UTILIZATION OF CRASH AND MEDICAL DATA TO REDUCE MOTOR VEHICLE CRASH SEVERITY

FINDINGS REPORT

March 2019

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1 INTRODUCTION

Introduction

Between 2012 and 2016, 1,820 people lost their lives and 15,662 were seriously injured on Massachusetts roadways [1]. Compounding the issue, Massachusetts has one of the lowest rates of seat belt usage in the nation at 81.6% [2].

One of the ways Massachusetts develops and improves policies and procedures for expanding traffic safety is through comprehensive analysis of accurate and complete crash data. Though a significant portion of crash data is sourced from police crash reporting, there have been substantial limits to the completeness and quality of these data. Furthermore, crash outcomes, including the medical consequences of such crashes, are not well known. In addition, crash data does not provide ample information on crash-associated citations nor in-depth roadway characteristics. As a result, there is a need to utilize a more complete range of statewide data sources to identify existing problems and quantify their impacts on the Commonwealth.

The University of Massachusetts Traffic Safety Research Program (UMassSafe) has investigated improved data linkage processes and strategies for linking highway safety data — crash, emergency medical services (EMS), roadway inventory, and citation — in order to improve the completeness as well as accessibility, integration, accuracy, and uniformity of Massachusetts crash data. The project was funded by the Executive Office of Public Safety and Security/Office of Grants and Research/Highway Safety Division, and its Traffic Records Coordinating Committee, with Section 405-c funding from the National Highway Traffic Safety Administration (NHTSA).

A completely linked dataset enables highway safety specialists and analysts to examine crashes comprehensively, including the associated citations and medical consequences. This enhances their ability to identify and prioritize highway safety problems. With improved data and stronger relationships between the various data owners, a deterministic linkage (or partial deterministic sample) becomes more viable than it has been in the past. A deterministic linkage generates links based on the number of individual identifiers or several representative identifiers that match among the available data sets.

1.1 Objectives

The primary goal of this project was to develop a methodology that would link police-reported crash data from the Massachusetts Crash Data System (CDS) to Emergency Medical Service (EMS) data from the Massachusetts Ambulance Trip Record Information System (MATRIS). A linkage of this nature would allow for an in-depth analysis of the injury trends associated with different crash types and patient demographics, as well as a data quality investigation of fields that exist in both datasets.

The secondary objective was to incorporate at least a third dataset into the linkage. This expanded the usability of existing data for researchers and practitioners, moving beyond a dual linkage to incorporate multiple relevant sources.

2 METHODS

2.1 Data Sources

2.1.1 Police-Reported Crash Data (Crash Data System, CDS)

Crash data is collected on the Commonwealth of Massachusetts Motor Vehicle Crash Report Form by the police officer responding to a motor vehicle crash. Information is gathered about the driver, owner, vehicle, passengers, and crash — including location, weather conditions, crash characteristics, causation, vehicle type, and damaged area. While the injury severity of each person involved in the crash is captured, this information is limited, as it is measured by the reporting officer using a scale of one to five (with 1 being the most severe [fatal] and 5 indicating no injury).

UMassSafe has access to CDS data via the UMassSafe Traffic Safety Data Warehouse, which contains 12 datasets and 15 years of crash-related data. Through a partnership with the Massachusetts Department of Transportation (MassDOT) Registry of Motor Vehicles (RMV), UMassSafe receives CDS data quarterly, which can then be linked to various datasets and analyzed in terms of crash characteristics or trends.

2.1.2 Massachusetts Ambulance Trip Record Information System (MATRIS)

MATRIS is the repository for ambulance trip data submitted by EMS providers and is maintained by the Massachusetts Department of Public Health (DPH).

This data set contains a record for every patient in Massachusetts evaluated and/or transported in an ambulance, and/or dispatched by an emergency call, including those resulting from motor vehicle crashes. MATRIS also includes the same basic demographic information captured by police, while also providing detailed information about the ambulance trip, the injuries observed upon arriving at the scene, and the procedures and medications administered during the transport trip to the hospital.

2.1.3 Citation Data

Motor vehicle related law enforcement citations, recorded at the RMV for licensing and registration purposes, sometimes match with crash records. This match is established through a manual deterministic linkage within the UMassSafe Data Warehouse and serves to partially connect the CDS crash data with citation data. It is important to note that this linkage is only successful for a portion of crashes which may have had a citation written, and therefore should not be used to establish rates or make other decisions, as the true denominator is unknown. Through UMassSafe's deterministic linkage, a crash number and person number are provided for joining data. The citation data itself is very straightforward with basic personal/vehicle identifiers, Chap./Sec./Sub. and description of offense, as well as violation amount and speed limit/speed actual when applicable.

2.1.4 Roadway Inventory Data

The Massachusetts Roadway Inventory is a geographic information system (GIS) file maintained by MassDOT, which contains information on each publicly-owned roadway segment in the Commonwealth. This data includes characteristics such as roadway type and classification, roadway width, shoulder type and width, number of lanes, approximate daily traffic, speed limit, clear zone size, median type and width, and various others.

If a crash in CDS has enough information from the Crash Report Form to be geolocated (either automatically or manually), a road segment ID is provided. The road segment ID can then be linked to the roadway inventory to provide details about the roadway characteristics associated with a given motor vehicle crash.

2.2 Linkage

2.2.1 Linkage Procedure

CDS crashes were linked with MATRIS incidents using a deterministic, rule-based linkage technique. This technique uses a set of match criteria expressed in terms of the similarity between common properties of each database, with the objective of matching each MATRIS incident with a CDS crash. We calculate the match rate as:

$$\frac{\text{\# MATRIS Incidents matched to a crash}}{\text{\# MATRIS Incidents}}$$

We elected to measure the match rate with respect to the pool of MATRIS incidents rather than the pool of CDS crashes, as many CDS crashes do not warrant an EMS response. The presence of a record in the MATRIS dataset is likely a stronger indicator of an EMS response than the attributes available in CDS; therefore, the match rate above is likely a better proxy for linkage completeness.

The MATRIS dataset used for this analysis includes incidents occurring between January 1, 2014 and December 31, 2016. We limited the scope of the CDS dataset to match these dates. The linkage process relies on correspondence between the fields shown in

Table 1:

Table 1 CDS and MATRIS Fields Utilized in the Linkage Process

Attribute	CDS Field	MATRIS Field
Incident Date	crash.crash_date	incident.incident_date
Incident Location	crash_loc_coord.latitude crash_loc_coord.longitude **OR** crash.city_town_code	incident.incident_postal_code
Patient Date of Birth	person.date_of_birth	incident.patient_date_of_birth
Patient Home Zip Code	person.pers_addr_zip_code	incident.patient_postal_code
Patient Gender	person.sex	incident.patient_gender

While MATRIS data uniquely identifies a patient, it is common for a CDS crash to involve multiple “person” records (e.g. drivers, non-motorists, passengers). As a result, all types of CDS persons were eligible for matching with MATRIS individuals. In order to address this issue, several steps were taken to normalize the representation of these fields.

- All location comparisons were performed by first normalizing into representation as latitude/longitude pairs. In many cases, CDS crashes were already annotated precisely with latitude/longitude pairs. In some cases, CDS crashes were annotated only with a city/town, in which case the latitude/longitude representing the centroid of the geographical extent of the town was taken. Similarly, the MATRIS town name was converted into a latitude/longitude. This allowed for similarity computation between two locations using the Haversine formula (yielding the distance between two points on a sphere).
- Dates were normalized to ISO 8061 format (e.g. 2018-01-01) to facilitate calculation of Levenshtein/edit distance (number of additions, deletions, and substitutions to transform one character string into another) when necessary.
- Zip/postal codes were normalized into 5-digit representations, also to facilitate edit distance calculation.

Rather than employing a probabilistic approach, we elected to use specific linkage rules based on background knowledge, given a lack of a “ground truth” match dataset with which to estimate the parameters of such models. Furthermore, the CDS and MATRIS datasets afforded several relatively “noise-free” characteristics, such as date of birth and crash date, where we expect disagreements on a true match to be limited in scale (e.g. by one day or by one digit).

2.2.2 Iterations to Improve Accuracy and Match Rate

The original linkage specification described a match as two records meeting the following criteria:

- Incident Date: Exact match
- Patient Date of Birth: Exact match
- Incident Location: Less than or equal to 10 miles

These initial match criteria resulted in approximately 50% of records in the MATRIS file successfully linking with a record in CDS. Without access to the patient name from MATRIS, it was impossible to determine with certainty whether a linked record was a true match. However, by using fields that weren’t included in the original criteria, such as patient zip code and gender, we were able to determine whether a linked record was a true match. A visual inspection of linked records using these criteria revealed that 100% of matched records appeared to be true matches.

While this approach had perfect precision (100% of matches were true), we aimed to improve on the recall (only 50% of the MATRIS sample was matched). Upon further inspection of the data, it was determined that this match rate could be improved using a multi-level matching criterion. Specifically, whenever a record did not meet the initial criteria, patient zip code and gender could be utilized in secondary matching criteria.

To improve the linkage rate, two additional cases were added:

- Date of Birth Edit Distance ≤ 1: Allowed the linkage process to match persons that may have had their date of birth entered with a typographic error in either the CDS or MATRIS dataset. Edit distance is the amount of character transpositions needed in one record to match a second record. For example, 9/14/1976 would have an edit distance of one, compared to 9/24/1976. Including an edit distance of one for date of birth meant that a potential match wouldn't be discarded just because of a typo in one of the datasets.
- Crash Date difference of one day: Allowed the linkage process to capture crashes that may have occurred around midnight. Police record the time of crash in CDS as either the time the crash occurred or the time when they arrived. Crash date is calculated in MATRIS based on the earliest time contained in any record (e.g. time of 911 call, time unit notified, etc.) Including a crash date leniency of one day was used to capture crashes that may have occurred around midnight.

To ensure accuracy when the date of birth and crash date did not perfectly align in the two datasets, two additional requirements were imposed for a linked record to be considered a true match. In addition to crash/incident location being ≤ 10 miles apart, a perfect gender match and patient home zip code match were required. In cases of imperfect matches on crash date, we required patient date of birth to match exactly. The three criteria used to define a match between records in each dataset are presented in **Table 2**.

Table 2 Criteria Utilized to Define a Match Between MATRIS and CDS Records

Field	Base Criteria	Crash Date Offset	Date of Birth Variance
Crash Date Difference	0	1	0
DOB Edit Distance	0	0	1
Gender Match	Not required	Y	Y
Patient Zip Match	Not required	Y	Y
Incident Distance	<10 miles	<10 miles	<10 miles
Records Matched	32997	1183	20831
Percent of Matched Records	60%	2%	38%

In some cases, a MATRIS incident matched multiple CDS crashes according to these criteria. In those circumstances, we selected the CDS record which minimized the sum of incident distance (in miles), gender difference (0 for a match, 1 otherwise), patient ZIP edit distance, and DOB edit distance.

2.2.3 Validation of Match Definition

To ensure the accuracy of the final linkage criteria, UMassSafe and the Massachusetts DPH collaborated to validate the data. While UMassSafe had access to patient names in CDS, the research team did not have access to this information in the MATRIS dataset. To overcome this challenge, UMassSafe (via a secure server) provided DPH with a sample of linked records with patient names from CDS. DPH then compared the names from CDS with the patient names in the MATRIS dataset. The results of this validation are shown in **Table 3**. Due to project timing, this validation occurred while the linkage process code was still being tested and improved. As such, the criteria validated by DPH did not perfectly match the final criteria used. Various improvements were made to the linkage process after receiving the results of the validation, which would likely have eliminated some of the false matches.

Table 3 Validation of Match Criteria Comparing Patient Names in Two Datasets

Criteria	Sample Size	Match		No Match		Inconclusive	
		#	%	#	%	#	%
Base	10	7	70%	0	0%	3	30%
Crash Date Offset	25	19	76%	1	4%	5	20%
Date of Birth Variance	20	15	75%	1	5%	4	20%

Note: Results were inconclusive when the patient name did not exist in the MATRIS dataset.

2.2.4 Accuracy of Match Criteria

Operating under the assumption that false matches were eliminated through subsequent enhancements to the linkage process, we expect that the inconclusive results (i.e. patient name did not exist in MATRIS) are true matches. If this is the case, then the aforementioned match criteria would have resulted in over 95% of linked records to be true matches. For the purpose of evaluating trends in data quality, as well as the relationship between crash types and the resulting injuries, this level of accuracy was sufficient.

In future studies, if perfect precision (100% of matches are true) is desired, the match criteria can be narrowed at the cost of the match rate/recall (fewer matches). Alternatively, given access to a larger dataset of true positive matches, we can improve match rates using probabilistic analysis on other fields in the dataset (injury status, destination, etc.). Here we attempted to balance achieving the highest possible recall while still maintaining excellent precision.

2.2.5 Resulting Linked Pairs

Utilizing MATRIS as the anchoring dataset, the linkage objective was to search for a crash record for each EMS incident record based on the criteria described above. The existing, unique data-set records listed below in **Table 4**, illustrate the broadness of the search, aiming for the highest recall with no filters applied to the provided EMS or Crash records. The resulting linkage rate of our 2014-2016 MATRIS pool was 58.3%.

Table 4 Match Pool Sample Sizes

Group	Number
Distinct EMS-Incident Records	94318
Distinct Crash-Person Records	1030639
Resulting Linked Pairs	**55011 (58.3%)**

Interestingly, when examining the linkage success over time (**Figure 1**), there is a noticeable dip in the trend between January and April of 2015.

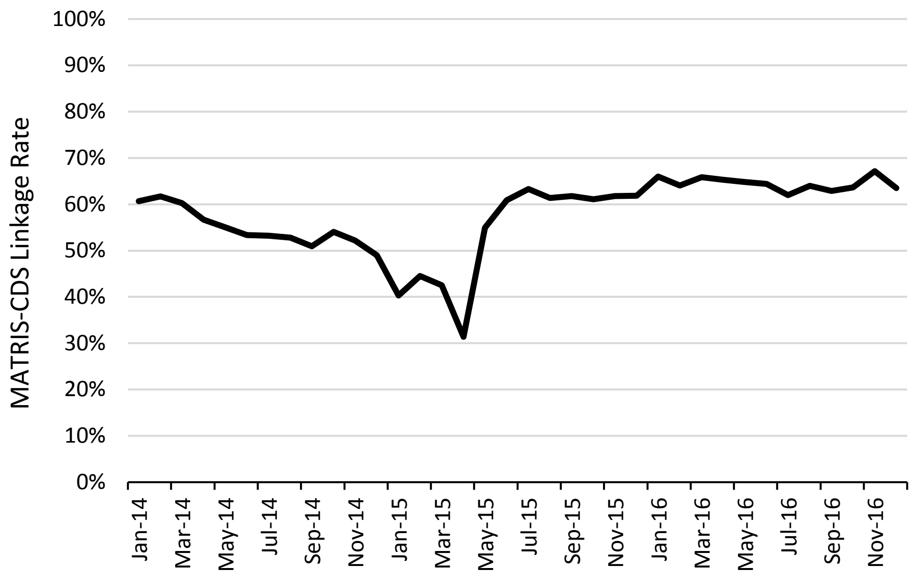


Figure 1 MATRIS-CDS Linkage Rate by Month/Year

Additionally, when quantifying the EMS records that were unable to be paired, it is worth noting that there was a higher prevalence of records where the Cause of Injury included attributes that were less clear than the most frequently used choice of Motor Vehicle Traffic Accident. The unmatched records included a Cause of Injury such as:

- Pedestrian Traffic Crash*
- Non-Motorized Vehicle Crash*
- Motor Vehicle Non-Traffic Crash*
- Motorcycle Crash*
- Not Available

The use of these indicators could mean that they were not truly state-reportable crashes, and therefore would never successfully find a pair (reducing the denominator and resulting in a higher linkage rate). However, in our attempt to seek the highest return of records, this notion was not pursued.

2.3 Data Dictionary

Fields from MATRIS and CDS that were commonly used in the analysis are described in the sub-sections below. Fields that were only used once are described in advance of the presentation of findings.

* Please note the word "crash" has been used in place of "accident" to communicate an accurate representation of the incidents. The word "accident" was used in the titling within the official report.

2.3.1 MATRIS Fields

Chief Complaint Anatomic Location – This field indicates the anatomic location of the primary injury sustained by the patient. Only one option can be selected, although a "global/general" option exists for cases where there are multiple injury areas of the same magnitude. Referred to in the document as *Primary Anatomic Injury Location*. A coded value was indicated in this field for 70.2% of patient records.

Vehicular Injury Indicators – This field identifies how the vehicle inflicted an injury on the motor vehicle occupant. Multiple fields can be selected. Referred to in the document as *Vehicle Inflicted Injuries*. A valid value was only used in 13.1% of motor vehicle occupant records and tended to be used when the CDS injury status was more severe.

EMS Response Time – This is calculated by taking the difference between the notification time and the arrival time.

2.3.2 CDS Fields

Injury Severity – This is the officer's determination as to the severity of the injury, ranging from no injury as the least severe to fatal injury as the most severe.

Driver Contributing Code – This field is used to indicate how the driver contributed to the crash causation. It is used to classify distraction and speeding-related crashes, among other improper driving actions.

Manner of Collision – This describes the type of collision that occurred. Common options are single vehicle, rear-end, angle, head-on, and sideswipe.

Sequence of Events – These are the actions that happened during the collision, including collision with a motor vehicle or running off the road. This field is used to identify lane departure crashes.

3 FINDINGS

The results of joining patient records from MATRIS to CDS, as well as to Citation and Roadway Inventory datasets, allowed for exploration into multi-faceted crash causations and outcomes. Additionally, data quality standards will be better established when comparing individual sources amongst the linkages. The analyses were conducted using three primary categories: (1) investigation of injury trends based on emphasis areas outlined in the 2018 Massachusetts Strategic Highway Safety Plan (SHSP), (2) investigation of injury trends from MATRIS and CDS in crash areas outside the SHSP that were of additional interest (as these analyses were not previously possible without linked data), and (3) comparison of fields from MATRIS and CDS that either existed in both datasets or could be used as a proxy in the other dataset, to gain a better understanding of the data quality considerations of these fields.

3.1 Basic Linked Dataset Comparisons

Before exploring the three categories outlined above, it is important to establish a baseline understanding of the two MATRIS injury fields that were utilized — *Primary Anatomic Injury Location* and *Vehicular Injury Indicators*. Furthermore, it is essential to establish the various levels of resulting injury severity within these two fields, along with their prevalence in different collision types.

3.1.1 MATRIS Injury Fields and CDS Injury Severity

Primary Anatomic Injury Location, which is officially named as *Chief Complaint Anatomic Location*, is a MATRIS field indicating the area of the patient's body that was most injured, wherein only one option can be selected per patient. **Figure 2** displays each of the eight options and the percentage of instances when the linked record indicated an incapacitating/fatal injury from CDS. General/Global, Head and Neck injuries occurred the most frequently within the linked dataset. Lower Extremity injuries were the fifth most common but had the highest proportion of incapacitating/fatal injuries. General/Global injuries, the most common type, had the next highest proportion of incapacitating/fatal injuries. Back and Neck injuries were the least severe, each resulting with fewer than 6% of incapacitating/fatal injuries.

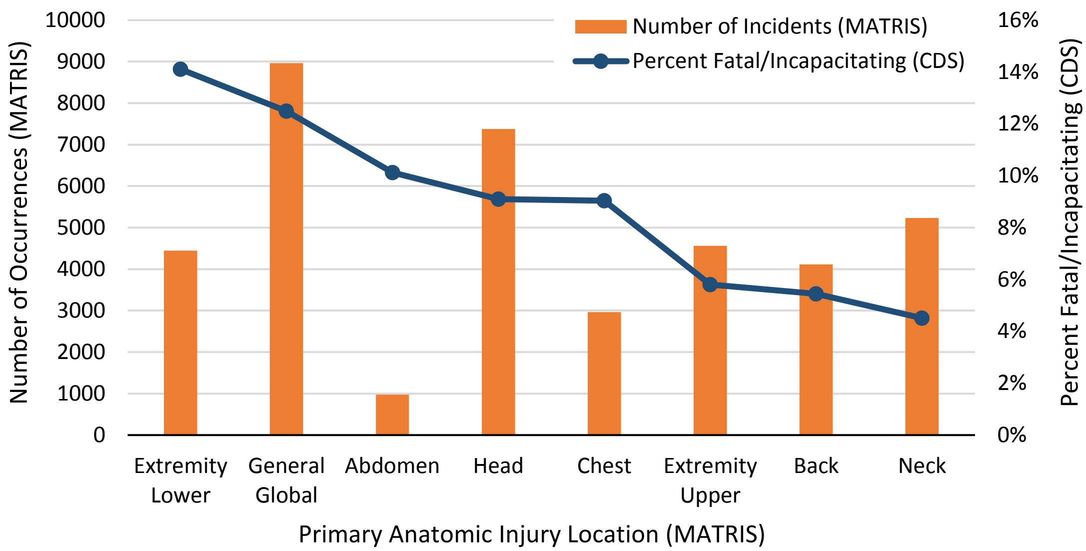


Figure 2 Relationship between Primary Anatomic Injury Location (MATRIS) and the Percent of Incapacitating/Fatal Injuries (CDS)

Vehicle Inflicted Injuries, officially named as *Vehicular Injury Indicators*, is a MATRIS field used to better define injury cause. Unlike *Primary Anatomic Injury Location*, EMS operators may select multiple *Vehicle Inflicted Injuries* per patient. The field indicates the physical result of the vehicle damage and area(s) of the vehicle that inflicted an injury upon the patient. Due to the nature of this field, *Vehicle Inflicted Injuries* were not present for non-motorists and were thus only used in analysis for motor vehicle occupants. In later sections of this report, it is shown that *Vehicle Inflicted Injuries* was used less frequently by EMS operators completing their report than *Primary Anatomic Injury Location and* was utilized more frequently when the crash was more severe. **Figure 3** displays the percentage of patients' incapacitating/fatal injuries relative to each *Vehicle Inflicted Injury* (from CDS). Ejections, although infrequent, were by far the most severe of the *Vehicle Inflicted Injuries*¸ with more than half the patients indicated (54%) sustaining an incapacitating/fatal injury. Windshield Spider/Star and Rollover/Roof Deformity were the most frequently-utilized codes. However, they also had the lowest proportion of incapacitating/fatal injuries.

Note that one *Vehicle Inflicted Injury*, DOA (Dead on Arrival), was omitted from analyses, as it does not indicate the part of the vehicle that inflicted the injury, but rather the state of the patient upon arrival on the scene.

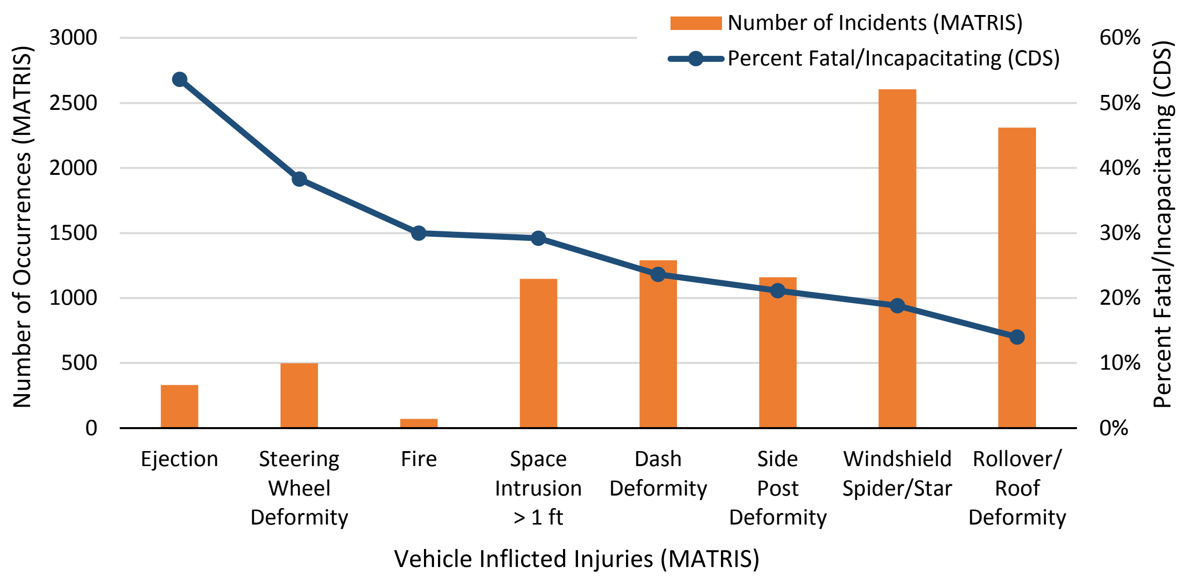


Figure 3 Relationship between Vehicle Inflicted Injuries (MATRIS) and the Percent of Incapacitating/Fatal Injuries (CDS)

Multiple codes can be indicated in the Vehicle Inflicted Injury field. **Figure 4** displays the frequency in which one or more attributes were indicated on a patient record, and the associated injury severity from CDS. For the vast majority of patient records where a Vehicle Inflicted Injury was recorded, only one code was indicated. There was, however, a direct correlation between the number of codes indicated and the percent of incapacitating/fatal injuries. In records where more than one Vehicle Inflicted Injury was indicated, the patient record was more likely to contain an indication of incapacitating/fatal injury.

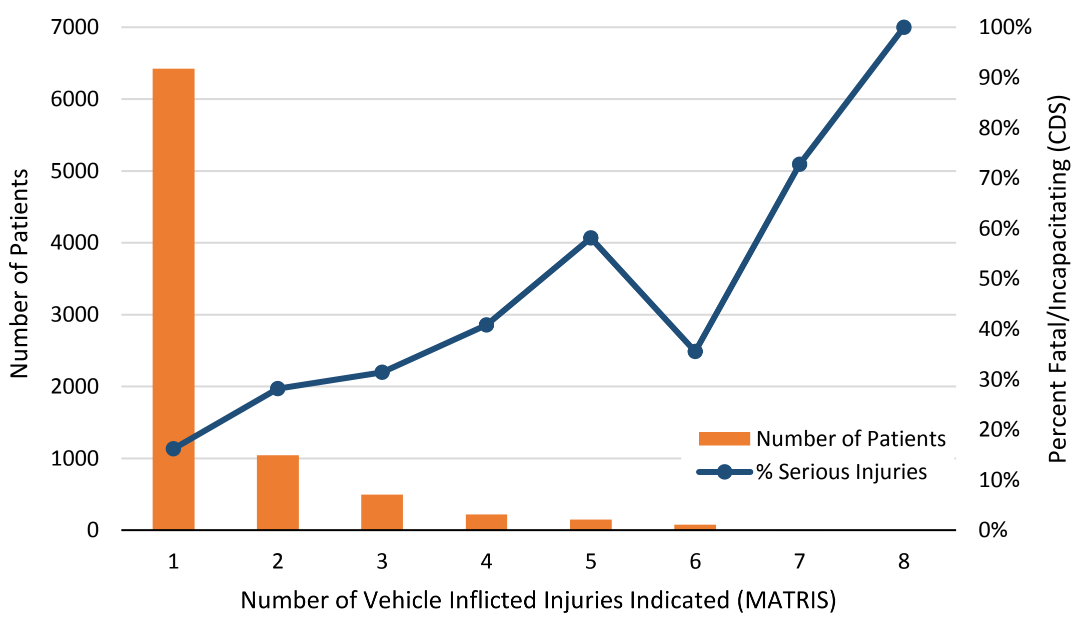


Figure 4 Relationship between the number of Vehicle Inflicted Injuries (MATRIS) and the Injury Status of the patient involved (CDS)

3.1.2 Manner of Collision (CDS) and Injury Codes from MATRIS

After examining the severity of both MATRIS injury-related fields, it was important to determine the prevalence of each injury-related attribute as well as collision type. **Figure 4** displays the distribution of *Primary Anatomic Injury Location* in crashes by *Manner of Collision* from CDS. The General/Global anatomic injury location, which resulted in the second-highest proportion of incapacitating/fatal injuries, was also the most frequently used attribute, having been indicated in 24% of patient records. These most commonly resulted from Angle and Single Vehicle Crashes. Lower Extremity injuries was the injury location with the highest resulting crash severities, although they were relatively infrequent (10% of crashes) with no single crash type accounting for a disproportionate occurrence. Rear-end crashes caused a large portion of neck and back injuries, but as previously shown in **Figure 2**, those injury locations resulted in the lowest proportion of incapacitating/fatal injuries.

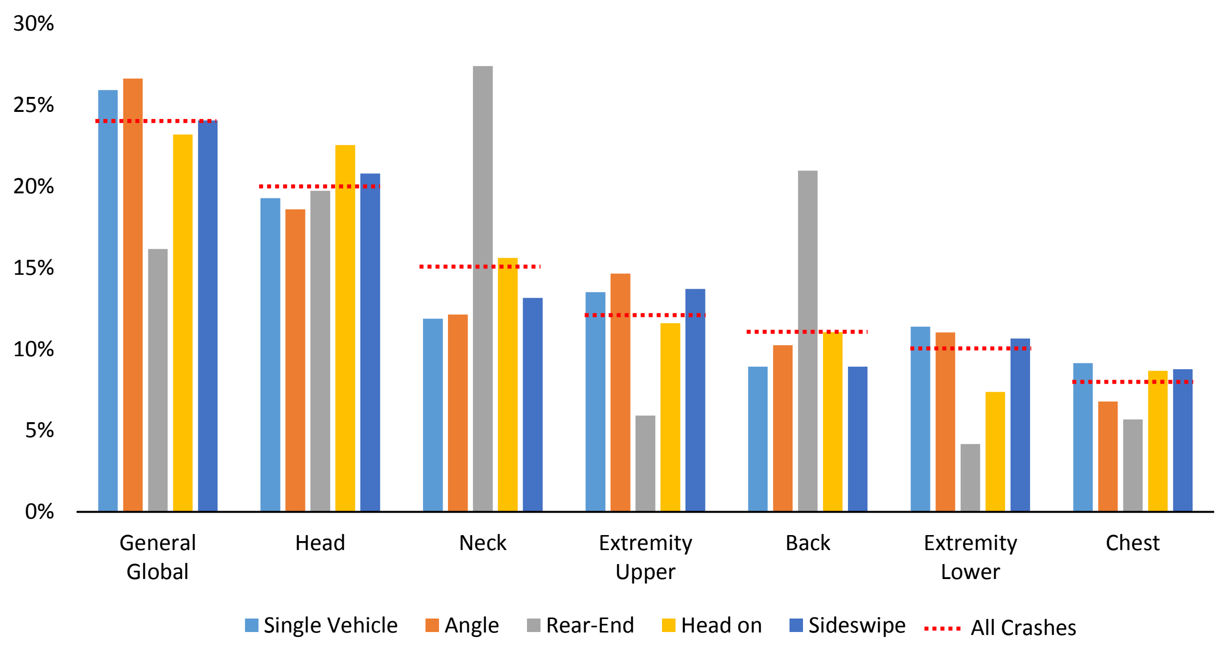


Figure 5 Correlation Between Primary Anatomic Injury Location (MATRIS) and Manner of Collision (CDS)

Figure 6 presents the same analysis for *Vehicle Inflicted Injuries* from MATRIS, although as multiple fields may be selected for a given patient, the percentage of occurrence does not equal 100%. Windshield Spider/Star and Rollover/Roof Deformity were by far the most frequent *Vehicle Inflicted Injuries* indicated, at 38% and 34% respectively. However, these were also the two codes which resulted in the lowest percentage of incapacitating/fatal injuries. A *Vehicle Inflicted Injury* of Ejection (although extremely rare), had the highest proportion of incapacitating/fatal injuries as identified in CDS, compared to all other vehicle injury types. Single Vehicle and Sideswipe crashes caused the highest number of ejections, although the difference was not substantial between the other collision types. Steering Wheel Deformity had the second highest proportion of incapacitating/fatal injuries of all *Vehicle Inflicted Injury* types, although only accounted for 7% of patients. Head-on crashes were the most likely crash type to result in a Steering Wheel Deformity injury (16% of crashes), with Single Vehicle crashes being the second most likely (9%).

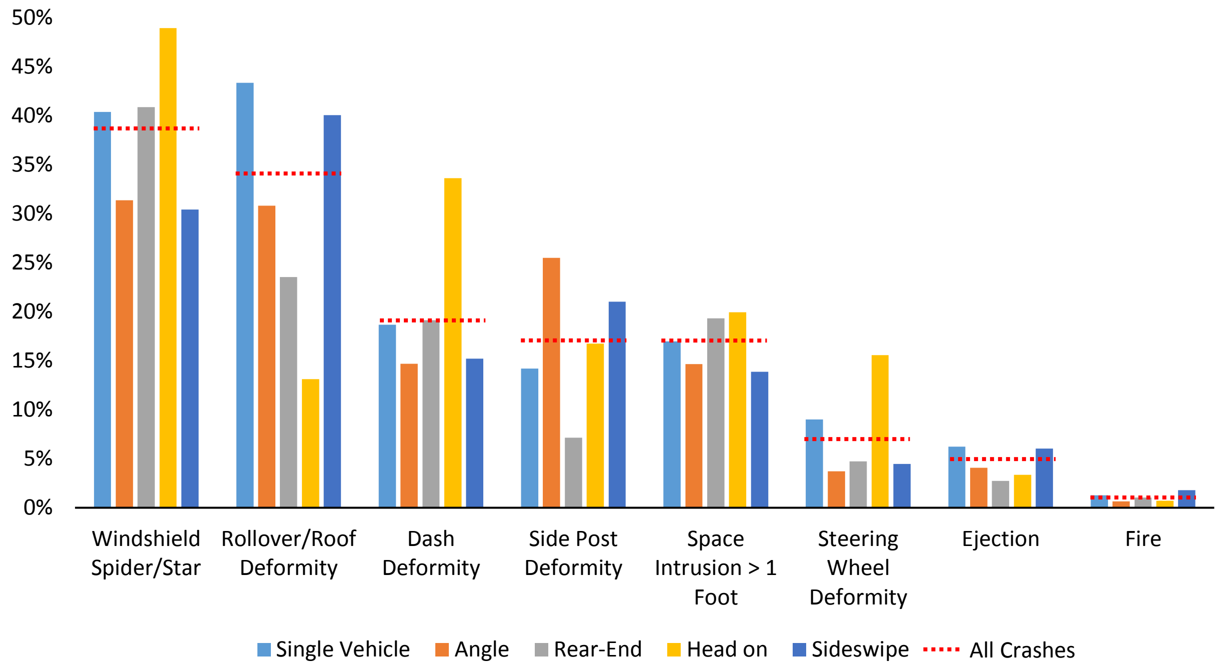


Figure 6 Correlation Between Vehicle Inflicted Injuries (MATRIS) and Manner of Collision (CDS)

3.2 Strategic Highway Safety Plan Emphasis Areas

The 2018 Massachusetts Strategic Highway Safety Plan identified 14 emphasis areas as the topics of primary concern to address in order to improve roadway safety, based on 2012-2016 fatality rates. Through the linkage of CDS and MATRIS data, injury trends in 10 of these emphasis areas were examined to provide insight that would not have been previously possible without the previously outlined linkage methodology. The four emphasis areas that could not be investigated were the following:

- Impaired Driving – Blood alcohol content (BAC) data was very limited in CDS, as the field was only implemented in 2014. BAC information did not exist in the MATRIS data which was provided for this project.
- Occupant Protection – Occupant safety belt status is known to be of poor quality in both CDS and MATRIS.
- Safety of Persons Working on Roadways and At-Grade Rail Crossings – These crashes were so infrequent that further analyses would not yield meaningful findings.

3.2.1 Lane Departure Crashes

In 2016, nearly 50% of all fatal crashes in Massachusetts were lane departure crashes. These crashes often occurred in rural areas, along horizontal curves, and were attributed to speeding [1]. Lane departures often result in more severe injuries due to collisions with fixed objects, such as trees, and a higher likelihood of a rollover than other crash types [3].

The *Primary Anatomic Injury Location* of motor vehicle occupants involved in lane departure crashes versus non-lane departure crashes were compared, along with the associated injury severity (from CDS). Lane Departure status was derived from the CDS field *Sequence of Events 1*. Only occupants with a known *Primary Anatomic Injury Location* were considered in the analysis, and only one field could be selected in MATRIS. As shown in **Table 5**, General/Global injuries (i.e. more than just one primary location) and Head injuries were more common in lane departure crashes. These injury types also correlated with higher occurrences of CDS incapacitating/fatal injury statuses in lane departure crashes. Furthermore, nearly every injury type had increased proportions of incapacitating/fatal injury severity (CDS) when the vehicle departed the roadway. Overall, in this linked dataset with recorded Primary Anatomic Injury Locations, 12% of occupants sustained an incapacitating/fatal injury in lane departure crashes compared to 8% in non-lane departure crashes.

Table 5 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Lane Departure Status (CDS)

Primary Anatomic Injury Location (MATRIS)	Lane Departure (LD) (CDS)				Incapacitating/Fatal Injury (%)	
	Non-LD		LD			
	n	%	n	%	Non-LD	LD
General/Global	7079	22%	1244	31%	11%	16%
Head	5980	19%	949	23%	8%	10%
Neck	4853	15%	316	8%	5%	8%
Extremity-Upper	3731	12%	480	12%	6%	5%
Back	3667	12%	253	6%	5%	9%
Extremity-Lower	3103	10%	406	10%	14%	17%
Chest	2604	8%	287	7%	9%	9%
Abdomen	819	3%	108	3%	10%	13%
Genitalia	19	0%	#	#	21%	#
Total Patients*	**31855**		**4047**		**8%**	**12%**

Note: Red shading highlights a percentage noticeably higher than non-lane departure. (*) only patients with a known primary anatomic injury location were included in the total. (#) indicates sample size fewer than 5 patients.

Injury trends were examined for occupants involved in lane departure crashes by the *Vehicle Inflicted Injuries* in MATRIS. Only occupants with a known *Vehicle Inflicted Injury* were included in the analysis. As depicted in the bottom of **Table 6**, the total number of occupants is much lower than the total in **Table 5**, indicating that the *Vehicle Inflicted Injury* field is completed less often in MATRIS than the *Primary Anatomic Injury Location*. Investigating further, by comparing the percentage of incapacitating/fatal injuries between **Table 6** and **Table 5**, it becomes apparent that the frequency in which *Vehicle Inflicted Injury* field is completed is correlated with the severity of the injury from CDS.

When investigating the crash outcomes from lane departure crashes, one notable finding is that while both Rollover/Roof Deformity and Windshield Spider/Star injuries were more common, only Roller/Roof Deformity injuries were correlated with higher occurrences of incapacitating/fatal injuries in lane departure crashes. Also, while Side Post Deformity injuries were slightly less common in lane departure crashes (15% versus 18% in non-lane departures), occupants who sustained an injury from a Side Post Deformity sustained incapacitating/fatal injuries in 29% of lane departure crashes, as compared to only 21% in non-lane departure crashes.

Table 6 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Lane Departure Status (CDS)

Vehicle Inflicted Injuries (MATRIS)	Non-Lane Departure (LD)		Lane Departure (LD)		Incapacitating/Fatal Injury (%)	
	n	%	n	%	Non-LD	LD
Windshield Spider/Star	1930	37%	612	44%	20%	18%
Rollover/Roof Deformity	1679	32%	567	40%	14%	17%
Dash Deformity	1012	19%	268	19%	24%	26%
Side Post Deformity	928	18%	215	15%	21%	29%
Space Intrusion	906	17%	230	16%	30%	35%
Steering Wheel Deformity	375	7%	121	9%	39%	43%
Ejection	250	5%	75	5%	55%	61%
Fire	58	1%	10	1%	33%	20%
Total Occupants*	**5272**		**1404**		**18.2%**	**18.6%**

Note: Red shading indicates a percentage noticeably higher than non-lane departure. (*) only patients with a known vehicle inflicted injuries were included in the total.

3.2.2 Speeding and Aggressive Driving

Speeding-related crashes, identified by a CDS *Driver Contributing Code* of Driving Too Fast for Conditions or Exceeding the Posted Speed Limit, accounted for 27% of Massachusetts motor vehicle fatalities in 2016 [1]. Younger drivers in particular were more likely to be involved in speeding-related crashes, which were also more prevalent in rural areas [4].

Table 7 shows the relationship between *Primary Anatomic Injury Location* and injury severity for speeding-related and non-speeding-related crashes. In comparing the distribution between the two, patients in speeding-related crashes had a higher proportion of General/Global and Head injuries. Furthermore, nearly all injury types/locations resulted in a greater occurrence of incapacitating/fatal injuries in crashes classified as speeding-related.

Table 7 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Speeding-Related Designation (CDS)

Complaint Anatomic Location (MATRIS)	Driver Contributing Code (CDS)				Incapacitating/Fatal Injury (%)	
	Non-Speeding-Related		Speeding-Related			
	n	%	n	%	Non SR	SR
General/Global	5841	23%	322	27%	12%	15%
Head	4522	18%	298	25%	8%	13%
Neck	3651	15%	79	7%	5%	8%
Extremity-Upper	3047	12%	164	14%	6%	6%
Back	2708	11%	91	8%	6%	12%
Extremity-Lower	2443	10%	128	11%	14%	20%
Chest	2018	8%	88	7%	9%	14%
Abdomen	549	2%	19	2%	10%	16%
Total Patients*	**24779**		**1189**		**9%**	**13%**

Note: Red shading highlights a percentage noticeably higher than non-speeding-related. (*) only patients with a known primary anatomic injury location were included in the total.

Table 8 shows *Vehicle Inflicted Injuries* and injury severity as they relate to speeding-related crashes. All *Vehicle Inflicted Injuries* correlated with higher occurrences of incapacitating/fatal injuries when a crash was speeding-related. While Rollover/Roof Deformity injuries were much more common in speeding-related crashes, the increase in injury severity over non-speeding-related crashes was only 2%, the smallest increase of all *Vehicle Inflicted Injuries*.

Table 8 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Speeding-Related Designation (CDS)

Vehicle inflicted injuries (MATRIS)	Driver Contributing Code (CDS)				Incapacitating/Fatal Injury (%)	
	Non-Speeding-Related		Speeding-Related			
	n	%	n	%	Non SR	SR
Windshield Spider/Star	2420	39%	185	33%	18%	26%
Rollover/Roof Deformity	2053	33%	258	47%	14%	16%
Dash Deformity	1183	19%	108	19%	22%	40%
Side Post Deformity	1056	17%	104	19%	20%	29%
Space Intrusion > 1 Foot	1048	17%	101	18%	29%	35%
Steering Wheel Deformity	433	7%	66	12%	37%	44%
Ejection	275	4%	57	10%	52%	61%
Fire	62	1%	8	1%	26%	63%
Total Occupants*	**6262**		**554**		**17%**	**23%**

Note: Red shading highlights a percentage noticeably higher than non-speeding-related. (*) only patients with a known primary anatomic injury location were included in the total.

3.2.3 Intersection Crashes

In 2016, intersection crashes constituted 22% of all motor vehicle fatalities in Massachusetts. Of these, the most common crash types were Angle and Rear-end crashes [1]. **Table 9** shows *Primary Anatomic Injury Locations* for intersection crashes and non-intersections, as well as the associated injury severity. The intersection crashes analyzed were limited to the following categories from the CDS field *Roadway Intersection Type*: Four-way Intersection, T-intersection, Y-intersection, Traffic circle, and Five-Point or More. The non-intersection crashes were simply identified by the Not at Intersection CDS code. There were no notable differences in injury types sustained in intersection crashes as compared to non-intersection crashes. Overall, intersection crashes resulted in less severe injuries than non-intersection crashes, with the exception of Lower Extremity injuries. This was likely due to the prevalence of pedestrian/bicyclist involvement in intersection crashes. In the next section, it is shown that, overall, these non-motorists sustained Lower Extremity injuries at a much higher rate and with greater severity.

Table 9 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Roadway Intersection Type (CDS)

Primary Anatomic Injury Location (MATRIS)	Roadway Intersection Type (CDS)				Incapacitating/Fatal Injury (%)	
	Non-Intersection (NON)		Intersection (INT)			
	n	%	n	%	NON	INT
General/Global	4605	24%	3335	23%	34%	29%
Head	3846	20%	2591	18%	19%	19%
Neck	2514	13%	2067	14%	6%	8%
Extremity-Upper	2221	12%	1764	12%	7%	8%
Extremity-Lower	2005	11%	1848	13%	16%	21%
Back	1961	10%	1582	11%	6%	6%
Chest	1432	8%	1210	8%	8%	7%
Abdomen	491	3%	353	2%	3%	2%
Total Patients*	**19075**		**14750**		**11%**	**8%**

Note: Red shading highlights a percentage noticeably higher than non-intersection. (*) Only entries with a known primary anatomic injury location were included in the total.

Table 10 shows the results of a similar analysis for *Vehicle Inflicted Injuries*. As this MATRIS field does not exist for non-motorists, *Vehicle Inflicted Injuries* with a higher injury severity for intersection crashes were not seen. A higher prevalence of Side Post Deformity injuries for intersection crashes was seen due to the higher proportion of Angle crashes. However, these Side Post Deformity injuries correlated with lower occurrences of incapacitating/fatal injuries at intersections than at non-intersections.

Table 10 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Roadway Intersection Type (CDS)

Vehicle Inflicted Injuries (MATRIS)	Roadway Intersection Type (CDS)				Incapacitating/Fatal Injury (%)	
	Non-Intersection (NON)		Intersection (INT)			
	n	%	n	%	NON	INT
Windshield/Spider Star	1831	40%	774	35%	19%	18%
Rollover	1654	36%	657	30%	17%	7%
Dash Deformity	916	20%	375	17%	27%	15%
Space Intrusion > 1 Foot	829	18%	320	15%	32%	21%
Side Post Deformity	689	15%	471	21%	26%	15%
Steering Wheel Deformity	392	8%	107	5%	39%	36%
Ejection	258	6%	74	3%	54%	53%
Fire	51	1%	19	1%	35%	16%
Total Occupants*	**4617**		**2199**		**19.4%**	**13.8%**

Note: Red shading highlights a percentage noticeably higher than non-intersection. (*) Only entries with a known vehicle inflicted injuries were included in the total.

3.2.4 Pedestrians and Bicyclists

Pedestrian and bicyclist safety are of primary concern in both Massachusetts and the country as a whole, largely due to the vulnerable nature of these road users. Additionally, while roadway fatalities overall have decreased in the past ten years, pedestrian and bicyclist fatalities have increased [1].

Table 11 compares the motorist/non-motorist *Primary Anatomic Injury Location* and associated injury severities. General/Global (i.e. more than just one primary location) and Upper Extremity injuries were more common for bicyclists than motor vehicle occupants, while Lower Extremity injuries were significantly more common for both pedestrians and bicyclists. While only 8% of motor vehicle occupants sustained an incapacitating/fatal injury in crashes overall, pedestrian and bicyclists sustained incapacitating/fatal injuries in 22% and 18% of crashes, respectively. This drastic increase was represented in all injury types, with the exception of Neck injuries, which rarely occurred for Non-Motorists.

Table 11 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Occupant/Person Type (CDS)

Complaint Anatomic Location (MATRIS)	Occupant/Person Type (CDS)						Incapacitating/Fatal Injuries (%)		
	MV Occupant		Pedestrian		Bicyclist				
	n	%	n	%	n	%	MV	Pedestrian	Bicyclist
General/Global	8326	23%	423	23%	133	28%	11%	31%	24%
Head	6932	19%	304	17%	70	15%	8%	29%	29%
Neck	5170	14%	18	1%	10	2%	5%	0%	0%
Extremity-Upper	4212	12%	215	12%	78	17%	6%	10%	9%
Back	3924	11%	106	6%	28	6%	5%	17%	11%
Extremity-Lower	3509	10%	691	38%	135	29%	13%	18%	16%
Chest	2891	8%	43	2%	13	3%	9%	37%	15%
Abdomen	927	3%	40	2%	#	#	9%	28%	#
Total Patients*	35891		1840		470		8%	22%	18%

Note: Red shading highlights a percentage noticeably higher than motor vehicle occupants. (#) indicates sample size fewer than 5 patients. (*) only patients with a known primary anatomic injury location code were included in the total.

3.2.5 Older and Younger Occupants

Older and younger driver safety was determined to be another emphasis area for improving overall traffic safety. Younger drivers (under 25 years old) are a focus due to inexperience and often aggressive driving behavior, while older drivers (ages 65+) are a focus due to their relative fragility and susceptibility to severe injuries.

Table 12 shows the results of analyzing *Primary Anatomic Injury Location* and associated injury severity by patient age. This analysis included all person types and did not just capture drivers. Rather than drawing conclusions about the crash likelihood of each age group, this analysis focused on the various injury types for each of these age groups. As shown in **Table 12**, patients 65 years old and above sustained incapacitating/fatal injuries in 12% of crashes, as compared to 9% for patients under 25, and 10% for the 25-64 age group. The only noticeable difference in injury patterns is that younger people were more likely to sustain Head injuries, while older people were more likely to sustain Chest injuries. Older patients also experienced higher occurrences of incapacitating/fatal injuries for Chest injuries than younger or middle-aged patients.

Table 12 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Person Age (CDS/MATRIS)

Primary Anatomic Injury Location (MATRIS)	Patient Age (CDS/MATRIS)						Incapacitating/Fatal Injury (%)		
	<25		25-64		65+				
	n	%	n	%	n	%	<25	25-64	65+
General/Global	2007	25%	5046	22%	968	24%	33%	32%	32%
Head	1871	23%	4029	18%	630	15%	21%	19%	15%
Neck	915	11%	3411	15%	457	11%	4%	7%	7%
Back	611	8%	2815	12%	342	8%	5%	7%	5%
Extremity Upper	1064	13%	2596	11%	472	12%	8%	7%	9%
Extremity Lower	988	12%	2487	11%	439	11%	22%	17%	15%
Chest	347	4%	1708	8%	682	17%	3%	8%	14%
Abdomen	184	2%	552	2%	85	2%	4%	3%	2%
Total Occupants*	**7987**		**22644**		**4075**		**9%**	**10%**	**12%**

Note: Red shading highlights a percentage noticeably higher than 25-64 age group. (*) only patients with a known primary anatomic injury location were included in the total.

Table 13 shows a similar analysis by patient age for *Vehicle Inflicted Injuries.* Younger patients were more likely to sustain an injury resulting from the vehicle inflicted injury type of Rollover/Roof Deformity, which could be due to younger drivers being more likely to be involved in Speeding-Related crashes. While there were very few patients age 65+ within the sample of injuries due to Ejections, these injuries had increased proportions of incapacitating/fatal injury severity (87%) for older patients than younger (47%) or middle-aged patients (57%).

Table 13 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Person Age (CDS/MATRIS)

Vehicle Inflicted Injuries (MATRIS)	Patient Age (CDS/MATRIS)						Incapacitating/Fatal Injury (%)		
	<25		25-64		65+				
	n	%	n	%	n	%	<25	25-64	65+
Windshield Spider/Star	916	39%	1422	38%	228	37%	16%	21%	21%
Rollover/Roof Deformity	863	37%	1286	34%	141	23%	12%	15%	19%
Dash Deformity	401	17%	742	20%	132	22%	26%	23%	24%
Side Post Deformity	392	17%	618	16%	124	20%	22%	22%	20%
Space Intrusion	421	18%	614	16%	100	16%	31%	28%	31%
Steering Wheel Deformity	156	7%	294	8%	45	7%	36%	40%	38%
Ejection	126	5%	185	5%	15	2%	47%	57%	87%
Fire	20	1%	41	1%	6	1%	40%	24%	#
Total Occupants*	**2349**		**3769**		**610**		**16%**	**19%**	**20%**

Note: Red shading highlights a percentage noticeably higher than 25-64 age group. (#) indicates sample size fewer than 10 patients. (*) only patients with a known Vehicle Inflicted Injury were included in the total.

3.2.6 Heavy Vehicles and Motorcycle Crashes

In 2016, motorcyclists constituted 10.8% of all motor vehicle fatalities in Massachusetts, and fatalities from crashes involving large trucks made up 8.5% of all motor vehicle fatalities [1]. In CDS, the *Vehicle Configuration* field allows for the responding officer to classify the type of vehicle. Passenger vehicles, which are classified as cars/minivans/pick-up trucks/SUVs/etc., comprised the vast majority of all vehicles involved in motor vehicle crashes. However, crashes involving motorcycles or heavy vehicles tended to have an increased likelihood of incapacitating and fatal injuries due to the vulnerability of the rider(s) and the size of the heavy vehicles.

Table 14 shows the *Primary Anatomic Injury Location* and associated injury severity for occupants based on the vehicle configuration. Motorcyclists sustained incapacitating/fatal injuries at a much higher rate (29%) than passenger vehicle occupants (8%), while heavy vehicle occupants sustained a lower rate of incapacitating/fatal injuries (6%). Motorcyclists were more likely to sustain Global/General, Upper Extremity, and Lower Extremity injuries. While Upper Extremity injuries were of similar severity, General/Global and Lower Extremity injuries correlated with higher occurrences of incapacitating/fatal injury statuses for motorcyclists than passenger vehicle occupants. For heavy vehicle occupants, General/Global injuries had more instances of incapacitating/fatal injury statuses than for passenger vehicle occupants, as did Back and Chest injuries.

Table 14 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Vehicle Configuration (CDS)

Primary Anatomic Injury Location (MATRIS)	Vehicle Configuration (CDS)						Incapacitating/Fatal Injury (%)		
	Passenger Vehicle (PV)		Motorcycle (M)		Heavy Vehicle (HV)				
	n	%	n	%	n	%	PV	M	HV
General/Global	7262	23%	524	32%	113	26%	31%	37%	42%
Head	6348	20%	129	8%	61	14%	20%	12%	8%
Neck	4839	15%	23	1%	47	11%	9%	1%	0%
Extremity Upper	3636	11%	294	18%	56	13%	8%	10%	8%
Back	3513	11%	110	7%	73	17%	7%	5%	12%
Extremity Lower	2771	9%	476	29%	45	10%	13%	28%	15%
Chest	2657	8%	66	4%	34	8%	9%	6%	12%
Abdomen	828	3%	32	2%	13	3%	3%	1%	4%
Total Occupants*	31854		1654		442		8%	29%	6%

Note: Red shading highlights a percentage noticeably higher than passenger vehicles. (#) indicates sample size fewer than 10 patients. (*) only patients with a known Vehicle Inflicted Injury were included in the total.

Table 15 shows *Vehicle Inflicted Injuries* (MATRIS) sustained in crashes by *Vehicle Configuration* (CDS). Motorcycle crashes were much more likely than Passenger Vehicle crashes to have a *Vehicle Inflicted Injury* of Ejection, while Heavy Vehicle crashes were more likely to result in a Rollover/Roof Deformity vehicle injury.

Table 15 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Vehicle Configuration (CDS)

Vehicle Inflicted Injuries (MATRIS)	Vehicle Configuration (CDS) Passenger Vehicle (PV)		Motorcycle (M)		Heavy Vehicle (HV)		Incapacitating/Fatal Injury (%)		
	n	%	n	%	n	%	PV	M	HV
Windshield Spider/Star	2490	39%	14	7%	28	26%	18%	64%	29%
Rollover/Roof Deformity	2149	34%	35	18%	62	57%	14%	37%	10%
Dash Deformity	1242	20%	9	5%	25	23%	24%	#	12%
Side Post Deformity	1128	18%	#	#	9	8%	21%	#	#
Space Intrusion	1114	18%	#	#	16	15%	29%	#	6%
Steering Wheel Deformity	483	8%	#	#	9	8%	39%	#	#
Ejection	178	3%	143	75%	#	#	58%	49%	#
Fire	66	1%	#	#	#	#	32%	#	#
Total Occupants*	**6357**		**191**		**108**		**17%**	**47%**	**12%**

Note: Red shading highlights a percentage noticeably higher than passenger vehicles. (#) indicates sample size fewer than 10 patients. (*) only patients with a known Vehicle Inflicted Injury were included in the total.

3.2.7 Driver Distraction

The proliferation of cell phones has increased the prevalence of distracted driving over the past decade. In 2016, distraction-affected fatalities comprised 9% of all motor vehicle fatalities in the United States [5]. **Table 16** shows injury trends from distraction-related crashes, defined by a CDS *Driver Contributing Code* indicating Inattention or Distraction. When examining the *Primary Anatomic Injury Location*, Head and Upper Extremity injuries were more common in distraction-related crashes, although both resulted in a lower share of incapacitating/fatal injuries when crashes were classified as distraction-related.

Table 16 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Distraction-Related Designation (CDS)

Primary Anatomic Injury Location (MATRIS)	Driver Contributing Code (CDS) Non Distraction-Related		Distraction-Related		Incapacitating/Fatal Injury (%)	
	n	%	n	%	Non DR	DR
General/Global	5613	24%	550	25%	13%	6%
Head	4370	18%	450	20%	9%	4%
Neck	3499	15%	231	10%	5%	4%
Extremity-Upper	2858	12%	353	16%	6%	3%
Back	2668	11%	131	6%	6%	6%
Extremity-Lower	2332	10%	239	11%	15%	13%
Chest	1906	8%	200	9%	10%	6%
Abdomen	515	2%	53	2%	10%	4%
Total Patients*	**23761**		**2207**		**8%**	**5%**

Note: Red shading highlights a percentage noticeably higher than non-distraction-related. (*) only patients with a known primary anatomic injury location were included in the total.

As shown in **Table 17,** there is a similar result among *Vehicle Inflicted Injuries*, with all injury types resulting in lower rates of incapacitating/fatal injuries in distraction-related crashes. Only Windshield Spider/Star injuries, previously shown to have the second lowest proportion of incapacitating/fatal injuries, were more common in distraction-related crashes. These findings do not indicate that distraction is a frivolous issue when addressing roadway safety. While distraction-related crashes tend not to be as severe as other crash types, incapacitating/fatal injuries still result from this highly preventable crash type, emphasizing the importance of addressing this traffic safety emphasis area.

Table 17 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Distraction-Related Designation (CDS)

Vehicle Inflicted Injuries (MATRIS)	Driver Contributing Code (CDS)				Incapacitating/Fatal Injury (%)	
	Non Distraction-Related		Distraction-Related			
	n	%	n	%	Non DR	DR
Windshield Spider/Star	2337	37%	268	48%	20%	8%
Rollover/Roof Deformity	2165	35%	146	26%	15%	5%
Dash Deformity	1183	19%	108	19%	25%	11%
Side Post Deformity	1097	18%	63	11%	21%	16%
Space Intrusion	1078	17%	71	13%	30%	13%
Steering Wheel Deformity	456	7%	43	8%	40%	21%
Ejection	322	5%	10	2%	54%	40%
Fire	67	1%	#	#	31%	#
Total Occupants*	**6258**		**558**		**18%**	**9%**

Note: Red shading highlights a percentage noticeably higher than non-distraction-related. (*) only patients with a known primary anatomic injury location were included in the total. (#) indicates sample size fewer than 5 patients.

3.3 Advanced Linked Dataset Comparisons

3.3.1 Relationship between EMS Response Characteristics and Accessibility

EMS Response Time is a highly studied element for influencing patient outcomes. Numerous studies have shown that faster response times lead to better survival rates in people who suffer out-of-hospital cardiac arrest [6]–[8]. There are a number of factors that contribute to emergency response times, such as time of the crash, location, and safety concerns.

In this analysis, response time was calculated by taking the difference between the fields *Date/Time Unit Notified* and *Date/Time Unit Arrived*. However, the time to arrival is only one factor that influences patient outcomes. Transport time is another highly studied-characteristic that was not evaluated here. Other essential factors that might impact patient outcomes include the quality of the nearest medical facility, the speed at which the crash occurred and the safety features of the motor vehicle(s) involved, among others that were not included in this analysis.

In total, 50,332 crash occupants were evaluated out of the 55,013 patient IDs. This 8.5% error resulted from blank entries in either field, arrival times recorded as having occurred before the notification time, and response times over 60 minutes, which were deemed to be possible errors and thus excluded from analyses. **Figure 7** displays the injury severity of patients by the total response time coded in MATRIS. While response times up to 60 minutes were deemed valid, **Figure 7** only displays up to 30 minutes, as the sample size of response times in excess of 30 minutes was very small. While the percent of incapacitating/fatal injuries was higher when EMS response times were longer, reasons for this may not be due to the response times themselves but possibly due to crash type characteristics that naturally result in longer response times and more severe injuries. These characteristics are further explored later in this section. The vast majority of incapacitating/fatal injury crashes had a response time under 10 minutes, as shown in the figure below.

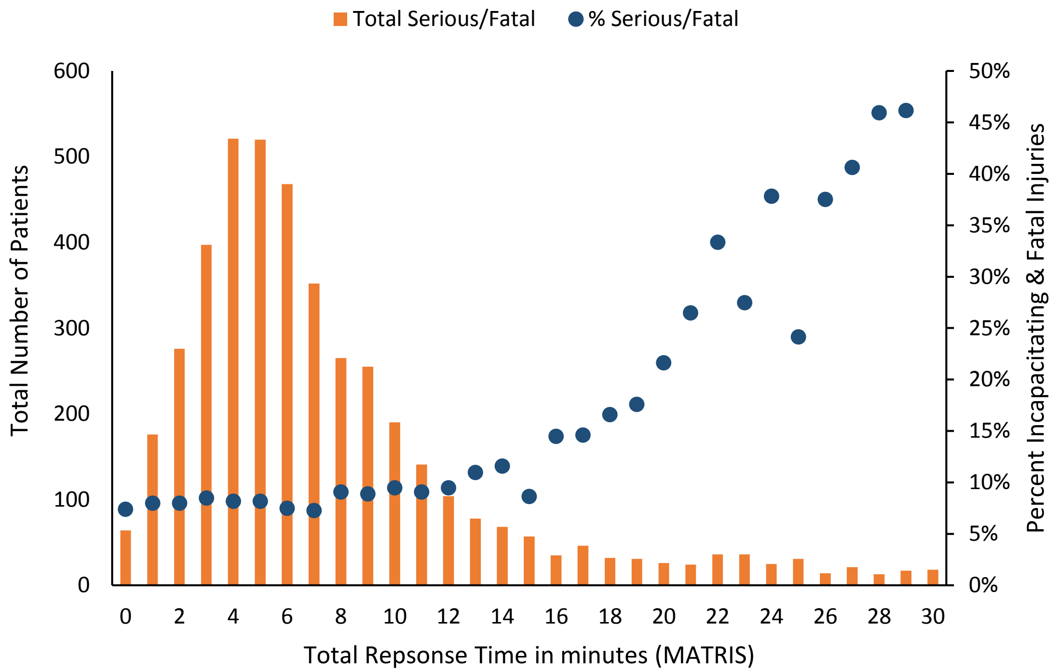


Figure 7 Relationship between EMS Response Time (MATRIS) and Injury Severity (CDS)

While **Figure 7** suggests a possible correlation between EMS response time and injury severity, it alone does not prove causation. Incapacitating/fatal injuries may simply occur more frequently on roadways, in areas, or at times where response times are inherently longer.

Crash time was examined as a possible influence on EMS response time as shown in **Figure 8**. Unsurprisingly, crashes that occurred at night resulted in the longest average response time. The percent of incapacitating/fatal injuries also followed the same trend.

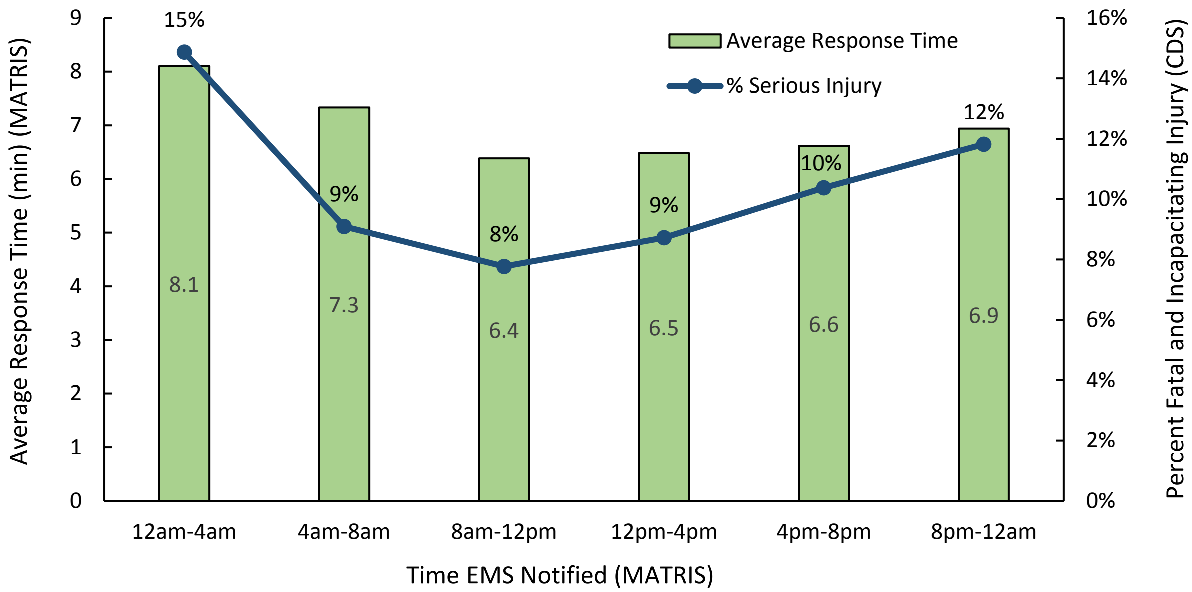
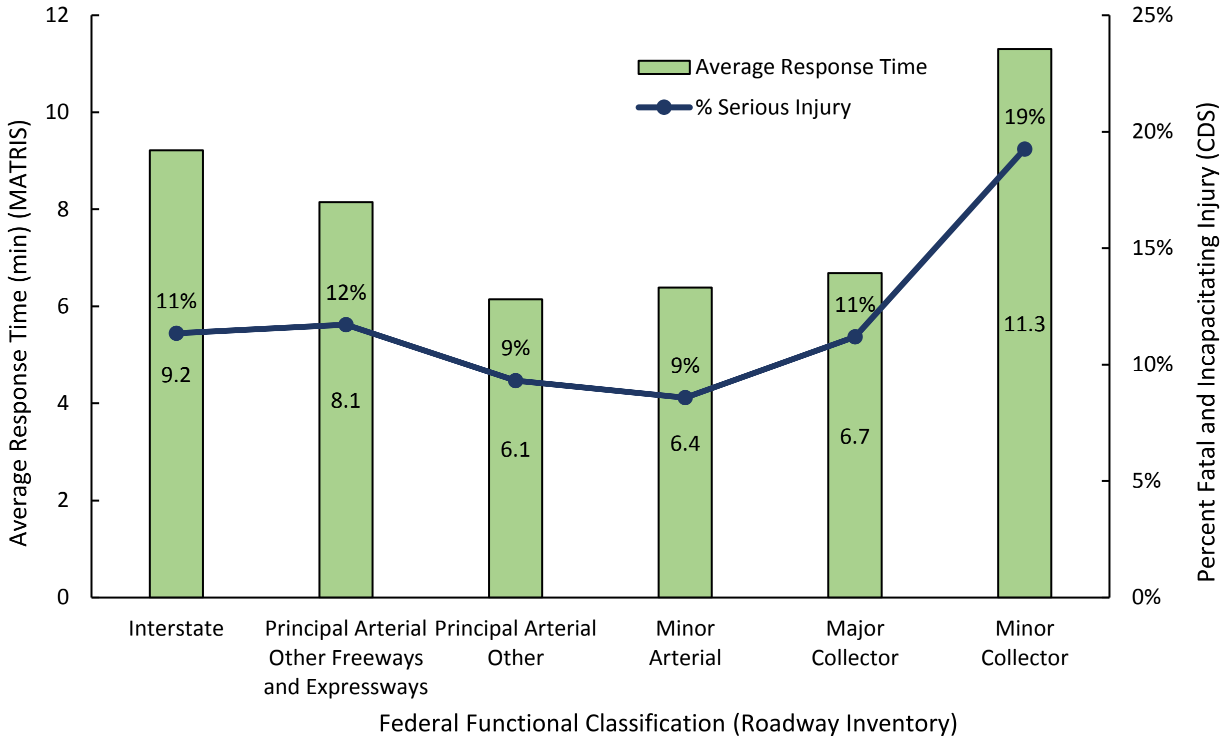


Figure 8 Average EMS Response Time (MATRIS) and Injury Severity (CDS) by EMS Notification Time (MATRIS)

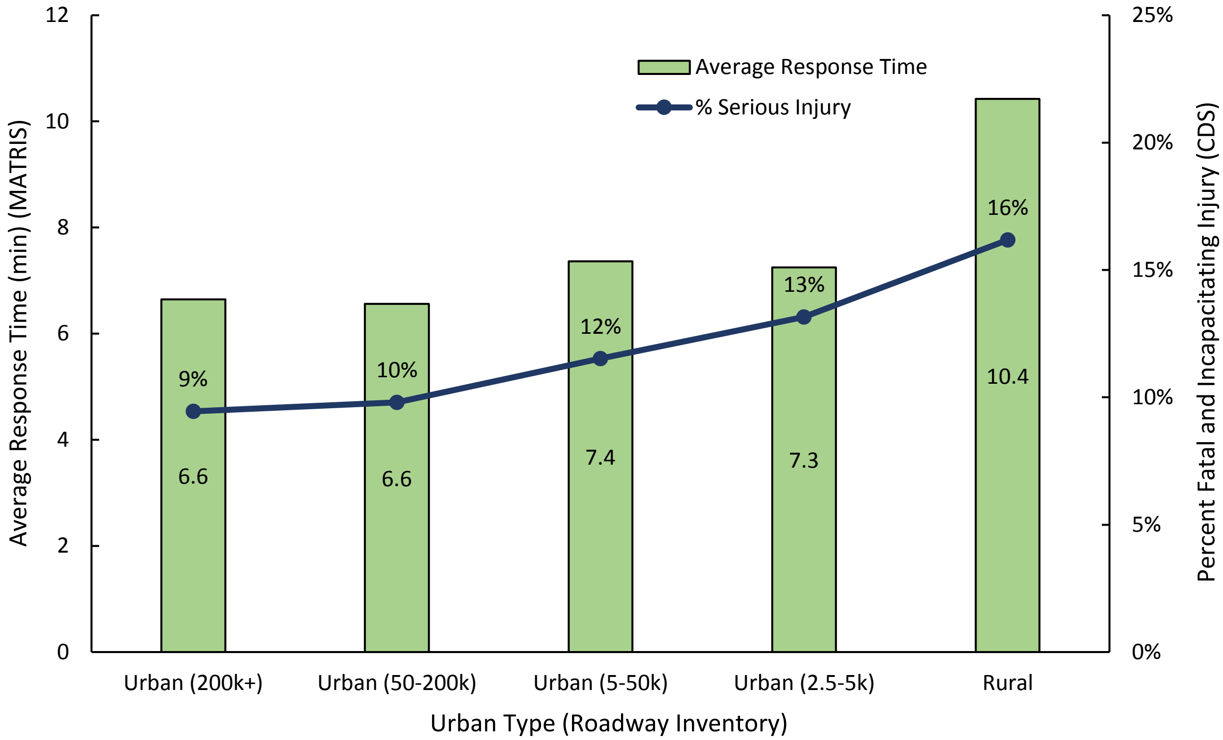
To investigate the relationship between location and response time, the Roadway Inventory dataset was linked to MATRIS via CDS. **Figure 9** displays the average response time by the *Federal Functional Classification*, a Roadway Inventory data field. Minor Collector roadways had the highest average response time and also the highest percentage of incapacitating/fatal injuries. Interstates and Principal Arterial (Other Freeways and Expressways) had the second and third highest response times, along with a higher percentage of incapacitating/fatal injuries than Other Principal Arterial and Minor Arterials. The reasoning for the higher response time could be due a number of possibilities including limited access to these roadways, their distance from urban centers, and traffic congestion. Higher occurrences of incapacitating/fatal injuries on the roadways could be explained by the higher speeds seen on these roadway types.



Note: Only patient records with a valid response time (between 0 and 60 minutes) and Federal Functional Classification were included in the average. Local omitted due to small sample size.

Figure 9 Average EMS Response Time (MATRIS) and Associated Injury Severity (CDS) by Roadway Classification (Roadway Inventory)

Average response time was also examined by *Urban Type*, another Roadway Inventory data field, as seen in **Figure 10**. Average response time, along with the percent of incapacitating/fatal injuries, increased as the size of the urban area decreased. Of the five *Urban Type* classifications, Rural had the highest average response time (10.4 minutes), and the highest share of incapacitating/fatal injuries (16%). A higher response time in rural areas could be due to a naturally smaller number of EMS providers and distance from urban centers. Crashes with increased proportions of incapacitating/fatal injury severity could stem from less traffic congestion, leading to higher speeds, and a prevalence of crash types with higher rates of incapacitating/fatal injuries such as run-off-the-road crashes.



Note: Only patient records with a valid response time (between 0 and 60 minutes) and Urban Type were included in the average.

Figure 10 Average EMS Response Time (MATRIS) and Associated Injury Severity (CDS) by Urban Type (Roadway Inventory)

This relationship between *Urban Type* and response time is further illuminated by comparing average response times in each county in Massachusetts, as seen in **Table 18** and **Figure 11**. Counties in Eastern Massachusetts, specifically surrounding the Boston Metro area, had the lowest average EMS Response Times in the state. With the exception of Dukes and Nantucket Counties, which had extremely small sample sizes, the longest average response times were all seen in Western Massachusetts counties – constituting the more rural area of the state.

Table 18 Average EMS Response Time (MATRIS) by County

County	Count	Average Response Time (min)
Norfolk	4650	5.8
Essex	8880	6.4
Middlesex	11559	6.5
Plymouth	5255	6.6
Worcester	7656	6.8
Suffolk	4912	7.0
Bristol	3831	7.2
Barnstable	1984	7.3
Hampden	5214	7.4
Hampshire	945	7.7
Berkshire	1116	7.8
Franklin	850	9.0
Dukes	96	13.7
Nantucket	#	#

Note: Only patient records with a valid response time (between 0 and 60 minutes) were included in the count and average. (#) indicates sample size fewer than 5 patients.

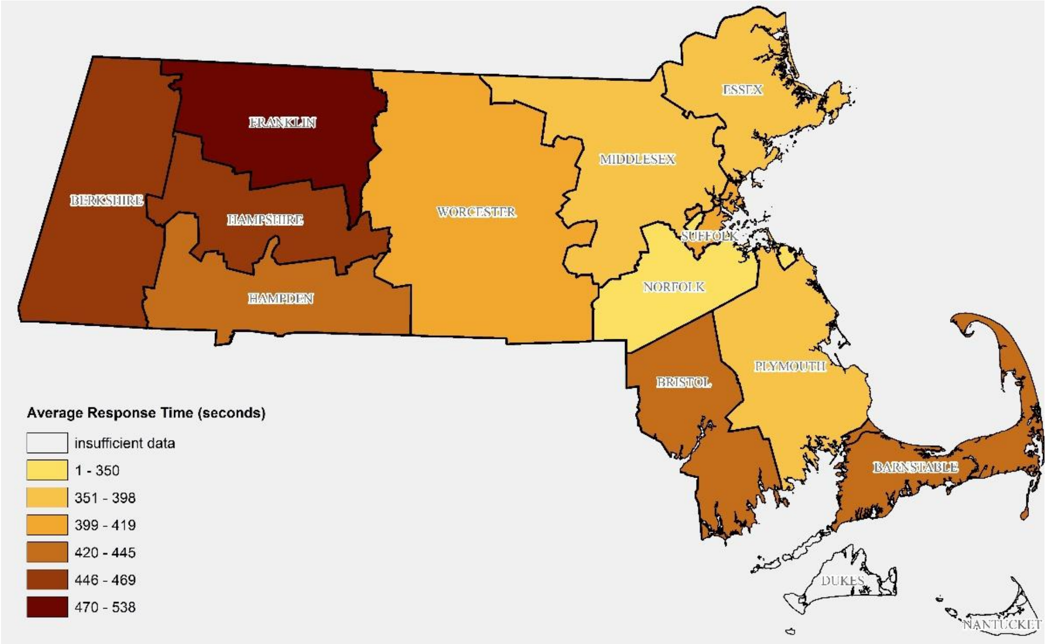


Figure 11 Average EMS Response Time (MATRIS) in seconds by County

3.3.2 Seating Position (CDS)

The *Seating Position* of motor vehicle occupants was recorded for each person in CDS and was studied in comparison to the *Primary Anatomic Injury Location*. Between Drivers, Front Passengers, and Rear Passengers, there were only subtle differences in the injury locations and associated severities, as seen in **Table 19**. Rear Passengers were more likely than both groups to sustain Head injuries, although these Head injuries had the same level of severity. Lower

Extremity injuries had higher occurrences of incapacitating/fatal injuries for Drivers than for both Front and Rear Passengers. Overall, among patient records with a coded *Primary Anatomic Injury Location*, Drivers had a slightly higher incapacitating/fatal injury rate (9%) than Front and Rear Passengers (8%).

Table 19 Primary Anatomic Injury Location (MATRIS) and Associated Injury Severity (CDS) by Seating Position (CDS)

Primary Anatomic Injury Location (MATRIS)	Seating Position (CDS)						Incapacitating/Fatal Injuries (%)		
	Driver (D)		Front Passenger (FP)		Rear Passenger (RP)				
	n	%	n	%	n	%	D	FP	RP
General/Global	6366	24%	915	20%	512	24%	12%	11%	10%
Head	5008	19%	914	20%	507	24%	9%	9%	8%
Neck	3824	14%	706	16%	299	14%	5%	5%	5%
Extremity Upper	3323	12%	431	10%	193	9%	6%	7%	8%
Back	2880	11%	519	12%	225	10%	6%	4%	5%
Extremity Lower	2653	10%	411	9%	179	8%	15%	12%	11%
Chest	2179	8%	415	9%	137	6%	10%	7%	7%
Abdomen	589	2%	162	4%	97	5%	10%	11%	9%
Total Occupants*	**26822**		**4473**		**2149**		**9%**	**8%**	**8%**

Note: Red shading highlights a percentage noticeably higher than drivers. (*) only patients with a known primary anatomic injury location were included in the total.

Table 20 shows *Vehicle Inflicted Injuries* based on occupant *Seating Position* (CDS). Rear Passengers were more likely than Drivers or Front Passengers to sustain a Rollover/Roof Deformity injury, although these injuries had lower occurrences of incapacitating/fatal status. Dash Deformity and Space Intrusion injuries had increased proportions of incapacitating/fatal injury severity for Front Passengers than for Drivers, but overall, Drivers and Front Passengers sustained the same rate of incapacitating/fatal injuries. Interestingly, Rear Passengers still sustained Steering Wheel Deformity injuries in about 4% of patient records — the same rate as Front Seat Passengers. This unlikely injury type for a Rear Passenger could indicate a data quality issue with the *Seating Position* field in CDS, although intuitively these Steering Wheel Deformity injuries had much lower occurrences of incapacitating/fatal statuses for Rear Passengers than Front Passengers or Drivers.

Table 20 Vehicle Inflicted Injuries (MATRIS) and Associated Injury Severity (CDS) by Seating Position (CDS)

Vehicle Inflicted Injuries (CDS)	Seating Position (CDS)						Incapacitating/Fatal Injuries (%)		
	Driver (D)		Front Passenger (FP)		Rear Passenger (RP)				
	n	%	n	%	n	%	D	FP	RP
Windshield Spider/Star	1960	38%	405	44%	121	28%	19%	16%	14%
Rollover/Roof Deformity	1714	33%	294	32%	182	42%	14%	16%	11%
Dash Deformity	1019	20%	190	21%	49	11%	23%	27%	12%
Space Intrusion	875	17%	144	16%	85	20%	29%	37%	22%
Side Post Deformity	863	17%	162	18%	91	21%	21%	22%	18%
Steering Wheel Deformity	436	8%	35	4%	18	4%	39%	40%	22%
Ejection	260	5%	26	3%	23	5%	54%	46%	61%
Fire	52	1%	#	#	#	#	37%	#	#
Total Occupants*	**5170**		**924**		**430**		**18%**	**18%**	**15%**

Note: Red shading highlights a percentage noticeably higher than drivers. (*) only patients with a known Vehicle Inflicted Injury were included in the total. (#) indicates sample size fewer than 5 patients.

3.3.3 Citation Trends based on Patient Outcomes

The Citation dataset was linked to MATRIS via CDS to determine whether a correlation existed between crash severity and law-enforcement citations. **Table 21** demonstrates the comparison of the transported status of the patient (*Destination Patient Disposition)* with the number of citations per incident. When patients needed to be transported due to injuries from a motor vehicle crash, there were 0.24 citations issued per crash, compared to 0.19 citations issued per crash when the patient was able to refuse care.

Table 21 Destination Patient Disposition (MATRIS) and Citation Status (Citation)

Destination Patient Disposition (MATRIS)	Number of Citations	Number of Incidents	Citations per Incident
Treated, Transported by EMS	9039	36544	0.24
Patient Refused Care	2279	12036	0.19

Note: Multiple citations may be issued for a single incident.

Figure 12 illustrates the relationship between the highest injury status sustained in a crash and any associated citations related to that crash. Incapacitating injuries tended to correlate with higher citation rates, though not fatal injuries. Only eight% of crashes which resulted in a fatal injury resulted in a citation, whereas 11% of crashes resulting in an incapacitating injury also resulted in a citation. The lower citation rate in fatal crashes could be due to the at-fault driver suffering the fatality, and therefore making a citation inapplicable.

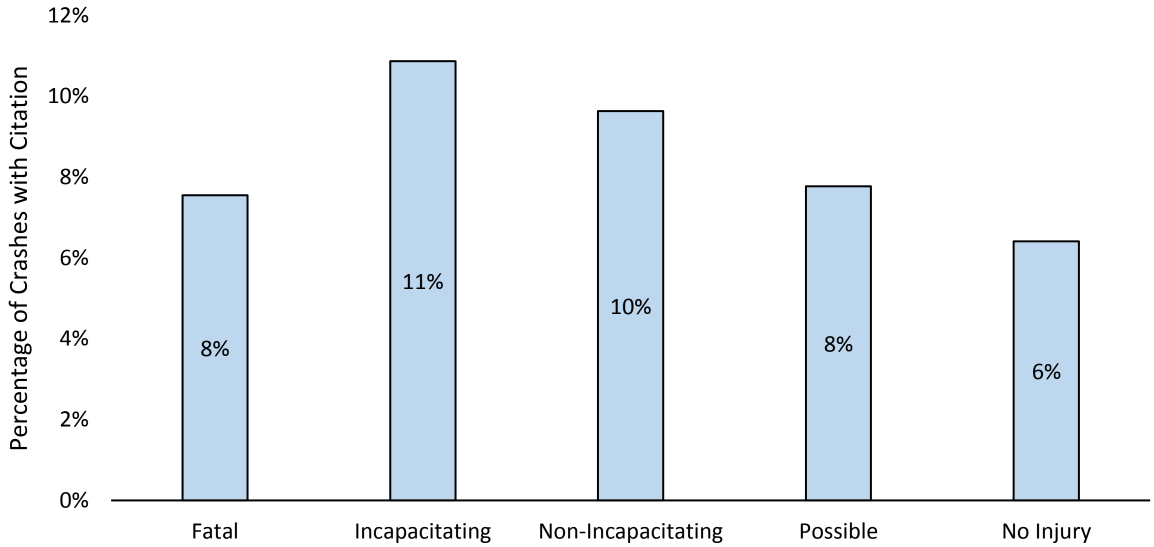


Figure 12 Percentage of Crashes with a Citation Compared to Most Severe Injury Sustained

3.4 Data Quality Comparisons

3.4.1 Alcohol and/or Drug Use Suspected

In 2014, fields indicating alcohol and drug use were added to the crash report form. Since then, the usage of these new fields has gradually increased as more police departments update their crash reporting software and officers become more familiar with the fields. In this analysis, two fields from CDS in particular were examined: *Law Enforcement Suspects Alcohol Use* and *Law Enforcement Suspects Drug Use*. **Table 22** displays the rate at which these fields appeared as valid entries since their implementation in 2014.

Table 22 Utilization in CDS of the fields *Law Enforcement Suspects Alcohol Use* and *Law Enforcement Suspects Drug Use* by year

Year	Valid Field Use	
	Law Enforcement Suspects:	
	Alcohol Use	Drug Use
2014	12.6%	12.3%
2015	20.4%	19.7%
2016	36.5%	35.6%

MATRIS contains a field, *Drug Use Indicators*, where multiple options can be selected; as such some of the entries in **Table 23** may be from the same patient record. Unlike CDS, drug and alcohol involvement are often indicated together. For this reason, the drug and alcohol fields in CDS were combined in order to compare with MATRIS. Similar to the CDS drug and alcohol fields, *Drug Use Indicators* was often left empty or unknown as EMS technicians, like police officers, are not trained in alcohol/drug detection. **Table 23** shows a matrix of various combinations of entries for occupants who had a valid entry for *Law Enforcement Suspects*

Alcohol/Drug Use in CDS. **Figure 13** displays the ratio in which the officer indicated a suspicion of alcohol/drug use versus the various drug use codes in MATRIS.

Interestingly, the Smell of Alcoholic Beverage on Breath/About Person (MATRIS) correlated with the highest rate of suspected alcohol/drug use (CDS), at 63.1%. The Patient Admitting to Drug Use (MATRIS) resulted in the lowest rate of suspected alcohol/drug use (CDS), at 53.9%. Only 2% of records showed that the responding officer suspected alcohol/drug use when EMS operators indicated No Apparent Alcohol/Drug use.

Table 23 Comparison of Drug and Alcohol Use Codes

MATRIS - Drug Use Indicators Code	CDS - Law Enforcement Suspects Alcohol and/or Drug Use				
	Yes	No	Unknown	Total	% Suspected
Smell of Alcoholic Beverage on Breath/About Person	257	96	54	407	63.1%
Patient Admits to Alcohol Use	445	209	81	735	60.5%
Alcohol and/or Drug Paraphernalia at Scene	60	32	13	105	57.1%
Patient Admits to Drug Use	82	58	12	152	53.9%
No Apparent Alcohol/Drug Use	126	6093	194	6413	2.0%

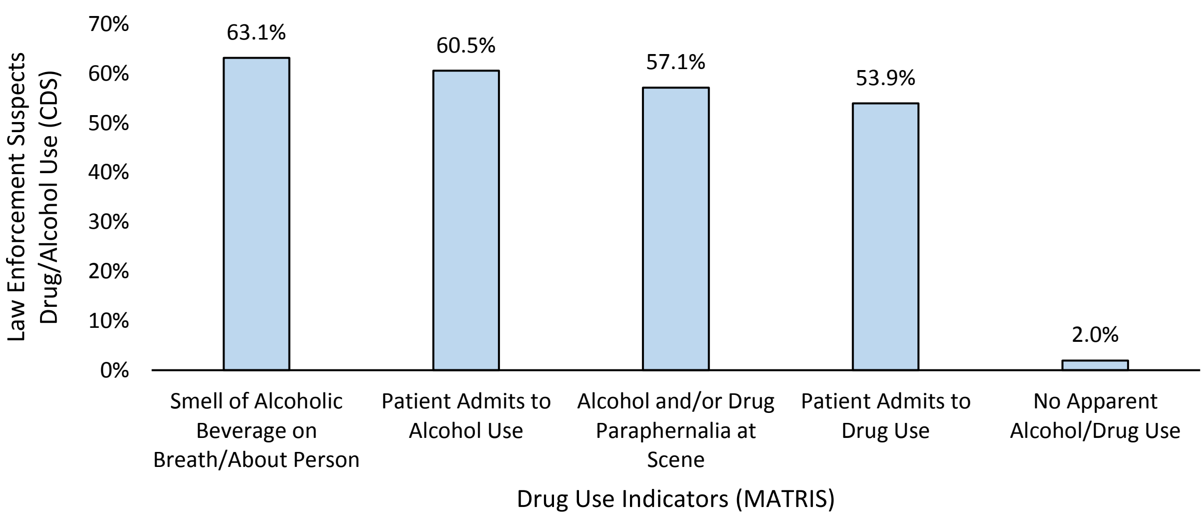


Figure 13 Percent of time Law Enforcement Suspects Alcohol and/or Drug Use from CDS versus Drug Use Indicator Codes from MATRIS

3.4.2 Transported By

The responding officer is tasked with recording on the crash report whether each person involved was transported to a medical facility due to injuries sustained in the crash. Because an ambulance was indicated as being dispatched for every record within this linked dataset, it is impossible to fully evaluate the "Not Transported" response in CDS. However, it is known that oftentimes an ambulance will arrive to the crash scene and the patient will not need additional medical attention or will refuse care. **Table 24** depicts the comparison of the CDS *Transported By* options with MATRIS fields, indicating whether the patient was transported to a medical facility or refused care. When the patient was transported, it was coded correctly in CDS 90% of the time. However, when the patient refused care it was only coded correctly 81% of the time and left blank in 16% of occurrences.

Table 24 Comparison of Transported By (CDS) with Destination Patient Disposition (MATRIS)

MATRIS - Destination Patient Disposition	CDS - Transported By							
	Not Transported		EMS		Other		Blank	
	#	%	#	%	#	%	#	%
Patient Refused Care	10519	81%	275	2%	109	1%	2128	16%
Treated, Transported by EMS	1729	4%	35886	90%	163	0%	2149	5%

Note: Green shading indicates the matching response between the two datasets.

Table 25 compares the transported status in MATRIS, *Destination Location Disposition*, versus the CDS *Injury Severity*. Immediately it can be seen that Patient Refused Care was selected for six fatal and 23 incapacitating injuries, indicating a deeper reasoning like Dead on Arrival or a data quality error.

Table 25 Destination Location Disposition (MATRIS) by Injury Severity (CDS)

Destination Location Disposition (MATRIS)	Injury Status (CDS)					% Fatal & Incapacitating
	Fatal	Incapacitating	Non-Incapacitating	Possible	No Injury	
Patient Refused Care	6	23	1294	2265	8300	**0.2%**
Treated, Transported by EMS (ALS/BLS)	368	4131	15760	15063	1853	**12%**

Figure 14 graphically displays the relationship between *Destination Location Disposition* (MATRIS) and *Injury Severity* (CDS). Moving from left to right on **Figure 14**, as the injury status becomes less severe, the proportion of patients that refuse care rather than get transported increases.

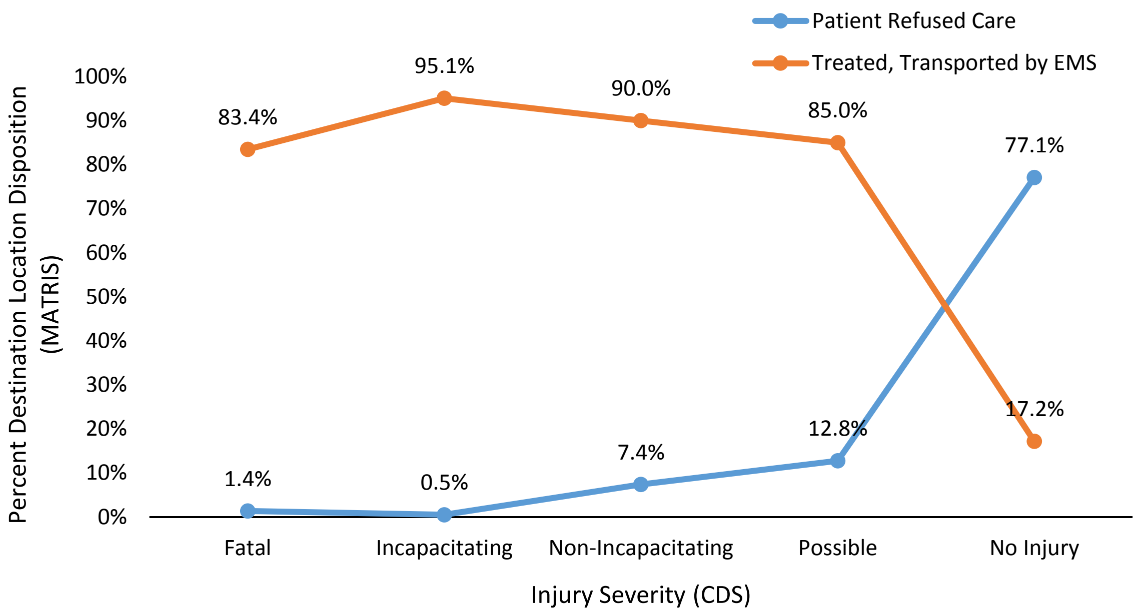


Figure 14 Destination Location Disposition (MATRIS) by Injury Severity (CDS)

3.4.3 Airbag Deployment

When the Airbag Status field was completed with valid entries (excluding unknown) in both data sets, they were found to be consistent 74.2% of the time. It is worth noting that this field was only completed with validity on 86% of CDS occupant records during this time period, and therefore some records were excluded. **Table 26** displays a matrix of the combinations of deployment codes from both CDS and MATRIS. The airbag deployment code indicated in CDS most frequently matched the deployment code in MATRIS when only the Front airbag was deployed, or no airbags were deployed (86.3% and 81.7% respectively). When the CDS field indicated that only the Side airbag deployed, MATRIS indicated the same in only 50% of records. When CDS indicated that both the Front and Side airbags deployed, it was only agreeable in less than one-third of their paired MATRIS records.

While it is not possible to definitively determine which dataset provides a more accurate airbag deployment determination, the distribution of responses allows for some conclusions about the level of detail collected from each dataset. By summing the rows in **Table 26**, it is possible to see the frequency of responses for each type from MATRIS. Similarly, by summing the columns, it is possible to see the frequency of responses from CDS. While Side airbag is indicated slightly more often in MATRIS than CDS, Front and Side air bag is indicated drastically more often in CDS than MATRIS. This finding suggests the possible conclusion that the CDS *Airbag Deployment* field contains a higher level of detail than the MATRIS field.

Table 26 Comparison of Airbag Deployment Codes (CDS and MATRIS)

MATRIS - Airbag Deployment	CDS - Airbag Deployed Code				Total (MATRIS)
	Front	Side	Front and Side	Not Deployed	
Front	6693	199	1987	1750	10629
Front and Side	412	140	1098	105	1755
Side	91	389	289	85	854
No Airbag Deployed	556	50	183	8689	9478
Total (CDS)	7752	778	3557	10629	**22716**
CDS Agrees with MATRIS	**86.3%**	**50.0%**	**30.9%**	**81.7%**	**n/a**

Note: Green shading indicates the matching response between the two datasets.

3.4.4 Ejected

A motor vehicle occupant's ejection status is coded in CDS as Not Ejected, Totally Ejected, Partially Ejected, Not Applicable, or Unknown. In MATRIS, occupant ejection is one of the nine possible *Vehicle Inflicted Injuries*. **Table 27** displays the combination of responses between the two datasets for ejections. CDS indicated that the patient was Totally or Partially Ejected in only 68.5% of the records where MATRIS indicated ejection. CDS did not indicate ejection in 93.5% of the records when no ejection was indicated in MATRIS, but other *Vehicle Inflicted Injuries* were used. It is worth noting that this field has known data quality issues. In order to examine the instances where the CDS field was improperly left empty, they were included for comparison in the third column below.

Table 27 Comparison of Ejection Code (CDS) with Vehicle Inflicted Injuries (MATRIS)

MATRIS: Vehicle Inflicted Injury	CDS: Ejection Code			CDS Entry Agrees with MATRIS
	Not Ejected	Totally Ejected or Partially Ejected	N/A, Unknown, or Blank	
Ejection	84	319	63	68.5%
No Ejection*	7684	196	338	93.5%

Note: Green shading indicates the matching response between the two datasets. (*) Only entries with a known vehicle injury were included in the "No Ejection" designation.

3.4.5 Vehicle Damaged Area

Vehicle Damaged Area is another field that is coded nearly identically in both CDS and MATRIS. One difference is that reporting officers can only enter three damaged areas in CDS, whereas there is no limit in MATRIS. **Table 28** displays the frequency in which the different number of Vehicle Damaged Area codes were utilized. While an indication of only one code was the most frequent response for both datasets, 87% of entries in MATRIS selected only one code as compared to only 46% of entries in CDS.

Table 28 Number of Damaged Area Codes Used (CDS and MATRIS)

Number of Codes Used	CDS		MATRIS	
	n	%	n	%
1	1886	46%	3614	87%
2	1003	24%	322	8%
3	1251	30%	177	4%
4	n/a	n/a	18	0%
5	n/a	n/a	#	#
6	n/a	n/a	5	0%

(#) indicates sample size fewer than 5 patients.

Figure 15 displays the frequency in which each *Vehicle Damaged Area* code was used in CDS and MATRIS, while **Figure 16** compares the percentage of instances when the two datasets agree for each *Vehicle Damaged Area* code. The denominator for each code in **Figure 16** is the sum of crashes in the three criteria: *Vehicle Damaged Area* code appears in both datasets, *Vehicle Damaged Area* code appears in only CDS, *and Vehicle Damaged Area* code appears in only MATRIS. Only Center Rear and Center Front damage areas had over 50% agreement between the two datasets, while Left Rear and Right Rear damaged areas had the worst rate of agreement. Based on the number of codes utilized in CDS and MATRIS, it can be reasonably concluded that CDS has more detailed vehicle damage information than MATRIS.

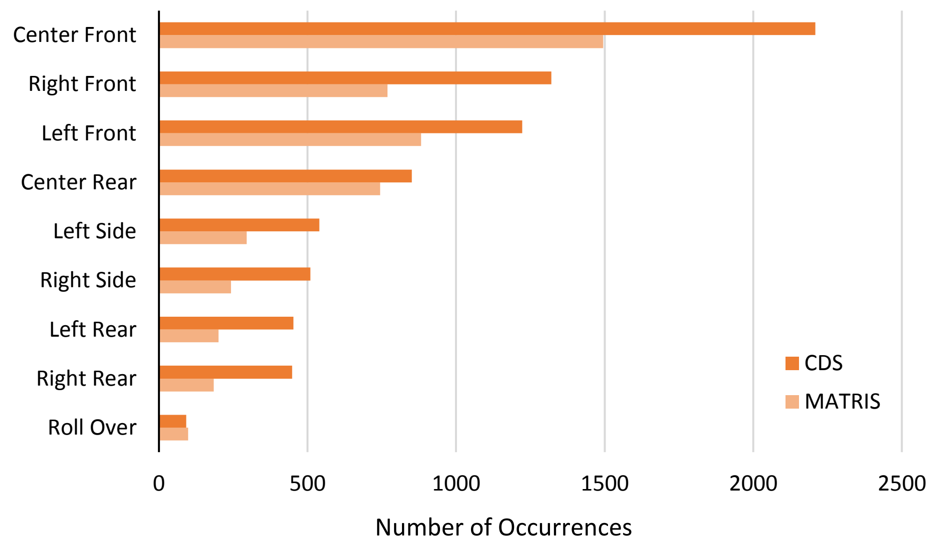


Figure 15 Damaged area codes used in each dataset in crashes indicating at least one damaged area

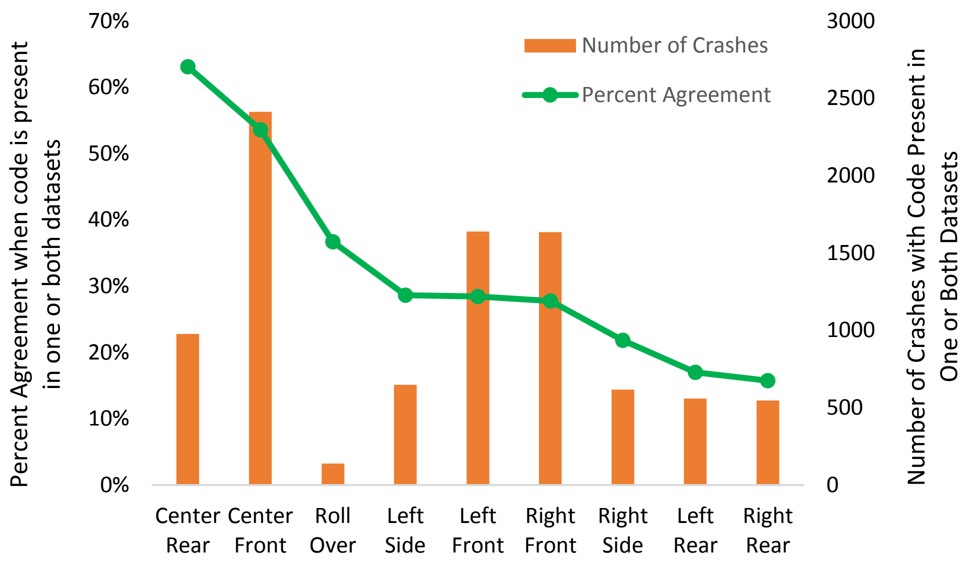


Figure 16 Number of crashes in which each damaged area code was indicated CDS and/or MATRIS and agreement rate between datasets

3.4.6 Weather and Road Surface Conditions

Weather Conditions and *Road Surface Conditions* are fields that are required to be collected for every motor vehicle crash in CDS. In an effort to evaluate the accuracy of these fields, the *Type of Response Delay* field in MATRIS was examined. This field includes weather as one of the possible reasons for an ambulance being delayed in arriving to the scene of the crash. However, **Table 29** shows that Weather was indicated as a reason for delay in only 1% of responses. **Table 30** shows the *Road Surface Conditions* (CDS) versus whether Weather was indicated as a reason for delay in MATRIS, while **Table 31** shows the same comparison but for *Weather Conditions* (CDS). These tables show that 7% of crashes occurred on inclement road surface conditions, and 8% of crashes occurred during inclement weather conditions. A weather delay in MATRIS only correlated with poor surface or weather conditions in two-thirds of crashes (36/58 and 38/58 respectively). Based on this, no conclusions can be drawn about the accuracy of these fields from CDS using MATRIS. Additionally, it appears that the *Type of Response Delay* field in MATRIS does not provide any value due to the large percentage of None and Other responses.

Table 29 Response Delay Types Indicated in MATRIS

Type of Response Delay (MATRIS)	Number of Crashes	Percent of Crashes*
None / Not Known / Not Recorded	9670	84%
Other	1624	14%
Distance	69	1%
Weather	58	1%
Traffic	51	0%
Staff Delay	17	0%
Directions	8	0%
Safety	#	#
Vehicle Crash	#	#
Vehicle Failure	#	#
Hazmat	#	#

(#) indicates sample size fewer than 5 patients.

Table 30 Weather Delays from MATRIS Compared to Road Surface Conditions from CDS

Type of Response Delay (MATRIS)	Road Surface Conditions (CDS)		Total
	Not Snow/Ice	Snow/Ice	
Not Weather	10674	770	**11444**
Weather	22	36	**58**
Total	**10696**	**806**	**11502**

Table 31 Weather Delays from MATRIS Compared to Weather Conditions from CDS

Type of Response Delay (MATRIS)	Weather Conditions (CDS)		Total
	Not Snow/Freezing Rain	Snow/Freezing Rain	
Not Weather	10522	922	**11444**
Weather	20	38	**58**
Total	**10542**	**960**	**11502**

4 CONCLUSIONS

4.1 Summary

The CDS Crash and EMS MATRIS linked dataset, with additional linkages to Citation and Roadway Inventory datasets, has allowed for a more in-depth analysis of crashes, providing expanded insight into injury types and causes in particular. Furthermore, this data linkage has enabled a comparison of fields within each dataset and the linked dataset, allowing for a data quality review of specific fields. Additional information on roadway characteristics and driver behavior – gleaned from crash data as well as roadway inventory and citation data – can expand the understanding of the roadway environment and high-risk behavior.

4.2 Contributions

The linked dataset established in this project serves many purposes, from research and trend identification, to surveillance and policy-shaping. Specifically, findings can be used to develop and modify a variety of highway safety policies, informing how the state responds to driver distraction and speeding, as well as risks involving younger drivers, older drivers, motorcycles, heavy trucks, pedestrians, and bicyclists. Additionally, this CDS-MATRIS linkage lays the foundation for future linkages between CDS and hospital data.

4.3 Benefits and Limitations of Datasets

Crash data provides information on the type of crash, which can help determine not only the details surrounding the vehicles and individuals involved, but also causation and protective factors. Many crashes, however, are not reported, while others include missing information. Furthermore, injury information may not be of the highest quality or completeness, as police officers are often not trained to determine detailed injury status.

EMS records often provide more detailed data on injury mechanisms (e.g. ejections from vehicle, crushing injuries, burns, etc.). However, this data often does not possess a comprehensive clinical assessment. Additionally, these data may also underrepresent motor vehicle crash injuries, as not all motor vehicle crash injuries are transported or treated by EMS respondents.

Roadway data provides additional information on the crash location's environmental design, such as functional classification and roadway speed limits. However, not every crash is successfully geolocated, and thus able to be linked to a specific road segment.

Police citation data can provide additional insights into the frequency and outcomes of high-risk behaviors, (e.g., drivers' histories of intoxicated, impaired or reckless driving, or their use of seat belts, helmets, and car seats). While the citation dataset does provide additional information into crash causation, the decision to issue a citation is dependent on officer discretion, and thus, the dataset should only be used to complement other causation fields.

4.4 Future Research

The successful linkage of the CDS and MATRIS datasets unlock a multitude of future research areas. The analysis presented here represents only an initial, limited investigation into the medical outcomes associated with various crash types. Primarily, we focused on two MATRIS fields — *Primary Anatomic Injury Location* and *Vehicle Inflicted Injuries*. With additional medical expertise, the MATRIS field *Procedure Name* could also be analyzed against various crash patterns. This field indicates each procedure performed on the patient in order to provide medical care. Therefore, further analysis of this field would provide more detailed information into the severity of each injury type.

4.3.1 Deeper Insight into Injury Severity

In previous research, there have been efforts to assign a dollar cost to the five injury classifications in CDS (fatal, incapacitating, etc.). Utilizing linked EMS data would allow for an even more accurate estimate. Ultimately, it would be insightful to calculate the impacts of each injury type in order to estimate not only the medical costs, but also the length of hospitalization, as well as patient rehabilitation time. This would require the addition of Hospital Emergency Room and In-Patient Case Mix data to the current linkage.

Most current traffic safety programs seek to prevent crashes that result in fatal and incapacitating injuries. However, not all incapacitating injuries have the same impact. For example, an incapacitating injury resulting in broken ribs and a broken arm may have significantly less impact than an incapacitating injury resulting in a permanent brain injury. By differentiating between various incapacitating injuries, researchers can develop a more nuanced picture of how crash-induced injuries impact those involved.

4.3.2 CDS to Hospital Linkage

Future research should focus on expanding this linkage to include Hospital Emergency Room and In-Patient Case-Mix data, as these data provide an even more accurate insight into the medical outcomes associated with motor vehicle crashes. As a result, one could better quantify medical costs. The *Medical Facility* field is of notoriously low quality in CDS but is of much higher quality in MATRIS. While we did not have access to this field for this project, it could be obtained for future linkages, ultimately replacing the CDS field when performing a CDS to hospital linkage. Expanding these datasets to include years of previously omitted records and merging fields from separate sources (such as hospital Emergency Departments, Inpatient and Trauma Registry) further enhances their scope and practical vitality as a resource for improving roadway safety.

5 ACKNOWLEDGEMENTS

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