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Building trauma capability: using geospatial analysis to consider military treatment facilities for trauma center development

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ABSTRACT

Background The Military Health System must develop and sustain experienced surgical trauma teams while facing decreased surgical volumes both during and between deployments. Military trauma resources may enhance local trauma systems by accepting civilian patients for care at military treatment facilities (MTFs). Some MTFs may be able to augment their regional trauma systems by developing trauma center (TC) capabilities. The aim of this study was to evaluate the geographical proximity of MTFs to the continental US (CONUS) population and relative to existing civilian adult TCs, and then to determine which MTFs might benefit most from TC development.

Methods Publicly available data were used to develop a list of CONUS adult civilian level 1 and level 2 TCs and also to generate a list of CONUS MTFs. Census data were used to estimate adult population densities across zip codes. Distances were calculated between zip codes and civilian TCs and MTFs. The affected population sizes and reductions in distance were tabulated for every zip code that was found to be closer to an MTF than an existing TC.

Results 562 civilian adult level 1 and level 2 TCs and 33 military medical centers and hospitals were identified. Compared with their closest civilian TCs, MTFs showed mean reductions in distance ranging from 0 to 30 miles, affecting populations ranging from 12 000 to over 900 000 adults. Seven MTFs were identified that would offer clinically significant reductions in distance to relatively large population centers.

Discussion Some MTFs may offer decreased transit times and improved care to large adult populations within their regional trauma systems by developing level 1 or level 2 TC capabilities. The results of this study provide recommendations to focus further study on seven MTFs to identify those that merit further development and integration with their local trauma systems.

Level of evidence IV.

BACKGROUND

The Military Health System (MHS) is challenged with the need to develop and sustain experienced surgical teams capable of providing combat casualty care in expeditionary environments. After the formal completion of Operation Iraqi Freedom and Operation Enduring Freedom, US and coalition casualty rates have markedly decreased.[1] Decreased trauma volumes threaten the loss of the hard-earned lessons of combat casualty care within the MHS. Furthermore, the development and increasing utilization of smaller surgical teams have led to increased deployment rates among military surgeons, who are therefore faced with greater amounts of time spent deployed in areas with fewer combat casualties.[2] Between deployments, military surgical teams typically work at military medical treatment facility (MTF) medical centers and community hospitals, where their surgical volumes do not match those of their civilian counterparts, except for very rare exceptions.[3] Military surgical teams are therefore faced with the additional challenge of maintaining their clinical skills in a setting of decreased opportunities to practice care.

A number of solutions to this dilemma continue to be presented and discussed within the military medical community. Among the initiatives proposed and under development are plans to develop select MTFs into designated trauma centers (TCs).[4] A Congressional mandate in the National Defense Authorization Act (NDAA) of 2017 stipulated that military medical centers must have "Level 1 or Level 2 trauma care capabilities."[5] Currently, only two MTFs in the continental USA (CONUS) are regionally designated TCs that actively participate in their local trauma systems.[6] Because of the current surgical team trauma readiness gap and the NDAA 2017, there is interest in determining which other MTFs might also offer trauma services or expand their current trauma capabilities.[7]

The benefits to developing CONUS military trauma capabilities extend to the civilian sector. The American College of Surgeons (ACS) has long recognized the mutual benefits of military–civilian collaboration on trauma care and has spent significant effort in advocating for a formal national trauma system.[8] Among other initiatives, the appropriate development of select MTFs into civilian TCs would make significant progress toward the College's goals. However, without careful planning at the regional level, there is little guarantee that a newly integrated MTF TC would meaningfully benefit its local community, improve trauma outcomes, or positively impact the patient volumes and experiences of its forward deployable surgeons and other critical wartime specialists.[9] It is well established that decreasing geographical distance to a TC improves time to definitive care and therefore improves patient outcomes. Prior work at the regional level has included geospatial analysis to determine where TCs might be placed to optimize trauma care delivery.[10] Although regional TC placement and distribution have been studied in civilian settings, no prior work has analyzed the potential impact of including MTFs within their local trauma systems. Using publicly available information on the locations of civilian TCs and MTFs, as well as CONUS population center information, it is possible to gain insight into which MTFs are advantageously located within their regional trauma systems. The goal of this study is to perform a pilot investigation into the proximity of MTFs to civilian TCs and CONUS adult population centers to determine which facilities might best benefit their local communities by developing into regionally active TCs.

METHODS

Publicly available data were used to compile a list of level 1 and level 2 adult TCs. The Trauma Center Association of America (TCAA) website, ACS website, and state and District of Columbia emergency medical system (EMS) websites were used to identify and gather data on CONUS civilian level 1 and level 2 TCs. For every state and the District of Columbia, the interactive map maintained by the TCAA was used to identify and include all facilities designated as adult level 1 or level 2 TC.[11] Facilities listed as pediatric TCs or level 3 or level 4 centers were excluded from the analysis. For every facility, the TC name, level, and street address were collected. These data were cross-referenced with the ACS Committee on Trauma database of TCs.[12] Each state's EMS or trauma system website was then used to confirm TC names, locations, and designations (online supplemental file 1).[13] Where discrepancies were found, state information was used as the definitive source.

The MHS Defense Medical Information System Identifier Tables database was used to produce a list of military hospitals and medical centers for inclusion in the study.[14] This list was cross-referenced with publicly available information through each of the service branch's medical department websites. Address information was obtained from the Defense Health Agency's (DHA) MTF search tool.

Population data were obtained from the US Census Bureau. Their best-known product, the decennial US Census, was last published from 2010 data and therefore believed to be too dated for use in this study. To provide more current population data, the Census Bureau performs an ongoing monthly survey titled the American Community Survey. On an annual basis, these data are used to update the definitive decennial population counts with current estimates. Updates are based on cumulative estimates in 1-year and 5-year periods.[15] The granularity of demographic data differs between these products. The most recent results of the 5-year American Community Survey, dated 2018, were used to obtain population estimates for all adults (defined as 18 years old or older) across CONUS.[16] These estimates were reported by Zip Code Tabulation Areas (ZCTAs). These are roughly equivalent to US Postal Service zip codes and represent the smallest available geographical unit within the analyzed American Community Survey data set.

Latitude and longitude data were obtained from publicly available information through the Google Maps platform. Google's geocoding application programming interface (API) receives human-readable address information and returns geographical coordinates.[17] The Python scripting language (Spyder V.4.1.5, MacOS V.10.15.6) was used to obtain geographical information for the collected data. For every TC and MTF, Google Maps API was used to obtain the latitude and longitude by providing a street address. For population data, the same API was used by providing each ZCTA's associated zip code, which returned the latitude and longitude of that zip code's geographical centroid.

Python was again used to determine the distances between every ZCTA and every civilian TC. The haversine formula was used to determine great-circle distances between points to minimize errors in straight-line approximation computations.[18] The script then determined which TC was closest to every ZCTA and compiled the results into a database for further analysis. A similar script was developed to determine the closest MTF for every ZCTA in this study.

The R statistical analysis suite (RStudio V.1.1.456, MacOS V.10.15.6) was then used for data analysis and visualization in conjunction with the Python scripts. A map of CONUS was developed to display the locations and relative sizes of every ZCTA, as well as their relative distances to their closest civilian TCs. A second map was generated after MTF data were included in the distance analysis. ZCTAs found to be closest to MTFs were then further analyzed to determine the overall reductions in distance compared with their closest TCs.

RESULTS

A total of 562 adult civilian level 1 and level 2 TCs were identified within CONUS during the study period. During the same time period, a total of 33 CONUS military medical centers and hospitals were identified. The 2018 ACS data from the US Census Bureau returned a total of 32 441 CONUS ZCTAs, with a total adult population estimate of 244 816 647.

The initial visualization of population centers yielded a maximum adult ZCTA population estimate of 85 256 and a minimum population of 0. Distance from the closest adult civilian level 1 or level 2 TC ranged from 0.03 to 232 miles. Disparities were noted in distance to TCs, with relatively short distances within major metropolitan areas and relatively longer distances in sparsely populated areas (figure 1).

When visualized with the addition of MTF data, several regions were identified with potentially significant improvements in distance to trauma care (figure 2). A total of 1663 ZCTAs were found to be closer to one of the 33 identified MTFs than any civilian TC. The mean distances from those ZCTAs to their respective MTFs ranged from 1.18 to 69.99 miles. CONUS MTFs were found to offer a reduction in mean distance from their respective civilian TCs, ranging from 0 to 30 miles, with a median of 15.08 miles (table 1).

To better understand the potential local effects of developing MTFs into level 1 or level 2 TCs, the data were visualized and tabulated at the state level for several regions. One such region was North Carolina, where both MTFs in that state offered mean distance reductions of over 20 miles to populations of 335 000 to over 680 000 adults. Furthermore, both MTFs were located in regions with relatively long distances to level 1 or level 2 trauma care (figure 3).

Finally, to determine which CONUS MTFs offered significant distance reductions to large populations, the results were visualized as a scatter plot (figure 4). The median values for affected population and mean distance reduction were used as axes to categorize MTFs by their relative rank in each category. Seven MTFs were found to offer greater-than-median reductions in mean distance while also serving a greater-than-median population: Womack Army Medical Center, Blanchfield Army Community Hospital, Winn Army Community Hospital, Naval Medical Center Camp Lejeune (NMCCL), Carl R Darnall Army Medical Center, Bayne Jones Army Community Hospital, and General Leonard Wood Army Community Hospital.

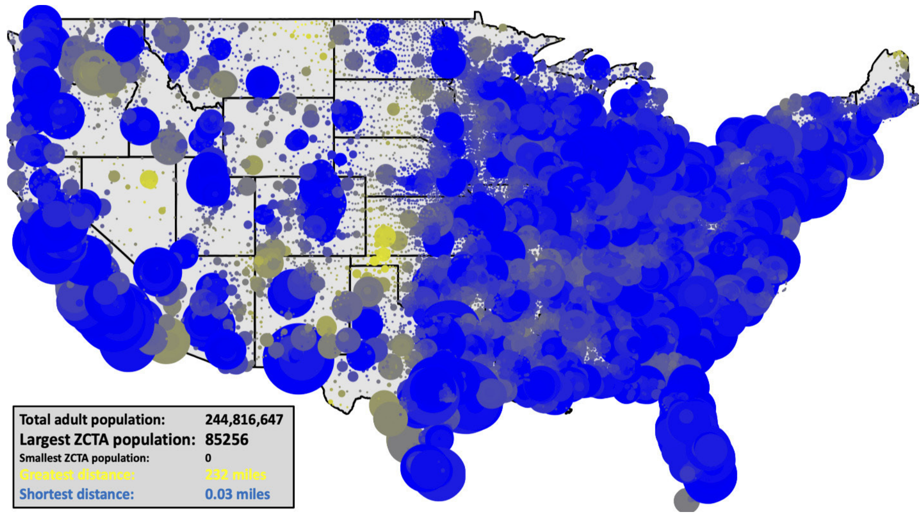


Figure 1 Map of CONUS with relative population sizes and proximities to a civilian level 1 or level 2 trauma center. Every dot represents a single ZCTA. Smaller dots represent sparsely populated ZCTAs, whereas larger dots represent densely populated ZCTAs. Blue dots are relatively close to a civilian trauma center, whereas yellow dots are relatively distant. CONUS, continental USA; ZCTA, Zip Code Tabulation Area.

DISCUSSION

The results of this study show that clear differences exist among MTFs with respect to their potential beneficial effects on their local trauma systems. This pilot study should be used to narrow the focus of analysis onto those MTFs that may best benefit their local communities' trauma networks. Defining this standard is more elusive than simply ordering the results by any one metric. The potential population served, the mean distance to the MTF, and the reduction in mean distance from the closest civilian TC may each contribute differently to a regional trauma system.

When sorted by the mean distance reduction, 10 MTFs offer improvements of 15 miles or greater compared with the TCs closest to the affected ZCTAs. However, in many cases the mean distance to the MTF itself remains quite high, perhaps too long to offer a meaningful improvement in trauma outcomes for the patients on those areas. Similarly, when sorted by the mean distance to their closest ZCTAs, many MTFs are located sufficiently close to offer an acceptable time to definitive care. However, several of these MTFs would only offer minimal reductions in mean distance from a civilian TC, and others serve populations that are relatively small and might therefore offer few opportunities to provide trauma care.

To gauge the potential community impact of bringing new trauma capabilities to an MTF, it may be beneficial to analyze the MTFs that currently accept and treat civilian trauma patients. Brooke Army Medical Center (BAMC) is the only MTF that is currently designated and verified as a level 1 TC. BAMC is part of the Southwest Texas Regional Advisory Council, and in 2019 had 4406 activations with 3035 admissions.[6] According to our results, this facility is the closest TC to 829 155 adults, the second highest population found in this study. The remaining MTFs in the top quartile with respect to populations served include Naval Medical Center San Diego (915 753), Fort Belvoir Community Hospital (700 467), Womack Army Medical Center (688 914), and Madigan Army Medical Center (601 220). Although it is a

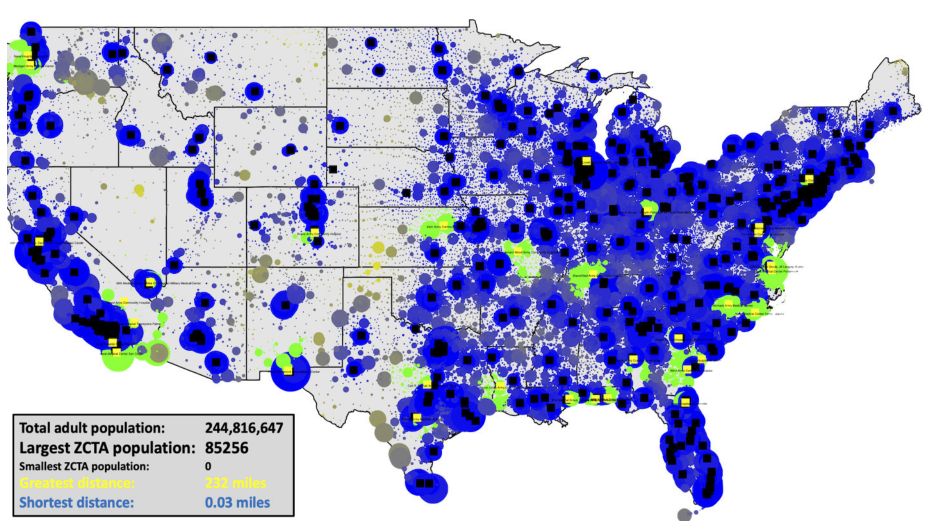


Figure 2 CONUS map with relative population sizes and proximity to the closest civilian trauma center or military medical center or hospital. ZCTAs closest to an MTF are colored green. Black squares represent the locations of civilian trauma centers and yellow squares represent the location of MTF. CONUS, continental USA; MTF, military medical treatment facility; ZCTA, Zip Code Tabulation Area.

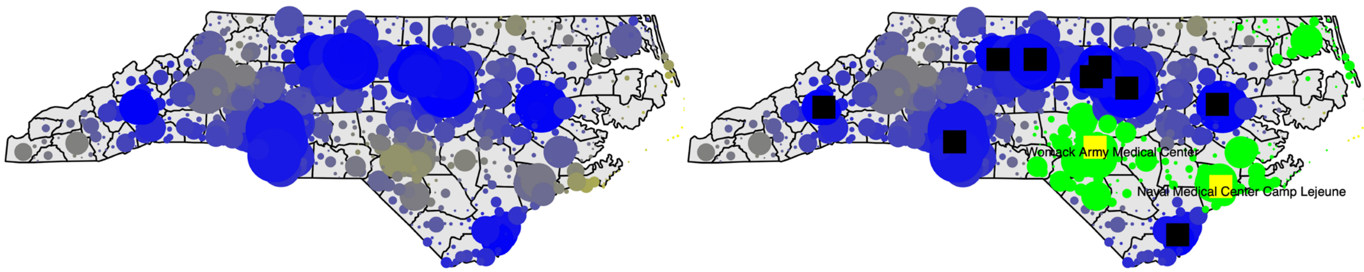
Table 1 List of CONUS MTFs

MTF name	ZCTAs served*	Total population†	Mean distance to L1/L2 TC (miles)	Mean distance to MTF (miles)	Mean distance reduction (miles)
Keller Army Community Hospital	41	256 087	15.59	8.89	6.71
Walter Reed National Military Medical Center	27	421 111	9.70	9.70	0.00
Fort Belvoir Community Hospital	76	700 467	32.43	27.69	4.75
Joint Base Langley-Eustis	96	200 222	49.79	46.11	3.69
Naval Medical Center Portsmouth	69	570 874	39.17	38.22	0.94
Womack Army Medical Center	72	688 914	50.28	26.05	24.22
Naval Medical Center Camp Lejeune	54	335 445	55.70	32.94	22.76
Naval Hospital Beaufort	37	189 570	40.11	25.58	14.53
Dwight D Eisenhower Army Medical Center	37	156 138	32.91	30.00	2.91
Winn Army Community Hospital	81	426 529	64.38	46.26	18.11
Martin Army Community Hospital	37	188 278	40.89	36.35	4.54
Naval Hospital Jacksonville	7	189 311	6.80	5.26	1.55
Eglin Air Force Base	17	139 788	28.16	25.09	3.07
Naval Hospital Pensacola	14	155 471	19.31	14.36	4.95
Blanchfield Army Community Hospital	128	546 441	68.59	47.81	20.79
Keesler Air Force Base	12	159 254	22.94	14.05	8.90
Wright-Patterson Air Force Base Medical Center	52	382 079	25.94	21.05	4.89
Captain James A Lovell FHCC	3	31 114	3.39	1.18	2.22
General Leonard Wood Army Community Hospital	115	307 787	73.14	46.06	27.08
Irwin Army Community Hospital	108	218 951	76.32	50.03	26.29
Bayne Jones Army Community Hospital	77	367 781	69.65	45.71	23.95
Carl R Darnall Army Medical Center	82	322 166	84.55	69.46	15.08
Brooke Army Medical Center	79	829 155	26.92	26.92	0.00
William Beaumont Army Medical Center	82	482 814	71.99	69.12	2.87
Evans Army Community Hospital	23	103 818	46.49	44.02	2.47
Naval Hospital Twentynine Palms	33	194 475	90.71	69.99	20.72
Mike O'Callaghan Military Medical Center	18	218 294	48.17	44.85	3.33
Naval Medical Center San Diego	39	915 753	24.74	23.46	1.28
Naval Hospital Camp Pendleton	6	177 232	13.29	6.71	6.59
Weed Army Community Hospital	14	60 311	72.55	42.54	30.00
David Grant Air Force Medical Center	4	12 362	15.71	12.20	3.51
Naval Hospital Bremerton	47	306 357	39.14	31.66	7.48
Madigan Army Medical Center	76	601 220	37.85	37.85	0.00

*Number of ZCTAs for which the MTF is closer than a civilian level 1 or level 2 TC.
†Estimated adult population for which the MTF is closer than a civilian level 1 or level 2 TC.
CONUS, continental USA; FHCC, Federal Healthcare Center; L1, level 1; L2, level 2; MTF, military medical treatment facility; TC, trauma center; ZCTA, Zip Code Tabulation Area.

designated level 2 TC, Madigan Army Medical Center does not currently accept civilian trauma patients on a regular basis, and accordingly only recorded 336 trauma admissions in fiscal year 2020, the majority of whom were Tricare beneficiaries.[19] Naval Medical Center San Diego and Fort Belvoir Community Hospital offer distance reductions of under 5 miles. The results of our study suggest that these two MTFs are not geographically positioned to benefit their local trauma systems by offering a significant improvement in access to care.

In 2018, NMCCL was designated by the State of North Carolina and verified by the ACS as a level 3 TC. The development and delivery of a verified TC at NMCCL were the result of a military–civilian partner effort that identified a need for trauma services in eastern North Carolina.[20] NMCCL participates in the local trauma system and regularly accepts civilian trauma patients. This collaboration between the Department of the Navy and the state trauma system resulted in 952 trauma activations with 430 admissions in 2019.[6] Because our study reviewed only level 1 and



MTFs closest to Adult Populations in North Carolina

MTF Name	ZCTAs Served	Total Population	Average Distance to L1/L2 TC (mi)	Average Distance to MTF (mi)	Distance Reduction (mi)
Womack Army Medical Center	72	688914	50.28	26.05	24.22
Naval Medical Center Portsmouth	47	129853	51.81	50.77	1.04
Naval Medical Center Camp Lejeune	54	335445	55.70	32.94	22.76

Figure 3 Visualized and tabulated results of analysis limited to North Carolina. L1, level 1; L2, level 2; MTF, military medical treatment facility; TC, trauma center; ZCTA, Zip Code Tabulation Area.

level 2 TCs, NMCCL was analyzed in this study as a potential TC. In this context, it was found to be among the seven MTFs that would provide a relatively large mean distance reduction to a large adult population, providing validation of this study's methods and results.

Ultimately, the development of new civilian trauma capabilities depends on the determination of a need within the local community. Effective regional trauma systems work best within a public health framework that includes cyclical assessment of population injury data, development of policies and allocation of resources to address unmet needs, and regular assurance that public health goals are being met.[21] It would be prohibitively resource-intensive for the DHA to engage in this level of analysis for all markets in which MTFs exist. However, the results of this study may be used to determine which MTFs would be best suited to augment their local trauma systems. The ensuing analyses would require a significant level of military–civilian partnership in the communities where candidate MTFs currently exist.

The results of this study must be viewed against some of the inherent limitations of the used data sources. Population sizes were used as proxies for trauma utilization. Although there is an intuitive correlation between these metrics, historical data

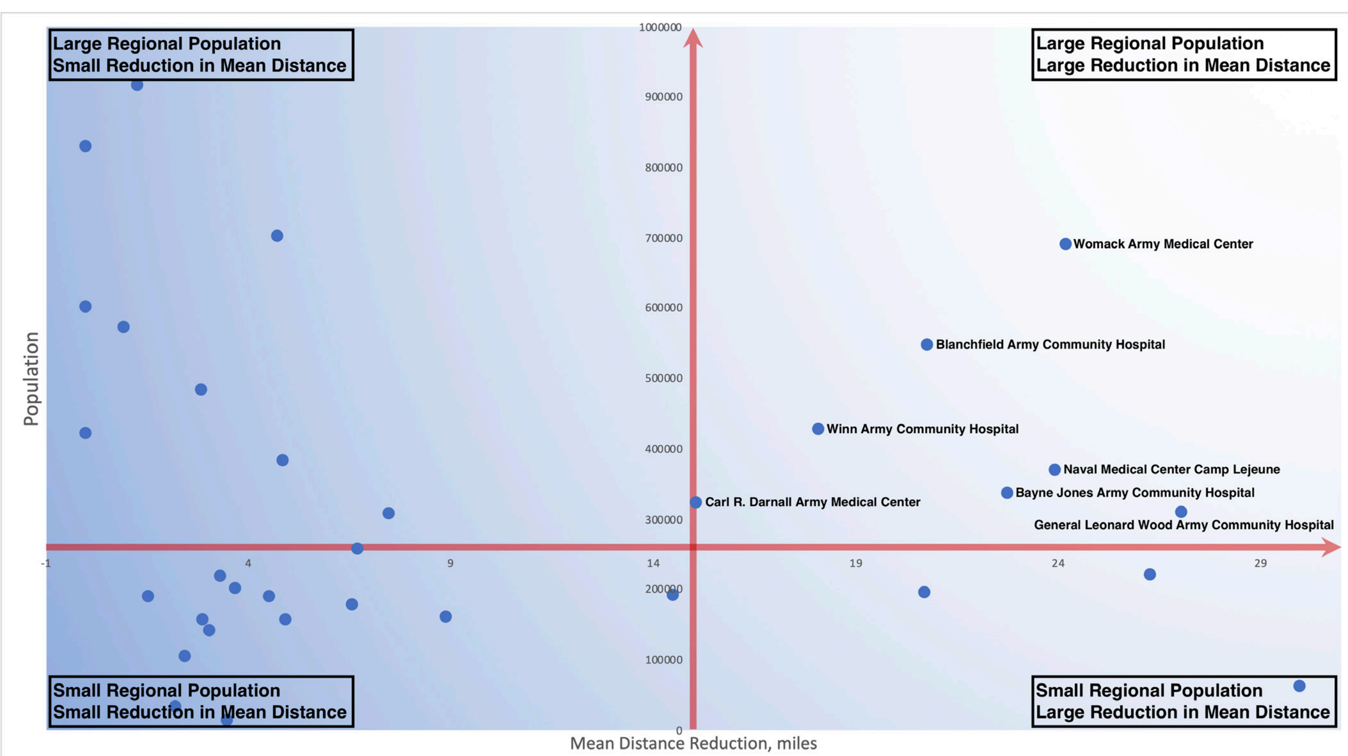


Figure 4 Scatter plot of all CONUS MTFs. Axes are placed at the median values for total population and mean distance reduction. MTFs found in the upper-right quadrant are those that offer the greatest reduction in distance to the largest populations. CONUS, continental USA; MTF, military medical treatment facility.

on trauma utilization, such as those available in the National Trauma Data Bank, may further refine the results of this study.

Distances in this study were determined by calculating haversine distances from ZCTA geographical centroids to medical facility street addresses. At the national level, this provides a sufficient estimate and relative measure of time to definitive care. However, distance calculations performed in this manner do not account for differences in traffic patterns and the availability of air transport for trauma patients. Further studies of MTFs and their regional trauma systems must obtain greater detail on transport times. This will likely require geospatial analysis down to a block or street level, using EMS historical data or geospatial drive time data.

Data on transport times, detailed trauma patient registry information, and TC admission information would augment the results of this study and enable the use of analytical tools such as the ACS Needs Based Assessment of Trauma Systems.[22] This would provide further information on regional trauma systems in which an MTF could develop level 1 or level 2 services.

Level 3 TCs were excluded when gathering data on civilian facilities for this study, in alignment with NDAA 2017's directive for MTFs to develop level 1 or level 2 trauma capabilities. The study results therefore indicate distances and populations served only by level 1 or level 2 TCs, which may overstate the potential benefit of some MTFs. During the past 20 years of military conflict, combat casualties underwent damage control resuscitation and/or surgery at forward surgical facilities and expedited transfer to an in-theater definitive care hospital with near equivalent capabilities of a civilian level 1 or level 2 TC. With this model in mind, NMCCL's success illustrates the potential value of developing MTFs into level 3 TCs, which serve a similar purpose in civilian trauma systems.[23] Further consideration should be done to consider the potential positive impact to civilian trauma systems and military medical readiness by developing more MTFs into level 3 TCs.

The major challenge of transforming MTFs into verified TCs must be carried out in the setting of current force restructuring initiatives and limited fiscal, administrative, and personnel resources. This study does not address all of the components required for an MTF to become a level 1 or level 2 TC fully integrated into a regional trauma system. Verified TCs necessarily constitute a robust general surgery foundation and high-quality critical care.[21] This simple statement belies the complexity and depth of the required resources, including surgical subspecialty care, experienced perioperative and critical care nursing, respiratory therapists, the ability to provide renal replacement therapy and advanced and interventional pulmonary/critical care, cardiology, gastroenterology, and radiology support. Regional cost analyses have shown that TCs require millions of dollars to maintain their readiness to accept trauma patients.[24] MTFs vary widely in their individual levels of infrastructure, funding, and manning, requiring detailed facility-level analyses to identify gaps for potential level 1 or level 2 TCs and determine the resources required to close them. Furthermore, the MHS does not generally collect payments from its beneficiaries and has limited means of collecting payments from non-beneficiaries. As most CONUS trauma patients are likely to be civilian non-beneficiaries, this limits the potential for revenue from billing to offset the costs of maintaining a TC.

Despite these challenges, the MHS remains committed to the expansion of its CONUS civilian trauma capabilities. A recent DHA analysis of NMCCL's performance since its designation and verification has lent support within the organization for its further development into a level 2 TC.[20] Furthermore, there is active work within the DHA to address collection issues, perform needs-based assessments of MTFs for their involvement in a national trauma system, and define a military-specific pathway to pursue new TC designation.[7]

CONCLUSION

In response to the challenges that face today's military trauma capabilities, there is particular interest and opportunity in increasing military participation in civilian trauma systems. By developing trauma capabilities and pursuing TC designation, MTFs may offer significant mutual benefits to the military and civilian communities in which they reside. Careful planning is required to identify those facilities that would provide the greatest benefit. The results of this study provide recommendations to focus further study on seven MTFs to identify those that merit further development and integration with their local trauma systems.

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