REFINING THE DEFINITIONS OF UNDER- AND OVER-TRIAGE: A DATA ANALYTICS AND CONSENSUS-BASED APPROACH

FINAL REPORT

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Submitted by

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Executive Summary

The optimal triage of trauma patients has been a source of vigorous debate over the years. As per Ohio's 2013 Trauma System Consultation Report "no knowledge exists regarding over- and under-triage rates and issues" for the state (ACS-TSCR, 2013). It is, therefore, critical to accurately measure the quality of trauma care in order to evaluate the performance of the current trauma system and optimize it. Current research in trauma indicates that under-triage (UT) and over-triage (OT) rates are good, measurable, surrogates for improving quality of system-wide trauma care; UT refers to transporting severely injured patients to a non-trauma center and OT refers to transporting less severely injured patients to major trauma centers.

Unfortunately, there is no clear consensus on the definitions of UT and OT. We believe, at the very minimum, three things must be clearly identified to accurately measure these rates:

(1) Identify severely-injured patients (major trauma);

(2) Identify reasons for mistriages (under and over) and categorize them accordingly; and

(3) Quantify mistriages using appropriate mathematical expressions.

While for (1), the American College of Surgeons suggests using Injury Severity Score (ISS) value of >15 as a good surrogate to predict major trauma, for (2), however, several factors contribute to the transport of a patient from the field (i.e., scene) to a non-ideal hospital, resulting in mistriages:

- Specific on-field trauma triage *protocol* (and the underlying limitations)
- *Patient* or family choice (likely due to past experience or current insurance coverage)
- *Network* of trauma centers in the region (and the corresponding maldistribution)
- *Operational* (e.g., weather, ED diversion, and EMS resource limitation)

Further, for (3), multiple mathematical expressions have been proposed in the literature with no clear consensus on which ones accurately reflect what the ODPS/EMS Division and trauma researchers want to measure.

In this study, we attempted to address (2) and (3) above. Specifically, we focused on (i) refining the aggregate mistriaged patient population into subgroups based on the underlying reasons (**Aim 1**) and (ii) defining UT and OT rates for each mistriaged subgroup by building a consensus on appropriate mathematical expression **(Aim 2**). For Aim 1 we proposed a data analytics approach that categorized the mistriaged patients into 4 subgroups: (a) patient/family choice, (b) protocol, (c) network, and (d) operational. To estimate (c) and (d), we developed an algorithm to delineate the corresponding mistriages (under and over) into these two categories. For Aim 2, we reviewed several prominent mathematical expressions in the trauma literature (e.g., Cribari Matrix, Newgard et al., and Peng and Xiang), provided an understanding of what each measures, and presented our findings to the Trauma Committee of the EMS Division at ODPS. We clearly specify the difference between on-field detection vs. prevalence alluded to by these expressions. Feedback from our collaborators and members of the Trauma Committee at the EMS Division allowed us to build a consensus around appropriate expressions to quantify UT and OT rates.

The key findings from Aim 1 suggest that the % of total mistriaged cases (UT and OT combined) across the 4 subgroups is reasonably consistent across the two years (i.e., 2011-2012). However, UT cases under the 'Closest Facility' subcategory appeared to dominate across all 8 regions during the two years. The reason for this could be lack of TCs in the region (e.g., Region 8) or other operational factors such as weather, traffic, ED diversion, or limited EMS resources may have caused such a transport. In contrast, OT cases under the 'Patient/Family Choice' subgroup almost always dominated other subgroups across the 8 regions. We conjecture that this may be because of the perception of a TC in the region, prior experiences, insurances, or similar others. Again, this would require additional investigation (potentially via a survey of EMS and local citizens) to better understand the root causes for high OT cases due to 'Patient/Family Choice.'

These findings, for the first time, revealed the underlying root causes for the occurrence of UT and OT cases. They create an opportunity to target EMS research and activities to improve on-field triage process. For instance, while the voice of the patient/family cannot be ignored when determining the destination hospital, it does allude to a possibility of better EMS education to improve communication between the EMS provider and the patient to ensure that the patient is clearly made aware of the best hospital type for their condition.

From Aim 2, we were able to nuance the three prominent mathematical expressions for estimating UT and OT rates; i.e., proportion (or %), detection, and prevalence. We were able to share our findings with the Trauma Committee with the EMS Division at ODPS. A consensus around UT=1-sensitivity and OT=1-specificity as the appropriate expression emerged. We used these expressions to estimate UT and OT rates for each of the 4 subgroups (as identified in Aim 1) across 2011-12. We also observed that the choice of TH_{UT} and TH_{OT} threshold values is critical as they affect how UT and OT cases are grouped affecting the corresponding rates 'Network' and 'Operational' subcategories, and should be defined working with local EMS agencies, and may be region-specific.

In summary, our study addresses several concerns related to estimating UT and OT rates in the state of Ohio. Our findings suggest that trauma care in the state of Ohio could be improved further by refining the aggregated UT and OT rates (often reported in state reports and academic literature) into various subgroups. This allows for a clear understanding of the root causes of UT and OT, which then could lead to better plans and training initiatives to mitigate such mistriages. A better understanding of these prominent reasons for scene-to-destination choice could also help improve communication between the state's EMS division and the regional EMS agencies to collaborate on such initiatives. We strongly believe that our findings would help the state of Ohio in achieving their goal of providing a "Framework for Improving Ohio's Trauma System" that was included in the Ohio EMS 2015 Strategic Plan.

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1. Investigators

Pratik J. Parikh, PhD (PI): Pratik Parikh serves as the PI and the Data Analytics/Engineering expert on this proposed study. He is a faculty in the Biomedical, Industrial and Human Factors Engineering and holds joint appointments in the Departments of Surgery and Computer Science at WSU. 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.

Peter Ekeh, MD (Co-I): Peter Ekeh is a Professor in the Department of Surgery and a practicing trauma surgeon at Miami Valley Hospital. He is also the Chief of the Division of Acute Care Surgery and Medical Director of the Injury Prevention Center. He is the creator of the "Drive Alive" program for juveniles convicted of drunk driving, partially funded by the Ohio EMS Injury Prevention Grant.

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.

Priti Parikh, PhD (Co-I): Priti Parikh serves as a 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.

2. Study Specific Aims

This was a multi-region, population-based, retrospective cohort study involving all counties in Ohio. The study protocol has been approved by Wright State University's (WSU's) Institutional Review Board (SC#6027). The specific aims of this study are as follows:

Aim 1: Refining the aggregate mistriaged patient population into subgroups based on the underlying reasons: We proposed a data analytics approach to categorize mistriaged patients into 4 subgroups based on the underlying cause: (a) network, (b) protocol, (c) patient/family choice and (d) other operational. To estimate (a) and (d), we developed an algorithm using Google Maps API to delineate the corresponding mistriages (under and over) into these two categories. We used 2011-12 data available from the ODPS/EMS Division. Both (b) and (c) were mined from the same data. These mistriage (UT and OT) rates corresponding to each of these 4 subgroups will enable the ODPS to identify root-causes for mistriages, which result in suboptimal performance of a regional trauma system.

Aim 2: Defining the UT and OT rates for each mistriaged subgroup by building a consensus on appropriate mathematical expression: While Aim 1 will help identify the 4 patient subgroups, in this aim we will focus on thoroughly reviewing the academic literature for various definitions or methods used to quantify UT and OT rates. We will first carefully understand what each expression actually uses as the numerator and denominator in the rate calculations. Then, we will work closely with our research team and with the EMS Division to compare what these expressions measure against what trauma stakeholders wish to measure. This consensus building approach is expected to converge to one or the other expression, which will then be used to quantify UT and OT rates for the 4 subgroups identified in Aim 1.

3. Significance

The optimal triage of trauma patients has been a source of vigorous debate over the years. As per Ohio's 2013 Trauma System Consultation Report "no knowledge exists regarding over- and under-triage rates and issues" for the state (ACS-TSCR, 2013). It is, therefore, critical to accurately measure the quality of trauma care in order to evaluate the performance of the current trauma system and optimize it. Current research in trauma indicates that under-triage (UT) and over-triage (OT) rates are good, measurable, surrogates for improving quality of system-wide trauma care; UT refers to transporting severely injured patients to a non-trauma center and OT refers to transporting less-severely injured patients to major trauma centers. While UT negatively impacts patient outcomes (e.g., short and long term disability, and mortality) and OT can cause higher trauma care cost.

The currently used aggregated rates of UT and OT, however, do not account for underlying causes. For instance, in our previous work we observed that Region 8 in Ohio had a high aggregated UT (87.3%) compared to Region 5 (UT=8.84%); per definition proposed in Newgard et al. (2016). Based on the aggregate value of UT, the performance of region 8 was worse than region 5. However, the fact that Region 5 has a total of 5 major trauma centers, while Region 8 has none might have contributed to such findings that current reporting of UT does not account for.

So can we really evaluate the performance of EMS and/or trauma system based on these aggregate UT and OT rates? If no, then what refinements in UT and OT definitions are critical to help aid such comparisons and eventual improvements?

Unfortunately, there is no clear consensus on the definitions and quantification of UT and OT. We believe, at the very minimum, three things must be clearly identified to accurately measure these rates:

(1) Identify severely-injured patients (major trauma);

(2) Identify reasons for mistriages (under and over) and categorize them; and

(3) Quantify mistriages using an appropriate mathematical expression.

For (1), the American College of Surgeons – Committee of Trauma suggests using Injury Severity Score (ISS) value of >15 as a good surrogate to predict major trauma (ACS-COT, 2014); Lossius et al. (2012) did not find any conclusive evidence against using the ISS approach when compared to other alternatives. For (2), however, anecdotal stories from EMT and trauma surgeons and evidence from our previous data analytics study with the EMS Division suggest that several factors contribute to why a patient may be transported from the scene to a non-ideal hospital, causing mistriages (under or over):

- *Patient/family* choice (likely due to past experience or current insurance coverage)
- Specific on-scene trauma triage *protocol* (and the underlying limitations)
- *Network* of trauma centers in the region (and the corresponding maldistribution)
- *Operational* (e.g., weather, ED diversion, and EMS resource limitation)

For (3), multiple mathematical expressions have been proposed in the literature with no clear consensus on which one of these accurately reflects what the ODPS/EMS Division and trauma researchers want to measure. Our initial review suggests that there are at least 2 unique expressions for each based on the Cribari Matrix Method (ACS-COT, 2014), Newgard et al.'s approach (2016), and Peng and Xiang's approach (2016). There are subtle nuances in each of these expressions that alter the quantification of the rates.

In this study, we address (2) via Aim 1 and (3) via Aim 2, as detailed below.

4. Approach and Findings from Aim 1

Recall, the objective of Aim 1 was to subgroup mistriaged patients based on the estimated underlying causes: 'Patient/family choice,' 'Protocol,' 'Network,' and 'Operational.'

<u>Data Source and Variables</u>

From the data available to us by the ODPS during our previous studies with them, we used the latest 2 years (2011 and 2012) for which we were able to use the Google Maps Distance API to estimate travel times. Data from previous years could not be used due to missing and incomplete information. The 2011-12 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 and reasons for transporting the patient to a given hospital, while the Trauma Registry tracks information from the arrival at the ED, hospital stay, and discharge diagnosis and destination. Using this combined dataset, we will 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 >15.

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. Table 1 shows the total number of patient records finally included in our analysis by year.

Table 1. Number of records from the field (scene) to the first hospital

Year	2011	2012
Total in EMSIRS 1 + 2	7405	8175
After exclusion of missing values	5528	6002

<u>Methodology</u>

We used the ACS-recommended ISS>15 as a reasonable surrogate to retrospectively analyze if a patient experienced severe injuries. We considered Level I and II centers as Trauma Centers (TCs), and Level III and other community hospitals as Non-Trauma Centers (NTCs); see Table 2.

Table 2. Number of NTCs and TCs in 2012

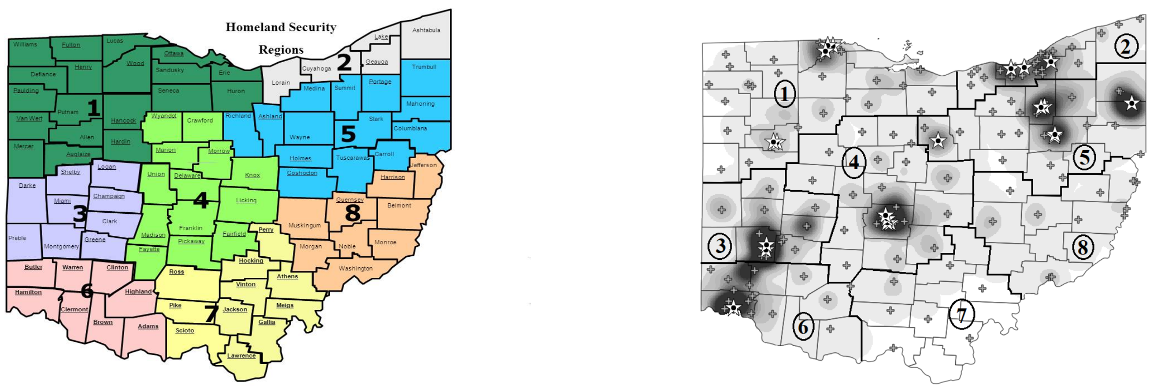
Region	NTC	TC	Total
1	26	5	31
2	24	3	27
3	14	2	16
4	18	4	22
5	22	6	28
6	18	1	19
7	7	0	7
8	11	0	11
Total	140	21	161

We then used the 'Reason for Choosing Destination' data field to identify the subgroups. While it was straightforward to identify decisions based on 'patient/family choice,' 'protocol,' and 'other reasons,' we used our proposed algorithm (see Appendix A) to analyze patient records for which 'Closest Facility' is indicated as the reason in the 'Reason for Choosing Destination' data field and then separate these patient records into 'Network' and 'Operational' Subcategories. We used

Google Maps Distance API to estimate travel times. No attempt was made to identify or report specific hospital names.

<u>Findings</u>

Figure 1(a) illustrates the 8 regions in in the state, while Figure 1(b) indicates the density of trauma incidences in the state for 2012, along with the network of LI/II and LIII/NTCs in that year.



(a) Current Ohio Regions

(b) Trauma Incidences

Figure 1: Distribution of triage incidences during 2012 (N=6,002); 'stars' indicate TCs and 'plus' indicate NTCs; darker shades of grey indicate higher values of incidences

Table 3 summarizes the number of incidences, UT and OT by year and 'Reason for Destination Choice' in the data. We combined 'patient choice' and 'family choice' as 'Pat-Fam Choice.' Here % refers to the ratio of number of cases divided by the total; i.e., for 2011, under Pat-Fam Choice, %-UT=30/2225 = 13.5% (and should not be misunderstood as rates; see Section 5 for more details). Figure 2 illustrates how these values were estimated for 2012. Figures 3 and 4 illustrate the variation in UT and OT cases, by each subgroup, across the 8 regions for 2011 and 2012.

Table 3: Summary of UT and OT cases in each subgroup
(Note: % are not rates; see Table 7 for rates)

Subgroup	**2011 cases (N=5528)**			**2012 cases (N=6002)**		
	Total	***UT***	***OT***	***Total***	***UT***	***OT***
Pat-Fam Choice	2225	30 (1.34%)	951 (42.74%)	2418	56 (2.32%)	1062 (43.92%)
Protocol	873	33 (3.78%)	389 (44.56%)	958	36 (3.75%)	429 (44.78%)
Closest Facility	1938	118 (6.09%)	608 (31.37%)	2041	87 (4.26%)	773 (37.87%)
Other	492	10 (2.03%)	254 (51.63%)	585	6 (1.03%)	350 (59.83%)

Terminology

		ISS	
		ISS>15	**ISS≤15**
Destination	**TC**	*AT-P*	*OT*
	NTC	*UT*	*AT-N*

All Reasons for Destination

		ISS		
		ISS>15	ISS≤15	
Destination	TC	742	**2614**	
	NTC	**185**	2461	
				6002

Family/Patient Choice

		ISS		
		ISS>15	ISS≤15	
Destination	TC	182	**1062**	
	NTC	**56**	1118	
				2418

Protocol

		ISS		
		ISS>15	ISS≤15	
Destination	TC	184	**429**	
	NTC	**36**	309	
				958

Closest Facility

		ISS		
		ISS>15	ISS≤15	
Destination	TC	230	**773**	
	NTC	**87**	951	
				2041

Other

		ISS		
		ISS>15	ISS≤15	
Destination	TC	146	**350**	
	NTC	**6**	83	
				585

Figure 2. Estimation UT and OT cases for 2012; aggregated and for each subgroup, using the ISS method (UT in orange and OT in gray backgrounds per the 'Terminology' specified at the top; AT-P = Appropriate Triage–Positive and AT-N=Appropriate Triage-Negative)

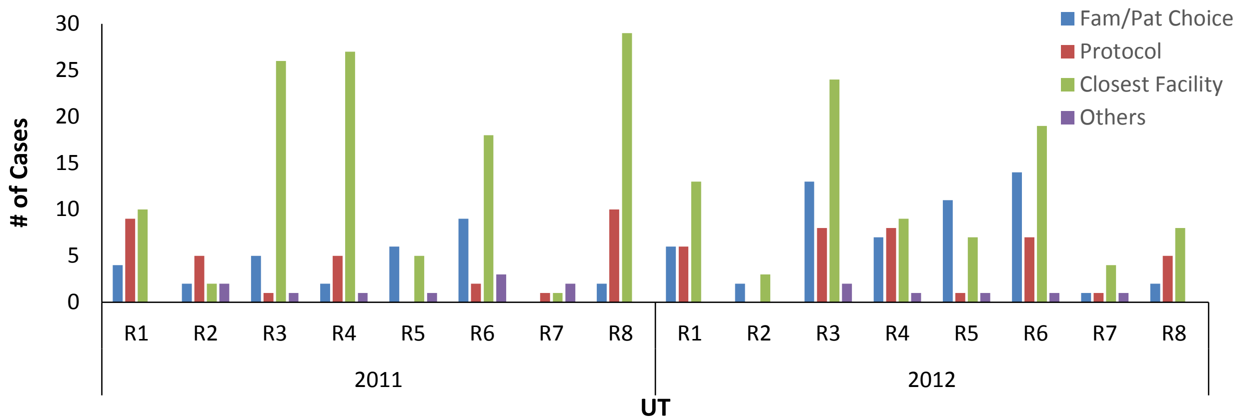


Figure 3. Variation in the UT cases across 4 subgroups by 8 regions and year (if the subgroup has 0 cases, then the corresponding bar is not shown)

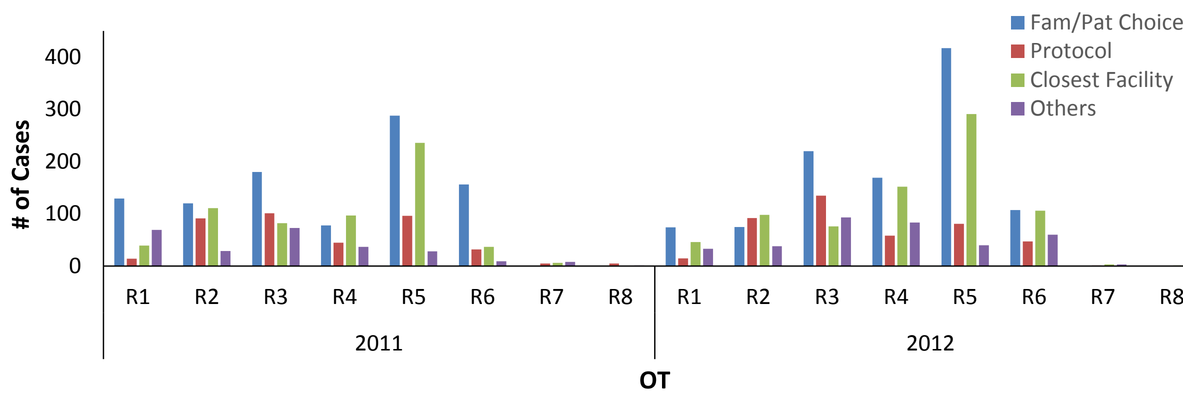


Figure 4. Variation in the OT cases across 4 subgroups by 8 regions and year (if the subgroup has 0 cases, then the corresponding bar is not shown)

The key observations from the above tables and graphs are as follows:

- The % of total mistriaged cases (UT and OT combined) across the 4 subgroups is reasonably consistent across the two years.
- Focusing on UT, 'Closest Facility' appears to be the dominant reason across all 8 regions during the two years. This is intuitive if (i) the patient's condition is quickly deteriorating requiring immediate resuscitation, and/or (ii) there is no major trauma center around; e.g., in Regions 7 and 8 there are no Level I/II TCs, which would induce the EMS to transport a severely-injured patient to an NTC. However, it is unclear why regions with several Level I/II TCs also have 'Closest Facility' as the cause of high UT cases. Could it be because of other operational considerations

such as weather, traffic, ED diversion, or limited EMS resources may have caused such a transport? This needs further investigation.

- Focusing on OT, 'Patient/Family Choice' almost always dominates other subgroups across the 8 regions. We conjecture that this may be because of the perception of a TC in the region, prior experiences, insurances, or similar others. Again, this would require additional investigation (potentially via a survey of EMS and local citizens) to better understand the root causes for high OT cases due to 'Patient/Family Choice.'

Having identified UT and OT across the 4 subgroups, we then used our proposed algorithm (see Appendix A) to further refined the UT and OT cases under the Closest Facility subgroup into 'Network' and 'Operational' subcategories (as per Aim 1). Figure 5 illustrates findings from this algorithm in the form of contingency tables; the 'Terminology' is similar as before, except that the 'UT' cell is now subcategorized into UT(Net) and UT(Oper) corresponding to the 'Network' and 'Operational' subcategories, respectively. The same holds true for OT. We present results for two threshold values for TH_{UT} and TH_{OT}, resulting into 4 combinations.

These results suggest that there could be a considerable effect of the network of TCs on UT(Net) and OT(Net), depending on the choice of the thresholds. As TH_{UT} increases, the estimated number of UT(Net) cases decreases (65 for (30,0) vs. vs. 8 for (60,0)). This means that when the EMS is required to transport a severely-injured patient (ISS>15) to a TC within 30 minutes, there is a low likelihood of finding a TC nearby the scene, resulting in they likely choosing a closer NTC. This is what we refer to as UT(Net) or UT caused due the underlying network of TC. But when this threshold goes up to 60 minutes, there is a higher likelihood of finding a TC nearby and hence the UT(Net) is lower.

Terminology

		ISS		
		ISS>15	**ISS≤15**	
Destination	**TC**	AT-P	OT(Net)	OT(Oper)
	NTC	UT(Net)	AT-N	
		UT(Oper)		

		ISS		
		ISS>15	**ISS≤15**	
Destination	**TC**	230	318	455
	NTC	65	951	
		22		

Thresholds (TH_{UT}, TH_{OT}) = (30, 0)

		ISS		
		ISS>15	**ISS≤15**	
Destination	**TC**	230	5	768
	NTC	65	951	
		22		

Thresholds (TH_{UT}, TH_{OT}) = (30, 15)

		ISS		
		ISS>15	**ISS≤15**	
Destination	**TC**	230	318	455
	NTC	8	951	
		79		

Thresholds (TH_{UT}, TH_{OT}) = (60, 0)

		ISS		
		ISS>15	**ISS≤15**	
Destination	**TC**	230	5	768
	NTC	8	951	
		79		

Thresholds (TH_{UT}, TH_{OT}) = (60, 15)

Figure 5. Estimation of 'Network' and 'Operational' UT and OT for the Closest Facility subgroup for 2012 for a given threshold pair (TH_{UT}, TH_{OT}); UT(Net)=Network UT and UT(Oper)=Operational UT; same for OT

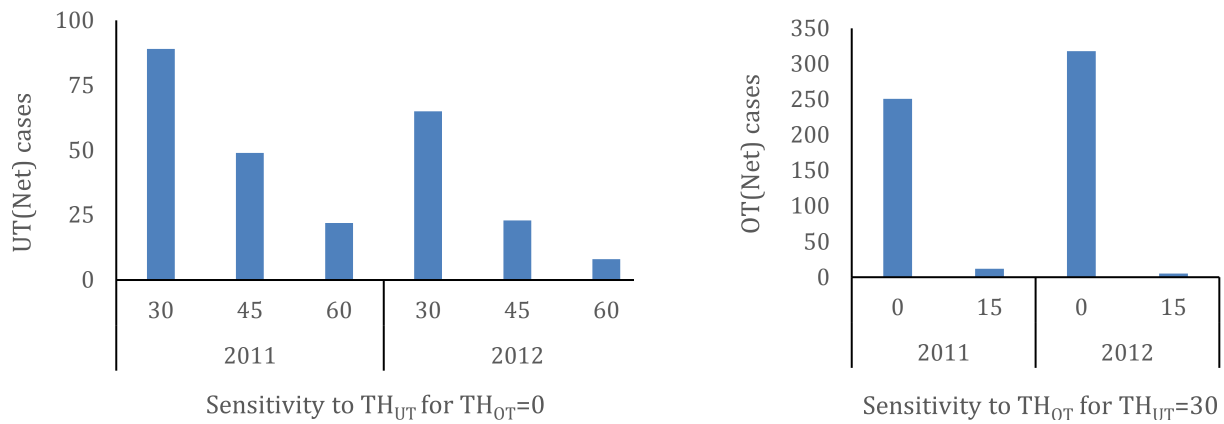


Figure 6. Sensitivity of estimated UT(Net) and OT(Net) cases to threshold values (TH_{UT} and TH_{OT})

The situation is slightly different in the case of OT(Net). In this case, TH_{OT}=15 means that the EMS is assumed to bypass a TC if an NTC (ideal hospital for a patient with ISS≤15) is up to 15 additional minutes away from this TC. Naturally, as this threshold value drops down to 0, this margin diminishes and the EMS will not bypass a TC even if an NTC is ≥1 minute further away. That is, the estimated OT(Net) cases will be much higher with a smaller TH_{OT} compared to a higher value. Clearly, the choice of TH_{UT} and TH_{OT} are critical, should be defined working with local EMS agencies, and could be region-specific.

5. Approach and Findings from Aim 2

In this aim, we attempted to nuance various existing mathematical expressions to quantify UT and OT rates, and build consensus around the most appropriate expressions. Our attempt was to try and address the following questions:

- What does each of the mathematical expression truly measure?
- Should the focus be on on-field errors (the EMS side of events) or should the focus be on whether or not the trauma team was activated (the hospital side)? That is, what should the denominator be in these expressions?

Methodology

To address these questions, we adopted the following process:

- We first nuanced the mathematical expressions to understand what each of these actually measure. The choice of the appropriate denominator was critical as it determined the patient class (ISS≤15 and ISS>15) within which the mistriage occurred. We considered differences in the UT expressions (Cribari Method vs. Newgard and Peng/Xiang approaches) and then the OT expressions (Cribari Method and Peng/Xiang vs. Newgard).
- We then met the Clinical and Health Service collaborators in our team to determine which approach accurately reflected what needed to be measured.

- We also presented our findings to the Trauma Committee within the EMS Division at ODPS during our January 2019 visit. This meeting was attended by trauma practitioners including surgeons, EMTs, fire fighters, trauma nurses, and ODPS personnel. (Further details on the composition of this committee and minutes from that January meeting are available here: https://www.ems.ohio.gov/trauma-committee.aspx.)
- We also had email/phone interactions with a few of these committee members as a follow up on some critical items.

We now summarize below our findings from this process.

Summary of Mathematical Expressions and their Meaning

To understand the various definitions, *we considered on-field triage* (i.e., scene-to-first hospital). We did not consider the triage process at a hospital (trauma activation at a hospital) in our analysis.

The three tables below summarize what has been proposed in the literature. We use actual cases from 2012 data (N=6,002) to help elucidate these methods. We considered Level I and II centers as Trauma Centers (TCs), while Level III and other community hospitals as Non-Trauma Centers (NTCs).

It is worth noting that distinguishing a severely-injured patient from a non-severely on the field is similar to a classification problem. Such binary decision making problems can lead to 4 outcomes – 2 correct and 2 errors (false positive and false negative). These outcomes are best reflected through a contingency table (aka confusion matrix). Tables 5 and 6 show three proposed ways in the trauma literature through which UT and OT rates can been calculated, along with their mathematical expressions and their meaning.

Table 4: Contingency table for 2012 cases (N=6,002)

		Underlying Injuries	
		Severe (ISS>15) Should have been taken to LI/II	**Less-Severe (ISS≤15)** Should have been taken to LIII/NTC
Actual EMS Transport	**Actually taken to LI/II**	True Positive (TP) 742 (12.36% of N)	False Positive (FP; OT cases) 2614 (43.55% of N)
	Actually taken to LIII/NTC	False Negative (FN; UT cases) 185 (3.08% of N)	True Negative (TN) 2461 (41.00% of N)

Table 5: Comparison of expressions for quantifying On-Field Under-Triage (N=6,002)

Method	Expression	Example	What does it measure?
Proportion: Proportion of total patients	$\frac{FN}{N}$	$= \frac{185}{6002}$ **= 0.0308**	• *Quantifies the <u>proportion</u> of all Severely Injured cases transported to LIII/NTC*
Newgard, Peng/Xiang, Parikh: 1 – Sensitivity	$\frac{FN}{TP+FN}$ *OR* $1-\left(\frac{TP}{TP+FN}\right)$	$= 1-\left(\frac{742}{742+185}\right)$ **= 0.1996**	• *Quantifies the <u>on-field detection</u> of severely injured patients (EMS perspective)* • *That is, among all severely-injured cases (ISS>15), what proportion were transported to LIII/NTC by the EMS*
Cribari: 1 – NPV, where NPV = Negative Predictive Value	$\frac{FN}{TN+FN}$ *OR* $1-\left(\frac{TN}{TN+FN}\right)$	$= 1-\left(\frac{2461}{2461+185}\right)$ **= 0.0699**	• *Quantifies the <u>prevalence</u> of severely-injured cases among all those taken to LIII/NTC (hospital perspective)* • *That is, among all cases transported to LIII/NTC, what proportion of these were severely-injured.*

Table 6: Comparison of expressions for quantifying On-Field Over-Triage (N=6,002)

Method	Expression	Example	What does it measure?
Proportion: Proportion of total patients	$\frac{FP}{N}$	$= \frac{2614}{6002}$ **= 0.4355**	• *Quantifies the <u>proportion</u> of all Less-Severely Injured cases transported to LI/II*
Newgard, Peng/Xiang, Parikh: 1 – Sensitivity	$\frac{FP}{TN+FP}$ *OR* $1-\left(\frac{TN}{TN+FP}\right)$	$= 1-\left(\frac{2461}{2461+2614}\right)$ **= 0.5151**	• *Quantifies the <u>on-field detection</u> of NOT severely injured patients (EMS perspective)* • *That is, among Less-Severely Injured cases (ISS≤15), what proportion of were transported to LI/II by the EMS*
Cribari: 1 – PPV, where PPV = Positive Predictive Value)	$\frac{FP}{TP+FP}$ *OR* $1-\left(\frac{TP}{TP+FP}\right)$	$= 1-\left(\frac{742}{742+2614}\right)$ **= 0.7789**	• *Quantifies the <u>prevalence</u> of less-severely injured cases among all those taken to LI/II (hospital perspective)* • *That is, among cases transported to LI/II, the proportion that were less-severely injured*

Upon discussion, there was a general consensus among the members of the state Trauma Committee that the definitions of UT = 1 – sensitivity and OT = 1 – specificity (both highlighted in the above tables) were the most appropriate. We, therefore, used these definitions to quantify UT and OT rates across all 4 subgroups (per Aim 1) across all years. Table 7 summarizes the resulting UT and OT for 2011 and 2012. Note that these are rates calculated using UT=1-sensitivity and OT=1-specificity, each having a different denominator, so they do not necessarily add up to 1.0.

As is evident, there is substantial variation in these rates compared to the overall (aggregated across all 4 subgroups) rates, suggesting the importance of refining how these rates are calculated to identify the root-causes and plan appropriate actions. Further, this variation is primarily in the 'Pat/Fam Choice' and 'Closest Facility' subgroups. We do not know yet what may have caused such variations. However, the 'Closest Facility' subgroup is consistently higher than the 'Overall (aggregated)' rates indicating factors beyond the patient and protocol that may cause such EMS decisions. We therefore, further refined the 'Closest Facility' subgroup into two categories, 'Network' (related to the distribution of TCs in the region) and 'Operational' (related to other on-field factors); see Tables 8 and 9.

Table 7. Summary of UT and OT rates for each subgroup, by year

By Subgroup	**2011**		**2012**	
	UT	***OT***	***UT***	***OT***
Pat-Fam Choice	0.14	0.47	0.24	0.49
Protocol	0.16	0.59	0.16	0.58
Closest Facility	0.37	0.38	0.27	0.45
Other	0.07	0.75	0.04	0.81
Overall (aggregated)	**0.21**	**0.48**	**0.20**	**0.51**

*ACS recommendation of UT is <0.05.

Table 8. UT/OT rates for 'Network' and 'Operational' subcategories of 'Closest Facility' for 2011

Subcategory in 'Closest Facility'		**TH_{UT}=30**		**TH_{UT}=60**	
		TH_{OT}=0	**TH_{OT}=15**	**TH_{OT}=0**	**TH_{OT}=15**
Network	UT(Net)	0.31	0.31	0.10	0.10
	OT(Net)	0.20	0.01	0.20	0.01
Operational	UT(Oper)	0.13	0.13	0.33	0.33
	OT(Oper)	0.26	0.37	0.26	0.37

Table 9. UT/OT rates for 'Network' and 'Operational' subcategories of 'Closest Facility' for 2012

Subcategory in 'Closest Facility'		**TH_{UT}=30**		**TH_{UT}=60**	
		TH_{OT}=0	**TH_{OT}=15**	**TH_{OT}=0**	**TH_{OT}=15**
Network	UT(Net)	0.22	0.22	0.03	0.03
	OT(Net)	0.25	0.01	0.25	0.01
Operational	UT(Oper)	0.09	0.09	0.26	0.26
	OT(Oper)	0.32	0.45	0.32	0.45

Subcategorizing the 'Closest Facility' subgroup suggests that, while weather, traffic, or similar operational reasons appear to cause mistriages (i.e., UT(Oper) and OT(Oper)), distance to a TC from the field can also play a role in inducing mistriages (i.e., UT(Net) and OT(Net)). Obviously, the choice of the threshold affects these rates; a lower threshold (e.g., 30-min from scene-to-hospital transport time) causes higher UT(Net) allowing less opportunity for the EMS to take a severely-injured patient to a TC outside of a 30-min radius, compared to UT(Net) for higher thresholds (e.g., 60-min). That is, the on-field EMS may be forced to make certain decisions in terms of their choices of the destination hospital in light of the underlying network of TCs. *So could an optimal network minimize such mistriages?* This is an interesting question worth investing in the future.

Appendix B provides UT and OT rates for 2012 where we include Levels I, II, and III as TCs; as expected, including LIII as a TC lowers the estimated UT=0.11 (vs. 0.2 when TC=LI/II), but increases the OT=0.67 (vs. 0.52 when TC=LI/II). This means that the choice of whether or not to include LIII (or lower level trauma centers) as part of the TC group can substantially alter the estimating of the UT and OT rates for the region. Clearly, all trauma centers (Level I through V) that provide definitive care to a severely-injured patient should be considered in the TC group. However, per our discussion with the state Trauma Committee and based on the current literature, care provided at LIII is not uniform, at least in the state of Ohio, and therefore, Level III should be considered in the NTC group, not TC (similar to most of our analysis in this report).

6. Conclusions

The two main aims of this study were to refine the definitions of UT and OT, and build consensus around an appropriate mathematical expression for quantifying UT and OT rates. For Aim 1, we contended that UT and OT cases should also be estimated based on the reason that led to the choice of the destination hospital from the scene. Using the data field 'Reason for Destination Choice,' we identify UT and OT cases for 4 categories; patient/family choice, protocol, network, and operational. While 'patient/family choice' and 'protocol' were straightforward to estimate, we proposed an algorithm to estimate 'network' and 'operational' subgroups. By 'network,' we meant those mistriages (UT or OT) that were caused due to the underlying distribution of TCs in the state. By 'operational,' we meant those that occurred due to other reasons such as weather, traffic, and lack of EMS resources. For each year from 2011-12, we estimated the UT and OT cases on an aggregate basis, and by the 4 subgroups. These findings suggested the importance of refining he approach to estimate these rates in order to identify the root-causes and plan appropriate actions to achieve the optimal performance of any trauma system.

With the UT and OT cases identified, in Aim 2, we focused on nuancing various mathematical expressions to quantify rates for UT and OT. We identified 3 key expressions, calculated UT and OT rates per each, and provide an easy-to-understand explanation of what each measures. Upon discussions with our research team and with the state Trauma Committee (within EMS) at ODPS in Columbus, we were able to build consensus on the use of UT=1-sensitivity and OT=1-specificity as the appropriate expressions. Using these, we estimated UT and OT rates, aggregate and for each of the 4 subgroups (per Aim 1), for 2011-12. Further, based on our discussion with the state Trauma Committee, the majority of committee members agreed to not include LIII as TC since the care provided at LIII is not yet uniform in the state. However, we redid the analysis assuming Levels I/II/III as TCs, which could provide us an idea on overall OT and UT rates if care provided at LIII could be standardized in the state.

7. References

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Appendix A: Algorithm to Subgroup Mistriaged Patients into 'Network' and 'Operational' Subgroups

We used the below algorithm that used Google API to estimate travel times from the incidence to the nearest TC (Level I/II) and NTC (Level III and other hospitals).

Begin Algorithm

Step 1: For each patient record, we determine if the patient was mistriaged using the ISS score and the hospital type (LI/II vs. LIII/NTC) this patient was actually transported from the scene.

Step 2: For each patient mistriaged to a LIII/NTC (i.e., under triaged), do the following:

a. Search through all the LI/II centers in that region and the neighboring regions (using the map of trauma centers), and record the time (in minutes) to each one of those from the scene using Google Maps API for distance. (We will use a reasonable EMS travel speed, say 60-70 mph, to convert distance into time.)

b. Identify the LI/II facility that is closest to the scene; call it the 'ideal' LI/II facility for this patient, and denote the time as $T_{ideal\text{-}L1}$.

c. Let $\Delta_{UT} = T_{ideal\text{-}L1}$

d. If $\Delta_{UT} > TH_{UT}$ (where TH_{UT} is the threshold value in minutes identified by our clinical collaborators), then this case is included in the 'network' subgroup of patients who likely experienced UT as the ideal LI/II was quite far away from the scene, in turn, inducing the EMS to take the patient to a nearby LIII/NTC.

e. If $\Delta_{UT} \leq TH_{UT}$, then this case is included in the 'operational' subgroup of patients who likely experienced UT as there was likely a LI/II not too far away from the scene for the EMS to transport the patient to, yet the EMS transported the patient to an LIII/NTC due to unknown operational reasons (e.g., ED diversion, weather, or EMS availability).

Step 3: For each patient mistriaged to a LI/II (i.e., over triaged), do the following:

a. Estimate the nearest LIII/NTC facility from the scene.

b. Identify $T_{ideal\text{-}NTC}$, the closest ideal LIII/NTC.

c. Let $\Delta_{OT} = T_{ideal\text{-}NTC} - T_{actual\text{-}L1}$.

d. If $\Delta_{OT} > TH_{OT}$, then this case is included in the 'network' subgroup of patients who likely experienced OT as the EMS was induced to take the patient to a nearby LI/II because an appropriate LIII/NTC was quite far away.

e. If $\Delta_{OT} \leq TH_{OT}$, then this case is included in the 'operational' subgroup of patients who likely experienced OT as there was likely a LIII/NTC not too far away from the scene for the EMS to transport the patient to, yet they did not end up doing so due to unknown operational reasons.

End Algorithm

Appendix B: UT/OT Cases and Rates Considering TC = Levels I, II, and III

All reasons for destination

		ISS			UT	0.1265
		ISS>15	ISS≤15		OT	0.6472
Destination	TC	780	3000			
	NTC	113	1635			
				5528		

Family/Patient Choice

		ISS			UT	0.0610
		ISS>15	ISS≤15		OT	0.6531
Destination	TC	200	1314			
	NTC	13	698			
				2225		

Protocol

		ISS			UT	0.0673
		ISS>15	ISS≤15		OT	0.7429
Destination	TC	194	494			
	NTC	14	171			
				873		

Closest Facility

		ISS			UT	0.2618
		ISS>15	ISS≤15		OT	0.5601
Destination	TC	234	908			
	NTC	83	713			
				1938		

Other

		ISS			UT	0.0194
		ISS>15	ISS≤15		OT	0.8427
Destination	TC	152	284			
	NTC	3	53			
				492		

Figure B1. UT and OT rates by subgroups for 2011

All reasons for destination

		ISS			UT	0.1090
		ISS>15	ISS≤15		OT	0.6735
Destination	TC	826	3418			
	NTC	101	1657			
				6002		

Family/Patient Choice

		ISS			UT	0.1176
		ISS>15	ISS≤15		OT	0.6495
Destination	TC	210	1416			
	NTC	28	764			
				2418		

Protocol

		ISS			UT	0.0864
		ISS>15	ISS≤15		OT	0.7331
Destination	TC	201	541			
	NTC	19	197			
				958		

Closest Facility

		ISS			UT	0.1514
		ISS>15	ISS≤15		OT	0.6311
Destination	TC	269	1088			
	NTC	48	636			
				2041		

Other

		ISS			UT	0.0395
		ISS>15	ISS≤15		OT	0.8614
Destination	TC	146	373			
	NTC	6	60			
				585		

Figure B2. UT and OT rates by subgroups for 2012