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Organisational structural predictors of ambulance crashes: an analysis

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Abstract

Objective: This study investigated the association between three organisational structural factors—organisational type, organisation status (staffing model), and level of service—and ambulance crash rates. The null hypothesis was that there would be no difference in ambulance crash rates during response or transport between any of the three factors. Methods: A cross-sectional design with a sample drawn from the 2019 National Emergency Medical Services Information System dataset was used to examine the relationship between these systems-level factors and ambulance crashes. After applying inclusion criteria, a sample of 2207 cases was drawn and analysed using the χ^2 test of association and multiple logistic regression. Results: There was a statistically significant but small association between level of service and ambulance crashes during transport, using the χ^2 test of association ($P<0.05$). Emergency medical technician (EMT)-level services had lower crash rates and paramedic-level services had higher rates than expected. There was no statistically significant association between organisational type or organisational status and ambulance crashes during either the response or transport phase of an emergency medical service (EMS) call, using the χ^2 test of association ($P>0.05$). Of the two logistic regression models performed, only EMT-level services had a statistically significant association with ambulance crashes during transport ($P<0.05$; OR 0.208 [0.050, 0.866]). Conclusion: The organisational structural factors examined in this study failed to explain most of the variance in ambulance crash rates. However, EMT-level services were associated with lower rates of ambulance crashes than paramedic level services. EMS healthcare administrators and researchers should continue to explore potentially modifiable factors to reduce the incidence of these events and promote positive social change by reducing the risk of injury to patients, EMS workers and the public at large.

Key words
● Emergency medical service ● Ambulance ● Crash ● Donabedian model ● Organisational factors

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Emergency medical services (EMS) is a healthcare specialty concerned with delivering prehospital emergency medical care and transporting patients to the hospital for further care (Office of EMS, 2021). In the United States, EMS workers include emergency medical technicians (EMTs), paramedics and others who work in fire departments, hospitals, non-fire-based governmental agencies, private companies and tribal departments. The EMS workforce of any of these organisations may be paid, volunteer or a mix of the two.

When responding to a scene of injury or illness and when transporting patients to the hospital, EMS workers often use lights and sirens (L&S) to signal traffic to yield to them to expedite their transit. Industry practice prioritises the rapid transport of patients to the hospital, based on the golden hour concept, attributed to R Adams Cowley, the founder of Baltimore's Shock Trauma Institute (Rogers et al, 2015). Cowley asserted that a trauma patient has the best chance of survival if they receive definitive care within 60 minutes of injury. This concept has led to an emphasis on rapid response and transport of trauma patients by EMS agencies, despite a lack of evidence supporting this (Newgard et al, 2010).

Ambulance crashes are a major contributor to EMS worker on-the-job injuries and deaths (Reichard et al, 2017), and there is an association between the use of L&S by EMS and an increased risk of ambulance crashes (Watanabe et al, 2019). Ambulance crashes also contribute to the injury and death of patients, other ambulance passengers (such as family members), occupants of other vehicles and pedestrians.

Research has described the characteristics of L&S use by urbanicity and geographic region (Kupas, 2017); however, a literature review did not find any studies examining the characteristics of EMS organisational structures that may be associated with ambulance crashes. Because there are many different organisational models in the EMS industry in the United States, it is essential to examine what, if any, role variables related to organisational structure play in the rate of ambulance crashes.

To frame this study, the Donabedian model was employed. The Donabedian model describes three measures for understanding quality in healthcare: structure; process; and outcome (Donabedian, 1988). This study focuses on structural variables. Structure indicates the 'conditions under which care is provided' (Donabedian, 2003) and includes organisational characteristics and other factors that make up the context or setting of care delivery. Within the context of EMS, structural variables can include facilities, staffing, credentials, deployment and other characteristics of the system (El Sayed, 2012).

Importance

This study's results add to the collective understanding of factors associated with ambulance crashes, which may inform future action to intervene and create a safer environment of care for EMS workers, patients and others on the road.

Additionally, little research has been carried out to examine structural factors and quality outcomes in EMS using the Donabedian model as a framework. This study helps identify the relationship between organisational structural factors and quality outcomes (in this case, rates of ambulance crashes), which may inform future research that applies the Donabedian model to the EMS setting.

Table 1. Organisation type, organisation status, level of service and ambulance crashes

Variable	Characteristic	Frequency	Valid percentage
Response mode	Lights and sirens	2106	95.4
	Other	101	4.6
Transport mode	Lights and sirens	375	17
	Other	1832	83
Organisational structural factors			
Organisational type	Fire department	895	40.6
	Governmental, non-fire	510	23.1
	Hospital	109	4.9
	Private, non-hospital	693	31.4
	Tribal	–	–
Organisational status	Mixed	394	17.9
	Paid	1776	80.5
	Volunteer	37	1.7
Level of service	Emergency medical technician	148	6.7
	Paramedic	2059	93.3
Dependent variable			
Ambulance crashes during response	Yes	74	3.4
	No	2133	96.6
Ambulance crashes during transport	Yes	133	6
	No	2074	94

Objectives

The purpose of this study is to investigate whether a statistically significant relationship exists between three organisational structural factors of EMS services and the rate of ambulance crashes by EMS agencies providing 911 transport. These structural factors are: organisational type; organisational status (staffing model); and level of service (*Table 1*).

Organisational type describes the overall structure of the department and includes the following: fire; governmental, non-fire; hospital; private, non-hospital; and tribal. Level of service describes the minimum certification level provided for every request for service, either EMT or paramedic. Organisational status describes whether the agency is staffed with volunteers, paid personnel or a mix of the two (National EMS Information System, 2020).

This study examines the association between these three organisational structural factors and ambulance crash rates. Using the Donabedian model as the study's guiding framework, the author hypothesises that an association exists between these organisational factors and ambulance crashes.

Methods

Study design and setting

This study uses a cross-sectional design with secondary data from the National Emergency Medical Services Information System (NEMSIS) dataset. The variables of interest in this study are organisational type, level of service and organisational status, and the dependent variable for this study is ambulance crash rates. This study examines the relationship and association between these variables and ambulance crash rates; all variables are measured at the categorical level (dichotomous and polytomous).

Institutional review board oversight and approval was provided by Walden University, which determined that no human subjects were included in this study.

To obtain an appropriate sample for this research study, inclusion criteria were set. Filters limited the cases included in the sample to those from EMS agencies that provide emergency response and transport of patients to hospital, and provide either EMT- or paramedic-level service. Cases that did not meet these inclusion criteria or had values missing

for any of the variables of interest were excluded from statistical analysis.

These study data were retrieved from the NEMSIS dataset, which includes data on more than 34 million EMS activations from 10 062 EMS agencies serving 47 states and territories (NEMSIS Technical Assistance Center, 2020). The NEMSIS dataset is a large convenience sample provided by approximately 47% of EMS agencies, based on the reported number of 21 283 EMS agencies in the United States in 2011 (National Highway Traffic Safety Administration, 2014).

There is some selection bias inherent in using these data as submission to NEMSIS is not uniform across states. Data deficiencies originating from contributing parties are carried over into the NEMSIS data. However, the NEMSIS technical assistance committee works to improve data quality data by checking for completeness, consistency and formatting; data that fail the NEMSIS technical assistance committee validation processes are removed or flagged, and a quality report provided to the sending agency.

Outcomes

The outcome variables for this study are whether an ambulance crash occurred during either the response or the transport phase of the ambulance response. These variables are indicated in the dataset within the data element of type of response delay and type of transport delay. Values for each of these data elements were consolidated to provide dichotomous levels: yes, an ambulance crash occurred; or no crash reported.

Analysis

All data analysis was completed using IBM SPSS 25 to perform two statistical tests: cross-tabulation with the χ^2 test of association; and multiple logistic regression. Cross-tabulation using the χ^2 statistic provided univariate frequency distribution of each of the variables (*Table 2; Table 3*). Logistic regression explained the relationships between the covariates and the dependent variable, controlling for the effect of one variable while examining the effect of the other (Agresti, 2013) (*Table 4; Table 5*). Cramer's V test and odds ratio (OR) were the measures of effect, and alpha for both χ^2 and logistic regression was set at 0.05. Multiple logistic regression was performed to determine the effects of organisational type, organisational status, and level of service on ambulance crashes while responding to the scene of the 911 call. For each variable analysed, a reference category was used to make comparisons; these reference variables were 'private, non-hospital', 'paid', and 'paramedic', respectively.

Table 2. Cross tabulation: predictor variables by ambulance crashes during response

Variable	Characteristic	Ambulance crash during response			
		No crash		Ambulance crash	
		n	%	*n*	%
Organisational type	Fire department	866	40.6	29	39.2
		(0.2)		(–0.2)	
	Governmental, non-fire	498	23.3	12	16.2
		(1.4)		(–1.4)	
	Hospital	105	4.9	4	5.4
		(–0.2)		(0.2)	
	Private, non-hospital	664	31.1	29	39.2
		(–1.5)		(1.5)	
	Tribal	–	–	–	–
Organisational status	Mixed	383	18	11	14.9
		(0.7)		(–0.7)	
	Paid	1713	80.3	63	85.1
		(–1)		(1)	
	Volunteer	37	1.7	0	0
		(1.1)		(–1.1)	
Level of service	Emergency medical technician	143	6.7	5	6.8
		(0)		(0)	
	Paramedic	1990	93.3	69	93.2
		(0)		(0)	

Results

Descriptive statistics

Applying inclusion criteria, the total case count was 4 950 856. This was much higher than the required sample size determined by the *a priori* power analysis of 202 with a power of 0.95, alpha=0.05 and effect size (OR)=1.83.

After all cases had been filtered according to the inclusion criteria, 207 ambulance crashes were identified in the dataset. Seventy-four of these occurred while responding to the scene, and 133 during transport. All cases of ambulance crashes and a random sample of 2000 cases where no ambulance crash occurred were drawn to give a combined study sample size of 2207 cases.

Univariate analyses

Response

χ^2 tests of association were conducted between: organisational type and ambulance crashes; organisational status and ambulance crashes; and level of service and ambulance crashes during response. Two cells (hospital—ambulance

crash; volunteer—ambulance crash) had a frequency that was less than the minimum expected (4 and 0, respectively—minimum expected was 5). There was no statistically significant association between organisational type, organisational status or level of service and ambulance crashes during response, with $\chi^2(3)=3.122$, $P=0.373$, $\chi^2(2)=1.873$, $P=0.392$, and $\chi^2(1)=0.000$, $P=0.986$ respectively. The adjusted standardised residuals were <2 for all categories (-1.5–1.5), indicating that the cell counts were close to expected by the null hypothesis (Kim, 2017).

Transport

χ^2 tests of association were also conducted between: organisational type and ambulance crashes; organisational status (staffing model) and ambulance crashes; and level of service and ambulance crashes during transport.

One cell had a frequency that was less than the minimum expected. There was a statistically significant association between level of service and ambulance crashes during transport, $\chi^2(3)=6.122$, $P=0.013$, with a small effect size as determined by Cramer's V, 0.052, $P=0.013$ (Kim, 2017). The adjusted standardised residuals were >2 within the cells for level of service, indicating that the cell counts did not match those expected by the null hypothesis (Kim, 2017).

Ambulance crashes occurred at a lower rate than expected in agencies providing an EMT level of service (2.0 versus 8.9) and at a higher rate than expected for paramedic-level services (131 versus 124.1). There was no statistically significant association between ambulance crashes by organisational type or organisational status during transport, with $\chi^2(3)=3.896$, $P=0.273$ and $\chi^2(2)=0.920$, $P=0.631$ respectively.

Table 3. Cross tabulation: predictor variables by ambulance crashes during transport

Variable	Characteristic	Crashes during transport			
		No crash		Crash	
		n	%	*n*	%
Organisational type	Fire department	840	40.5	55	41.4
		(–0.2)		(0.2)	
	Governmental, non-fire	474	22.9	36	27.1
		(–1.1)		(1.1)	
	Hospital	100	4.8	9	6.8
		(–1)		(1)	
	Private, non-hospital	660	31.8	33	24.8
		(1.7)		(–1.7)	
	Tribal	–	–	–	–
Organisational status	Mixed	367	17.7	27	20.3
		(–0.8)		(0.8)	
	Paid	1,673	80.7	103	77.4
		(0.9)		(–0.9)	
	Volunteer	34	1.6	3	2.3
		(–0.5)		(0.5)	
Level of service	Emergency medical technician	146	7	2	1.5
		(2.5)		(–2.5)	
	Paramedic	1928	93	131	98.5
		(–2.5)		(2.5)	

Multivariate analysis

Response

Multiple logistic regression was performed to determine the effects of organisational type, organisational status and level of service on ambulance crashes while responding to the scene of the 911 call.

The results of this test demonstrated adequate goodness-of-fit as assessed by the Hosmer-Lemeshow test ($P=0.579$) and were not statistically significant, with $\chi^2(6)=6.150$, $P=0.407$. The model explained 1.1% of the variance in ambulance crashes (Nagelkerke R^2) and correctly classified 96.6% of cases. L&S were employed at all of the 74 ambulance crashes that occurred during response in this sample.

Transport

A second regression model was performed to determine the effects of organisational type, organisational status and level of service on ambulance crashes during transport. The overall model demonstrated adequate goodness of fit as assessed by the Hosmer and Lemeshow test ($P=0.152$) and was not statistically significant, $\chi^2(6)=12.208$, $P=0.057$. The model explained 1.5% of the variance in ambulance crashes (Nagelkerke R^2) and correctly classified 94% of cases.

Of the 133 ambulance crashes that occurred during transport in this sample, L&S were used during 39 (29.3%) of these cases. EMT-level agencies had statistically significantly lower odds of reporting an ambulance crash during transport ($P=0.031$, OR=0.208 [0.050, 0.866]).

Limitations

There are several limitations associated with this study. First, it used a convenience sample of data provided by NEMSIS. The limitations of the dataset, therefore, are inherent to the results of the study. For example, not all ambulance crashes may have been recorded in the medical record. Additionally,

the use of L&S may have been inaccurately recorded in some cases.

An ambulance is only one type of emergency vehicle dispatched in response to requests for emergency medical aid in many locations. This study did not examine crash rates of non-transporting vehicles, such as supervisor cars, fire department rescue squads, community paramedic vehicles or others.

Because of limitations in the data, this study was also unable to account for extraneous factors that may influence rates of ambulance crashes, such as driver age, driver history/experience, type of emergency vehicle response training, road type and visibility at the time of the crash.

Therefore, the results are an examination of systems-level factors under all-conditions crashes, i.e. regardless of weather or road conditions or the experience of the driver. Because these factors are not directly associated with the macroscopic variables of interest in this study, it is assumed that their relevance applies to individual crashes, which was beyond the scope of this study.

The inclusion criteria for this study limit its applicability to EMS agencies whose organisational type is not represented in the dataset and those that provide a different level of service (such as advanced EMTs, nurses or physicians).

The sample was also specific to services providing an emergency response with transport capabilities so agencies that offer only EMS first response or transport between facilities were not represented.

Finally, small sample sizes for volunteer and EMT-level services may influence the reliability of inferential statistical tests. All cases with missing values were excluded from statistical analysis to ensure the most reliable data.

Discussion

To the author's knowledge, no previous studies have examined the relationship between systems-level factors and ambulance crashes using the Donabedian model as a theoretical framework. Previous researchers have established the validity of this model and its application to the EMS setting; however, few have explored this in practice.

The results of this study are consistent with other work explaining the overall weak effect of structure on quality outcomes (El Sayed, 2012), with statistically significant results limited to only one factor—level of service—in this study.

The generalisability of these findings is limited to US services providing emergency response and transport at the EMT or paramedic level of service.

Overall, the results suggest that the organisational structural factors assessed in this study are not strongly associated with ambulance crash rates. Safe ambulance operation depends on many skills, including driver attentiveness, judgement, and reaction time (Weaver et al, 2015). Given that services use different staffing models, there may be organisational structural factors that influence these events, such as level of training, shift length, policies on fatigue mitigation, and emergency vehicle operations training. If so, it does not appear that these factors are aligned to organisational type, organisational status or level of service provided by the EMS agency.

Table 4. Logistic regression test results regarding ambulance crashes during response

Covariate	*n*	OR	95% CI	*P*
Organisational type				
Fire department	29	0.793	(0.453, 1.387)	0.416
Government, non-fire	12	0.553	(0.276, 1.107)	0.095
Hospital	4	0.858	(0.293, 2.507)	0.779
Private, non-hospital	29	(Ref)	(Ref)	(Ref)
Organisational status				
Volunteer	0	-	-	-
Mixed	11	0.838	(0.424, 1.656)	0.611
Paid	63	(Ref)	(Ref)	(Ref)
Level of service				
Emergency medical technician	5	0.949	(0.367, 2.452)	0.914
Paramedic	69	(Ref)	(Ref)	(Ref)

Table 5. Logistic regression test results regarding ambulance crashes during transport

Covariate	*n*	OR	95% CI	*P*
Organisational type				
Fire department	55	1.132	(0.711, 1.803)	0.602
Government, non-fire	36	1.361	(0.830, 2.230)	0.222
Hospital	9	1.594	(0.739, 3.441)	0.235
Private, non-hospital	33	(Ref)	(Ref)	(Ref)
Organisational status				
Volunteer	3	1.972	(0.582, 6.688)	0.276
Mixed	27	1.146	(0.723, 1.815)	0.562
Paid	103	(Ref)	(Ref)	(Ref)
Level of service				
Emergency medical technician	2	0.208	(0.050, 0.866)	0.031
Paramedic	131	(Ref)	(Ref)	(Ref)

Key points

- Ambulance crashes are a major contributor to injury and death among emergency workers, patients and other workers on the road
- A literature review did not find any studies examining the characteristics of emergency medical services (EMS) organisational structures that may be associated with ambulance crashes
- This study examined the role of organisational structural variables on ambulance crash rates in United States EMS departments.
- Structural variables indicate the conditions of the care environment, such as facilities, staffing, credentials, etc
- Of the variables studied, only level of service was associated with different rates of ambulance crashes

James Reason introduced the Swiss cheese model of accident prevention in 1990, which asserts that layers of prevention exist between an adverse event and decisions by organisational leaders and that accidents occur when holes in these layers align (Musgrove, 2021). This concept has been widely applied to patient safety (Stein and Heiss, 2015) and may apply to the incidence of ambulance crashes in the prehospital environment as well. If this is true, there is no silver bullet for preventing ambulance crashes, nor macroscopic deterministic organisational features that can predict them. Instead, these factors may serve only as layers of prevention that interact with processes such as the use of L&S and external circumstances like adverse weather. All of these may ultimately lead to or prevent disaster.

This study addresses a gap in the literature regarding the role of three organisational structural factors on ambulance crashes, including organisational type, organisational status and level of service. Data analysis indicated that only the level of service has a statistically significant association with ambulance crashes, with EMT-level services experiencing lower rates of ambulance crashes than paramedic-level services during transport.

Conclusion

The organisational structural variables assessed in this study failed to explain the majority of the variance in ambulance crashes, suggesting that other variables account for the majority of incidents. These may include driver competence, weather conditions, vehicle status, time of day, driving conditions, and use of L&S. EMS administrators should continually assess the preparedness of their agency for these types of events, take precautionary action to intervene before a crash occurs, and investigate the causes of crashes after they occur. Future research should attempt to analyse organisational factors along with other event-related variables, such as driver age, experience level, weather and road conditions. **JPP**

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CPD Reflection Questions

- What policies or practices does your organisation employ to manage the risks of emergency vehicle operations?
- What training do you think would be beneficial for emergency medical services (EMS) providers to teach safe vehicle operations? How often should EMS providers receive this training?
- If you have been in an ambulance crash, what interventions do you think may have prevented it?