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Creating a Dataset of Naturalistic Ambulance Driving

A Pilot Study of Two Ambulances

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EXECUTIVE SUMMARY

Motor vehicle collisions (MVCs) are an everyday occurrence in the United States. This pressing transportation and health care topic affects millions of citizens each year, and in many cases may result in fatality or lifelong injury complications. Despite best efforts, and notable success, to improve the frequency and severity of MVCs, these events are still a prevalent issue.

In the wake of an MVC, crash occupants rely on emergency responders to quickly respond to the scene, control hazards, and administer necessary medical care. Efficiency within the emergency response event, to an MVC or some other medical care need, is contingent on a properly working transportation system, allowing emergency medical services (EMS) to travel to and from scenes both quickly and safely. Previous research has revealed that complex interactions with other road users not only hinders emergency response efficiency, but often results in hazardous and dangerous interactions on roadways. To capture these complex interactions from a firsthand perspective, this report details a naturalistic driving study that involved two ambulances and the subsequent dataset that was generated, which is the first of its kind. A custom data acquisition system was used to collect four external and three internal video perspectives on each vehicle, with continuous vehicle data that included vehicle speed, GPS location, and emergency system activation (i.e., emergency light or siren use).

Following data collection, the dataset was summarized in the context of each participating agency, the consented drivers, trip type (emergent vs. non-emergent), trip duration, trip distance, and the time of day that the trip took place. The dataset was also processed through a map-matching algorithm that utilized the collected GPS data to provide additional context, including posted speed limit road classification. Finally, the dataset was subsampled to assess and interpret other road user behavior during emergent trips. The work outlined in this report serves as the foundation for additional research that could be leveraged from this dataset, as this dataset is intended to support the inquiry of future research questions within the scope of emergency vehicle operation and transportation. Additionally, some findings of this study and their implications apply beyond the scope of emergency MVC response and may be related more broadly to emergency response for all first responders and emergency events.

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LIST OF ABBREVIATIONS AND SYMBOLS

EMS	emergency medical services
EMT	emergency medical technician
IRB	Institutional Review Board
MVC	motor vehicle collision
NHTSA	National Highway Traffic Safety Administration

CHAPTER 1. INTRODUCTION

Motor vehicle collisions (MVCs) are a pressing issue in transportation and health care fields. Despite a steady decline in MVC-associated fatalities since the 1970s, 2020 marked an unexpected upswing that has reemphasized the prevalence of crashes in the U.S. and the impact they have on the people injured (National Center for Statistics and Analysis, 2020). For example, in 2022, the National Highway Traffic Safety Administration (NHTSA) reported 42,514 fatal crashes and an estimated 2.38 million people injured on roadways in the United States (National Center for Statistics and Analysis, 2024). Previously, efforts to eliminate MVCs as a whole have been championed by roadway safety campaigns, which primarily emphasized pre-crash phase interventions (National Safety Council, 2022b). However, a recent shift in perspective, colloquially named the "Safe Systems Approach" (U.S. Department of Transportation, 2022b), provides a more realistic perspective that centers on eliminating fatal crashes, rather than all crashes, by reconsidering the roles that road users, vehicles, and infrastructure play in MVCs (U.S. Department of Transportation, 2022a).

Adoption of the Safe Systems Approach in the U.S. Department of Transportation's 2022 National Roadway Safety Strategy has increased recognition of the importance of post-crash care as one of the five named complementary objectives (U.S. Department of Transportation, 2022a). During the post-crash phase of an MVC, crash victims rely on emergency responders for an efficient and effective response. In the United States, emergency responders typically consist of law enforcement officers, emergency medical services (EMS), fire services, and other rescue services. Especially for higher severity crashes that result in major or life-threatening injuries, crash victims depend on EMS to respond rapidly and administer appropriate care and treatment. Despite the crucial role EMS play in responding to MVCs, post-crash EMS care is underrepresented in research and literature, as little work has been conducted to investigate the intricacies of the multi-capacity role of EMS personnel, identify areas of improvement from the first responder perspective, or address such areas.

One such area of improvement is that of EMS transportation. When emergency medical technicians (EMTs) were interviewed about their experiences while responding to vehicular crashes (Valente & Perez, 2020), some EMTs expressed concern about their traffic interactions with other road users when in active emergency response. These EMTs often described these interactions as both complex and dangerous. Despite these concerns, limited work exists that identifies and analyzes specific challenges that emergency responders encounter when traveling to and from emergency calls. Nevertheless, EMS transportation does include two unique factors, among others, that greatly complicate the process: time pressure and emergent driving.

Regarding time pressure, the EMS community uses response times as both a quality of care and efficiency metric. This is largely due to the established relationship between response time and crash mortality for seriously injured trauma patients——longer EMS response times are associated with higher rates of MVC mortality (Byrne et al., 2019; Hsieh et al., 2022; Ma et al., 2019; Mahama et al., 2018; Tansley et al., 2019; Watanabe et al., 2019). In most cases, response time is defined as the time interval that either begins from the time a call center receives a 911 call or from the time a response unit is dispatched to the time of on-scene arrival (Al-Shaqsi, 2010; Ingolfsson, 2013), but response time can be expressed in other ways. With that understanding, it is logical that emergency response performance is often evaluated by analyzing response time and additional time-based standards that agencies and providers aim to meet (Al-Shaqsi, 2010; El Sayed, 2012; McLay & Mayorga, 2010), despite the fact that such metrics ignore downstream EMS interventions that also contribute to patient outcomes. Therefore, to properly assess EMS effectiveness, events within the whole response event must be considered. For EMS transportation, this includes both the response and transport phases.

In regard to emergent driving, there are rules, regulations, and laws that can come from the state, city, town, or agency and govern how emergency vehicle operators drive during emergency response events (New York State, 2000; North Carolina General Assembly, 2024; Virginia, 2022). These laws and guidelines outline the operation of emergency vehicles, even in conditions that are otherwise traditionally unlawful (e.g., driving at high speeds, driving through red lights, driving in the opposite direction of intended travel), but all require operators to exhibit "due regard" for other people, vehicles, and property. Even while operating with "due regard," emergency vehicles are still susceptible to crashes due to many factors, including operating at high speeds, operating in unsafe locations such as active roadways, and interfacing with complex roadway environments such as intersections (Abdelwanis, 2013; Maistros & Schneider, 2015; Sanddal et al., 2008; Watanabe et al., 2019). This can result in an emergency vehicle causing or becoming involved in a crash (Custalow & Gravitz, 2004; Donoughe et al., 2012; Hines Duncliffe & Batt, 2019; National Safety Council, 2022a). It is estimated that each year in the U.S. there are 4,500 ambulance MVCs, 29 of them fatal (Smith, 2015). The influence of a crash involving an ambulance on the intended emergency response event also needs to be considered, where the initial medical unit is taken out of service, new patients may be introduced to the emergency response system from the new crash, supplementary emergency response needs to be summoned for the initial and new incidents, and onboard patients could incur treatment delay and/or additional injury.

We conducted an initial inquiry into emergency response transportation via a survey of U.S. driving manuals to establish a baseline of the prescribed response that regular drivers should exhibit when encountering an emergency vehicle. The survey results indicated that most U.S. drivers are taught to yield the right of way by merging to the right side of the road when approached by an emergency vehicle. As a follow-up, an initial research investigation of naturalistic data collected from the Second Strategic Highway Research Program Naturalistic Driving Study was conducted to gain greater insights into firsthand emergency vehicle interactions. Due to the low frequency of emergency response events observed in the dataset, and the fact that videos were collected from the perspective of road users in their personal vehicles, a majority of the emergency vehicle interactions in that dataset involved stationary emergency vehicles responding to roadside events (e.g., traffic stops and roadside assistance) and did not provide sufficient insight into the dynamics and variability associated with emergent events.

Therefore, to directly observe the type of complex scenarios that emergency vehicles encounter during active response and the type of reactions that road users have when faced with an emergency vehicle in those scenarios, this study instrumented two ambulances to participate in a 6-month naturalistic driving study. The participating ambulances were instrumented to directly collect all interactions with other road users to provide detailed insight into the types of scenarios ambulance operators navigate every day. The study was intended to capture data that can lead to the development of engineering solutions to improve safety and reduce response times surrounding emergency vehicle interactions, ultimately leading to decreased crashes and improved mortality and morbidity outcomes for patients being assisted by these emergency services. As a result of the study, a unique dataset of naturalistic ambulance driving was compiled, which is the first of its kind.

CHAPTER 2. METHODS

RECRUITMENT AND INSTRUMENTATION

The Virginia Tech Institutional Review Board (IRB) approved the protocol for this study (IRB #21-540). Participating EMS agencies were recruited through both private and public safety points of contact. Eligibility requirements for candidate participating agencies were self-identification as a 911 transport agency and service to a high call-volume area. Additionally, agencies that were within driving range of Virginia Tech (5 to 6 hours) and non-volunteer-based were preferred due to logistical constraints. This study included naturalistic driving data from two ambulances, one located in North Carolina and one in Virginia. Once an EMS agency agreed to support the study and instrumentation permission was obtained, ambulance operators within that agency who were known to drive the candidate ambulance were contacted to gauge their general level of interest in the study. Once enough operators were expected to participate, the driver recruitment phase began. Any driver who was employed by the participating agency and was approved to operate an agency ambulance was eligible to participate in the study. All eligible participants also needed to be 18 years old or above and to speak English. Qualifying drivers who had interest in participating in the study were then scheduled for an intake meeting where they completed the study consent process and the demographics and pre-study questionnaires. Participants were compensated if permitted by the agency of employment. A total of 18 consented drivers participated in the study. Note that the experimenters had no control or influence over the drivers assigned to instrumented ambulances, but these drivers were, to the experimenter's knowledge, all comprised of full-time staff.

The two participating agencies, which will only be referred to as "Agency 1" and "Agency 2" to protect participant privacy, had some notable differences in enrollment, vehicle type, and service area. Agency 1's ambulance was a 2019 Chevrolet Express (van body) and had six consented drivers throughout the data collection period (i.e., May 2022 to January 2023). This vehicle was continuously in service during data collection and rotated between urban, suburban, and rural stations within the agency's run area. The Agency 1 ambulance operated within a county of approximately 850 square miles and served an estimated population of 1.15 million residents. Geographically, Agency 1's service area was centered around a major urban city and included many less densely populated communities that surrounded the city. In contrast, Agency 2's ambulance was a 2019 Ford F-450 (truck body) and had 12 consented drivers throughout the data collection period (i.e., September 2022 to April 2023). This vehicle was also continuously in service during data collection but was assigned to a single station, where it predominantly served the same communities throughout the study period. The Agency 2 ambulance operated within a county of approximately 251 square miles and served an estimated population of 97,000 residents. Although Agency 2's run area surrounded an urban center, as Agency 1's did, that urban center was not included in the agency's jurisdiction. Thus, Agency 2's run area predominantly included suburban and rural communities that surrounded the urban center. At the state level, specific ambulance operation guidelines were similar between Virginia and North Carolina; however, locality and/or agency specific policies may have varied slightly and were not provided to the research team.

A Virginia Tech Transportation Institute FlexDAS data acquisition system was used to collect continuous video and vehicle data from all participating ambulance drivers any time the vehicle was turned on and in motion. A digital still image was taken of each participating driver's face during the consent process to identify the correct participant in the videos during subsequent data processing. All recorded data pertaining to non-participating drivers were excluded from any processing or analysis. While the ambulance was active, the FlexDAS collected continuous video of the driver's face, an over-the-shoulder view of the driver, the ambulance accelerator and brake pedals, the forward roadway, the rear roadway, and the driver and passenger sides of the ambulance (Figure 1 and Figure 2; note that blurring in Figure 2 was added to protect participant privacy, as the collected video was not blurred). Cameras were placed and directed in such a way as to prevent capturing patient information to the extent possible. The FlexDAS also collected continuous vehicle data that included vehicle speed, longitudinal and lateral acceleration, steering data, GPS location, emergency light use, and emergency siren use. Both ambulances were instrumented with forward-facing radar units that collected data about leading objects and vehicles throughout the study; however, only one of the ambulances could be additionally instrumented with a rear-facing radar. As an additional means to limit the collection of patient information, the FlexDAS was also configured to go into standby mode (i.e., stop writing a data file) any time the vehicle speed was at 0 mph for 5 minutes or longer and resume data collection (i.e., begin writing a new data file) following a pause once the vehicle speed reached 5 mph.

Figure 1. Photos. Exterior instrumentation camera angles including the front (A), the driver side (B), the passenger side (C), and the rear (D).

Figure 2. Photos. Interior instrumentation camera angles including the driver face (A), the pedals (B), and over the driver's right shoulder (C).

DATA SUMMARY

Following the end of data collection, there were a total of 8,044 data files. All files were initially processed to standardize the variable units and names across both vehicles. Files were then retained for analysis if they showed ambulance operation by a consented driver, had a duration of 3 minutes or longer, and captured data for a distance of at least 1 mile. These remaining files were considered "trips" for the purpose of the analysis. Next, trips were classified as either non-emergent or emergent, where any trip that included the use of emergency lights and/or sirens for any portion of time was classified as emergent. Only those drivers who had both non-emergent and emergent data were included in further data analysis since the emergent driving periods were key to many subsequent analyses and their analysis was one of the primary goals. This criterion resulted in the removal of one consented driver (Driver 7). Thus, the final dataset contained 2,520 total trips taken by 17 drivers, of which 926 trips were emergent. Descriptive statistics were then used to summarize the number of trips, mileage, and duration for both non-emergent and emergent trips per driver, along with relevant driver demographic characteristics. The dataset was also assessed for agency-specific distributions of trip duration, trip distance, and the time of day of the trip.

Statistical analyses consisted of t-tests on the relevant metrics. Significance was determined using a Type I error of 0.05.

MAP-MATCHING

The dataset was also contextualized to roadway infrastructure through a map-matching process using the recorded GPS coordinates collected from the instrumented ambulances. Raw GPS data were sampled at 10 Hz. The data were then down-sampled to 1 Hz and input into a local instance of the Valhalla map-matching platform. The Valhalla platform matches the route, inferred from GPS data, to an OpenStreetMaps map. This process also leveraged GPS coordinate timestamps to improve accuracy. Key data elements including posted speed limit and road classification[1] (i.e., motorway, trunk, primary, secondary, tertiary, residential, unclassified, or service) were derived from the map data. This process was applied to all consented trips, but only trips that had defined road classifications for the entire length of the trip were considered. This resulted in a total of 2,444 map-matched consented trips, of which 890 were emergent.

DRIVER BEHAVIOR

To identify interactions between emergency vehicles and other vehicles, trip files were categorized by road class and divided into 21-second segments during which the ambulance was moving. For each road class, 50 of these segments were randomly selected from the emergent trip subset. Each video was manually assessed for traffic interactions, considering travel direction, vehicle type, time of day, and weather conditions. A vehicle interaction required the other vehicle to be adjacent to the instrumented ambulance without a barrier. If there was a large traffic queue, only the first 20 vehicle interactions were considered to avoid artificial inflation of the findings.

For each documented interaction, yield response of the other road user was categorized as "appropriate," "inappropriate," or "appropriate but delayed." In general, "appropriate" responses were assigned to vehicles that yielded the right of way quickly and to the maximum of their ability (e.g., used the entire shoulder; Figure 3). Similarly, "appropriate but delayed" responses were assigned to vehicles that either delayed their yielding behavior such that it required the ambulance operator to make a noticeable adjustment, or to vehicles that did not yield using the full extent of the roadway (Figure 4). Finally, "inappropriate" responses were assigned to vehicles that failed to yield (Figure 5). The distinction in yield response was made using all relevant video angles and considering factors such as visibility, estimated travel speed of other vehicles, and roadway layout. The safety of yield responses was judged by a member of the research team who had firsthand experience as an EMT and ambulance operator. Ultimately, the safety of yield responses was categorized as either "safe" or "safety critical." Safe yields were those where "appropriate" yield behavior was observed, whereas "inappropriate" and "appropriate but delayed" yields were classified as safety critical. The proportion of yields that were safety critical was then assessed to examine the baseline occurrence of these situations across roadway type.

[1] https://wiki.openstreetmap.org/wiki/United_States/Road_classification

Figure 3. Photo. Drivers of vehicles on both sides of the two-lane road yield to their respective right-side shoulders to provide a path for the emergent ambulance. All pictured drivers were deemed to have responded appropriately.

Figure 4. Photo. Drivers on a motorway attempt to clear a path for the emergent ambulance. The driver of the light-colored vehicle on the left was deemed to have an "appropriate but delayed" response. Although the light-colored vehicle did yield, they had ample time to merge into the right lane (which would have been the preferred response due to the small left side shoulder) and did not come fully to a stop, which made overtaking the vehicle more challenging for the ambulance. Before passing the light-colored vehicle, the ambulance operator had to come to a stop and wait for more room to open on the right in order to drive around the light vehicle and pass them on the right.

Figure 5. Photo. The driver of the blue pickup truck in the left lane was deemed to have responded "inappropriately." The blue truck was the sole occupant of the left lane for some time as the ambulance approached it. There was ample opportunity for the blue truck to merge into the right lane, but the driver did not execute that maneuver. Once the ambulance caught up to the blue truck, the ambulance operator was forced to brake and use the left shoulder to maneuver around the blue pickup truck.

CHAPTER 3. RESULTS

DATA SUMMARY

Except for the reported number of miles driven in the past year and the reported number of weekly driving hours, the answers to the demographics questionnaire showed similar results between the agencies (Table 1). If at least one driver left any question unanswered, the total number of respondents for that question is indicated in the table.

Table 1. Driver demographic summary.

	Agency ID	
	Agency 1	**Agency 2**
Gender		
Male	4	1
Female	2	11
Age		
Mean (SD)	38.5 (12.37)	33.25 (8.62)
Use of corrective lenses when driving		
Yes	3	5
No	3	7
Use of hearing aid when driving		
Yes	0	0
No	6	12
Number of motor vehicle crashes		
Mean (SD)	1.67 (2.07)	1.33 (1.97)
Number of years' experience driving an ambulance		
Mean (SD)	12.67 (10.56)	10.04 (9.74)
Number of years at current agency		
Mean (SD)	4.67 (4.89)	7.41 (7.86)
Are you involved in new driver training (n = 17)		
Yes	0	7
No	6	4
Number of miles driven in the past year (n = 14)		
Mean (SD)	16,825 (3,431)	2,935 (3,417)
Number of average duty hours per week		
Mean (SD)	51.67 (9.09)	57.5 (20.30)
Number of average driving hours per week		
Mean (SD)	32.83 (11.46)	26.83 (15.21)

The number of trips per driver ranged from 9 to 394. The number of miles driven was also totaled for each driver and trip type, ranging between 11 and 1,780 for emergent trips and 56 to 2,270 for non-emergent trips (Table 2, recall that Driver 7 was excluded due to a lack of emergent trips). Of the data collected, 36.7% of trips were emergent (corresponding to 36.1% of captured miles driven and 35.3% of driving duration; Figure 6).

Table 2. Trip summary by driver and trip type.

Agency	Driver	Trip Type	Number of Trips	Mileage (mi)	Time (min)
Agency 1	Driver 1	Non-Emergent	233	2,115.3	4,573.4
		Emergent	161	1,780.9	3,493.6
	Driver 2	Non-Emergent	150	1,274.2	2,553.7
		Emergent	117	1,011.0	2,007.2
	Driver 3	Non-Emergent	200	1,903.8	3,890.7
		Emergent	127	1,340.2	2,516.3
	Driver 4	Non-Emergent	77	744.2	1,462.8
		Emergent	15	180.2	335.3
	Driver 5	Non-Emergent	251	2,270.9	4,609.0
		Emergent	105	1,049.8	2,003.0
	Driver 6	Non-Emergent	9	56.2	132.1
		Emergent	6	36.5	95.8
Agency 2	Driver 8	Non-Emergent	19	158.0	358.4
		Emergent	1	16.8	17.8
	Driver 9	Non-Emergent	121	1,025.1	2,075.2
		Emergent	67	356.5	774.9
	Driver 10	Non-Emergent	37	401.9	714.2
		Emergent	26	198.7	335.3
	Driver 11	Non-Emergent	7	73.0	129.2
		Emergent	2	11.7	26.0
	Driver 12	Non-Emergent	94	711.4	1,631.5
		Emergent	53	326.6	724.2
	Driver 13	Non-Emergent	34	340.3	653.2
		Emergent	5	33.4	75.7
	Driver 14	Non-Emergent	18	137.4	294.2
		Emergent	10	86.0	173.5
	Driver 15	Non-Emergent	119	1,215.4	2,198.4
		Emergent	114	919.7	1,738.6
	Driver 16	Non-Emergent	93	749.8	1,509.0
		Emergent	42	234.9	502.5
	Driver 17	Non-Emergent	50	339.7	756.2
		Emergent	30	164.8	393.9
	Driver 18	Non-Emergent	82	760.7	1,476.8
		Emergent	45	311.8	639.3

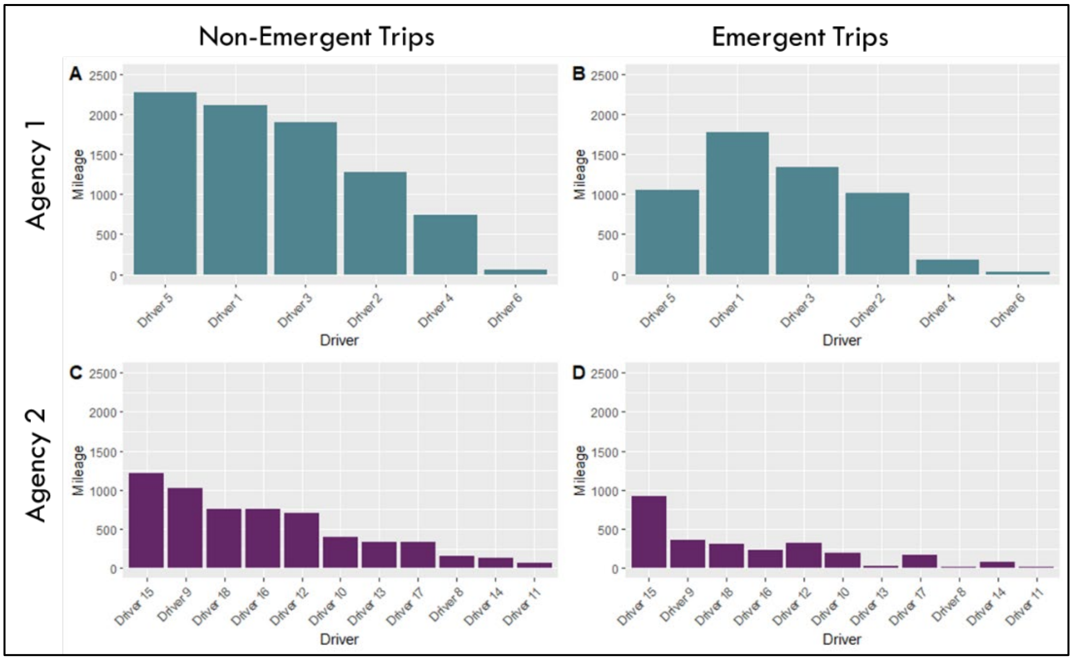

Figure 6. Graphs. Summation of trip mileage per driver by agency and trip type.

For trip duration (Figure 7) in Agency 1, emergent trips (which were less frequent overall than their non-emergent trips) followed roughly the same distribution as the non-emergent trips recorded. This same trend generally held true for Agency 2, except for emergent trips that lasted 7 to 12 minutes, which were nearly double the number of non-emergent trips of the same length.

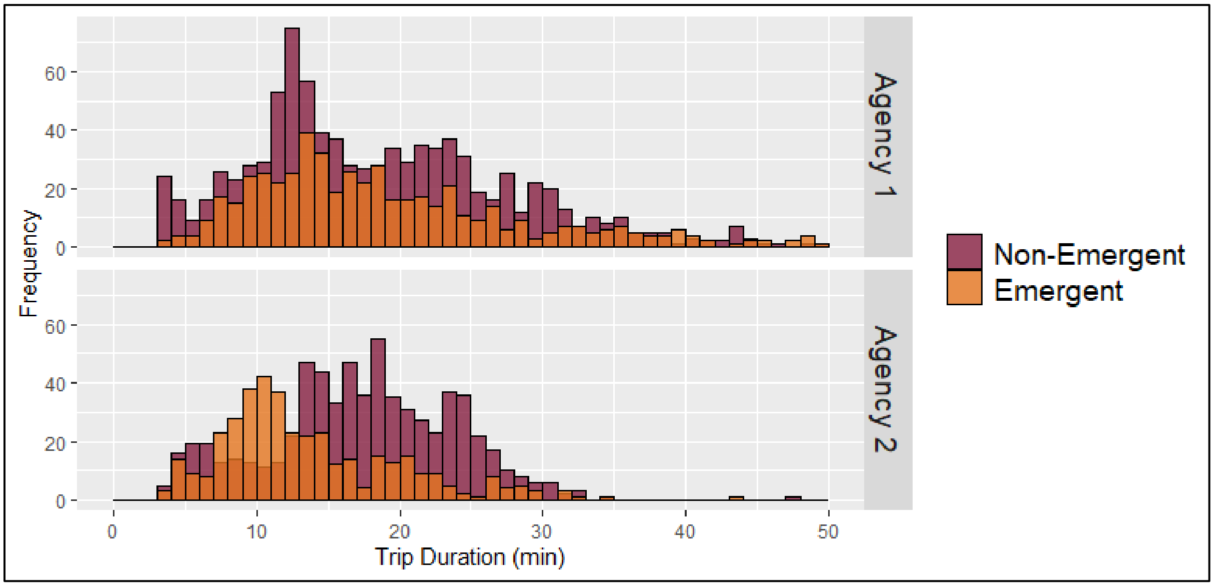

Figure 7. Graphs. Trip duration by agency with overlap between the non-emergent and emergent distributions. Note that emergent trip data (in orange) were layered in front of the non-emergent trip data (in maroon), which produces variations in the color of the two distributions when they overlap.

Similar results were observed for the trip distance in Agency 1, where the emergent trips followed the same distribution as the non-emergent trips (Figure 8). However, while there was also general alignment in the distributions for Agency 2, there were two noteworthy distinctions. First, emergent trips under 4 miles outnumbered non-emergent trips. Second, there were two very large spikes in non-emergent trip distance at 8 miles and 17 miles.

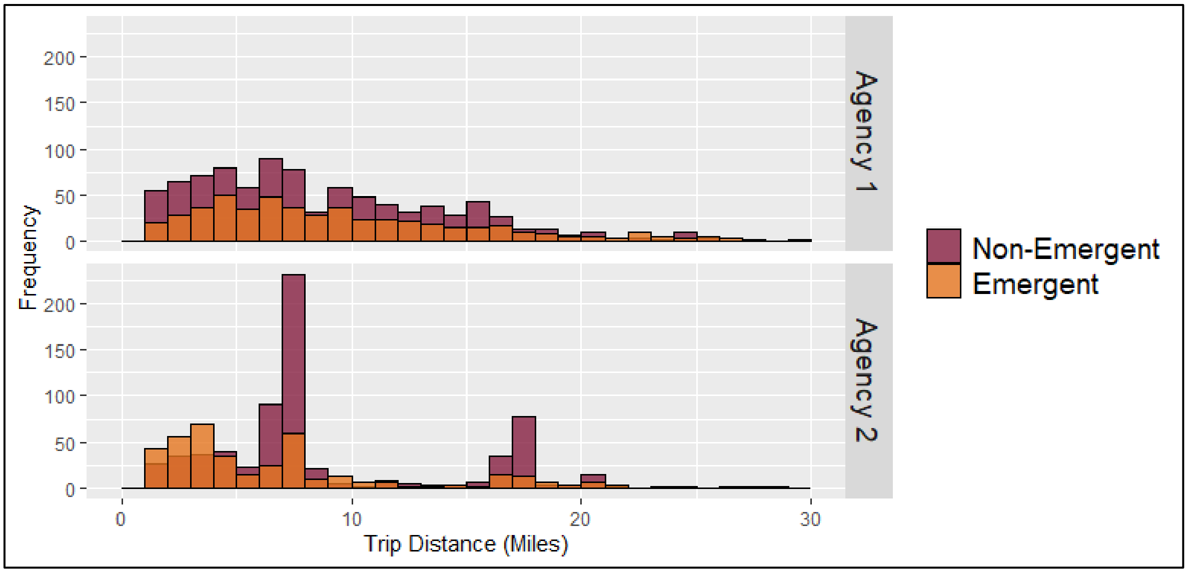

Figure 8. Graphs. Trip distance by agency with overlap between the non-emergent and emergent distributions. Note that emergent trip data (in orange) were layered in front of the non-emergent trip data (in maroon), which produces variations in the color of the two distributions when they overlap.

With respect to trip time of day, both agencies showed midday peaks in call volume from about 10 a.m. to 3 p.m.; Agency 1 showed an additional nighttime peak from about 8 p.m. to 2 a.m. (Figure 9).

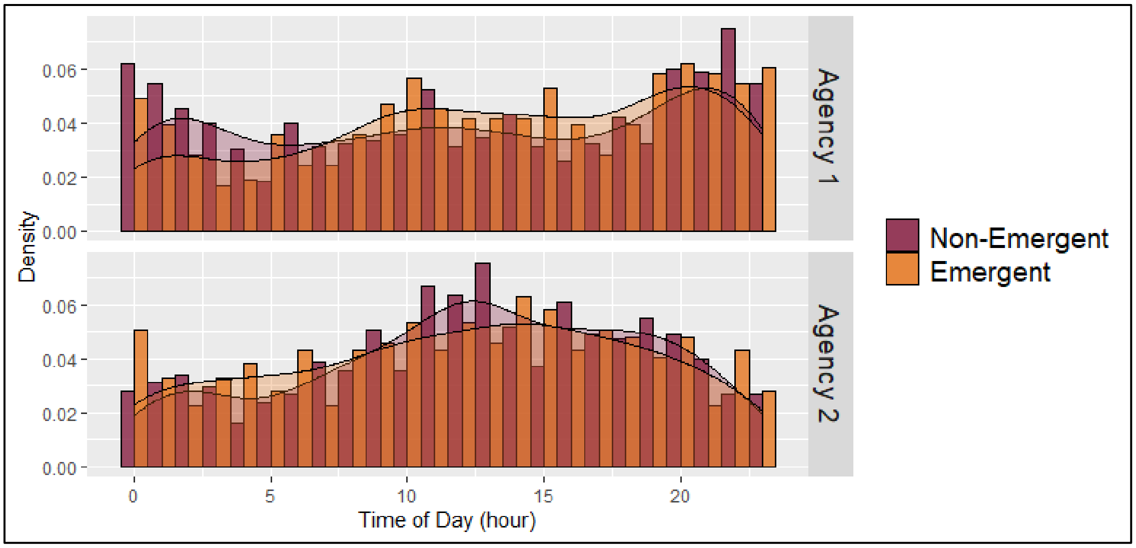

Figure 9. Graphs. Histogram density of trip time of day by agency, where time 0 corresponds to midnight. Note that emergent trip data (in orange) were layered in front of the non-emergent trip data (in maroon), which produces variations in the color of the two distributions when they overlap.

MAP-MATCHING

The proportions of use for the eight road class levels defined in the map-matching process were plotted by agency (Figure 10). For Agency 1, secondary roads were the most traveled, with a general trend of decreased prevalence as road classes both increased (moving towards motorway) and decreased (moving towards residential) in size and complexity. On the other hand, for Agency 2, primary roads were the most traveled, followed by a general trend of decreased prevalence as road classes decreased (moving towards residential) in size and complexity. Agency 2 showed very limited use of motorways (e.g., interstates, freeways) or trunk roads (e.g., high-speed arterials, divided highways). When contrasting only emergent and non-emergent trips, the only noteworthy difference was found for residential roads, where Agency 2 emergent use (15%) was more frequent than Agency 2 non-emergent, Agency 1 emergent, and Agency 1 non-emergent use (6%, 6%, and 4%, respectively).

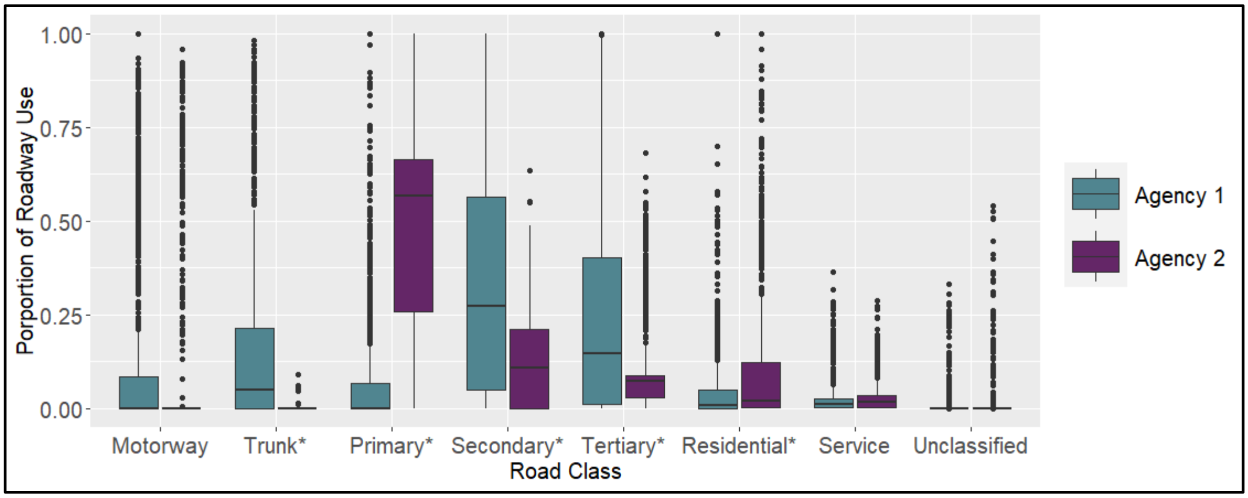

Figure 10. Graph. Prevalence of roadway use across all road classes, separated by agency. Road classes decrease in size and complexity from left to right. Road classes with a * denote a significant main effect from agency level.

DRIVER BEHAVIOR

Most observed traffic interactions during emergent periods took place on primary roads, followed by trunk, tertiary, secondary, motorway, and residential roads (Table 3). The prevalence of safety-critical interactions ranged from 1.0% to 8.5% among the different road classes. Overall, there were 588 observed traffic interactions in these sampled observation periods, where 3.74% were deemed safety critical.

Table 3. Roadway traffic interaction observations.

Road Class	Interactions	Safety-critical Interactions (%)
Motorway	59	8.47
Trunk	135	4.44
Primary	190	1.05
Secondary	89	7.87
Tertiary	100	1.00
Residential	15	6.67
Total	588	3.74

CHAPTER 4. DISCUSSION

The two agencies were generally comparable with respect to driver demographics, with the main noteworthy differences present in the reported number of miles driven in the past year and the number of average driving hours per week. For both metrics, the mean of Agency 1 driver responses was larger, with a smaller standard deviation, than for Agency 2. This finding is likely a result of differences in the operating domain of each agency/vehicle. Recall that Agency 1 covers a geographical area about four times greater than Agency 2, and additionally serves a population about 10 times larger than that of Agency 2. This difference likely results in Agency 1 experiencing a much higher call volume than Agency 2, as informally supported by the approximated call volume values gathered from administrative points of contact within each agency during agency recruitment. Although it can be assumed that each of the agencies scales their staff and fleet to accommodate their relative jurisdictions and call volumes, it is not unreasonable to expect that Agency 1 drivers would drive longer and further than drivers in Agency 2.

As expected, trip summaries by driver and trip type confirmed a larger prevalence of non-emergent driving than emergent driving. This is reflective of an emergent response bias, where many 911 calls are considered critical until arrival on the scene, where call acuity can be fully and accurately assessed. Consequently, many calls that elicit an initial emergent 911 response may then be followed first by a non-emergent transport to a treatment facility, then by another non-emergent trip back to the station or local staging point. Although this pattern can be interrupted by occurrences like patient refusals or back-to-back calls, the anticipated 2:1 non-emergent to emergent ratio is supported by the collected data, where just over one third of trips were emergent.

Emergent trips generally followed the same distributions for trip duration and distance as the non-emergent trips, with only a few exceptions specific to Agency 2. First, for Agency 2 trip duration, emergent trips lasting 7 to 12 minutes largely outnumbered non-emergent trips. This may be a result of the proximity that the Agency 2 ambulance has to particular regions of high call volume in their run area. One reason that an exception like this was not observed for the Agency 1 ambulance may be that it rotated to different stations within the agency's run area, reducing any potential proximity bias. Second, Agency 2 non-emergent trips of 8 and 17 miles in length largely outnumbered emergent trips. This is likely due to the proximity of the two main treatment facilities in Agency 2's run area to the station; these distances perfectly align with the distances between the Agency 2 station and the local and regional hospitals. Finally, although both agencies showed midday increases in trip volume, Agency 1 showed an additional increase in trip volume at nighttime, likely as a result of a much larger urban center with a more prominent night life.

With respect to roadway class, although eight road classes were considered, the results of interest focus on the six most common road classes (i.e., motorway, trunk, primary, secondary, tertiary, and residential). Noteworthy differences in road class use were observed between the agencies for five of these six main road classes. Not only did the agencies differ in road class use, but they each showed unique trends in the context of roadway complexity traversed. On one hand, as road complexity increased, Agency 1 showed a gradual increase in road class use that peaked at secondary roads, then gradually decreased. This trend may be a result of how the Agency 1 ambulance rotated between stations, serving a larger assortment of communities. For Agency 2, however, peak road use took place on primary roads followed by a steady decrease as road complexity decreased, with a noticeable minimal use of motorways and trunk roads. Some of the differences in road class utilization between the agencies may be a function of the accuracy of road classification within the map-matching process, which is noted to be limited by the definitions associated with each road class. This is especially relevant for neighboring classes, where, for example, some motorways could also be defined as trunk roads, or some tertiary roads could perhaps be better defined as secondary roads. More likely, however, differences between agencies are a result of different roadway and community infrastructure associated with each jurisdiction, which justifies the incorporation of agency as a model effect in future investigations that use this dataset. Noteworthy differences in road class use between emergent and non-emergent trips were only observed for residential roads, where Agency 2 did have a larger residential road use overall.

Road classes were also assessed through video reduction, via random sampling, to understand the types of traffic interactions that were taking place during emergent driving. The assessed data sample revealed primary roads to have the highest frequency of interactions but one of the lowest frequencies of safety-critical events. Motorways, however, which were found to have a relatively low frequency of traffic interactions, were associated with the highest frequency of safety-critical events. This relationship is most likely a result of a combined effect between roadway complexity and motorist use frequency. For example, motorways are typically large, multilane roads that can accommodate large volumes of motorists. Therefore, due to the larger amounts of available space, drivers can more easily yield or be pre-positioned out of the way of the emergency vehicle, even to a degree that would eliminate the interaction altogether (e.g., separated by one or more lanes, which was not counted as an interaction in this analysis due to the unlikely nature that the motorist could relatively easily obstruct the path of the ambulance). However, when traffic flow is disrupted (e.g., due to a crash), the large volume of motorists quickly overwhelms the roadway and results in limited available space to yield and more difficult conditions to effectively detect emergency vehicles. Thus, it is understandable that although only a moderate number of interactions (i.e., motorists directly in front of or next to the subject ambulances) were observed on motorways, there was still a relatively high number of safety-critical interactions present, specifically when traffic density was high. In a similar vein, residential roads revealed a low number of interactions, yet still saw a relatively high percentage of safety-critical interactions. Here, the higher rate of safety-critical interactions may be reflective of less available space to yield or of surprise encounters based on restricted views due to trees, houses, or other objects. In contrast, tertiary roads were found to have a high number of interactions, but a low percentage of safety-critical interactions. In these instances, motorists appeared to yield to emergency vehicles both sooner and in a more seamless fashion, likely attributed to a better balance between motorist volume and roadway characteristics. Hence, it appears that road class may greatly influence the types of interactions that emergency vehicles have with other road users, but additional effects (e.g., traffic volume, number of lanes, shoulder presence) should be considered to fully capture the relationship.

CHAPTER 5. CONCLUSION

This pilot study was the first of its kind to capture point-of-view ambulance operation through a naturalistic driving study. Although the data are limited to two participating agencies and the drivers who consented into the study, these agencies were distinct in their geographical operational area and call volume, increasing the extent to which specific results may be generalized to other agencies. Agency 1's ambulance operated continuously throughout the data collection period and captured data from urban, suburban, and rural environments based on station rotation. Agency 2's ambulance was also in continuous service and able to capture multiple use environments but favored suburban and rural communities. The participation of both agencies allowed the study to collect a variety of emergency vehicle use data that support generalizable findings. However, the expected differences between the agencies were evident in the findings. Future studies should aim to recruit more agencies and vehicles from various locations and communities to expand the dataset, minimize agency-specific effects, and address broader questions about emergency vehicle operations and interactions. Despite this, the collected dataset is anticipated to be useful in answering questions about emergency vehicle operation well beyond the initial scope of this study.

Specifically, further analysis could provide new insights into the possible interactions that ambulance operators have with other road users, with a particular interest in intersection traversals. Furthermore, the data collected in the study could be used to assess how ambulances are being driven under different conditions and roadway environments. Safety-critical events experienced by these vehicles could also be identified and analyzed to illustrate confusing and/or dangerous interactions that occur between emergency vehicles and other road users. Assessment of these aspects should consider both emergent and non-emergent driving and consider the extent to which emergent driving influences potentially harmful interactions. Finally, the impact of these situations on patients being transported, presumably receiving medical care en route to a care facility, could also be evaluated. This dataset is now available to answer these and many other similar research questions.

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