TRAUMA COST VS. CARE: ESTIMATIONS FOR OHIO'S CURRENT TRAUMA SYSTEM AND EVLUATION OF ALTERNATIVE CONFIGURATIONS

FINAL REPORT

Submitted to

Division of Emergency Medical Services (EMS)
Ohio Department of Public Safety (ODPS)

Submitted by

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Executive Summary

Trauma remains a top 10 leading cause of death in the U.S. and among the top 3 for people <45 years of age accounting for 30% of all life-years lost (cancer=16%, heart disease=12%). It is the most expensive, yet predictable and preventable public safety problem. An effective trauma system must provide prompt response and definitive care to a patient with severe injuries. This starts with a 9-1-1 call to the Emergency Medical Service (EMS), followed by on-scene evaluation of the patient, transport to a trauma center and treatment, and subsequent rehabilitation and follow up care. However, the high cost of trauma care raises concerns about cost-effectiveness and overall value. As a result, the State Board of Emergency Medical, Fire, and Transportation Services in Ohio included *Improving System Sustainability* as a strategic priority with a key objective aimed at reducing per capita health care costs in their 2018 strategic plan.

Our review of the literature suggests that previous studies did not include any MSAs in OH, so the cost of trauma care in OH is unclear. Further, the current literature discussing trauma cost employs hospital charges (accounting for cost-to-charge ratios), which typically underestimate the actual costs that comprise 'fixed direct' and 'indirect' costs (to ensure 'readiness') and 'variable direct' to capture per patient cost of care. A relationship between cost (due to changes in the number of TCs) and the corresponding impact on care (in terms of mistriages) is lacking. No approaches exist on how to use these findings to evaluate alternative trauma system designs.

Through proposed Aims 1-4, this study attempted to fill some of these gaps, with specific focus on 'prehospital' and 'inpatient' costs and care. Specifically, while in Aim 1, we take an econometric approach to estimate cost of trauma care in terms of 'fixed direct,' 'indirect,' and 'variable direct' cost terms (for both prehospital and inpatient phases), in Aim 2, we use 2012 data to estimate trauma care in terms of mistriages. Through Aims 3 and 4, we characterize the relationship between trauma system cost and corresponding estimated care. The key findings from our study include the following:

- Per Aim 1, the estimated total system cost ($2.79 billion annually) and per-patient cost ($42,312 annually) we derived for the 2021 trauma system (11 LI, 10 LII, 20 LIII, and 795 EMS stations) are within the range suggested by prior literature, which validates our approach.
- Per Aim 2, the estimated system-related mistriages corresponding to the 2021 network (using 2012 incidence map as a surrogate) were srUT=86 (rate=0.093) and srOT=3512 (rate=0.692).
- Per Aims 3 and 4, we noticed that there is a trade-off between cost and care; opening additional TCs can improve care (i.e., reduce undertriage), but can significantly increase the cost. For example, our results estimate that for every decrease of a srUT case, the per-patient cost increases by $198.37 (due to increase in TCs). While an increase of $198.37 in per-patient cost reduces 1 srUT case, our estimates also suggest that it increases 7.69 srOT cases.

In summary, this report provides comprehensive and quantitative information and estimates on the trauma system cost for the state of Ohio that is currently not available to them. Moreover, the proposed approach to assess alternative trauma system configuration could help ODPS identify implications on cost vs. care corresponding to an expected change in the overall trauma system; i.e., opening or closing of a trauma center. We strongly believe that our study will serve as a foundation for a more comprehensive analysis of the entire spectrum of cost of trauma care for the state in the future.

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1. Investigators

Priti Parikh, PhD (PI): Priti Parikh serves as the PI on this project and Research Director and faculty in the Department of Surgery. She has significant experience in healthcare systems and informatics areas where she has worked on predicting discharge disposition at a point of admission of trauma patients, system analysis of surgical operations, and developing ontologies to answer critical questions. She has led IRB approved projects along with surgery and engineering co-PIs using the state data from Ohio Department of Public Safety. That work has also been presented at scientific national conferences and submitted to a peer-reviewed journal for publication.

Brendan Deere, EMT-P (Co-I): Brendan has been the EMS Coordinator for the Premier Health EMS Center of Excellence since 2010. He is based out of Miami Valley Hospital. He has been an EMS provider since 1992, a Paramedic since 1998, and a Fire Fighter since 1990. He has also been involved with the CareFlight MICU as a Paramedic during 2005-2010. He is a certified BLS provider/instructor, ACLS provider/instructor, ITLS provider/instructor, and PALS provider/instructor.

McCarthy, MD (Co-I): Dr. McCarthy is a Board-Certified Surgeon in both general and critical care surgery and a Fellow of the American College of Surgeons. She is also the Professor in the Department of Surgery in the Boonshoft School of Medicine. She is primarily affiliated with the Miami Valley Hospital (MVH), a regional Level I trauma center in Dayton, OH. Her experience includes over 30 years working with challenges affecting patients and staff at a Level 1 Trauma Center, from pre-hospital through rehabilitation. Her extensive clinical research background includes studying patient care, quality outcomes, and ICU and resuscitation interventions with over 200 publications. She most recently served as the 2nd Vice President (2016-17) at the American College of Surgeons. She is also a member of American Association for the Surgery of Trauma, the Society of Critical Care Medicine, the American Medical Association, the Association for Surgical Education, and the Association of Women Surgeons. She has collaborated with the PI for over 10 years now.

Pratik J. Parikh, PhD (co-PI): Pratik Parikh serves as the co-PI and the Data Analytics/Engineering expert on this proposed study. He is a Professor and Chair of the Department of Industrial Engineering at the University of Louisville; prior to that he was a Professor at Wright State University until July 2020. For over 10 years, he and his graduate student researchers have focused on exploring the interdependencies between various healthcare subsystems and identifying alternate methods to improve the system performance. His recent projects include assessment of triage errors, trauma network design, inpatient discharge planning, and scheduling staffing and surgeries. Dr. Parikh has extensive experience in leading multidisciplinary and multi-institutional projects supported by federal grants.

2. Significance and Specific Aims

While it is becoming widely recognized that the treatment trauma patients receive on the field can significantly alter their outcome and that the trauma centers save lives [1], effective trauma systems should address the economic impact of the injury as well. This could be achieved through (i) analyzing the total cost of trauma care in the current system and (ii) identifying alternative system designs and compare their effectiveness. This process can help determine the best alternative designs considering additional socio-political impacts in the region before piloting, and subsequently implementing and sustaining. In so doing, the state can continue to progress towards improving trauma care without increasing costs.

The economic cost of trauma care comprises costs of pre-hospital care (including transportation mode), inpatient care, readmissions, rehabilitation, and injury prevention efforts in a regionalized trauma system. Because these costs are not appropriately recorded in EMS or Trauma databases, the only way to estimate them is through billing records, which would require a prospective study across multiple sites involving hospital systems, EMS, etc. One such study by MacKenzie et al [2]. focused on collecting cost data prospectively from 15 Metropolitan Statistical Areas (MSAs) across 10 different states in 2007, but none of the regions in OH were part of this study.

Note that the cost categories mentioned above are only reimbursed when a trauma patient is treated. However, regardless of the patient volume, a trauma system must be ready 24/7. The cost of such 'readiness' to respond to injuries at varying levels result from capital expenditures, building maintenance, utilities, providers and permanent staff salaries, medical practice premiums, and staff training and education [3]. These costs for 'readiness' are often referred to as 'fixed' costs. Trauma providers attempt to include in their charges to the patient (or insurance agency) some of these 'fixed' costs as 'overhead' costs on top of the 'variable' cost of supplies, test, medicines, and similar. However, the current reimbursement models do not reimburse such 'fixed' costs in its entirety [4], which places tremendous burden on the trauma system to remain financially viable.

It goes without saying that *changes in the system configuration would alter the 'fixed' cost; similarly changes in the patient volume would alter the 'variable' cost of supplies, medicines, and alike.* The current lack of understanding the sources of trauma costs (both 'fixed' and 'variable') in the state of OH and the evaluation of the effectiveness of alternative designs have motivated this project.

Given the duration and scope of this project, we focused on 'pre-hospital' and 'in-hospital' costs of trauma care, which addressed (i) and (ii) above; we did not consider costs associated with post-discharge care, loss of wages, and quality of life. The following were the key aims of this study; Figure 1 provides a schematic of how these four aims are related.

Aim 1. Estimating the cost of 'pre-hospital' and 'in-hospital' care for the current trauma system in OH

We present an approach to estimate fixed direct, indirect, and variable direct costs associated with trauma care. 'Fixed direct' costs comprise annualized cost of EMS facilities and equipment (ground and air), trauma center capital costs (including emergency department), utilities, and salaries for clinical medical staff. 'Indirect' costs include annualized cost of staff training and education, and salaries for administration and permanent providers. 'Variable direct' costs include per incidence cost (transportation mode and distance), testing services, medical supplies, cost of semi-permanent or temporary staff, and similar.

While this econometric approach provides an in-depth understanding of the sources of various costs, it soon became apparent to our team that such estimates are not readily available; trauma systems or even a specific hospital would not be willing to share these for their hospital. We, therefore, estimated these costs based on existing literature and inputs from our research team. The total annualized 'fixed direct' and 'indirect', and per patient 'variable direct,' cost estimates helped estimate annualized cost of trauma care for a given patient volume, and the corresponding 'per-patient' cost of trauma care for the Ohioans.

Aim 2. Estimating trauma care corresponding to these costs

It is also important to quantify what level of trauma care corresponds to the cost estimates from Aim 1. To do this, we used the available 2012 sample dataset (from our prior projects) as a surrogate for the incidence profile for the most recent trauma network (i.e., 2021). Using our proposed notional tasking algorithm, that attempts to mimic the EMS decision making at the scene (related to destination determination for given severity of injury), we estimated potential system-related under-triage (srUT) and over-triage (srOT) for the 2021 network. We used the modifier 'system-related' to distinguish this form of mistriage from a clinical triage (which is a diagnostic test focused on evaluating the severity of patient injuries). The 'system-related' triage focuses on the network of hospitals and transportation resources that impact the determination of the destination hospital type (TC vs. NTC). These srUT and srOT estimates helped quantify the expected level of care provided by the current trauma system in the state.

Aim 3: Characterizing a given trauma system across a various cost-care measures

It is critical to characterize a given trauma system in terms of both cost and care. Because of a lack of appropriate metrics in the literature, and limitations of the metrics originally proposed in our proposal, we focused on characterizing the relationship between cost and care.

Aim 4. Comparative effectiveness of alternative trauma system configurations in terms of cost and care

While Aims 1-3 helped estimate trauma burden (total annual cost) and per-patient cost, and estimate the underlying quality of care provided by the current system, they do not allow comparing alternative systems where both cost and care may vary. To do this, we explored several alternative trauma system configurations in terms of number and locations of major trauma centers (Level I, II and III), which affect mistriages.

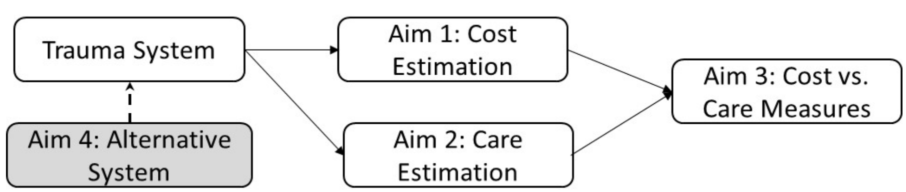


Figure 1. Relationship between the 4 aims

3. Approach and Findings from Aim 1

Recall that this aim focuses on estimating the cost of 'pre-hospital' and 'in-hospital' care for the current trauma system in OH. Our cost estimates will be categorized into 'fixed direct', 'indirect', and 'variable direct' costs (see Figure 2). As pointed out earlier, 'fixed direct' costs represent cost of infrastructure, equipment, utilities, and alike. 'Indirect' costs identify cost of administration, program support, and staff training and education. Both 'fixed direct' and 'indirect' costs are independent of the trauma volume. In contrast, 'variable direct' costs depend upon trauma volume and include cost of transportation mode and distance, temporary/semi-permanent staffing, medical supplies, tests, and associated treatment costs.

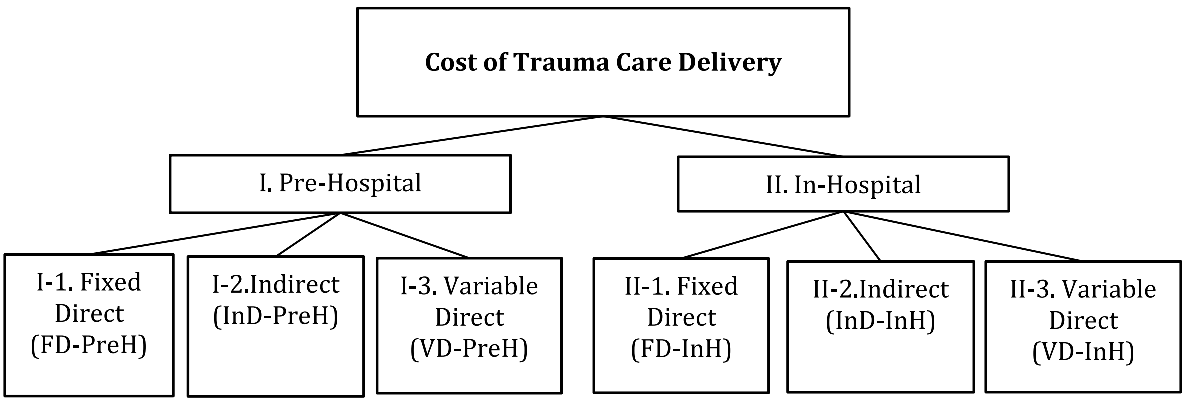


Figure 2. Approach to Estimate the Cost of Trauma Care Delivery

Approach: We followed the below steps to accomplish this aim:

i. Conducted a thorough literature review and explored various online resources to identify all relevant 'fixed direct', 'indirect,' and 'variable direct' costs during 'pre-hospital' and 'in-hospital' stages and discussed with our collaborators and experts to get consensus.
ii. Used the annual trauma volume across the state to derive per-patient cost.

Findings: We summarized our findings related to pre- and in-hospital costs in each cost category in six tables shown in Appendices A and B. Table 1 below shows the estimated annual trauma care cost for the 2021 OH trauma system with 11 LI trauma centers, 10 LII trauma centers, 20 LIII trauma centers, 795 EMS stations according to 2020 EMS station list from ODPS website [5]. Because the dataset we were provided was a sample of the total cases in 2021, we used the most recent trauma volume available for 2020 on ODPS website [6] to scale up the estimates from 2012 sample dataset (scaling factor = 11).

Validation of our estimates: Research suggests that the per-patient cost associated with trauma care is between $13,500 and $54,950 in trauma centers, and this range changes to $7,000-$54,950 after including non-trauma centers [7-11]. As shown in Table 1, our analysis with OH data revealed it to be $42,312, which is within this range. Further, the trauma literature identified 'fixed direct' and 'indirect' cost as the majority of total cost in hospital care, ranging from 58% to 84% [11-13]. Our analysis with OH data suggests it to be 84.86%. For per-patient prehospital cost, our analysis with OH data revealed it to be $2,053, which is close to $2,147 suggested in MacKenzie et al [8].

These results suggest that our proposed method is not only able to provide a good approach (based on first principles of econometrics) on how to estimate the cost of any trauma system, but also provides estimates for the state of Ohio based on data from other trauma systems.

Table 1. Estimated annualized trauma care cost for the current OH trauma system.

	Cost Category	Annualized TC cost	Annualized NTC cost
In-hospital	Fixed Direct	$2,111,941,047	-
	Indirect	$57,714,404	-
	Variable Direct	$387,034,523	$101,297,655
Prehospital	Fixed Direct	$57,742,127	-
	Indirect	$42,714,321	-
	Variable Direct	$35,076,470	-
Total Cost			$2,793,520,546
Per patient cost			$42,312

*The fixed direct and indirect in-hospital costs for NTC are ignored here. Please see Appendices A and B for details.

4. Approach and Findings from Aim 2

The objective of Aim 2 was to quantify what level of trauma care could be provided in 2021 to Ohioans corresponding to the 'fixed direct', 'indirect,' and 'fixed variable' costs.

Data Source and Variables: To estimate care for the 2021 network, we used as surrogate the incidence profile from the most recent, complete, data (2012) available to us from the prior projects. This dataset combines fields from the data registries, EMSIRS (1 and 2) and Trauma, using a sophisticated probabilistic linkage algorithm used internally by the ODPS/EMS Division. The EMSIRS database maintains records of the patient's on-scene evaluations, while the Trauma Registry tracks information from the arrival at the ED, hospital stay, and discharge diagnosis and destination. Using this combined dataset, we were be able to reveal the sequence of events (as depicted by this combined dataset) that occurred in transferring a trauma patient from the scene to a trauma center. We primarily focused on the group of trauma patients with age ≥16.

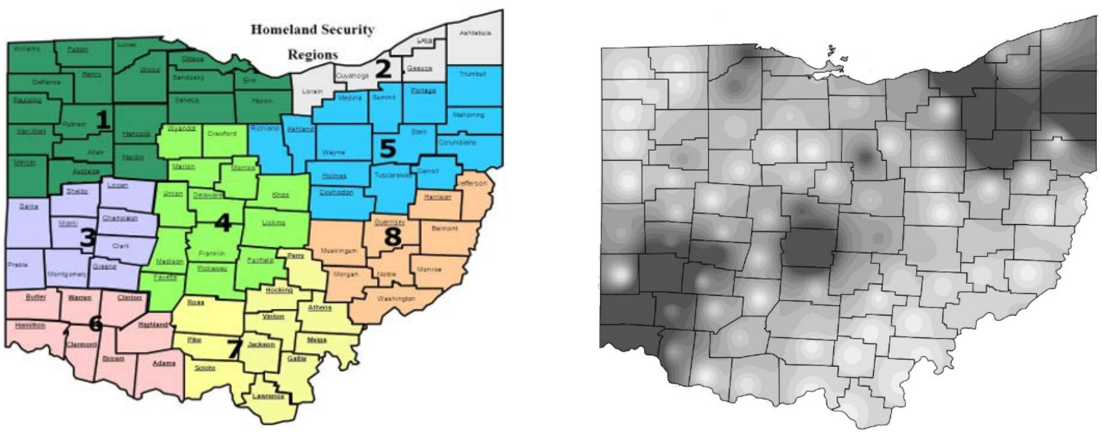
Based on our discussions with the ODPS team, we excluded patient records that had missing Injury Severity Score (ISS), ISS=99, secondary transfers, and missing/incorrect addresses. We also reanalyzed the assignment of regions originally provided to us and fixed the incorrect ones. The total number of patient records finally included in our analysis is 6002, among which 927 had ISS>15.

Approach: We used the ACS-recommended ISS>15 as a reasonable surrogate to retrospectively analyze if a patient experienced severe injuries. We considered Level I, II, and III centers as Trauma Centers (TCs), and other community hospitals as Non-Trauma Centers (NTCs); see Table 2. We then identified srUT and srOT cases directly from dataset. srUT refers to the mistriage of severely injured (ISS>15) trauma patients to NTC, while srOT refers to non-severely injured (ISS≤15) trauma patients to TC. A correct match in the injury severity of a trauma patient and the destination hospital is considered an appropriate triage.

Findings: Figure 3(a) illustrates the 8 regions in the state, while Figure 3(b) indicates the density of trauma incidences in the state corresponding to the 2012 sample dataset of 6,002 cases. Table 3 provides an estimate of the state-wide srUT and srOT cases in the 2021 dataset; we did this using a notional tasking algorithm that attempts to mimic the EMS decision making process of destination determination for a trauma patient (see Appendix C). Taken together, these observations will serve as the basis for Aim 3.

Table 2. Number of NTCs and TCs in 2021

Region	NTC	TC	Total
1	22	10	32
2	20	7	27
3	11	4	15
4	16	5	21
5	20	9	29
6	14	4	18
7	7	0	7
8	8	2	10
Total	118	41	159



(a) Current Ohio Regions (b) Trauma Incidences

Figure 3. Distribution of triage incidences from the sample 2012 dataset (N=6,002)

Table 3. Estimated srUT and srOT cases for 2021 using the notional tasking algorithm

	srUT	srOT
Cases	86	3512
Rate	0.093 (86/927)	0.692 (3512/5075)

*Note: Out of 6,002 cases in the sample dataset, total cases with ISS>15 = 927 and total cases with ISS≤15 = 5075.

5. Approach and Findings from Aims 3 and 4

Recall that the objective of Aim 3 is to devise appropriate cost-care measures to enable characterization and evaluation of a given trauma system. On the other hand, the objective for Aim 4 is to compare alternative trauma system configurations in terms of cost-care measures we proposed in Aim 3.

Approach for Aim 3: We first conducted a thorough literature review and explored various online resources to search for existing trauma cost-care measures, but we could not identify any that could be used in a quantitative manner for our study. We, therefore, focused on the relationship between cost and care of alternative network configurations to quantify the impact of changes in adding/removing TCs from the network on care (srUT and srOT cases).

Approach for Aim 4: In order to illustrate the use of our cost-case approach, we used the 2021 trauma network in the state of OH (available through the ODPS website). As mentioned earlier, because we did not have the incidence dataset for 2021, we used the most recent available sample dataset from 2012 (used in our prior work with ODPS). We, then, used this 2021 network as the 'baseline' and generated 4 more alternative configurations by either opening or closing different number of TCs at chosen locations. These new networks were as follows:

- '2021': network of TCs and NTCs in 2021
- '2021 + 3 TCs': 3 TCs added to the 2021 network (1 each of Level I, II, and III)
- '2021 + 6 TCs': 3 more TCs added to '2021 + 3 TCs' network (1 each of Level I, II, and III)
- '2021 – 3 TCs': 3 TCs removed from the 2021 network (1 each of Level I, II, and III)
- '2021 – 6 TCs': 3 more TCs removed from '2021 – 3 TCs' network (1 each of Level I, II, and III)

For this illustration, when adding Level I and Level II TCs, we first considered suburban areas with population density ≥1000 per sq mile (using OH population density available in [14]); in contrast, when adding Level III TCs, we considered a lower population density <1000 per sq mile. However, ODPS personnel or other users of our proposed models could use any location per their need or desire to assess the potential impact of opening of new or closing of existing trauma centers in the state.

When removing Level I, Level II, and Level III TCs from a network, we chose regions with 'clustering' of Level I or Level II TCs. The priority of closing locations is first given to those who have relative low number of severely injured trauma incidences around, and at the same time have other TCs nearby.

Cost-Care Estimates: For these alternative networks, we then employed our cost estimation method to get the corresponding per-patient costs. To identify srUT and srOT cases, we used our proposed notional tasking algorithm (see Appendix C).

Findings: Figure 4 shows the five representative networks used in Aim 4 analysis, while their corresponding mistriage cases and costs are listed in Table 4. Figure 5 represents the trend in the number of srUT cases and per-patient cost in different networks. The key findings are as follows:

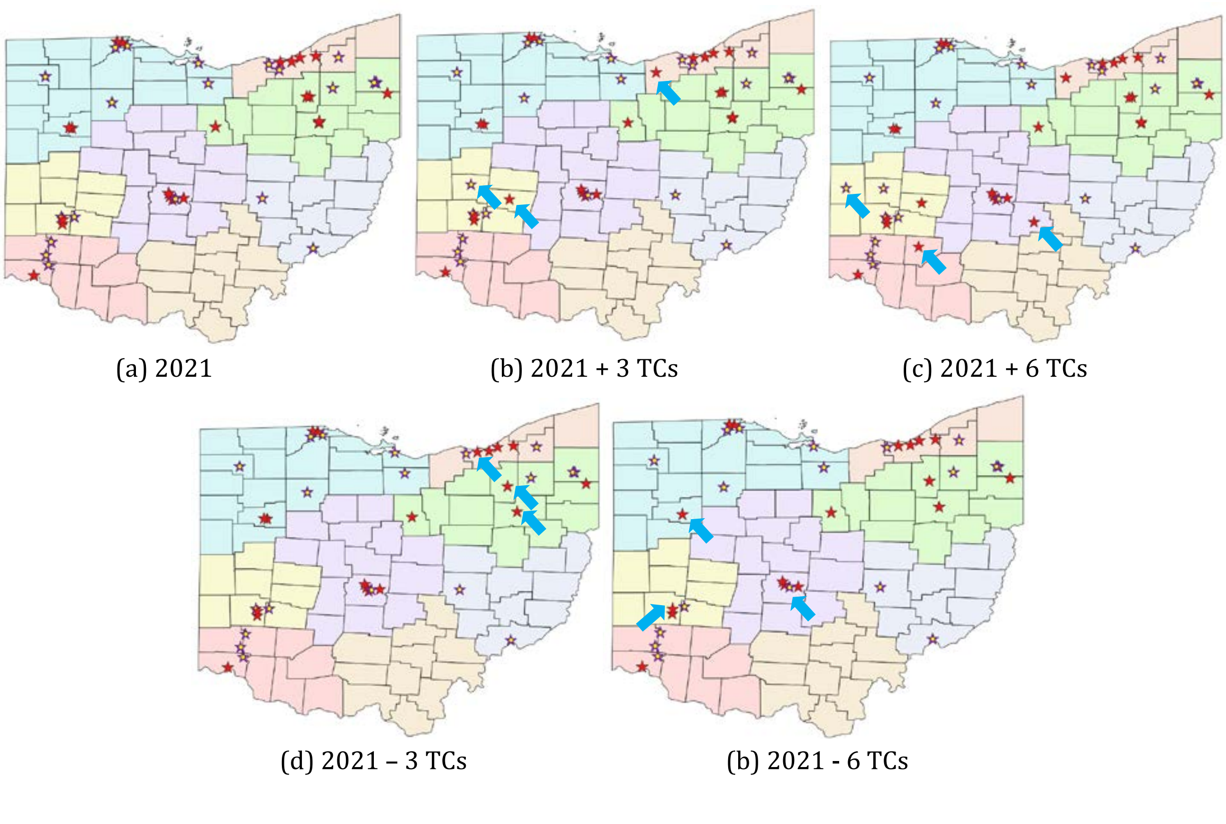
- There is a trade-off between cost and care when modifying the number of TCs (Level I, II, or III) in a network.
- Specifically, compared to the 2021 Network, the number of srUT cases decreased by 37 (from 86 to 49) after opening 6 TCs (all Level III), but this came at the cost of an additional $400 million in system cost (which is additional $5,457 in per-patient cost) and 291 more srOT cases.
- In contrast, the network with 6 less TCs was estimated to have a lower system ($350 million) and

per-patient cost ($5,301) compared to the 2021 Network. The number of srOT was also lower by 84. However, the number of srUT cases increased by 15 more.

- Considering the regression lines in Figures 5(a) and 5(b), we notice that for every decrease of a srUT case, the per-patient cost increases by $198.37 (due to increase in TCs). In contrast, an increase of a srOT case is associated with an increase of $25.79 increase in per-patient cost. *Collectively speaking, an increase of $198.37 in per-patient cost reduces 1 srUT case, but increases 7.69 srOT cases.*

Table 4. Summary of mistriage cases and costs for representative networks.

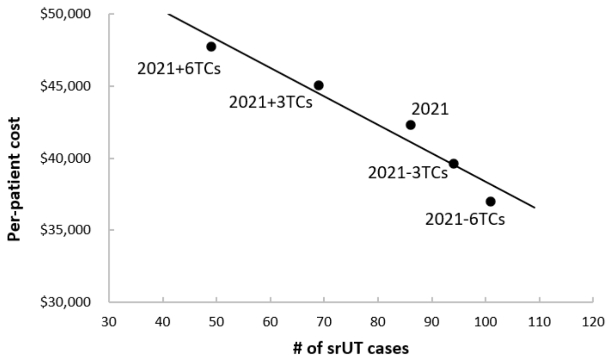
	2021-6TCs	**2021-3TCs**	**2021**	**2021+3TCs**	**2021+6TCs**
srUT cases	101	94	86	69	49
srOT cases	3,437	3,477	3,521	3,696	3,812
System cost ($x10^6$)	$2,444	$2,617	$2,794	$2,975	$3,154
Per-patient cost	$37,011	$39,636	$42,312	$45,056	$47,769



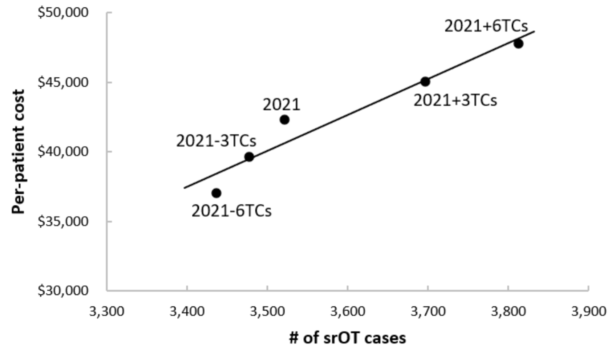
(a) 2021 (b) 2021 + 3 TCs (c) 2021 + 6 TCs

(d) 2021 – 3 TCs (b) 2021 - 6 TCs

Figure 4. Representative networks used in Aim 4; blue arrows point to the change of TC locations



(a) Per-Patient Cost vs. srUT
(y = -198.37 x + 58187; R^2=0.95)



(b) Per-Patient Cost vs. srOT
(y = 25.79 x – 50186; R^2=0.93)

Figure 5. Comparison of all 5 trauma networks; 'solid black' line suggests a near-linear relationship between cost-care across alternative network configurations

6. Conclusions

While current trauma cost literature continues to focus on billing/charge data to estimate costs, they are reactive (costs have occurred already), aggregate in nature (do not separate fixed and variable costs), and are limited in their predictive capability (cannot use it to estimate the cost of a new system). There is a parallel stream of literature in healthcare that focuses on econometric models. These models separate costs into its various elements; fixed direct, indirect, and variable direct. 'Fixed direct' costs comprise annualized cost of EMS facilities and equipment (ground and air), trauma center capital costs (including emergency department), utilities, and salaries for clinical medical staff. 'Indirect' costs include annualized cost of staff training and education, and salaries for administration and permanent providers. 'Variable direct' costs include per incidence cost (transportation mode and distance), testing services, medical supplies, cost of semi-permanent or temporary staff, and similar.

The goal of this study was to develop a method to appropriately estimate the cost of a trauma system. This study is novel in that we provide a comprehensive cost model that includes both prehospital (not included in prior literature) and inpatient costs. Such a model is not available for the state of OH, although some foundational work has been done by a couple other US states.

Further, this model allows the needed predictive capability to the state when the trauma network is altered due to the upgrading/downgrading of hospitals to/from Level I, II, or III status. To demonstrate this feature, we estimated the resulting care of a trauma network to allow for an effective cost-care comparison. Such analysis has not been presented in the literature before but has been called for by many as a needed component when designing/redesigning a trauma network.

Some of the key findings include the following:

- The estimated total annual cost for the 2021 trauma system (11 LI, 10 LII, 20 LIII, and 795 EMS stations) and per-patient cost ($2.79 billion and $42,312, respectively) are within the range suggested in prior literature, which serves as evidence of the credibility of our approach.

- The estimated system-related mistriages corresponding to the 2021 network are srUT=86 (rate=0.093) and srOT=3512 (rate=0.692).
- There is a trade-off between cost and care; opening additional TCs can improve care (i.e., reduce srUT), but can significantly increase cost. For example, our results estimated that for every decrease of a srUT case, the per-patient cost increases by $198.37 (due to increase in TCs); however, this increase in cost can lead to an estimated 7.69 srOT cases as well..

We strongly believe that the cost model, derived based on first principles in economic theory, and the cost-care estimates of alternative trauma networks will provide the ODPS a much-needed quantitative approach for baselining and benchmarking. We expect that once this model has been automated (in Excel or suitable program), then it can quickly provide quantitative estimates of what the increase or decrease in the system (and per-patient) cost would be when a hospital system proposed a change in the trauma centers in their region within the state. In so doing, they can evaluate not only the local impact of adding/removing a TC, but also its cascading effect on other nearby regions in the state. This method can also provide recommendations to trauma legislators in the state for any changes in the current trauma system, i.e., opening or closing of any trauma center.

References

(Note: References for Appendices A-C are summarized separately at the end of each appendix)

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Appendix A. Trauma Cost Details and Corresponding References

(Note: References for the below are summarized as a separate section at the end of this appendix)

I.1. Total Fixed Direct Pre-Hospital Cost (FD-Pre): FD-Pre = Human Resource + Infrastructure + Other

Category	Components	Include	Cost Estimate Mean	Cost Estimate Range	Reference
Human Resource	Human Resource	Salaries, benefits, overtime paid to all personnel involved in organized EMS response (Operations Manager, Paramedic, EMT, etc.)	$142,824	$120,000 - $175,971	Maruca [1], Western Lane Ambulance District [2], Wronski [3]
Infrastructure	Physical Plant	Annualized cost across 10 years at 10% interest	$162,755	$101,722 - $195,306	Broden [4], Rogan [5], Shaffer [6], Summers [7]
	Physical Plant Maintenance (annualized)	Building remodel, new furniture and appliances, canopy for vehicles, etc.	$24,529	-	Western Lane Ambulance District [2]
Other	Equipment	Medical, personal protective equipment, both durable and consumables	$51,488	$25,000 - $117,185	Amherst EMS District [8], Maruca [1], Wronski [3], Western Lane Ambulance District [2]
	Communications	Emergency services, dispatch center, in-vehicle/portable communication devices, etc.	$205,624	$159,935 - $251,312	Lake Emergency Medical Services [9], Western Lane Ambulance District [2]
Total			$587,220		

I.2. Total Indirect Pre-Hospital Cost (InD-Pre): InD-Pre = Administrative + Training

Category	Include	Cost Estimate Mean	Cost Estimate Range	Reference
Administrative	Salaries, benefits, overtime paid to administration personnel, technology, services, legal, office materials, etc.	$400,000	-	Western Lane Ambulance District [2]
Training	Training equipment, staff training and conference, education reimbursement, PM/EMT certification, etc.	$34,392	$17,938 - $50,845	Amherst EMS District [8], Western Lane Ambulance District [2]
Total		$434,392		

I.3. Total Variable Direct Pre-Hospital Cost (VD-Pre): VD-Pre = Patient Care + Travel (Ground) + Travel (Air)

Category	Notation	Cost Estimate Mean	Cost Estimate Range	Reference
Travel Ground	Cost per Ground transport	$470	$397 - $545	United States Government Accountability Office [10]
Travel Ground Travel Air	Cost per Air Transport	$6,500	-	Delgado et al. [11]

II.1. Total Fixed Direct In-Hospital Cost (DF-In): FD-In = Infrastructure + Clinical Care Staff

Category	Notation	L1 Cost Estimate Mean	L2 Cost Estimate Mean	L3 Cost Estimate Mean	Reference
Infrastructure	In House OR Availability	$541,154	$252,160	$126,080	Ashley et al. [12]
	Physical Facility(annualized)	$60,785,356	$48,628,285	$24,314,143	Assets America [13], FIXR [14]
	Facility Maintenance (annualized)	$1,962,561*	$1,570,049*	$785,025	HI-Desert Medical Center [15], Estes Park Hospital District [16]
	Utility	$1,098,224*	$878,579*	$439,290	
Clinical Medical Staff	Trauma Surgery	$1,388,013	$1,049,326	$524,663	Ashley et al. [12]
	Trauma Physician Extender	$187,141	$94,361	$47,181	Ashley et al. [12]
	Orthopedics	$1,099,369	$718,621	$359,311	
	Neurosurgery	$539,953	$326,717	$163,359	
	Anesthesia	$296,122	$121,764	$60,882	
	Hand Surgery	$122,249	$52,269	$26,135	
	Microvascular Surgery	-	-	-	
	Cardiothoracic	$221,693	$30,306	$15,153	
	Ob/Gyn	$36,701	$17,710	$8,855	
	Ophthalmology	$227,024	$16,672	$8,336	
	Oral/Maxillofacial	$50,166	$87,011	$43,506	
	ENT	$87,121	$38,940	$19,470	
	Plastics	$237,612	$40,059	$20,030	
	Critical Care Medicine	$5,891	$165,893	$82,947	
	Radiology	$108,086	$72,053	$36,027	
	Urology	$46,547	$22,066	$11,033	
	Vascular	$164,066	$16,374	$8,187	
	Internal Medicine Specialists	$555,683	$270,047	$135,024	
	Gastroenterology	$4,033	$8,396	$4,198	
	Infectious Disease	$4,208	-	-	
	Pulmonary Medicine	$40,129	$12,348	$6,174	
	Nephrology	$1,947	$10,718	$5,359	
	Surgical Resident Support	$110,124	-	-	
Total Cost		$99,010,166	$ 77,540,723	$38,770,361	
Adjusted Total Cost for Trauma		$79,208,133	$ 62,032,579	$31,016,289	

*Estimated from NTC.

II.2. Total Indirect In-Hospital Cost (InD-In): InD-In = Administrative and Program Support Staff + Education and Outreach

Category	Notation	L1 Cost Estimate Mean	L2 Cost Estimate Mean	L3 Cost Estimate Mean	Reference
Administrative	Senior Admin Support	$41,424	$34,119	$17,060	Ashley et al. [12]
	Program Administrator: Trauma Director	$81,522	$45,752	$22,876	
	Trauma Program Manager	$113,269	$88,169	$44,085	
	Trauma Coordinator	$109,978	$26,190	$13,095	
	Participation costs for state, regional, and national activities	$7,282	$3,547	$1,774	
	Secretarial Staff	$28,342	$8,497	$4,249	Ashley et al. [17]
	ED medical director	$3,201	$14,668	$7,334	
	ICU surgical director	$30,710	$5,489	$2,745	
Program Support Staff	Education/Outreach Coordinator	$57,216	$41,003	$20,502	Ashley et al. [12]
	Case Management/Discharge Planning/social services	$638,267	$234,041	$117,021	
	Physical Therapy	$651,115	$255,546	$127,773	
	Occupational Therapy	$593,093	$242,012	$121,006	
	Speech Therapy	$591,401	$235,546	$117,773	
	Injury Prevention Coordinator	$90,507	$39,000	$19,500	
	Research Coordinator	$16,118	-	-	
	Performance Improvement (PI) Coordinator	$46,397	$9,582	$4,791	
	Trauma Registrar - employed	$183,430	$48,457	$24,229	
	Trauma Registrar - contract	$85,621	$3,632	$1,816	
	Trauma Program Secretary	$25,488	$10,141	$5,071	
	TMD	$153,850	$44,314	$22,157	
	TMD Participation Costs	$8,983	$1,416	$708	
	ED Liaison	$4,817	$1,283	$642	
	ICU Surgical Liaison	$4,062	$563	$282	
	Ortho Liason	$14,370	$9,827	$4,914	
	Neurosurgeon Liason	$6,044	$4,716	$2,358	
	Registry Hardware and Software	$10,821	$11,473	$5,737	
	SBIRT	$4,650	$930	$465	
	TEG	$59,623	$990	$495	

II.2. Previous table continued …

Category	Notation	L1 Cost Estimate Mean	L2 Cost Estimate Mean	L3 Cost Estimate Mean	Reference
Education and Outreach	Injury Prevention	$31,338	$15,223	$7,611	Ashley et al. [12]
	Community outreach	$20,903	$5,965	$2,983	
	Professional Education	$13,715	$8,911	$4456	
	Outlying hospital education	$4,250	-	-	
	Trauma Medical Director CME (16 h/y)	$4,157	$2,996	$1,498	
	Trauma Program Manager CME (16 h/y)	$3,886	$1,051	$526	
	Trauma Program Coordinator CME (16 h/y)	$1,527	$646	$323	
	Trauma Registrar CME (16 h/y)	$2,063	$839	$420	
	ED Liason CME (16h/ yr)	$1,762	$201	$101	
	ICU Liaison CME (16h/ yr)	$1,708	$50	$25	
	Neurosurgical Liaison CME (16h/yr)	$1,833	$514	$257	
	Orthopedic Liaison CME (16h/yr)	$1,870	$825	$413	
	ED Education	$20,412	$45,834	$22,917	
	ICU Education	$5,708	$14,002	$7,001	
	Surgery/PACU Education	-	$11,987	$5,994	
Total Cost		$3,776,733	$1,529,947	$764,974	
Adjusted Total Cost for Trauma		$3,021,387	$1,223,958	$611,979	

II.3. Total Variable Direct In-Hospital Cost (DV-In)

Category	Notation	L1 Cost Estimate Mean	L2 Cost Estimate Mean	L3 Cost Estimate Mean	Reference
Hospital Care	Patient Care Cost	$10,079	$6,753	$6,753	Taheri et al. [18], Mabry et al. [19], Newgard et al. [20]

References for the Tables in Appendix A

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Appendix B: Cost Estimation Calculation with Corresponding Assumptions

(Note: References for the below are summarized as a separate section at the end of this appendix)

1) In-hospital fixed direct cost

- *Physical facility annual cost*
  We use Equivalent Annual Cost (EAC) (formula showed below) to estimate physical facility annual cost, with assumptions of discount rate of 10% and periods of 20 years.

$$\text{Asset Price} * \frac{\text{Discount Rate}}{1-(1+\text{Discount Rate})^{\text{-Periods}}} + \text{Annual Maintenance Costs}$$

- *Physical facility bed size*
  We assume L1 TC has a total bed number of 460 [1,2].
- *Physical facility construction cost*
  FIXR [3] suggests 2500 sqft is required for an average hospital. An average construction cost of $450 per sqft was estimated from Delvit [4] with the data of Cleveland and further adjusted to Turner Building Cost Index of 2020.
- *Trauma vs. total cost ratio*
  The Trauma vs. total cost ratio is set to 0.8, indicating if a TC becomes an NTC, the total direct fixed and indirect cost will decrease by 80%.
- *Equipment cost*
  Equipment cost is ignored in our estimation based on the feedback from the Co-I McCarthy.
- *Infrastructure cost for L2 TC*
  The infrastructure cost for L2 is assumed to be 0.8 * infrastructure costs for L1 TC if no direct reference is available.
- *Costs for L3 TC*
  All costs for L3 TC are set to be equal to 0.5*cost at L2 TC.

2) In-hospital variable direct cost

- *The real in-hospital variable direct cost from literature*
  We assume the average per patient cost reported in literatures have already included the fixed and indirect part. Thus, to get the real in-hospital variable fixed cost from literatures, we used a ratio of 0.345 to adjust that part [5].
- *Per patient cost at L2 and L3 TC*
  Per patient cost at L2 TC is estimated with the L1:L2 per patient cost ratio in Marby et al. [6]. Per patient cost at L3 TC is set to be the same as L2 due to lack of knowledge for L1:L3 per patient cost ratio.
- *Per patient cost in NTC*
  Per patient cost in NTC is calculated as 0.58*mean (per patient cost in L1, per patient cost in L2) [7].
- *Cost of srUT and srOT incidences*
  We use length of stay as an indicator of srUT cost. We assume srUT incidences will spend 1 day at NTC and transferred to TC with an average length of stay of 6.88 days (from 2012

dataset), then the cost of srUT will be (1/7.88) * per patient cost at NTC + (6.88/7.88) * per patient cost at TC. srOT incidences are directly assumed to have all cost same as TC.

3) **In-hospital indirect cost**
- *Indirect cost at L3 TC*
  Similar to in-hospital fixed direct cost, we assume the indirect cost at L3 TC is equal to 0.5 * indirect cost at L2 TC.

4) **Pre-hospital fixed direct cost**
- *Number of EMS locations*
  In 2020, according to "Ohio EMS agency list" [8], there are 795 EMS locations that are available of transport with EMT/AEMT/Paramedic protocols, among which 572 are co-located with fire station.
- *Adjusted number of total EMS stations*
  70% calls to a fire station are asking for EMS service based on data listed in National Fire Protection Association website [9]. Thus, we use (795-572) + 572*0.7 = 623 as the number of total EMS stations in OH.
- *Physical facility cost of per EMS station*
  We assumed $1,000,000 for initial building of an EMS station [10-13]. Equivalent annual cost is calculated with 10% discount rate and period of 10 years.
- *Percentage of trauma out of all EMS calls*
  There are only 15.78% of EMS calls are related to trauma according to "2019 Ohio Trauma Registry Annual Report" by Ohio Trauma Registry [14]. Thus, we estimate the total prehospital fixed direct cost = 623* $1M (before annualized) *0.1578.

5) **Pre-hospital indirect cost**
- *Administrative*
  We assumed for each EMS station, there will be administrative costs of $150,000 for 1 Chief, $50,000 for 1 office manager, and $200,000 for materials and services [15].

6) **Total patient volume in system**
   Using 2012 dataset, the total patient volume in system is estimated as 6,002*11 = 66,022, with 10,197 severely injured and 55,825 non-severely injured.

7) **Patient volume to L1 and L2 TC**
   Patient volume to L1 and L2 TC is assumed to be proportional to the number of L1 and L2 in the system.

8) **Number of L1 and L2 TC in a given network**
   Since our notional tasking algorithm doesn't differentiate L1 and L2 TCs in a given network, we assume the number of L1 and L2 TCs are equal (1 more in L1 TC group if the total number of L1 and L2 is odd) based on the observation of 2012 and 2021 OH trauma system.

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Appendix C: Notional Tasking Algorithm to estimate srUT and srOT

(Note: References for the below are summarized as a separate section at the end of this appendix)

Based on the existing trauma literature [1] and our discussions with EMS providers in our region, we realized that the EMS decision making process around 'destination determination' requires estimating the time to nearby TC and NTC based on the injury severity of the patient. To mimic this decision-making process, we propose two thresholds; (i) 'access' and (ii) 'bypass.'

For a severely injured patient, the EMS providers often first check if a TC (the appropriate hospital) is accessible within the 'access' threshold time. If yes, then the patient is transported to that TC. If no, then they check if an air ambulance can be called in to transport the patient to the nearest TC. However, if the sum of the inbound-to-field, loading, and transport-to-TC times for the air ambulance is higher than the 'access' threshold, then the EMS would most likely transport the patient to a nearby NTC, resulting in a srUT.

In contrast, the case of a srOT is a bit more complicated. A TC may be located close to the trauma incidence site compared to an NTC. In this case, if for a less severely injured patient, the additional time (beyond the time to TC) to reach an NTC (the appropriate hospital for this patient) is within the 'bypass' threshold, then the EMS will likely take the patient to the NTC. Otherwise, the EMS would likely take the patient to the nearby TC resulting in a srOT. A negative value of 'bypass' threshold indicates that the EMS would likely take a less severely injured patient to a TC (instead of an NTC) even if the TC is slightly further away. Anecdotally, such situations may arise due to EMS-perceived TC's reputation to be higher (i.e., the-bigger-the-hospital-the-better-the-care), patient/family choice, insurance situation, and even negotiated contracts between the EMS and TC.

Further, in line with the existing trauma literature, we use Injury Severity Score (ISS) as a surrogate for the severity of injuries on the field; ISS is a post-hoc metric evaluated after the patient arrives at the hospital. Note that while (i) was used in Jansen et al. [1], (ii) has never been discussed in the literature. In that sense, our notional tasking algorithm illustrated in Figure A1 generalizes previous work.

The schematic of the notional tasking algorithm is presented in Figure C1. Accordingly, let $t_{TC\text{-}gnd}$ and $t_{TC\text{-}air}$ refer to the total time from field to the TC via ground and air, respectively, and t_{NTC} is the time from field to NTC via ground. While t_{in} and t_{load} refer inbound and loading time for the air ambulance, respectively. If t_{access} and t_{bypass} refer to the 'access' and 'bypass' thresholds, then

- Ifs ISS>15 (i.e., severe injuries), then
  - If $t_{TC\text{-}gnd} \leq t_{access}$, then transport to TC
  - Elseif (helicopter available), then
    - If $t_{TC\text{-}air} + t_{in} + t_{load} \leq t_{access}$, then transport to TC
  - Else transport to NTC (and mark the case as srUT)
- Elseif ISS ≤ 15 (i.e., less severe injuries), then
  - If $t_{NTC} - t_{TC\text{-}gnd} \leq t_{bypass}$, then transport to NTC
  - Else transport to TC (and mark the case as srOT)

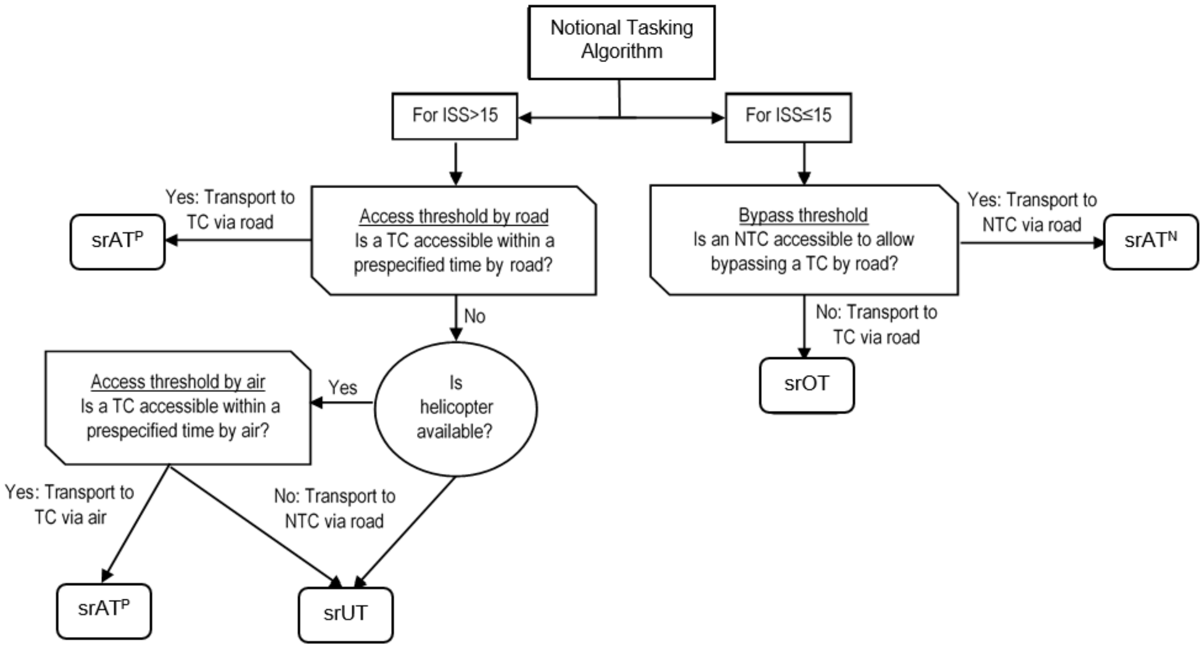

Figure C1. Notional Tasking Algorithm

To derive the values of 'access' and 'bypass' threshold values, we experimented with a range of values for 'access' and 'bypass.' We subsequently found 'access' = 31.5 minutes and 'bypass' = -9 minutes as the best values; the resulting srUT with these values was 105 (similar to 101 in 2012 data) and srOT was 3444 (close to 3418 in 2012 data). This gave us confidence to use this algorithm to estimate srUT and srOT for alternative networks discussed in Aims 3 and 4.

Reference for Appendix C

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