A Dissertation

entitled

Optimally Locating Level I Trauma Centers and Aeromedical Depots for Rural Regions of the State of Ohio

by

Linda R. Pepe

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy Degree in

Spatially Integrated Social Science

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An Abstract of

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Fifty years ago, trauma was called a public health crisis by the National Academy of Science. Their report was the stimulus to create an organized trauma system in the United States. Experience from the Korean War led to the inclusion of helicopter transport in the early 1970’s. Also in the early 1970’s, standards for hospital and physician trauma qualifications were developed by the American College of Surgeons Committee on Trauma with the goal of having a tiered, integrated and multilayered system to improve patient survival. As of six years ago, most states have some type of multi-level trauma system but trauma continues to be the leading cause of death in people under the age of 50. This is despite over forty years of trauma system development and technological advancements in medicine and automobile safety. This significantly high mortality is partly related to the poor placement of the trauma resources themselves.

This problem of access impacts those living in the state of Ohio, particularly those living in rural areas and approximately 3% of Ohio’s population, or over 340,000 people, do not have access to a Level I trauma center (TC) within an hour. Sixteen
counties in Ohio had insufficient access to Level I TCs within one hour although there are 11 Level I TCs and 32 staffed helipads (ADs).

The objective of this study was to use a resource allocation model to optimally locate Level I TCs and ADs in Ohio such that the rural population in the state (those currently being underserved) could access definitive care within sixty minutes. By utilizing the vertex substitution method, it was hypothesized that full population coverage could be achieved in Ohio with the same number or fewer resources. The patient population was limited to adults with an Injury Severity Score (ISS) of 15 or higher. The patient’s home zip code was used as a proxy for injury location. Only those resources available in the state were included for model simplicity.

There were two phases to the study. In the first phase, Euclidean distances were calculated from existing AD resources to weighted zip code centroids. Then, times were calculated from the zip code centroids to all existing hospitals and the optimal location was selected based on lowest cost (time). The model was initially run trying to optimize 11 TC locations, the current number in the state, then once results were obtained, the number of TCs was incrementally decreased until a feasible solution could not be obtained.

In the second phase of the study, all current airfields and helipads in Ohio were considered as potential staffed AD locations and the optimal AD sites were calculated, and then incrementally decreased. Those optimal ADs were then set and then optimal TC locations were obtained. Again, the number of TCs were incrementally decreased until no feasible solution could be calculated.
Full coverage for rural populations in Ohio was able to obtained in both phases of the study given the existing number of resources or even fewer resources. The fewest facilities able to fully cover the state were obtained in the second phase of the study with 17 optimal ADs and 4 TCs. The number of TCs was not realistic given that urban populations would not have been served by 4 TCs, but even by adding resources to urban areas not covered, full coverage could still be achieved with 9 or 10 optimal TCs; one or two less than what currently exist. Across both parts of the study, the number of TCs were consistently at least one less than the existing 11.

Since results were so readily obtained with fewer resources, it is evident that if resources in Ohio were fairly and optimally located, all patients in Ohio, particularly underserved rural populations, could reach definitive care within one hour.
For Jack and Sophia.
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Chapter 1

Introduction

According to the Centers for Disease Control, in 2010 the leading cause of death for ages 1-44 in the United States was unintentional injury and the majority of deaths in this age group were caused by motor vehicle crashes (MVCs). Over 2 million people are hospitalized in the U.S. for traumatic injuries per year (MacKenzie, Weir et al. 2010) and more than 180,000 deaths from injury occur each year, or the equivalent of one person dying from injury every three minutes (aast.org). In 2005, injuries accounted for $406 billion in medical and work loss costs *ibid*. Not only does traumatic injury have high potential for adverse outcomes immediately or in the short term, but also in the following months or year after injury. A substantial number of trauma patients die from their injuries in the year after discharge and differences in long term death risk are greater among younger versus older patients (MacKenzie, Rivara *et al.* 2006).

High trauma mortality rates, especially in young people, are not a recent phenomenon. In 1966 the National Academy of Sciences published a report entitled *Accidental Death and Disability: The Neglected Disease of Modern Society*. This report highlighted trauma as a significant cause of death in society with unacceptable mortality
rates, and viewed trauma as a public health crisis. This call to action was the start of the organized trauma system concept in the United States (Acosta, José et al. 1998).

By the 1970s, there were two significant changes with trauma patient care in the United States. First, there was the introduction of helicopter transport (HT) for civilian trauma patients. Implementation of helicopter patient transport derived from military medical experience in the Korean War. Initially, they were utilized in dual-purpose public safety missions but by the early 1970s, helicopters were being based at hospitals and dedicated fully to emergency medicine situations. The first “flight for life” helicopter was stationed at St. Anthony Central Hospital in Denver, Colorado in 1972 (Baxt, Moody et al. 1985, Anderson, Rose et al. 1987).

Second, prior to 1976, there were no clear guidelines on what services and physician qualifications hospitals had to offer in order to be called a trauma center (TC). In response to the trauma mortality crisis, the American College of Surgeons Committee on Trauma (ACS/COT) developed criteria for trauma centers and established a tiered structure for hospitals based on complexity of care provided with the level I designation being the highest to level V. The tiered approach relies on coordination of emergency medical service (EMS) personnel to properly triage patients, timely transportation from site of injury to the nearest care facility as well as patient transfer from a hospital to another center that can provide an appropriate level of care. The goal of an integrated, multilayered trauma system is to, “optimize the chances of survival for trauma victims by decreasing the risks, deleterious consequences, and overall burden of injury” (Becher and Meredith 2010).
As of 2010, about two-thirds of the U.S. had some type of a trauma system, and this could be a very basic informal one. According to one hospital study, almost all state chairs for the Committee on Trauma reported that they lacked adequate funding to sustain a system and over 90% agreed that funding was a significant barrier because of lack of federal and state support (Eastman 2010).

According to 2010 data from the Trauma Information Exchange Program, there were 11 level I TCs in Ohio and 32 aeromedical depots (ADs). Per the 2011 Ohio Trauma Registry Annual Report, 81.9% of Ohio trauma patients were treated with definitive care at a TC and level I TCs definitively cared for 18,355 patients, or about 56.6% of all trauma patients in Ohio. The most common cause of injury was blunt trauma (90.3%) and the overall mortality for Ohio Trauma Registry patients was approximately 4%.

1.1 Statement of the Problem

Unfortunately, in the 1970s, an important issue was not addressed with creation of the ACS/COT guidelines. At the time of implementation, there was no consensus achieved to define what an “adequate” number of trauma centers is to serve a given population. The American College of Surgeons suggests that one TC per million people is sufficient to maintain expertise of medical personnel and address the average volumes of severely injured patients, but this number is speculative and vague (Branas and Revelle 2001). Any hospital, regardless of location or number of other TCs in the area, could apply to become a designated TC as long as they meet the requirements set by ACS/COT.
For a level I TC, the requirements currently are to have immediate availability of trauma surgeons, anesthesiologists, specialists, nurses and resuscitation equipment. There are volume criteria which also must be met and TCs need to treat 1200 admissions per year, of which 240 need to be major trauma patients or an average of 35 major trauma patients per surgeon. These centers are expected to be a regional resource and leaders in providing education, research and system planning (MacKenzie, Hoyt et al. 2003).

As a result of this lack of consensus, the trauma system has lacked a quantitative approach to locate TCs and placement has instead been based on historical precedence or politics. TCs originally arose from existing inner-city hospitals that assumed their status “de facto” due to their expertise in dealing with severely injured patients (Branas and Revelle 2001). The absence of a quantitative approach in planning an integrated trauma system has caused substantial variation among states with regards to number and distribution of TCs (MacKenzie, Rivara et al. 2006). “Although the availability of trauma centers has improved, challenges remain to ensure the optimal number, distribution, and configuration of trauma centers. These challenges must be addressed, especially in light of the recent emphasis on hospital preparedness and homeland security” (MacKenzie, Hoyt et al. 2003).

There is a clear need for evidence-based criteria to dictate the ideal number and location of level I and II TCs, not only because timely transport and treatment of these severely injured patients is crucial and locations of these facilities should be carefully planned, but also for two additional factors that warrant consideration.

Firstly, operating a level I TC is costly. Maintaining a helicopter fleet, hiring specialized staff and buying high-tech equipment is a significant financial commitment
and these costs are passed on to insurance companies which in the end affect premium rates for their customers (The Ledger, 2014). These TCs also have the ability to charge “trauma activation fees” and raise their rates of services to help off-set the high cost to do business. (Palmer, 2014) Trauma centers located in inner cities are more likely to lose money because of the high volume of gun and knife violence with patients who are uninsured than trauma centers in the suburbs where patients are more frequently insured automobile accident victims (Galewitz, 2012). The public also may have to help keep TCs viable. This can be achieved through taxes or other levies. In Texas, drivers pay an additional fee on traffic tickets to help TCs with their uncompensated costs (Walters, 2013).

Secondly, it also is important from a patient outcome standpoint. By concentrating the number of severely injured patients to limited facilities, patient volumes and provider experience are also increased. This increased level of experience translates into potentially improved outcomes of these patients in the hours, days or even years following injury. The differences in risk of death were more significant among younger vs. older patients with regard to experience of the TC (Pandya, Yelon et al. 2011, Pracht, Langland-Orban et al. 2011).

In 2010 nearly 83% of the U.S. population had access to a level I TC in an hour and less than one quarter of the land area was covered (University of Pennsylvania’s Traumamaps.org). As of 2010, the state of Ohio had approximately 97% of its population living within 60 minutes to a Level I within 1hr and over 89% of the region was covered. The calculations were based on 32 helicopter bases and 11 level I TCs in the state. *ibid*
There are several areas in the southern, south east, far eastern and western parts of the state not accessible to a level I TC within 60 minutes (including utilizing adjacent state resources). Affected areas in Ohio are parts of Van Wert, Mercer, Adams, Scioto, Jackson, Lawrence, Meigs, Athens, Washington, Monroe, Belmont, Guernsey, Muskingum, Noble, Morgan and Ashtabula counties.

There is a clear need for this research for Ohio. In summary, the problem and ultimate goals are as follows:

1. There is no organized method for determining the location of trauma centers in the state of Ohio, therefore, there is unequal coverage and not all patients will be able to reach a level I trauma center (TC) in an hour;
2. Sixteen Ohio counties are affected by the lack of coverage although there are 37 adult ADs and 11 level I TCs in the state. Three percent of the population, or over 340,000 Ohioans are affected;
3. The goal of this research is to use a model to simultaneously locate TCs and aeromedical depots (ADs) in Ohio such that every patient, regardless of location, will be able to reach a level I TC within an hour;
4. Additionally, it is theorized that 100% coverage can be achieved for the state using the existing number of resources or even fewer resources, thus saving cost.

Figure 1 shows the location of level I TCs in Ohio. The light areas demonstrate underserved regions.
Figure 1. (source: University of Pennsylvania’s Trauma Center Maps

http://www.emergencymap.org/Trauma.aspx)
1.2 Research Questions and Contributions

The primary objective of this research is to use a resource allocation model to find the optimal location for both level I TCs and HTs in the state of Ohio such that every severely injured patient can reach definitive care within an hour. In most related literature, and also for the purposes of this research, a severely injured patient is defined as a patient with an Injury Severity Score (ISS) of at least 15. The ISS is a scoring system based on various anatomical injuries and it provides a score for polytrauma patients to give an indication of overall injury severity. Each specific injury is assigned an Abbreviated Injury Scale (AIS) score, for each of the follow six regions: Head, Face, Chest, Abdomen, Extremities (including Pelvis), and External. Only the single highest AIS score for each body site is used towards calculating the ISS and the 3 most significantly injured anatomical regions have their scores squared (Brohi, 2007).

By optimally locating existing resources, it may be possible to provide access to the entire state of Ohio (100% land coverage versus 89% as of 2010) with over 346,000 additional Ohioans being able to receive appropriate care that would otherwise not be available. In an era of cost saving measures in healthcare, it may be possible to discover that the current coverage (97% of population and 89% for the state land area) can be achieved with fewer resources or, perhaps, that Ohio can achieve 100% coverage with less resources. By using fewer resources, this could allow any expenses saved to be directed to other services such as injury prevention or public education measures, or concentrating patient volumes so as to improve patient outcomes by having more experienced medical staff, or even potentially lowering the cost of healthcare services.
This research could provide awareness for health care administrators, planners, and policy makers to more closely examine the placement of such costly services. Hopefully, those involved with TC designation and policy will entertain the thought of being able to do more with less and still provide a high level of patient care. Rural populations are at higher risk for trauma mortality and an unbiased placement of resources could help minimize this risk.

Researchers could further enhance this model or modify it in order to include a more detailed analysis of ground transport (GT), a more cohesive trauma system including level I, II and III facilities with adjacent state resources, examine pediatric TCs or apply the model to other states.
Chapter 2

Literature Review

This chapter presents a review of the literature and will discuss the following issues: Geographic Accessibility, Inequality of Access to Appropriate Trauma Care/Rural Access to Trauma Care, Benefit of TC care and Benefit of Direct TC Transport, TC Volume and Benefit, Benefit of Level I vs II TCs, Benefit of HT, Cost/Duplication of TC/HT Care, and Challenges with TC care.

2.1 Geographic Accessibility

There is a great deal of literature regarding access to healthcare (Aday and Andersen 1974, Andersen and Aday 1978, Pirie 1979, Andersen, McCutcheon et al. 1983, Branas, MacKenzie et al. 2005, Carr, Branas et al. 2009, Hameed, Schuurman et al. 2010). Healthcare access, according to Aday and Anderson, has five dimensions; accessibility is one of those dimensions. Accessibility can be viewed from a socio-organizational perspective or from a geographic perspective, which is a function of space. For the purpose of this research, this study will focus on geographical accessibility.
2.2 Inequality of Access to Appropriate Trauma Care/Rural Access to Trauma Care

The term “rural” can describe an area in terms of size, population density, geography or even as more abstract social concepts such as lifestyle factors, values or behavioral patterns (Rogers, Shackford et al. 1999). A region where the population is less than 2,500, a population density of less than 50 persons per square mile, “has only basic life support prehospital care, has prehospital transport times that exceed 30 minutes on average, and is lacking in subspecialty coverage for specific injuries (such as neurosurgeon to manage the patient with head injuries) would be a rural trauma region.”

Ibid There are several healthcare access disparities for rural populations, including emergency medicine departments staffed with residency-trained emergency physicians, trauma centers and other specialized services. Approximately 20% of the nation’s population is rural, but fewer than 11% of physicians practice in rural areas (Ryb and Dischinger 2011). Only 72% of the US population has access to an emergency room within 30 minutes and 98% has access within an hour (Carr, Branas et al. 2009). If one lives in a rural area, they are 50% more likely to die from trauma than their urban counterparts, and every cause of traumatic injury has a higher mortality in a rural versus urban setting (Gonzalez, Cummings et al. 2006). Multiple studies have examined the causes for high rural injury mortality and the common factors identified are: distance from emergency medical services, distribution, type and distance to facilities, training and resources of the hospital and staff, lack of 911 availability and the lack of appropriate
triage to a higher level facility with lack of recognition of injury severity (Young, Torner  
et al. 2003). In a setting of rural motor vehicle accidents, increased EMS response time,  
distance to scene and time on scene are associated with high mortality rates for trauma  
victims and there is a strong association with timeliness of care and increased mortality in  
the rural prehospital setting. Rural response times are double that of urban areas and  
these longer response times have a significant impact on rural mortality. If response  
times are under 5 minutes, there is an increased chance of survival (Gonzalez, Cummings  
et al. 2006). In the examination of pedestrian fatalities, it was shown that a larger  
percentage of rural fatalities died out of the hospital and within the first hour after injury  
versus urban fatalities. “It is possible that Emergency Medical Services care is less  
rapidly available and that accessibility to trauma centers is more limited in rural areas.”  
(Mueller, Rivara et al. 1988) In rural areas, approximately 80% of prehospital providers  
are volunteers which can significantly impact response times (Young, Torner et al. 2003).  

As of Jan 2005, 46.7 million Americans lacked access to a Level I or II TC within one  
hour and most of these residents were rural (Branas, MacKenzie et al. 2005). 13.6  
million Americans had access to Level III but not a level I or II TC. Although the  
number of Level III TCs has increased since the 90s, they only provide initial evaluation  
and assessment of trauma victims because of a lack of advanced treatment options.  
(Branas, MacKenzie et al. 2005) Helicopters provide 81.4 million Americans who  
otherwise wouldn’t have access to a TC within an hour (Branas, MacKenzie et al. 2005).  
Hsia, et al. reported in their research that 38.4 million people in the US lack access to a  
TC within one hour driving time (Hsia and Shen 2011). In Canada there is a similar  


problem with lack of rural access to level I/II TCs within one hour, with 22.5% of rural Canadians lacking access (Hameed, Schuurman et al. 2010).

2.3 Benefit of TC Care and Direct Transport to TCs

Research has consistently shown that if a severely injured patient gets to a TC, they will have a better outcome. Several articles cite a 15-20% reduction in risk of death if treated at a TC (Jurkovich and Mock 1999), and MacKenzie, et al. showed a 25% reduction in mortality (MacKenzie, Rivara et al. 2006). The improved survival and functional benefits are very well-documented for vulnerable populations such as pediatrics and the elderly if care is delivered at a designated TC (Bensard, McIntyre Jr et al. 1994, Potoka, Schall et al. 2000, Osler, Vane et al. 2001, Pandya, Yelon et al. 2011, Pracht, Langland-Orban et al. 2011). Even among minimally injured patients, there is a difference in functional outcomes between lower tiered or undesignated TCs and higher tiered centers, particularly in penetrating traumas. One study theorized that this is due to the ability for higher tiered TCs to deliver complex care which then improves functional outcomes (Nirula and Brasel 2006).

States with a mature trauma system as a whole see improvement in outcomes of injured patients, like those in North Carolina whose trauma system is over four decades old (Becher and Meredith 2010). In Florida, counties with an organized trauma system are associated with lower trauma-related death versus counties without TCs. TC counties
also had significantly lower MVC death rates than non-TC counties independent of rural/urban location and prehospital resources (Papa, Langland-Orban et al. 2006).

Rapid transport to a proper level TC is imperative with the severely injured. The so-called golden hour is quite relevant for certain injuries. The term “golden hour” originated in a trauma setting and is “now a general concept in emergency medicine that is applied to conditions in which hyper-acute therapy is more effective than later intervention, including trauma, myocardial ischemia, septic shock, cardiopulmonary resuscitation, and stroke.” (Saver, Smith et al. 2010) Craniocerebral injuries are very time sensitive and are the most common traumatic injury at 35.8% (Sogut, Sayhan et al. 2011).
It is estimated that 50,000 patients die per year from traumatic brain injury and these patients tend to be older with more severe injuries. (Härtl, Gerber et al. 2006) Direct transport to a TC versus indirect transport significantly reduces mortality. It is recommended that even if a non-TC is closer, that patients with traumatic brain injuries be transported direct to a level I/II TC. *ibid*

Minimizing the time from injury to appropriate definitive care can have a positive influence on outcome. There is literature promoting the concept of “scoop and run” where basic life support is administered in the field versus advanced life support and the patient is taken directly to the nearest TC. Nirula, et al. have shown that if a severely injured patient is taken to a non TC first, there is an increase in mortality (Nirula, Maier et al. 2010). This is possibly attributed to less aggressive resuscitation if a patient transferred to TC from non TC versus those to a TC direct. *ibid* Traumatic brain injury patients saw a 50% increase in mortality if transported to a non TC first with subsequent
transfer versus a TC direct. *ibid* If the time from the field to the closest hospital is not significantly longer than the time to the nearest TC that can deliver definitive care, it may be beneficial to bypass the closest hospital in favor of improved definitive care. “What constitutes an unacceptably long field to TC transport time requires further investigation”. *ibid*

### 2.4 Benefit of Helicopter Transport

Helicopters can be a costly resource and should be used judiciously. There have been several studies looking at what patients benefit from HT (if any at all) and when is HT superior to GT. Two studies by Brown, *et al.* showed that HT was an independent predictor of survival (Brown, Stassen *et al.* 2010, Brown, Stassen *et al.* 2011). In the 2011 study examining HT benefit, it was observed that patients who tended to be transported by helicopter were more severely injured, had a higher likelihood of a severe head injury and hypotension compared to those transferred by ground ambulance. (Brown, Stassen *et al.* 2011) These patients also had a longer LOS, higher rates of ICU stay with mechanical ventilation, and a higher rate of emergent operations. It was shown that only 8% of patients transported by helicopter versus 16% of those transported by ground ambulance were discharged within a 24-hour period after being admitted to a TC. Also of note were that response times to a referring hospital and time spent at the referring hospital before patient transfer were longer for the HT population versus GT population. Actual transport time was markedly shorter for patients in the HT group versus GT group with an average transfer distance of 154 miles (assuming 150 mph
speed) for HT and 49 miles for GT. They concluded that, HT was “an independent predictor of survival to discharge after adjusting for covariates” in more severely injured patients. Their HT group had an average 17-minute advantage in prehospital time versus the GT group. “For patients with ISS >15, HT was an independent predictor of survival to discharge when compared with GT.” *ibid*

An earlier study by Thomas, *et al.* showed a 24% reduction in severely injured blunt trauma patient mortality if transported by helicopter (Thomas, Harrison *et al.* 2002). “Primary transfer by HEMS into a Level I trauma center reduces mortality markedly.” Mortality of the AMB-REG (ground ambulance into regional hospital) group was almost doubled (41.2%) compared with HEMS-UNI (helicopter to university) patients (22.1%) (Biewener, Aschenbrenner *et al.* 2004).

It is also important to note the professional skills of those on helicopters. Baxt, *et al.* observed that all helicopter medical services in their study used more advanced techniques than those used in a traditional prehospital setting (Baxt, Moody *et al.* 1985). Because helicopter medical crews are smaller and practice their skills frequently, they are quite proficient with nearly a 100% success rate in their performance of medical techniques in the field. The success of hospital-based helicopters is the same for why TCs have a reduction in patient mortality because both, “are profiting from a timely, organized, and coordinated approach to patient treatment which, as embodied in the ‘systems’ concept of trauma care delivery, has been held responsible for an improved patient outcome in the past.” *ibid* Hospital-based helicopter act as “an active treatment arm of the hospital at which it is based; the regional land EMS service is usually a
separate entity.” *ibid* For patients, this results in “fully integrated” prehospital and definitive TC care. Because critical resources can be prepared, treatment plans developed, and triage priorities could be decided before admission thus saving time. In contrast, in patients who are transported by GT, there isn’t typically a significant warning time given to prepare before arrival (Baxt, Moody *et al.* 1985).

Transportation by HT is not always the fastest method of patient transport. Diaz, *et al.* analyzed at what distance threshold ground transport would be faster than HT. They determined that GT would be faster at distances less than 10 miles from the hospital. At distances greater than 10 miles, simultaneously dispatched air transport was faster than GT, and at greater than 45 miles, non-simultaneously dispatched HT was faster than GT.

### 2.5 Trauma Center Volume and Outcomes

There is also debate in the literature whether trauma patient volumes positively affect outcomes. For specialized surgery, such as cardiothoracic surgery or neurosurgery, volumes do positively affect outcomes and this has been well documented with little debate, but in correlating TC volume with outcome, there is no consensus in the literature.

There are several articles stating that increased patient volumes at TCs result in improved outcomes. Smith *et al.* studied seven TCs in Chicago, and they observed a 30% decrease in mortality among those taken to a higher volume center. For the purpose of their study, a “high-volume center was defined as more than 200 severely injured
patients per year (Smith, Fratetschi et al. 1990). Another study looked at pediatric trauma mortality rates in low volume versus high volume centers. In analysis of the National Pediatric Trauma Registry, there were 37 TCs and the authors concluded that moderate volume centers had the lowest risk-adjusted mortality. It was proposed that high-volume TCs operated at a lower level than moderate volume TCs because of an extremely high number of patients admitted with minimal trauma.” (Tepas, Patel et al. 1998)

Nathens, et al. showed that the odds of death in patients with penetrating abdominal injury and shock declined dramatically with higher trauma volume TCs. A reduction in LOS with increased TC volume was only seen when patients had an ISS of 15 or higher. Adjusted odds of death decreased in coma patients at higher volume institutions, and penetrating or blunt trauma victims had better survival chances at higher volume TCs. ASC/COT recommends 1200 trauma admissions per year, of which 20% need an ISS of 15 or higher. Volume of at least 650 patients per year with an ISS of greater than 15 was associated with better outcomes, but only 6 of 31 level I/II TCs met that amount (Nathens, Jurkovich et al. 2001). One could then propose based on only 6 of 31 TCs potentially improving outcomes by meeting volume criteria, that if there was more than 1 TC in an area and none of those TCs could meet the 650 patient per year threshold to affect outcomes, that it would be better patient care to concentrate those patients into one center only.

Other literature states that volume doesn’t necessarily positively affect outcome. Trauma program commitment may be a better measure of outcome rather than volume. Cooper, et al., analyzed outcomes from New York State TCs, and reported that the
overall mortality in low-volume centers was 7.62% versus 5.25% in the high-volume centers. They surmised that volume criteria shouldn’t be required for the designation of trauma centers. Nathens, in his critique of Cooper’s work, pointed out that only high risk patients may benefit from the experience and resources of a high-volume center and that the low mortality in Cooper’s work shows that a large number of minor injuries were included in his study. Also, Cooper’s research did not include any patients who were admitted alive but subsequently died in the emergency room. The elimination of this patient demographic could favor smaller centers where patients might expire in the ER instead of expeditiously being brought to the operating suite (Cooper, Hannan et al. 2000).

Another study by Margulies, et al. examined 1754 severely injured patients (ISS >15) from 5 different level I TCs. Their analysis showed that volume actually correlated negatively with patient survival. Their work included patients admitted without vital signs, which may also favor small centers that treat fewer penetrating injury patients who arrive at the TC without vitals and receive effective resuscitative thoracotomies (Margulies, Cryer et al. 2001).

Glance, et al. conducted a study including 7371 patients with ISS at least 15 who were admitted to the TC alive. Their logistic regression analysis did not show any relationship between volume and outcome for both blunt and penetrating trauma. They concluded again that volume criteria for level I TCs needs to be revisited (Glance, Li et al. 2006).
In work by London, et al. and their analysis of 38 level I and II TCs, they showed that trauma volume was not a significant factor contributing to high morbidity or high LOS in patients with both an ISS of greater and less than 15 (London and Battistella 2003).

Finally, Demetriades, et al. conducted a study that also showed that the volume criteria for level I TCs is not valid, at least with the specific set of critical injury patients in their study. Their study included patients with an ISS >15, greater than 14 years of age with aortic, vena cava, iliac vessels, cardiac, or grade IV/V liver injuries, quadriplegia, or complex pelvic fractures. Intuitively, one would expect an inverse relationship between trauma volume and outcomes because of the experience gained by the trauma program in the management of severe injuries. They propose that it may be that the “high standards required by the ACS for level I designation compensate adequately for the relative lack of high-volume experience.” It is also possible that the optimal volume may not be the 240 patients as dictated by ACS/COT but another lower number (Demetriades, Martin et al. 2005).

Although there is no consensus whether TC volumes predict outcomes, it could be argued that if there is no proven harmful effect to patients if a TC has a high volume of severely injured patients, then consolidating care into a smaller number of TCs is not detrimental. TCs and ADs are a costly commitment and perhaps that money saved could be better directed towards lowering costs, patient education and injury prevention.
2.6 Level I vs II Trauma Centers

There is also debate in the literature whether there is any benefit for patients to be treated at a level I TC versus a level II. Two studies showed no benefit to level I care. Pasquale, et al. looked at the Pennsylvania trauma system and examined 9 injury types. Their logistic regression did not show any benefit of level I or II designation with regard to survival except in injuries of the spleen (Pasquale, Peitzman et al. 2001).

The second study by Helling, et al. reviewed mortalities from liver injuries for two level I TCs and four level II TCs. Overall mortality in level I TCs was 16% and for level II TCs 15%. The mortality for liver injuries treated in level I TCs was 51% for 43 patients, and for level II centers, it was 71% for 14 patients. They concluded that there is no benefit to level I care when looking at survival of liver injuries. It should be noted that there was a very small patient population examined in the study (Helling, Nelson et al. 2005).

Demetriades, et al., on the other hand, argue that there is a survival benefit to being treated at a level I vs II TC. They speculate that the immediate presence of an operating room team is an important factor in survival since time to definitive care is so important (Demetriades, Martin et al. 2005). Other factors they identified that may play a role are the in-house surgical intensive care physician and computed tomography scan technician. “The effect of these variables on outcome is not known and is difficult to be assessed.” ibid Also level I centers may attract better, more experienced practitioners. Finally, they
propose that “research in the field of trauma in level I centers may improve outcomes by modifying practices and protocols” *ibid.*

### 2.7 Cost and Duplication of Trauma Center and Helicopter Transport Services

Trauma care is costly. Per AAST.org, an intensive care bed costs on average $3,500 to $4,000 per day and the average patient cost for trauma care ranged from $14,022 in the Northeast to $18,929 in the West (Obirieze, Gaskin *et al.* 2012). Although critically ill patients benefit from helicopter transport (HT), it is a costly resource and costs five to ten times that of ground transport. Almost 10 years ago, operating costs for fuel and maintenance were approximately $650 a flight hour. If a helicopter is simultaneously dispatched with a ground ambulance, there could be a cancellation rate of as high as 55%, which is a waste of resources that can threaten the viability of an air program (Diaz, Hendey *et al.* 2005).

Although there can be a significant reduction in mortality after designation as a TC, the expense for call pay for subspecialists can be as high as $1.5 billion and it is estimated that the “price of commitment” to be a TC is 15 million dollars per year. This equates to every life saved costing approximately $87,000 but 173 patients survived who would otherwise be dead. It is estimated that it costs an additional 3 million dollars per year for a hospital to operate as a level I TC. (Rotondo, Bard *et al.* 2009)
One-year unadjusted treatment costs averaged over $85,000 for a TC versus over $47,000 for a non TC. Costs for initial hospitalization were 71% higher for patients in TCs. This extra cost resulted in 3.4 net lives saved per 100 major trauma patients treated at a TC versus non TC. This results in a cost effectiveness ratio of $36,319 per life-year gained or $790,931 per life. Although treatment at a level I TC is expensive, the benefits in terms of quality adjusted life years gained saved outweighed the costs (better if under 55 years of age) (MacKenzie, Weir et al. 2010).

Another problem is “excessive” access where 42.8 million Americans could reach 20 or more TCs within an hour. These areas were prominent in the Northeastern US (Branas, MacKenzie et al. 2005). According to the American Association for the Surgery of Trauma, only approximately 5% of injured patients need to receive care at a TC. To ensure these patients reach a TC, it is accepted that at least 10% of injured people should be taken to a TC for evaluation. The remaining 90% should be treated locally.

**2.8 Challenges with TC care**

There are those involved with rural health research that make the argument that TC and HT services are costly, and especially in rural populations, the money would be better spent on educating the public. This is due to the fact that many rural trauma victims die before they are even discovered, and have lower use of safety measures like seatbelts and helmets. Stewart, et al. analyzed traumatic deaths at level I TCs, and they discovered that central nervous system injury was the most common cause at 51%, and 93% of deaths
were not preventable. Of those that were unintentionally injured, 58% had an identifiable factor that contributed to the presence or severity of injury such as alcohol, restraint use, helmets etc. Alcohol consumption was the most common factor at 28%. With regard to intentional injuries, alcohol was involved 44% of the time. Their argument was that even if therapy were dramatically improved, there would only be a 13% decrease in traumatic injury mortality whereas if prevention were the focus, there would be at least a 50% decrease in mortality (Stewart, Myers et al. 2003).

There was a similar study looking at fatalities in rural Michigan and a “relatively small percentage” could have been prevented by more appropriate or timely medical care. This research stated that changes in acute rural trauma care will only marginally reduce the overall rural trauma death rate, since only a relatively small percentage of rural trauma fatalities in northern Michigan could have been prevented by more appropriate or timely medical care” (Maio, Burney et al. 1996).

Although TCs have slightly higher incidence of complications after adjusting for the patient case mix, this is due to the aggressive nature of the treatment delivered (with interventions such as pulmonary artery catheterization, intubation and sepsis due to multiple operations) (Ang, Rivara et al. 2009).

Finally, TC care is expensive. Length of stay (LOS) is a targeted metric to reduce costs and is a standard metric for quality improvement and also a good measure for resource utilization. Approximately 10% of those admitted to a level I TC had an excessive LOS. This subset of patients consumed 30% of expenditures for care and developed the majority of complications. A prolonged LOS is also associated with
adverse outcomes and TCs do have higher mortality rates, but they also care for more severely injured patients (O’Keefe, Jurkovich et al. 1999).

2.9 Previous Trauma Center Location Research

Currently, there is little research available using an optimization model to locate trauma resources. Branas and Revelle created the TRAMAH model that was one of the first to be devoted to locating both helicopter pads and TCs simultaneously (Branas and Revelle 2001). It was based on previous resource allocation models (ReVelle, Bigman et al. 1977, Schilling, Elzinga et al. 1979, Moore and ReVelle 1982, Marianov and ReVelle 1995). It has the ability to simultaneously locate both TCs and ADs within a given time constraint. Coverage was measured by the percent of severely injured patients having access to a TC within the specified time constraint by ground and/or air transport. The TRAMAH objective function is maximizing coverage of severely injured patients:

Maximize \( Z_{TRAMAH} = \sum_{i \in I} q_i y_i \)  \hspace{1cm} (1) Objective
Subject to the following constraints:

\[ \sum_{j \in J} x_{ij}^{TC} = p_{TC} \quad \forall j \in J \]  
(2) Number of TCs

\[ \sum_{k \in K} x_{ik}^{AD} = p_{AD} \quad \forall k \in K \]  
(3) Number of ADs

\[ y_i - v_i - u_i \leq 0 \quad \forall i \in I \]  
(4) Ground/Air Logic

\[ v_i - \sum_{j \in N_i} x_{ij}^{TC} \leq 0 \quad \forall i \in I, j \in J \]  
(5) Ground

\[ u_i - \sum_{(i,j,k) \in M_i} z_{kj} \leq 0 \quad \forall i \in I, j \in J, k \in K \]  
(6) Air

\[ z_{kj} - x_{ij}^{TC} \leq 0 \quad \forall j \in J, k \in K \]  
(7) Ground Logic

\[ z_{kj} - x_{ik}^{AD} \leq 0 \quad \forall j \in J, k \in K \]  
(8) Air Logic

\[ 0 \leq y_i \leq 1 \quad \forall i \in I \]  
(9) Bounds

\[ x_{ij}^{TC}, x_{ik}^{AD} \in \{0,1\} \quad \forall j \in J, k \in K \]  
(10) Integers

where:

\[ y_i = 1 \text{ if demand node } i \text{ is covered by air or ground, } 0 \text{ otherwise;} \]

\[ a_i = \text{population demand at node } i; \]

\[ v_i = 1 \text{ if demand node } i \text{ is covered by ground, } 0 \text{ otherwise;} \]

\[ u_i = 1 \text{ if demand node } i \text{ is covered by air, } 0 \text{ otherwise;} \]

\[ I = \text{the set of demand nodes, } i; \]

\[ x_{ij}^{TC} = 1 \text{ if a TC is sited at node } j, 0 \text{ otherwise;} \]

\[ J = \text{the set of eligible TC locations;} \]

\[ x_{ik}^{AD} = 1 \text{ if an AND is sited at node } k, 0 \text{ otherwise;} \]

\[ K = \text{the set of eligible AD locations;} \]

\[ z_{kj} = 1 \text{ if an AD is sited at node } k \text{ and a TC is sited at node } j, 0 \text{ otherwise;} \]

\[ p_{TC} = \text{the number of TCs to be sited;} \]

\[ p_{AD} = \text{the number of ADs to be sited;} \]

\[ N_i = \left\{ j \mid t_{ij}^g \leq S \right\} = \text{TC sites within the time standard, } S, \text{ of node } i \text{ by ground;} \text{ and} \]

\[ M_i = \left\{ (j,k) \mid (t_{ik}^A + t_{kj}^A) \leq S \right\} = \text{TC/AD pairs within the time standard, } S, \text{ of } i \text{ by air.} \]
Their problem was assessed on a network with arcs and nodes and only the constraints (5) and (6) were held to a time constraint.

Branas, et al. conducted an iterative switching heuristic using vertex substitution to reduce processing times and was “the equivalent in concept to the subjective elimination of eligible AD and TC sites typically performed by a trauma systems administrator” (Branas and Revelle 2001). The heuristic works with a sequence of one-opt substitutions. First, the best AD sites are selected while the TC locations are fixed. The best TC sites are then calculated while holding the AD sites fixed. The process repeats until no further improvement in the objective function is achieved.

Figure 2. Image from Branas and Revelle. Schematic showing coverage for TRAMAH with solid arrows representing air coverage and broken arrow ground coverage.
The TRAMAH model is particularly applicable here because it recognizes that both ADs and TCs are interdependent upon one another and accounts for this with the switching heuristic. If one is to examine the concept of coverage for trauma patients in Ohio, one needs to consider both location of transport depots and also the TCs themselves. It is a two-part problem.

The time constraint for their research was 30 minutes. Historically, as stated earlier in this chapter, 60 minutes is also an acceptable standard. TRAMAH included both Level I and Level II TCs in their study of the state of Maryland and they achieved 100% coverage within the 30-minute time limit. While there is little difference in the level of care delivered for many types of severe injuries between Level I and Level II TCs, it is reasonable to limit the TCs to Level I only since it provides the highest level of care and ensures adequate care for neurological injuries. Given that this study would limit the TC type, 30 minutes seemed unreasonable, especially since the 60-minute time standard is valid.

Ground transport times (with street speeds lowered to reflect added response time) were included in the TRAMAH matrix calculations but whether this was an entirely necessary endeavor is uncertain. It may be reasonable to assume that since Level I TCs are more likely historically to be located in urban areas, those that live in urban areas are already covered by the 30-minute constraint. The same effect could be achieved by eliminating those zip codes within a 5 or 10-mile radius around a single Level I TC located in an urban area. One must then ensure that the final solution set includes TCs in those urban areas and then it is up to redundant urban facilities to be relocated to better provide rural
access, Level I TCs be optimally located within urban areas to allow for optimal access or finally, AD location optimize urban TC location. Ground transport times were assumed to be within the time constraint in urban areas (5-mile and 10-mile radius given existing TCs) so those were not included in the matrix calculations. Warm up times were not accounted

Another interesting approach to the Branas et al. work was that they used both a “clean slate” approach and then ran the model again to optimize existing facilities, then compared the difference. In their clean slate approach, the authors opted to use zip code centroids as eligible sites for ADs. It may have been more realistic to instead to have all existing airfields and helipads as candidate nodes instead of zip code centroids. Due to topography, several contiguous zip codes may be ineligible to be AD sites. Using existing, proven air fields and pads may be a better option. For their TC sites, they only considered standing hospitals and did not use zip code centroids which is practical and realistic. In their optimization method of existing facilities, they held constant the existing nine TCs in Maryland and optimally located the ADs. They achieved better coverage for injured patients with fewer resources in both scenarios.

As in previous trauma survival research, ISS of 15 or higher is the standard. The TRAMAH research data utilized scores equal or greater to 15 and limited the study to adults only. Since the bulk of existing research uses an ISS of 15 or higher, it only makes sense to include those with a minimum score of 15 so that one’s results can be compared to existing studies. Pediatric trauma is highly specialized and in order to examine the
Optimal location for those facilities, that work would best be served by a study focusing solely on that patient population.

Branas et al. used patient home zip code as a proxy for injury location. Most people experience trauma close to home so this is an entirely reasonable assumption as proven by Myers et al. While it is not optimal, home zip code data are easily obtainable since trauma registrars collect that data as a standard. Injury location can be difficult to obtain since it can be vague and inaccurate, especially in a rural setting. Home zip codes can easily be represented as centroids where injury location data could be reported as latitude and longitude, street address, county, mile marker on a highway, etc. Unfortunately, those who are traveling away from home and are injured severely would not be accurately represented in the study, but they would be in the minority and those few cases would not affect the weighted centroids significantly.

While the TRAMAH model appears to generate effective results, it is argued that trauma research could be just as well-served by utilizing the vertex substitution method (VSM) developed by Teitz and Bart (Teitz and Bart, 1968). This method is well-documented and represented in the literature. This discussion will focus on a variation of the VSM used for this research that permits the optimization of both AD sites TCs. The model is more parsimonious than the switching heuristic utilized in TRAMAH, but has been proven to be highly effective among a variety of scenarios, is easier to code and likely would generate just as effective results. The model used for this research is:

\[
\text{Min } Z = \sum_{i=1}^{n} \sum_{j=1}^{o} \sum_{k=1}^{d} w_i c_{ijk} a_{jik} f_k g_j
\]
Where:

i = ith demand node

j = jth origin facility

k = kth destination facility

n = total demand nodes

o = total origin facilities

d = total destination facilities

w = weight associated with the ith demand node

cjik = transaction cost between origin j, node i, and destination k

\( a_{jik} \) = decision variable

\( f_k \) = destination facility set

\( g_j \) = origin facility set

In the model, cost, or distance, is minimized. The sum of the distance from the origin facility “j” (ADs) to the weighted (w) demand nodes “i” (zip code centroids representing patient populations) and then to the destination facility “k” (TC) is calculated. The “ajik” represents the solution where it is “1” if it the least cost or “0” if otherwise. If it is 0, it will not be included in the solution set. The “f” is the solution set of AD nodes and “g” is the solution set of TCs.
Vertex substitution is a heuristic that works in the following way:

- A random solution set of nodes (facilities) is selected from given candidate nodes;
- Shortest distances are calculated from the demand points to the selected solution set nodes;
- Total cost is calculated based on the initial random solution;
- Incrementally replace the initially selected nodes in the solution set with other available candidate nodes. A candidate node is any facility which is eligible to become part of the solution set;
- Recalculate the total cost and determine if an improvement has been achieved;
- If there is an improvement, disregard the previous solution and continue replacing candidate nodes in the solution set and recalculating total cost; and
- Repeat the process until there is no further improvement in the total cost.

For purposes of this study, the constraint will be one hour, although in the future, this could be changed to reflect injury urgency. Not all nodes will be considered eligible to have a TC or AD located on them since this is not practical. Due to topography or practical reasons, not all nodes could function as an AD and building TCs de novo while
there is existing infrastructure (hospitals) would be too costly. All nodes were considered possible injury locations.

With air transport, the model takes into account the sum of flying time from the AD to site of injury and then from the site to the TC within the same time requirement. To account for ground coverage, shortest driving times will be calculated and as with the previous study, interstate speeds will be 60 mph, highways 50 mph and road speed 40 mph. The location of ground ambulance depots were implied due to the complexity of taking into account all of the existing ground depots in the state. Ground transport speeds were set lower than normal to allow for a more realistic depiction of ground travel time. Previous studies have demonstrated that in areas with TCs, ground depot-to-scene times average about 5 minutes (Pepe, Wyatt et al. 1987, Feero, Hedges et al. 1995). This amount of time has been considered negligible and therefore ground depot to scene time will not be included in my research.

Air speed data obtained from the state of Ohio shows consistency with previous research and average travel speed of 120 mph is reasonable. Euclidean distances between zip code centroids will be calculated and flying times inserted into an air travel matrix.

An intuitive weakness of the model is the use of zip code/county of residence to proxy injury location (i). This is a potential obstacle because traumatic injury can happen anywhere and people are mobile. MVCs are the most common cause of traumatic injury and highways carrying travelers are frequent sites of injury. Obtaining injury site zip code data from fire or police departments for all trauma calls and then later correlating that same patient to a hospital admission with an ISS would be difficult and cumbersome.
When a trauma patient is admitted to the TC, a registry is required to collect and submit anonymous patient data which includes zip code of residence, type of injury and ISS etc. This data is well-organized and easy to obtain. In addition, Myers, et al. demonstrated that home location is an appropriate proxy for injury location (Myers, Branas et al. 2011). Their analysis revealed that the majority (73.4%) of injury deaths occur within the county of residence. If one were to include contiguous counties the percentage would rise to 87.7%. Unintentional deaths were less likely to occur within the county of residence (68.1%) than intentional deaths but both still happen near county of residence most of the time.
Chapter 3

Methodology

3.1 Data Set Construct

Data required for analysis were obtained from a variety of sources. Ohio zip code data with geographic coordinates were provided courtesy of the Department of Geography and Planning at the University of Toledo. Patient injury location and severity data were obtained from the Ohio Department of Public Safety Division of Emergency Medical Services, which consisted of trauma injury data for Ohio from 2000-2010. The data were publicly available as the identities of the patients were masked. These data included zip code, home of record for the patient, age and injury severity score. As previously discussed, home of record was used as a proxy for injury location since those data aren’t always obtained by the trauma registry. Those who were not residents of Ohio were eliminated from the dataset, as well as those under the age of fifteen, and patients with an ISS of below 15. The number of patients was then tallied for each zip code and this served as the weight for analysis. Both datasets were then combined and it was noted that the geocoded zip code data were missing 14 zip codes that were recorded in the patient home of record dataset. These all had a weight of one and were not included in analysis.
A comprehensive list of Ohio public airfields and helipads with latitude and longitude was obtained online from Ohio Department of Transportation website and https://www.airnav.com. Latitude and longitude were then converted to Cartesian coordinates using the Ohio State Plane (Southern Zone), and in units of miles to match the zip code dataset units. A list of currently staffed helicopter sites was obtained from the Ohio Association of Critical Care Transport. One staffed helipad was dedicated for pediatric trauma only and was eliminated from the study. Trauma center location and level of care information were gathered online from the Ohio Department of Public Safety Emergency Medical Services website.

Since rural access to trauma care is an issue in Ohio, it was considered as the main focus of analysis since air transport is required for timely transport of these patients. Those living within ground transport distance of existing Level I or II TC (those living in urban areas of Ohio) do not typically utilize air transport so they were not crucial to analysis. It is assumed that major urban areas in Ohio will have a level I TC given the population, so this analysis presumed that a Level I TC will be present in Toledo, Columbus, Cincinnati, Cleveland and Akron areas. A five-mile radius and then a 10-mile radius were calculated around each Level I and II TC in Ohio. Those zip codes that fell within the radii were eliminated from the dataset. As a result, there were two zip code datasets: one with all zip codes within a five-mile radius of a Level I/II TC eliminated and a second with all zip codes within a ten-mile radius eliminated. Analysis was performed on both datasets.

This analytical approach then involved a two-part problem. First, level I trauma centers would be optimally placed based on existing staffed AD locations to determine whether
or not it was feasible to achieve one hundred percent coverage in Ohio if the trauma centers were optimally placed. Then, the number of trauma centers would be decreased to determine a minimum number of centers required to cover all trauma patients in the state given existing staffed helicopter pads. It is also theorized that one hundred percent coverage for patients in the state could be achieved with existing staffed ADs if the TCs were optimally placed, and, it could even be achieved with fewer TCs.

The steps involved in analysis were as follows:

1. Geocode all hospitals and current staffed AD sites in Ohio;

2. Geocode zip code centroids to serve as a proxy for injury location. Twenty-two zip codes had to be eliminated due to lack of latitude and longitude data. Zip code centroids were weighted based on historical number of injuries in a given zip code compiled between 2000-2010. The data were obtained from Ohio Emergency Services. The patients included in the dataset were over the age of 15 with an ISS of at least 15. The decision for age and ISS was based on previous research. The zip codes that had historical data had a weight of 1;

3. Remove all zip code centroids from the dataset that are currently within 5 and 10 miles of an existing Level I or II TC. This would eliminate the population in urban areas that would not be served by air ambulance, but rather solely by ground transport. It is reasonable to assume that there will be a Level I TC in major metropolitan areas;
4. Calculate Euclidean distance for flying time from existing staffed AD sites to weighted zip code centroids (using latitude and longitude) and create a matrix. This calculation would be done for the zip centroids with the 5-mile radius elimination and also for the 10-mile radius elimination. The flying time was based on an average cruising speed of 164 mph with warmup, acceleration and deceleration times of two minutes each added to the calculation. The data for all helicopters used in the state was obtained from Ohio Emergency Services and it was proven that an average cruising speed of 164 mph was reasonable across all helicopter types. Not all helicopters required 2 minutes each to warmup, acceleration and deceleration, but it was decided to be conservative and include it for all staffed ADs regardless if needed for that particular type of aircraft;

5. Calculate Euclidean distance from zip code centroids to all existing hospitals in the state of Ohio and create a matrix; and

6. Vertex substitution was then run on a specified number (set) of randomly selected candidate nodes). Total cost (travel time) was calculated for the randomly selected initial set of candidate nodes, and each node was then systematically swapped out for a different candidate node and total cost is recalculated. This was repeated until no further improvement was achieved. It was specified that travel time should not exceed 60 minutes to be considered a candidate node.
The second part of the research involved optimizing helicopter pads sites and then using these ADs to determine optimal TC locations. The steps were as follows:

1. All existing airfields and helicopter pads were geocoded for the state of Ohio. These 376 airfields and helicopter pad locations were obtained from the Ohio Department of Transportation. All sites, unless privately owned, were considered candidate nodes;

2. 37 ADs were initially specified to reflect the same number of resources that currently exist in the state. Each weighted zip code centroid was then assigned to a candidate AD based on maximum travel time of 30 minutes;

3. The number of ADs was gradually decreased until it was impossible to cover all zip codes within 30 minutes;

4. After these optimal ADs were obtained, the steps were then repeated as previously described. Both AD and TC resources were minimized until coverage was impossible. A distance matrix was calculated from the optimized ADs to zip centroids and then a second matrix was created from the zip centroids to all hospitals. Vertex substitution was performed with the time constraint of one hour. The number of TCs was systematically decreased until full coverage for the state could not be achieved; and

5. Times were decreased and given existing AD resources and optimal AD and TC resources, there was an attempt to see if coverage for the entire state could be maintained while incrementally decreasing the 60-minute time constraint.
Table 1. Table of Current Staffed ADs

<table>
<thead>
<tr>
<th>STUDY ID</th>
<th>CITY</th>
<th>NAME</th>
<th>X_COORD</th>
<th>Y_COORD</th>
<th>Warmup</th>
<th>Accel</th>
<th>Dec</th>
<th>Cr_sp</th>
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<td>1</td>
<td>Hamilton</td>
<td>Butler County Regional Airport-Hogan Field</td>
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<td>95.28395</td>
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<td>2</td>
<td>2</td>
<td>164</td>
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<td>2</td>
<td>2</td>
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<td>2</td>
<td>2</td>
<td>164</td>
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<td>2</td>
<td>2</td>
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<td>Fulton County Airport</td>
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Chapter 4

Results

Using vertex substitution and two datasets, the 5-mile and 10-mile, the study was carried out in two phases. The first phase was conducted as follows:

1. The ADs were held constant given their existing locations. Optimal TCs were calculated using the 10-mile dataset.
2. ADs were again held constant, and optimal TCs calculated using the 5-mile dataset.
3. Holding existing ADs constant, using both the 10-mile and 5-mile datasets, the TCs were incrementally decreased until no further result could be obtained.
4. 37 optimal ADs were then obtained from the 5-mile and 10-mile datasets using a 30-minute time constraint.
5. Using 37 optimal ADs, 11 optimal TC locations obtained using 5-mile dataset.
6. Using 37 optimal ADs, 11 optimal TC locations obtained using 10-mile dataset.
7. 37 optimal ADs held constant, then incrementally decreased the number of TCs for both the 5-mile and 10-mile datasets until no further results achieved.
8. Incrementally decrease the number of optimal ADs and also TCs for both the 5-
mile and 10-mile datasets until no further results achieved.

The first phase of the study began with determining where optimal TCs would be
placed given the existing 37 staffed ADs. This was attempted using both the 5-mile and
10-mile zip code datasets. Solutions were easily achieved for both datasets. The first
map (Figure 3) is with the 10-mile dataset and shows 11 TCs with the 37 existing ADs.
The TC locations were as follows:

- Blanchard Valley Hospital, Findlay;
- Genesis Good Samaritan Hospital, Zanesville;
- St. Charles Hospital, Oregon;
- St. John West Shore Hospital, Westlake;
- Trumbull Memorial Hospital, Warren;
- UHHS - Geauga Regional Hospital, Chardon;
- West Chester Medical Center, Beavercreek;
- Soin Medical Center, West Chester;
- Aultman Hospital, Canton;
- Lima Memorial Hospital, Lima; and
- Grant Medical Center, Columbus, Ohio.

The white areas on the map represent the eliminated zip codes in urban areas, currently
serviced by a level I/II TC. This is illustrated on the corresponding map. It is evident in
this first trial that several urban areas were left uncovered and that the solution is not
practical for those living in urban areas. Since the focus of this study is providing coverage for rural populations, the result of urban populations being uncovered is not a primary concern. It is given that urban populations would have an existing level I TC.

Figure 3.

The second map (Figure 4) displays the 37 existing ADs and 11 TCs using the 5-mile dataset. The facilities in this trial were as follows:

- Bethesda North - Cincinnati, Montgomery;
- Blanchard Valley Hospital, Findlay;
- Fisher-Titus Medical Center, Norwalk;
• Genesis Good Samaritan Hospital, Zanesville;
• St. Joseph Health Center, Warren;
• Soin Medical Center, West Chester;
• Aultman Hospital, Canton;
• Fairview Hospital, Cleveland;
• Lima Memorial Hospital, Lima;
• Mount Carmel West Hospital, Columbus; and
• University of Toledo Medical Center, Toledo.

Again, the white areas represent urban areas that were eliminated from the dataset. Since there was more of a pull with higher-weighted suburban populations, several TCs were located in more urban areas in Cleveland, Toledo, Canton and Columbus, but all rural areas were provided coverage. Those residing in Cincinnati were left uncovered, but it is assumed a level I TC would be present in the city, bringing the total back to the existing amount of 11.
Figure 4.
The number of TCs were then incrementally decreased. It was possible to decrease the number of TCs to 6 for the state using the 5-mile radius zip code set and down to 4 with the 10-mile radius set. For the 5-mile dataset, the TCs were:

- Blanchard Valley Hospital, Findlay;
- Genesis Good Samaritan Hospital - Zanesville, Zanesville;
- St. Joseph Health Center, Warren;
- Mount Carmel West Hospital, Columbus;
- MetroHealth Medical Center, Cleveland; and
- Miami Valley Hospital, Dayton (See Figure 5).

Additional TCs in Toledo, Cincinnati, Youngstown, Akron would have to be added for urban populations, bringing the total number of TCs to 10 which is one less than what is currently in the state and still covering rural populations.
The next map, Figure 6, shows the 4 TCs with the 10-mile dataset. The facilities were:

- Genesis Good Samaritan Hospital - Zanesville, Zanesville;
- Greene Memorial Hospital, Xenia;
- Fairview Hospital, Cleveland; and
- St. Rita's Medical Center, Lima.
One TC is located in an urban area (Cleveland) so there are only 3 TCs that are dedicated solely to a rural population. Six additional TCs would have to be added to cover urban populations, bringing the total number of TCs needed to achieve 100 percent coverage in Ohio to nine. Again, rural coverage can be achieved for the state using fewer resources.

Figure 6.
In the second phase of the study, ADs were optimally placed given a 30-minute time constraint for both the 5 mile and 10 mile zip code dataset. The phase began with optimally locating 37 ADs which is the same total number as those that exist currently for adults.

A number of trials were run in order to locate optimal ADs for both the 5-mile and 10-mile datasets and all of the results displayed redundant helipads when setting the total number at 37 ADs. This confirmed the author’s suspicion that helicopter coverage could be achieved with fewer ADs because of these redundancies in the initial trials. Once the ADs were optimally placed, that information was used for the existing AD input file in order to optimally place the TCs. Again, the model was performed with both the 5-mile and 10-mile zip code datasets.

For the 5-mile zip code dataset and 37 optimally placed ADs, the TCs were as follows:

- Blanchard Valley Hospital, Findlay;
- Firelands Regional Medical Center, Sandusky;
- Marietta Memorial Hospital, Marietta;
- Northside Medical Center, Youngstown;
- Trumbull Memorial Hospital, Warren;
- Soin Medical Center, West Chester;
- Lima Memorial Hospital, Lima;
- Riverside Methodist Hospital, Columbus;
- St. Rita's Medical Center, Lima; and
- The University Hospital - Cincinnati, Cincinnati (see Figure 7).
What is remarkable about these results is that two TCs were placed in Lima, Ohio which is not necessary or practical when a single facility would suffice given the population. Given the redundancy, it was again obvious that coverage for rural areas could be achieved with fewer resources.

Figure 7.
The map for the 10-mile zip code dataset shows a similar division of the state as the 5-mile dataset. Given 37 optimal ADs, the TCs were as follows:

- Firelands Regional Medical Center, Sandusky;
- Marietta Memorial Hospital, Marietta;
- Southwest General Health Center, Middleburg Heights;
- Trumbull Memorial Hospital, Warren;
- West Chester Medical Center, Beavercreek;
- Aultman Hospital, Canton;
- Lima Memorial Hospital, Lima;
- MedCentral - Mansfield, Mansfield;
- Grant Medical Center, Columbus;
- Miami Valley Hospital, Dayton; and
- University of Toledo Medical Center, Toledo (see Figure 8).

In this case, many urban areas are covered as well as all rural areas with no redundancy of resources. More resources than the current number would be necessary to cover both urban and rural areas, but all rural areas in this case achieved coverage.
Figure 8.
After the initial results were achieved in the second phase of the study, the TCs were incrementally decreased simultaneously with the number of ADs in order to determine a minimum number of both types of facilities. First, the optimal 37 ADs were held constant and the number of TCs was decreased. For the 5-mile zip code dataset, the TCs were able to be decreased down to 8. They were:

- Atrium Medical Center, Middletown;
- East Ohio Regional Hospital, Martins Ferry;
- Marietta Memorial Hospital, Marietta;
- St. Charles Hospital, Oregon;
- St. Joseph Health Center, Warren;
- Fairview Hospital, Cleveland;
- Grant Medical Center, Columbus; and
- The University Hospital - Cincinnati, Cincinnati (see Figure 9).

Four TCs are in urban or suburban locations while the other four are dedicated to rural populations. A total number of nine TCs would likely be required to cover both the urban and rural populations in Ohio, which is still less than the current number and providing service to the entire state including rural populations.
Figure 9.
For the 10-mile zip code dataset the number of TCs required for rural coverage beyond was able to be decreased to fewer than what was able to be achieved with the 5-mile dataset. Figure 10 displays 37 optimally placed ADs with 7 TCs:

- Atrium Medical Center, Middletown;
- Blanchard Valley Hospital, Findlay;
- Firelands Regional Medical Center, Sandusky;
- Marietta Memorial Hospital, Marietta;
- Southwest General Health Center, Middleburg Heights;
- West Chester Medical Center, Beavercreek; and
- Mercy Medical Center - Canton, Canton.

All rural areas were able to be covered and by adding at least three additional TCs complete coverage could be obtained for the state using only 10 TCs.
Figure 10.
The next map, Figure 11, is again with the 10-mile zip code dataset with 37 optimal ADs and 6 TCs:

- Defiance Regional Medical Center, Defiance;
- Marietta Memorial Hospital, Marietta;
- St. Joseph Health Center, Warren;
- Mount Carmel West Hospital, Columbus;
- Akron General Medical Center, Akron; and
- The Toledo Hospital, Toledo.

In this case, only three TCs are solely dedicated to the rural population and the entire rural population is covered.
Figure 11.
One additional TC was removed for a total of five and a solution was able to be generated. In this case the optimal TCs are as follows:

- Bethesda North – Cincinnati, Montgomery;
- Firelands Regional Medical Center, Sandusky;
- Marietta Memorial Hospital, Marietta;
- Trumbull Memorial Hospital, Warren; and
- St. Rita's Medical Center, Lima (Figure 12).

It is obvious that essentially all urban areas are left uncovered but all rural areas were covered in this scenario. At least 5 additional TCs would be required to cover the state but this would still be under the current total, thus saving cost.
Figure 12.
In this trial yet another TC was able to be removed while holding the 37 optimal ADs constant and achieve a solution. The four TCs are: Marietta Memorial Hospital, Marietta, Robinson Memorial Hospital, Ravenna, Lima Memorial Hospital, Lima, and Miami Valley Hospital, Dayton. Three TCs are devoted in this case to rural populations so an additional six TCs would be required to cover the state, again below the current number.

The next goal in the second phase of the study was to incrementally reduce the number of ADs and see if the TC placement could be achieved with fewer helicopter resources and if the results would significantly differ from the previous trials. For the 5-mile zip code data set, the ADs were able to be reduced down to 29 while providing transport of patients within one hour to a TC. The results of 29 optimal ADs to 11 optimal TCs were as follows:

- Bethesda North - Cincinnati, Montgomery;
- Marietta Memorial Hospital, Marietta;
- Robinson Memorial Hospital, Ravenna;
- St. Charles Hospital, Oregon;
- Trumbull Memorial Hospital, Warren;
- Aultman Hospital, Canton;
- Kettering Memorial Medical Center, Kettering;
- MedCentral - Mansfield, Mansfield;
- Mercy Medical Center - Canton, Canton;
- Mount Carmel West Hospital, Columbus; and
- St. Rita's Medical Center, Lima (Figure 13).

There is a redundancy of resources in Canton, thus the second TC in Canton be removed. All rural populations are covered.

Figure 13.
Since there were redundant TC resources, it was suspected that the number of TCs could be reduced. Again, the same optimally located 29 ADs were used and the number of TCs were incrementally reduced. Full coverage was achieved with five TCs. The facilities were:

- Atrium Medical Center, Middletown;

- Marietta Memorial Hospital, Marietta;

- Northside Medical Center, Youngstown;

- UHHS - Geauga Regional Hospital, Chardon; and

- Lima Memorial Hospital, Lima (Figure 14).

Four of the five facilities are dedicated to rural populations in this case, so TCs would need to be added in Akron-Canton, Toledo, Columbus and Cincinnati to cover the entire state. Even with adding the additional TCs, it is quite possible to achieve coverage with 29 ADs and 10 or 11 TCs.
Figure 14.
Next, the 10-mile zip code dataset was implemented to determine if the results would be different. The number of ADs was able to be reduced down to 17 and this was significantly fewer than the result that was able to be achieved with the 5-mile dataset. It is logical to want to place ADs optimally using the 10-mile dataset because it would more accurately reflect the population that would require helicopter transport versus ground transport in an emergency. Once the 17 ADs were set, the TCs were optimally located. This trial started with eleven of them and they were:

- Affinity Medical Center, Massillon Campus, Massillon;
- Fisher-Titus Medical Center, Norwalk;
- Genesis Good Samaritan Hospital - Zanesville, Zanesville;
- Marietta Memorial Hospital, Marietta;
- St. John West Shore Hospital, Westlake;
- Trumbull Memorial Hospital, Warren;
- West Chester Medical Center, Beavercreek;
- Soin Medical Center, West Chester;
- Lima Memorial Hospital, Lima;
- Grant Medical Center, Columbus; and
- University of Toledo Medical Center, Toledo.
Several TCs were placed in the suburbs for Cincinnati, Dayton, Akron, Youngstown and Cleveland.

The number of TCs were then reduced until a result was no longer achievable. Full coverage was able to be achieved with four TCs and 17 ADs. The TCs were:

- Marietta Memorial Hospital, Marietta;
- West Chester Medical Center, Beavercreek;
- Hillcrest Hospital, Mayfield Heights; and
- St. Rita's Medical Center, Lima (Figure 15).

In this case, none of the TCs are located in a central urban area and all rural regions are covered. It would likely be possible to cover all of the state of Ohio with only nine or ten Level I TCs.
10 miles 17 Optimal ADs 4 TCs

Figure 15.
4.1 Discussion

The first point of interest in examination of the results is that while for the purpose of optimally locating ADs, the 10-mile dataset makes sense because those in urban areas won’t utilize the service, it is better to locate the TCs using the 5-mile dataset. This allows the TCs to be pulled toward more urban areas and avoids having to add extra TCs in urban areas after the trial is run. The zip code centroids were weighted based on population, therefore, the TCs would be drawn to more populated regions while ensuring coverage for rural populations. In order to keep the results consistent amongst the datasets, the trials were not run with 10-mile dataset optimal ADs to patient zip code centroid, then, to the optimal TCs using the 5-mile dataset.

The patterns that the state was divided into by TC service were fairly consistent with most parts of the state being partitioned and served by metropolitan areas. Those regions that were the exceptions to being served by metropolitan areas were more rural parts of the state that may not have been traditionally not covered. There were several towns that were reoccurring across a variety of trials and datasets: Findlay, Zanesville, Warren, Lima, Marietta, and Sandusky. Given that southeastern Ohio is so underserved, Marietta and Zanesville are much-needed facilities and were frequent TC sites. Instead of locating facilities in Youngstown, the model frequently chose Warren to compensate for the far northern reaches of eastern Ohio that would possibly not be covered if the TC were placed further south into Youngstown. The southern-most point of the state that has been traditionally underserved was either covered by a TC in the Columbus area, Marietta or Zanesville area. The optimal AD was situated commonly just north of Portsmouth.
Currently, there are three ADs that serve the Portsmouth region. At no point was a TC located in the Portsmouth area which is no surprise since the zip code centroids in that entire region have a low weight and therefore would not pull a TC toward that region. Ohio trauma hospital administrators and those involved with Ohio emergency medicine and public health initiatives at the state level should take note of those reoccurring facilities that service predominantly rural areas that were previously not covered. Those TCs should be strongly considered to be future Level I centers, or, at least Level II facilities.

The next item of note was that when the TCs were incrementally decreased given the existing 37 ADs, the minimum number that was able to be achieved was four, yet with 37 optimal ADs, the minimal number was only able to be whittled down to five. This then begs the question: How much impact does AD location really have on TC placement in this study? In examining the map of current ADs, there are areas that are easily visualized to be perhaps overserved or redundant versus the optimal AD placement which was far more evenly dispersed. This appearance of redundancy could be what led to the achievement of four TCs versus five with the optimal ADs. Both maps show a remarkably similar division of the southern half of the state with the main difference being the northwestern Ohio region requiring an additional TC. It would make sense that those financing the helicopter transport of injured patients examine the current system to look for redundancies, but many of those involved in transport are competing entities that want a certain corner of a market and may not care that an existing AD already serves that region. This is made abundantly clear given that 37 existing ADs can serve an area
with only 4 TCs. Nearly the exact same map can be generated using the same 10-mile dataset with only 17 optimal ADs and again, 4 TCs. Fifteen ADs can be eliminated from the system and if optimally located, can also cover roughly the same area. The idea that 4 TCs can service urban populations in Ohio is not realistic but the important point is that there are many ADs that are not needed and are a waste of resources. Having only seventeen ADs may not be reasonable given patient volume, topography, and that on some level, there needs to be an overlap of service as a safety net, but clearly, 37 ADs is not required. If the state were funding these ADs, this finding would be very insightful and beneficial to the Ohio taxpayers; however, since these services are privately owned, this question of optimization for the whole state would never be asked. The questions that an AD service provider would ask are that given a specific market, in a specific region of Ohio, should one of their fleets be eliminated to save cost or can an AD be added to serve an area that has a population base large enough to generate a profit. Technically, some of these providers of AD service are non-profit hospitals, but their non-profit status does not mean that they are not concerned with profit since they are a business and no business wants to operate at a loss. As stated previously, trauma patients, especially those involved in motor vehicle accidents, tend to be payers so hospitals are eager to pick up this business to off-set other services provided that may not be as lucrative.

Even though many TC location results were by no means realistic for urban populations, they still are valid. This is because even though most of the trial results required at least one TC to be added to urban location, the results were consistently one
or two TCs fewer than what currently exist even when the TCs were added to urban areas. Having only five TCs for the entire state is not prudent or even a remote consideration, but adding four more TCs in addition to the five to ensure adequate care for those in urban or suburban populations is more than reasonable. It is important to provide fair and equal trauma care to all inhabitants of Ohio and this can be done with the same number or frequently fewer facilities as hypothesized.

A major contributing factor to why coverage was consistently obtained given the existing number of resources was because there is a redundancy of TC resources. Those redundant resources can be relocated to provide service to areas that are not covered currently. It was obvious when running the trials that there was a redundancy in TCs because frequently a facility would be duplicated in a trial result or two different facilities in the same city or town would be appear in the results. The argument could be made that the TCs should be capacitated and that perhaps there is no true redundancy and that facilities could become overburdened if too many were eliminated. In looking at the current location and number of Level I TCs in Ohio, three are located in Toledo area alone. The region those three TCs serve is smaller than either Cincinnati, Cleveland and Columbus, which have a higher population and fewer than three TCs each. If two of the Level I TCs in Toledo were moved to serve rural areas like Marietta, Zanesville, Lima or Findlay, the entire state would be covered. Also, as stated previously with regards to facility capacity constraints, there is no magic number to know what that constraint (maximum number of ISS 15 or above trauma patients that can be treated) should be. It is dependent on a variety of factors such as staff size, bed capacity, number of operating
room suites, etc. What is known is that Cincinnati and the surrounding region can be served by one Level I TC, so, it is more than reasonable that a city the size of Toledo, including surrounding areas, can also be served with a single Level I TC. As stated in Chapter 2, there is conflicting data linking improved patient outcomes with volume and that high volume isn’t that important. There is no data linking experience in trauma care (high patient volume) to poorer outcomes.

Some degree of analysis is required outside of the model in order to determine what makes sense and the solutions were not always intuitive, such as bypassing Youngstown and placing a facility in Warren. This version of vertex substitution is a good starting point to get an idea of where to place facilities for fairness of coverage, but there ultimately needs to be input from administrators and planners on the best location for resources. Models can identify weaknesses in a system and point out areas that are underserved, but as seen in the results, there needs to be a realistic determination of where to place facilities.

One advantage to the TRAMAH model was that one could aim to keep the current existing percentage of coverage the same, but decrease resources. In this model, there is either a feasible solution or no solution. If 97% is deemed acceptable coverage for Ohio, how many resources are required to provide that level of coverage? How many facilities can be eliminated while providing the same level of service? In the TRAMAH Maryland study, the authors were able to answer that question. Given the need for fairness in accessibility to trauma care, it is perfectly reasonable to view any other solution less than 100% as unacceptable so that line of research was never pursued.
Chapter 5

Conclusions and Recommendations

Fifty years ago, trauma was called a public health crisis by the National Academy of Science. Their report was the stimulus to create an organized trauma system in the United States. Experience from the Korean War led to the inclusion of helicopter transport in the early 1970’s. Also in the early 1970’s, standards for hospital and physician trauma qualifications were developed by the American College of Surgeons Committee on Trauma with the goal of having a tiered, integrated and multilayered system to improve patient survival (Acosta, Jose et al. 1998, Baxt, Moody et al. 1985, Anderson, Rose et al. 1987). As of six years ago, even though most states have some type of multi-level trauma system, trauma continues to be the leading cause of death in people under the age of 50 despite over forty years of trauma system development and technological advancements in medicine and automobile safety. This significantly high mortality is related to the organization of the trauma resources themselves.

One problem with the current trauma system is that there is no consensus on an adequate number of facilities required to serve a given population, and there is no quantitative approach to planning a fully-integrated trauma system complete with air and ground transport and varying levels of trauma centers. This haphazard arrangement of
resources has led to variation amongst states with access to trauma care. This problem of access impacts those living in the state of Ohio, particularly those living in rural areas. Approximately 3% of Ohio’s population, or over 340,000 people, does not have access to a Level I TC within an hour. Sixteen counties in Ohio had insufficient access to Level I TCs within one hour although there are 11 Level I TCs and 32 ADs.

The objective of this study was to use a resource allocation model to optimally locate Level I TCs and ADs in Ohio such that everyone in the state could access definitive care within sixty minutes. The TRAMAH model developed by Branas et al. used an iterative heuristic to place both TCs and ADs in their study location of Maryland. Their model successfully placed resources within a thirty-minute time constraint with improved coverage, many times with fewer resources (Branas and Revelle 2001). Due to the TRAMAH model coding complexity and the belief that vertex substitution could achieve similar results, the author opted to use a variation of the method developed by Teitz and Bart (Teitz and Bart 1968). Perhaps this model can be further refined with a simultaneous trip changing calculation that combines accessing the zip code centroid from the AD as well as transporting to the TC from that zip code. It was hypothesized that full population coverage could be achieved in Ohio with the same number or fewer resources.

As in previous trauma research, the patient population was limited to those with an ISS of 15 or higher. For the purpose of this study, only those 15 years or older were included due to pediatrics being a highly-specialized patient population. The patient’s home zip code was used as a proxy for injury location since obtaining actual, accurate injury location can be challenging and previous studies have found that home zip code is more
than reasonable as a substitute. Home zip code data is routinely collected through hospital trauma registries and those who were out-of-state were eliminated from the study. Only those resources in the state were included for model simplicity so hospitals or helicopter resources in Detroit, Ann Arbor, Wheeling and Fort Wayne were not included.

The centroids for all zip codes were calculated and then weights were added based on the aforementioned patient population within that zip code. Zip codes with no patient data were assigned a weight of one. Zip codes in urban areas currently surrounding Level I and II TCs within a five and ten-mile radius were eliminated from the study since they would not utilize helicopter resources. It is also assumed that there would be a Level I TC in the most populous cities in Ohio so those in urban areas would automatically have access to a Level I TC within one hour.

In the first phase of the study, Euclidean distances were calculated from existing AD resources to weighted zip code centroids based on cruising speed of 164 mph with warmup, acceleration and deceleration times added. Then, times were calculated from the zip code centroids to all existing hospitals and the optimal location was selected based on lowest cost (time). The model was initially run trying to optimize 11 TC locations, the current number in the state, then once results were obtained, the number of TCs was incrementally decreased until a solution could not be obtained. Both the 5-mile and 10-mile zip code datasets were used to run the model.

In the second phase of the study, all current airfields and helipads were considered as potential staffed AD locations and the optimal AD sites were calculated starting with 32, the current number in Ohio, and then incrementally decreased. Those optimal ADs were
then set and then optimal TC locations were obtained. Again, the number of TCs were incrementally decreased until no feasible solution could be calculated. As in the previous step, both the 5-mile and 10-mile datasets were used.

Full coverage for Ohio was able to obtained in both phases of the study given the existing number of resources or even fewer resources. The fewest facilities able to fully cover the state were obtained in the second phase of the study with 17 optimal ADs and 4 TCs. The number of TCs was not realistic given that urban populations would not have been served by 4 TCs, but even by adding resources to urban areas not covered, full coverage could still be achieved with 9 or 10 optimal TCs; one or two less than what currently exists. Across both parts of the study, the number of TCs were consistently at least one less than the existing 11. Frequently in the TC results the same facility was being listed as a solution twice proving that there was a duplication of resources and the number of TCs could be further reduced while still providing adequate coverage.

The results for both phases of the study came up with common facility locations, and they were: Findlay, Zanesville, Warren, Lima, Marietta, and Sandusky. In every iteration of the model with at least 5 TCs, coverage was achieved in the southern-most point of the state and also the southeastern area which currently have no access to a level I TC within an hour. Genesis Good Samaritan Hospital in Zanesville was one of the options of a facility location to cover the southeastern portion of the state, but more commonly, Marietta Memorial Hospital in Marietta was selected.

The five-mile dataset pulled the TCs to more suburban areas due to the higher population weight, which was desirable, but using the ten-mile dataset was more realistic to reflect rural patient population utilizing the AD resources. Although two different
datasets were utilized in both parts of the study, the resulting allocation maps were similar.

Although full coverage was easily attainable for the state given the vertex substitution method, there was still a need to locate resources outside of the model to urban areas. This is not unexpected since urban zip codes were eliminated from the study since they would not utilize AD resources.

Since results were so readily obtained with fewer resources, it is evident that if resources in Ohio were fairly and optimally located, all patients in Ohio could reach definitive care within one hour. Politics, institution image, desire for profit and poor planning have negatively impacted the severely injured in Ohio with those in rural areas being the most severely affected by poor decision making.

There are several limitations of this research. Firstly, as previously stated, there has been criticism of the use of home of record as a proxy for injury location. Injury location site would have to be obtained from a variety of resources including 911 records, hospital patient charts, paramedic reports, police reports, etc., and even then, the exact location for the injured patient is not guaranteed. Given the complexity in obtaining accurate injury location, the use of home location of the patient is still prudent since most are injured close to home (Myers et al. 2011). Patients at a clear disadvantage for using home location as a proxy are areas that are popular tourist destinations and interstate highways with large amounts of out-of-state traffic.

Optimally locating helipads and transporting trauma patients by air is complex and limited by topography. This study simplifies the process a great deal by eliminating several steps and attempts to compensate by slowing down air speeds. Patients that are
injured in a rural environment must first be reached by the rural care givers who are frequently volunteers. Then the patient must be transported to either a local hospital or an area where a helicopter can land. To try and model the multiple steps in this process would have been extremely difficult due to the multitude of variables (whether EMTs are on duty or volunteer, topography of injury location, length of time needed to stabilize patient before they are able to be moved, quality of roads and speed of land travel to injury location, etc.). While slowing down air speeds for the helicopters is not ideal, there was an attempt to account for warm up and cool down times of helicopters. Also the air speeds were slowed down to account for the travel from injury location to rendezvous location with the helicopter for transport to the TC.

Another limitation of the study was not including out-of-state resources. The decision to limit trauma providers to Ohio was done to simplify the study. Trying to include resources in Fort Wayne, IN; Huntington, WV; Wheeling, WV; Pittsburgh, PA; Erie, PA; Ann Arbor, MI; and Detroit, MI would have been logistically difficult. The determining factors for what patients get transferred out of state and which do not vary widely and thus, difficult to include in a model. Their transfer could be determined by type of injury, weather, distance, or even whether the patient is a state Medicaid recipient.

As a result of not including out-of-state resources, it is possible that populations could be unfairly designated as “uncovered”, but in fact, they are covered by an out-of-state resource. Additionally, it may make more sense logistically due to population concentrations, to place a Level I TC resource in another state, given the density of people over the state border.
While there are Level I TC resources in Ann Arbor, MI, Detroit, MI, and Pittsburgh, PA, there are no Level I TCs in Fort Wayne, Erie, Huntington or Wheeling. Given that the only three cities with a Level I TC are over an hour away for most of the Ohio population, it is more than reasonable to not include them in the study. Since the main focus of the study was only examining Level I TCs and not including Level II, the fact that Fort Wayne, Erie, Huntington and Wheeling have Level II facilities still does not solve the coverage issue and the fact remains that populations living in Ohio, close to these out-of-state Level II facilities, still do not have access to a Level I TC within one hour. It may be a more significant benefit to more people, not just those living in Ohio, to place a Level I TC in Wheeling or Huntington rather than in many of the suggested southeastern Ohio locations in this study, providing needed service not only to those in southeastern Ohio, but also in West Virginia, which currently only has two Level I TCs for the state.

Another limitation of the study was the assumption of ground transport time traveling to the accident location and then potentially to a rendezvous point with a helicopter or to a hospital for stabilization and then subsequent transport. Ground transport time in rural areas is highly variable due to the volunteer nature of the service providers and location of the trauma incident.

Clearly, the placement of TCs is not based entirely on need or optimal location, given that there are three Level I TCs in northwest Ohio which is more than adequately served, while other areas in Ohio do not have Level I TC service. Another potential limitation of this study is that it doesn’t address the impact of policy and other factors.
such as image or profitability. TCs can be used as a way to expand market share into areas not currently served or as a way to provide consumers with an image of advanced medical care thus leading them to choose one facility over another for medical care that is not trauma related. Surgery residency programs may also have a desire to have a Level I TC at their training hospital in order to make their program more competitive or to provide trauma surgery as a fellowship even though an unaffiliated Level I TC may already provide service to that area. The placement of TCs is not strictly a geographical question alone, but given the numerous reasons that may go into locating medical assets, they all could not possibly be addressed here. Survival from a trauma is not merely dependent upon speed at which one arrives at a Level I TC but also the weather, staff on the helicopters and quality of the hospital the patient arrives at.

5.1 Areas for further research

This study was limited to adults in Ohio. It would be interesting to compare the locations of ADs and TCs including a pediatric population in Ohio. Pediatric trauma is extremely specialized and was not included in this study for that reason. There is a great amount of research dedicated to the need for specialization of emergency medicine services both in the transport and treatment of pediatrics in trauma and as a result, many TCs are located in urban areas to develop a team that is experienced because they have a higher volume of patients, therefore can achieve better outcomes. A question that is interesting would be where to locate the ADs such that pediatric patients can reach a TC, which will be located in a more urban area, and if those locations would be different from the adult population.
It would also be interesting to obtain the same data that was used for the TRAMAH Maryland study, and using the method used in my research, see if the results are similar. Is there an advantage to using their switching heuristic, or is it unnecessary and is a simple vertex substitution adequate? TC and AD locations are interdependent, having a switching heuristic that alternately selects optimal locations, since the initial set selected can impact the final location. A switching heuristic may give a more accurate result.

A third area that would be interesting to research would be to compare optimally placed facilities based on existing resources to resources that would be placed *de novo*. If facilities were placed on a clean slate, how different would those results be from those currently in the state of Ohio and those optimally placed using existing resources? The *de novo* method would be straight-forward and could be accomplished using zip code level census data and then specifying a finite number of desired ADs and TCs. The final set of facilities could then be whittled down to the lowest number of resources required to cover the state completely.

It was interesting to note in this study that existing AD facilities had faster travel times to TCs than those that were optimally located. Evenly spreading out resources may not be the best way to achieve optimal coverage for trauma patients, particularly rural trauma patients. Many of the existing ADs were located in suburban and rural areas. Because of the population weights in this study, ADs gravitated to suburban areas. Those in the suburbs may still travel by ground transport. It may be smarter to locate ADs strictly in rural areas (and in turn, recommend new rural locations) since that is the population most in need for that method of transport. There may be a need to transfer patients from one
urban hospital to another, but the available data did not show the frequency of occurrence and whether it is superior to ground transport, especially given the high cost (see the Ohio Patient Transfer Study) (Knotts, Price et al. 2008). Rather than optimally locating ADs excluding those within five or ten-mile radius around urban areas, maybe it needs to be expanded to twenty-miles. What is the cut-off for ground versus rural transport taking into account roads, type of injury, weather and distance to definitive care? The author does not believe that basing ADs in urban locations is not optimal, but then hospitals, more often than not, must bear the burden of cost to cover call for a dedicated team that may not be utilized in other areas like they would be if they were based at a hospital. Hospitals must incur the cost of two or three people to sit on call and wait versus being utilized in an emergency department, ward etc. In an era of cost savings, hospitals may be reluctant to dedicate the on-call cost of two specially-trained individuals who may or may not have their skills utilized.

As stated in Chapter 1, there are high social costs incurred in maintaining helicopters, helipads, staff competencies and trauma centers. Due to the highly variable nature of type of helicopters, the training level (thus pay) of staff assigned to the air ambulances, and the detailed costs to run a level I TCs, a total cost is difficult to ascertain. Trying to calculate a total social cost is best left to economists and is beyond the scope of this dissertation.

Trauma administrators, public health advocates, and trauma providers have an interest in trauma resource allocation. Although vertex substitution had limitations and did not include a number of outside factors that could impact resource placement, it did provide a
solid, fast generalizable guide for the placement of trauma facilities and easily identified facility sites for populations that were vastly underserved. It is now up to those that have the authority and funds to make decisions on trauma resource placement to do so in a fair manner. This should take into account the higher populations in urban areas with higher rates of service utilization contrasted with those who require care in rural settings.

Medical care, and more specifically trauma care, in this country is based on profit, not necessarily on equity. Until policy, image concern and the business-centered mindset of health care delivery changes in the trauma care industry in Ohio (and the country), there will still be over 340,000 Ohioans with limited access to trauma care.
References


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