you just use census tracks for every state and then come up with the same kind of solution?

Again, great paper. Thanks for presenting.

Dr. Thomas Weiser (Stanford, California): Tom Weiser from Stanford. So I share Dr. Ciesla's enthusiasm for this tool and think ArcGIS provides an amazing opportunity to physically geolocate trauma centers.

I'm interested in the way that you used ZIP codes. ZIP codes are a very poor proxy for actual travel time. Have you explored other options? For example, there is Open Street Maps or other open software databases that you can use to overlay onto GIS.

Second, as you approach a state and place trauma centers in their appropriate geolocations is there a way to also use actual location of injury? Do you have geolocations for those? I ask because I think a more accurate use for this GIS platform might be to use locations from where patients are actually injured and not just where they live.

Dr. Howard Champion (Annapolis, Maryland): I'm not quite sure the purpose of this. Is it to make it geographically tidy? Or is this rearrangement in some way meant to have some impact on the quality of care and the outcome of the patients?

It's particularly disturbing that there are no dependent variables of that nature in the model. And that, combined with all of the assumptions that are in the model, leads me to just wonder if we ought not to be a little bit cautious with respect to this.

It's been used in Scotland to develop their trauma system and we don't really know what the impact on patient outcomes has been there. And it's also been used in another state in this country and that remains obscure, as well.

Dr. Michael A. Horst (Lancaster, Pennsylvania): Thank you for the opportunity to respond to these very good questions. And I will talk about Dr. Stewart's questions first.

In terms of the travel times, we did use 45, 60, 90, and 120 minutes. We were primarily trying to look at travel times that represented a maximum to determine optimal numbers of trauma centers and placement, and not focus on shorter travel times.

I will say as we went into smaller and smaller travel times you do see, the number of centers needed increased and the coverage decreased. But we did not go below 45 minutes. Running the model with additional travel times would be pretty easy to do.

In terms of the urban/rural dichotomy, yes, in the Philadelphia metro region we found that the model suggested fewer trauma centers as it tended to better optimize the capacity of the centers that were selected and select more optimal geospatiall locations. In the Pittsburgh metro region, the model trended toward a potential need for additional trauma centers. We did not adjust for traffic congestion, only the road network and speed limits.

I would recommend additional research looking at the differences between urban and rural regions.

We had presented a paper at EAST in January where we actually did change some of the assumptions in the metro Pittsburgh and Philadelphia regions.

In terms of Level III centers, we did not include Level III centers. At the time we started this study, there was only one in the state of Pennsylvania. And so we just elected to not address Level III centers for that purpose.

I am out of time and am unable to address some of the additional questions, but please contact me directly as I would be happy to discuss the study.