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Hazard Analysis and Vehicle Safety Issues for Emergency Medical Service Vehicles: Where is the State of the Art?

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Introduction

Emergency Medical Service (EMS) vehicles, ambulances, are relatively familiar vehicles to those of us in the general community. We see them as 'life savers' racing through the streets to provide emergency medical care to the public. However, what are the safety issues that pertain to this important public service and public safety industry? What do we know of the risks and hazards, how can we measure these and how can we optimize the safety of this system? This paper provides an outline of the known hazards, some tools that can be applied to evaluating these safety issues, some of the current safety challenges and addresses some of the multidisciplinary techniques for optimizing the safety of the system as a whole.

Background

History of EMS

EMS is a relatively new industry, an industry that has an unusual history of beginnings within the mortician industry. Actually the first ambulances were hearses, usually a Cadillac, a vehicle in which an occupant could be transported in the recumbent position. Over the past 100 years, the sophistication of the medical care possible to provide in the EMS environment has advanced dramatically, with EMS providers over that short time becoming highly skilled and expertly trained emergency health care professionals – with use of high tech medications and equipment.

Statement of the problem

The transport and occupational safety issues pertaining to the delivery of EMS care have not kept pace with the advancement of the medical emergency care provided. Nor has it kept pace with the developments of the automotive safety industry. This is possibly due to ambulance graduating from a Cadillac to a combined chassis with a mounted box, somehow outside of the purview of both the automotive safety and also occupational safety and health arenas. Compounding this also is that ambulance vehicles are a very diverse fleet: vans, light and heavy trucks and freightliners. Despite the large strides that the general automotive industry has made in the last 30 years in the safety of passenger vehicles, this expertise has not yet been translated substantively to the safety of ambulance vehicles. There are few safety standards and no crash safety testing guidelines that pertain to ambulance vehicles in the USA. Thus ascertaining the safety of EMS transport vehicles (and products in that environment) remains limited to expert opinion and peer evaluation in a piecemeal fashion. EMS has been generally demonstrated recently to be a dangerous profession, and vehicles crashes have been shown to be the most likely cause of a work related fatality in EMS (Maguire 625). The most dangerous part of the ambulance vehicle has been demonstrated in both biomechanical and epidemiological studies to be the rear patient compartment (Becker 941, Levick 454. 452, 36), which currently is a part of the ambulance vehicle that is largely exempt from the Federal Motor Vehicle Safety Standards (FMVSS). Also, unfortunately, no reporting system or database exists specifically for identifying ambulance crash related injuries and their nature, so specific details as to which injuries occurred and what specifically were the mechanisms which caused them are scarce, and there is not yet a national system for this data capture. What we do know is that ambulances have high crash fatality rates per mile, well above those of passenger vehicles, or even when compared to similar sized vehicles (Ray 412).- and there is approximately one ambulance crash fatality per week in the USA, and a number of serious injuries for each fatality, with over 4,000 reportable crashes per year (Becker 941).

There has been a limited number of peer reviewed automotive safety engineering testing conducted for the EMS environment (Best 17, Levick 45, 1173, 454. 452). That which has been conducted has clearly identified some predictable and largely preventable hazards, particularly pertaining to intersection crashes and the hazards of the rear patient compartment, demonstrating the benefit of use of existing restraints for occupants, the importance of over the shoulder harnesses for the recumbent patient and firmly securing all equipment (Best 17, Levick 45, 454, 1173, 452). These studies also identify hostile and hazardous interior surfaces of the rear compartment, as well as a need for head protection. Many fatal and injurious ambulance crashes are related to risky driving practice by EMS personnel, particularly when in emergency use. Failure to stop at intersections has been identified as an extremely high risk practice, and some of the larger EMS services have clear policies in place that ambulances must come to a complete stop at a red light or stop sign at an intersection. Lack of use of seatbelts by EMS personnel is cited frequently in the literature as a predominant cause for the high injury and fatality rates in EMS crashes (Becker 941). The hazards resulting from the failure to secure equipment in the patient compartment, which has also been found to cause serious injury in the event of a collision has also been documented. This is supported by the engineering data from ambulance safety research involving crash tests (Levick 1173), as well as insurance and litigation records.

The very recently developed American National Standards Institute/American Society of Safety Engineers Z15.1 Fleet Safety Standard (ANSI 2006) is possibly the only nationally approved safety standard that is now applicable to the safety management of EMS vehicle fleets. It is likely that the implementation of this standard will enhance the data collected regarding EMS vehicle safety, and hopefully provide more emphasis on EMS vehicle safety generally and assist in bringing EMS vehicle safety more inline with state of the art automotive safety practices.

Approach to hazard analysis and optimizing safety

Given the unique nature of EMS, in that it bridges, public health, public safety, emergency medical care, automotive safety and also occupational health and safety – it is paramount that the safety of this system be addressed with a multidisciplinary approach. The key disciplines that are involved in the assessment of risk and hazard and in optimizing EMS safety are:

- Public Health: Epidemiology and Emergency Health Care Delivery
- Safety Engineering: Automotive and Environment
- Ergonomics and Biohazards
- EMS Practice, Fleet Management and Policy

Multidisciplinary Hazard Analysis and Optimizing Safety

Public Health: Epidemiology and Emergency Health Care Delivery

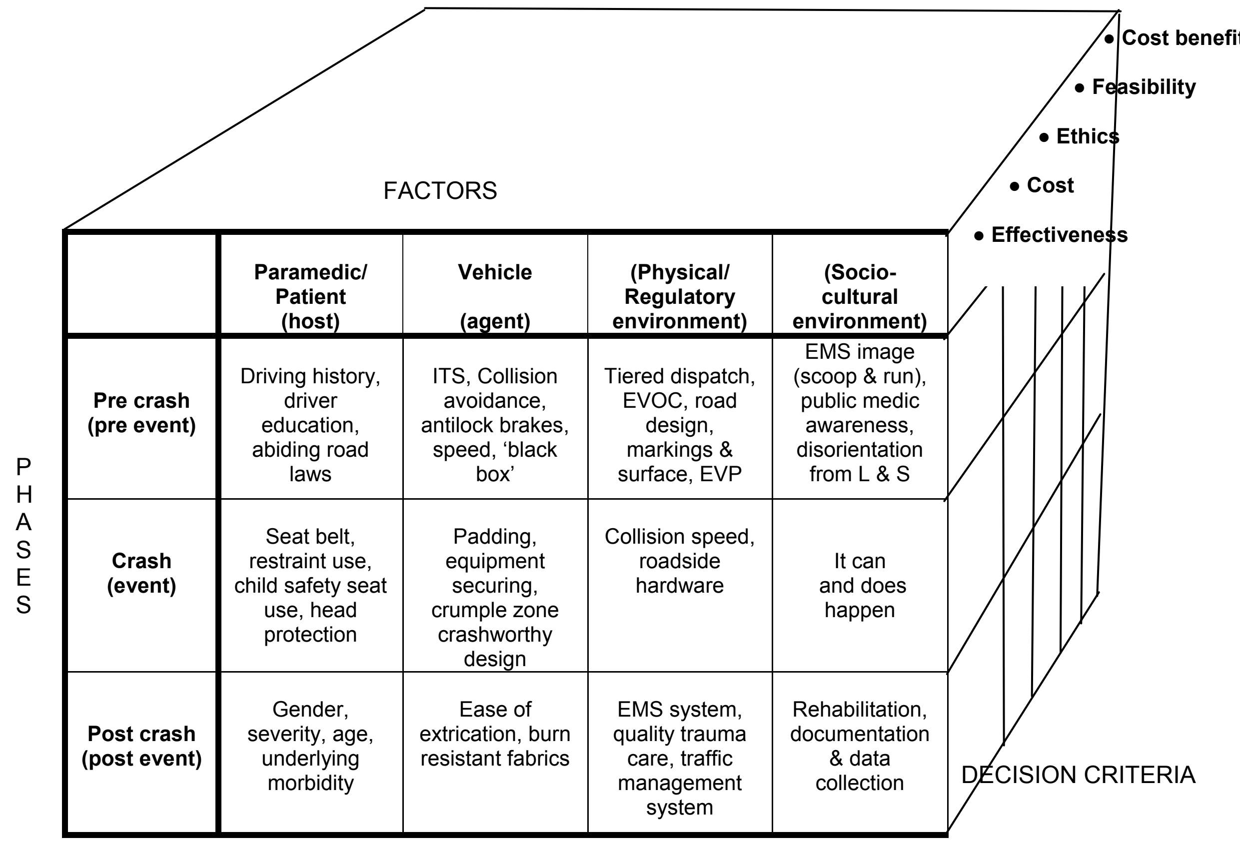
The passenger vehicle automotive safety industry has a well honed public health approach to the assessment of risk and safety. There are a number of well funded detailed databases that capture passenger vehicle crash and safety data. Such is not the case for EMS.

In the absence of a database to specifically identify EMS associated morbidity and mortality, evaluation of injury risk and hazard has to be pieced together from diverse data sources (Maguire 625). These sources include non specific fatality data bases or occupational databases, where EMS providers are sometimes difficult to identify as a unique group, and some of the insurance or larger individual EMS system data bases. However in these databases it is often not possible to identify the non-EMS provider morbidity or mortality associated with EMS crashes.

Over the past 5 years there have been a number of publications in the epidemiology literature addressing these EMS morbidity and mortality crash related statistics (Auerbach 1487, Becker 941, CDC 154, Heick 121840, Kahn 261, Ray 412, Maguire 625, Levick 10.1). Most of these publications reach very similar conclusions and identify serious risk and hazard from intersection collisions, use of high speed and lights and sirens, as well as serious injuries and fatalities from failure to use seat belts in the rear patient compartment. There are also risks to EMS providers at an emergency scene such as the scene of automotive crash events, where they are at risk of being struck by a passing vehicle due to poor visibility (Heick 121840).

Unfortunately most of the large EMS agency databases, which are very robust, and the insurance data bases also, are proprietary and hence not easily accessible to the public health researchers. Thus opportunities for mining such databases have been scarce, however the information contained in them would be of great advantage for better understanding, at a population level, EMS injury mechanisms and the clearer identification of risk and hazard. Ideally, given the nature of EMS, in that it is a public service, out side of the hospital environment, where acute health care is delivered at an emergency scene or in a transport and automotive environment – it is paramount that such research data be evaluated with input from a cross disciplinary team of experts, familiar with emergency medical care, ergonomic and biomechanical aspects and issues well as transportation risks and automotive safety science. A detailed understanding of EMS care delivery is as essential to appreciating EMS safety and risk as is the science of automotive safety and biomechanics. Expertise in all related fields of potential risk and hazard- automotive safety, and also including those of biohazards and ergonomic aspects - are key as part of the epidemiological approach to evaluation of the safety of EMS.

A model that applies well to understanding the EMS vehicle crash arena is the multidisciplinary Haddon's Phase Factor Matrix, which addresses a crash scenario both temporally and by the composite components of the vehicle, host, agent and environment. Particularly relevant is the enhanced model by Baker and Runyon (Runyon 302), which includes the important dimensions of cost effectiveness, societal acceptability and ethics. This model approaches the complex crash event and any resultant morbidity or mortality in a very structured fashion. It disaggregates this one event into separate 'cells', that identify the issues that could be addressed prior, during and after the crash event that could have prevented it from occurring or minimized the injuries sustained. This matrix is applied not only to each phase of the crash event, (before, during and after), but also to each factor involved (in this case, the medic, the patient, the vehicle, the physical environment, and socio-cultural and regulatory environment). The third dimension is that of decision criteria, (such as cost, effectiveness, ethics and feasibility), see Diagram 1.



	Paramedic/ Patient (host)	Vehicle (agent)	(Physical/ Regulatory environment)	(Socio-cultural environment)
Pre crash (pre event)	Driving history, driver education, abiding road laws	ITS, Collision avoidance, antilock brakes, speed, 'black box'	Tiered dispatch, EVOC, road design, markings & surface, EVP	EMS image (scoop & run), public medic awareness, disorientation from L & S
Crash (event)	Seat belt, restraint use, child safety seat use, head protection	Padding, equipment securing, crumple zone crashworthy design	Collision speed, roadside hardware	It can and does happen
Post crash (post event)	Gender, severity, age, underlying morbidity	Ease of extrication, burn resistant fabrics	EMS system, quality trauma care, traffic management system	Rehabilitation, documentation & data collection

Diagram 1.
The Runyan/Baker Haddon's Phase–Factor Decision Criteria Matrix applied for analysis of the determinants of an EMS crash event

Safety Engineering: Automotive and Environment

There are many peer reviewed environments for sharing research and developments for general automotive safety, such as the Society of Automotive Engineers (SAE), Enhanced Vehicle Safety (ESV) and Stapp conferences to name just a few. However, ambulance vehicle safety research has essentially not had the benefit of being part of this infrastructure and vehicle safety peer review. This is despite light and heavy trucks being well represented in these forums. The author was involved in the coordination of the first and only SAE TopTec on Emergency Vehicle Safety in 2001, and authored the only 2 papers to date at ESV on ambulance safety (Levick, 454, 452).

Biomechanical evaluation and automotive safety testing are the tools used to assess injury mechanisms and to predict injury patterns. To better understand specific injury mechanisms there are two basic modalities employed, either detailed crash reconstruction or crash testing (either sled/barrier testing or full vehicle testing). There has been very limited research in the area of ambulance crash testing published in the peer reviewed literature (Best 17, Levick 45, 454, 1173, 452). Given the comments above regarding industry based data, access to crash reconstruction data is often proprietary and not easily accessible to researchers. Also, as described, the fleet of ambulance vehicles ranges from vans, to trucks (light and heavy) to freightliners – a challenge for generally assessing safety. Full ambulance vehicle crash testing as well as barrier testing show similar outcomes and predicted injury results for frontal impacts (Levick 45, 1173, 454. 452). Side impact full vehicle testing similarly demonstrates predictable and frequently preventable injury mechanisms. These studies have addressed the vans (Type II ambulances), light trucks (Type I ambulances) and heavy trucks (Type III ambulances). To date the published engineering data concurs with the epidemiological findings that there are clearly identifiable biomechanical risks and hazards in ambulance vehicles (Levick 2000), particularly in the rear patient compartment. Hostile interior surfaces, hazardous head strike zones, poor design and interior layout and a non crashworthy rear compartment (Levick 1173, 454. 452).

Personal protective equipment, to protect occupants in the EMS vehicle environment in the USA, is at best limited. There exists no head protection standard specifically for ground EMS in the USA, and protective clothing similarly has not been addressed for ground EMS providers as it has for other emergency services (Levick 117405). Currently, the author is involved in initiatives to address this, particularly with regard to head protection, as this environment is unique in the injury hazards and exposure, being both on scene exposures and in vehicle transport risks and hazards

Furthermore, unlike EMS air medical vehicles (ie. helicopters), restraint systems for ambulance vehicles have no specific design or safety standards. Thus there are restraint systems available on the market that have either not been safety tested at all, or may have been tested and yet in the absence of a standard, claims being made that may or may not have any bearing on the actual safety of the said devices. Access to the patient whilst seated is a constant challenge in the larger EMS trucks, so that design of a seat which slides toward the patient can offer enhanced access to the patient, whilst still allowing the medic to remain in the seat. However, there are even seat/seat belt systems being developed and available on the market that when the medic attempts to slide the seat forwards, the seat belt restrains the medic and the seat from doing so, or that once the seat has been slid to the forward position, it is then not possible to access the seat belt. These are the type of design flaws that can exist in the absence of safety and design standards.

To enhance collision avoidance there are a number of new technologies currently available and on the horizon, pertaining to driver behavior modification, intelligent vehicle design and other safety technologies.

Driver feedback “black box” technology with real time driver monitoring and feedback has been implemented in some regions in the USA, and has shown very promising enhancements of driving behavior in a number of studies (De Graeve 111, Levick 2005). These devices provide real time immediate feedback and data recording that has shown great promise in optimizing safety in the EMS transport environment. They have been demonstrated to reduce the number seatbelt and speed violations by EMS personnel, decrease the number and severity of vehicle collision events and also minimize vehicle maintenance costs. Additionally, these findings have been in a setting with optimized response times. The data from these devices is generated and downloaded automatically – and hence there is a large savings in administrative time involved in data capture and management. Also in the setting of a crash or adverse event occurring, all the vehicle crash and driver data is captured automatically and easily reviewed and analyzed (Levick 2005), saving time and money invested in crash reconstruction and analysis. Other devices are available that provide video capture of the driver and vehicle. These devices are both more

intrusive and also require a heavy administrative burden for monitoring and feedback – and appear to have less impact on preemptively addressing risky driving practices.
There are also training simulators being developed and trialed, in some of the major centers, (notably Fire Department of New York EMS Training Department), for evaluation of performance and judgment under simulated high risk driving situations so as to enhance driver training programs for medics.

There are many aspects of Intelligent Transportation Systems (ITS) technology currently being developed by state of the art automotive safety engineers and researchers, and these technologies are being applied to passenger vehicles, and even to some heavy and light trucks. These safety systems make use of information, communications and positioning technologies to provide solutions for improving road safety. With such technology - which can operate either autonomously on-board the vehicle or co-operatively based on vehicle-to-vehicle or vehicle-to-infrastructure communication - the number of accidents and their severity can be reduced. (ITS D7.11)

However it appears that EMS providers and EMS vehicle development are not formally integrated with these ITS programs and thus EMS is not generally involved in the application of these initiatives. This situation needs to be rectified as soon as possible as ITS technologies are likely of great benefit to EMS system safety. ITS preventive safety applications, assist drivers to avoid or mitigate an accident through the use of in-vehicle systems that sense the nature and significance of the danger, while taking the driver's state into account, and support drivers to:

- Maintain a safe speed
- Keep a safe distance
- Drive within the lane
- Avoid overtaking in critical situations
- Safely traverse intersections
- Avoid crashes with vulnerable road users
- Reduce the severity of an accident if it still occurs

These are systems that can assist in the very areas that it has been demonstrated that EMS vehicles are most at risk – such as intersection safety, warning the driver if they are about to run off the road, supporting safe speed and safe following, protecting vulnerable road users and optimizing collision mitigation. ITS achieves this, depending on the significance and timing of the threat, by informing the driver as early as possible and by providing a warning if there is no driver reaction to the information, and actively assisting or ultimately intervening in order to avoid an accident or mitigate its consequences. (ITS D7.11) These safety enhancements, in the setting of the potential stress and chaos of an emergency transport are likely to be most valuable.

One aspect of ITS that is being considered for enhancing EMS safety is Emergency Vehicle Preemption (EVP). This is a technology that addresses traffic signals at intersections with an approaching emergency vehicle. There are a number of systems that have been trialed and implemented around the USA for emergency vehicle preemption at intersections governed by traffic lights. There have been some positive findings to date, however the studies conducted have been limited in addressing confounding variables (that may have also resulted in improving the safety of EMS transport outcomes), such as changes in policy or general change in awareness about EMS safety coinciding with the studies (ITS 14097). The value of these technologies in congested traffic situations has yet to be demonstrated. The 2006 National Highway Traffic Safety Administration (NHTSA), cross cutting project summarizes these studies (ITS 14097).

Ergonomics and Biohazards

An important role of the occupational safety and health infrastructure in the USA, has in many industries, historically been focused on ergonomics and biohazard protection. However, although there has been some focus on biohazards in the EMS environment, there has been very limited to almost non existent focus on ergonomics in the EMS environment by the government or any other occupation safety and health infrastructure in the USA. Ergonomic research in many industries is extensive, however there is to date only one peer reviewed published paper on the ergonomics of the EMS transport environment, and this was only just recently published and it is from the UK. (Ferreira 97) There are no peer reviewed published ergonomic papers identified relating to the EMS transport environment in the USA.

A proper understanding of the ergonomics of this work place would assist greatly in enhancing and optimizing ambulance vehicle design and safety. The complexities of tasks performed in the ambulance vehicle, lend it well to ergonomic evaluation. This is very much an important area of EMS systems safety that requires focused attention from those expert in this field of ergonomics and particularly the government agencies whose charter it is to address safety in the workplace. Historically in the USA, the National Highway Traffic Safety Administration (NHTSA) is focused and expert in automotive safety, crashworthiness and vehicle crash research. Ergonomic research being the purview of The National Institute for Occupational Safety and Health (NIOSH), an organization that is historically geared, focused and staffed toward epidemiology, biohazards and ergonomic research in contrast to vehicle crashworthiness and vehicle crash testing. It would appear most unfortunate for the organization that is skilled and equipped to conduct epidemiological and ergonomic research not to be performing this important work, yet to be conducting vehicle crash testing and in the absence of a track record in that field. This is particularly alarming when the epidemiological and ergonomic work is seriously lacking. This population based epidemiological and ergonomic research is so needed in EMS, as it is a fundamental foundation for automotive engineering and crashworthiness research to be conducted effectively. Automotive crash testing research based on proper real world population based EMS practice and injury profile data, and not anecdote - so as to properly enhance the safety of EMS.

EMS Practice, Fleet Management and Policy

One aspect of EMS that does make addressing the safety of this situation more easily manageable than many other fleet workforces, is that EMS practice and policy are well structured. EMS providers are a fundamentally highly responsible cohort as well as closely monitored. They are accustomed to following highly structured policy and procedure, particularly in reference to delivery of medical care, and also to expect close supervision and scrutiny. It would appear that this should also clearly extend into the realm of vehicle operations and safety.

Given that there have been longstanding exemptions for ambulance vehicles from the Federal Motor Vehicle Safety Standards (FMVSS), even in the face of the National Transportation Safety Board (NTSB) making recommendations to the contrary, as far back as in 1979 (NTSB HAR-79/04) – identifying best safety practice with respect to vehicle safety has been a challenge for the EMS industry (Levick 20, 36).

To optimize driver performance and fleet safety, there are a number of driver training courses available, one is the Emergency Vehicle Operators Course (EVOC), a result of the 1979 NTSB recommendations and is an expert panel derived risk and safety awareness driver training program. There are also now a few comprehensive driver training programs utilizing simulators as a part of a structured driver training program, one such program referenced above is at the Fire Department of New York, EMS Training Program – where the simulator is used as an adjunct to assess judgment, skill and performance under simulated stressful circumstances. However even

EVOC is not mandated across the USA and there has been limited guidance nationally for general EMS fleet vehicle safety management. There are national EMS associations and accreditation organizations, the Committee on the Accreditation of Ambulance Services (CAAS) and the Committee on the Accreditation of Medical Transport Services (CAMTS) for example who provide guidance and certification for the management of an ambulance service. The guidelines for these organizations cover the broad scope of what is involved in an ambulance service and do also advance awareness for ambulance vehicle safety issues.

In Australasia and Europe there exist specific ambulance vehicle safety standards: The AS/NZS 4535:1999 in Australasia (Joint Standards 4535), and the EN 1789:2002 (European CEN 1789) in Europe. Both standards specifically address the design, restraint system integrity, safety performance testing, dynamic crash testing and safety features of ambulance vehicles. The only guidelines in the USA specifically addressing ambulance vehicles are the KKK specifications, which are Federal purchase specifications for a General Services Administration (GSA) Star of Life ambulance (GSA KKK - 1822). These purchase specifications do not address crashworthiness issues or any dynamic performance testing. There is also the Do's and Dont's guideline for the transport of children in ambulances (EMSC/NHTSA 1999), but these do not address vehicle design or safety performance, and are rather practical guideline to optimize the safety of transporting pediatric patients in ambulances.

Until the newly approved American Society of Safety Engineers and American National Standards Institute (ASSE/ANSI Z15.1) fleet vehicle standard there was no national standard in the USA specifically for fleet management that encompassed EMS fleets (ANSI 2006). The ANSI/ASSE Z 15.1 fleet management standard is a major advance and should benefit EMS safety substantively by providing a template for the safety oversight and management of its fleet of vehicles.

Conclusion

Although automotive safety and occupational safety and health are well developed sciences in the general community and workforce, it appears that the application of these sciences to the EMS transport environment has been slow, and is only now just beginning to be addressed. This is despite EMS being recently described as a hazardous profession. There are some clearly defined hazards and risks associated with EMS transport that are now identified by peer reviewed publications in the epidemiology, engineering and ergonomic literature. There exist also a number of epidemiology, engineering, ergonomic and policy tools to evaluate and address many of these risks. An innovative framework bridging an understanding of the delivery of EMS care, key EMS safety research, ergonomic and current automotive safety and intelligent transport technology is necessary to facilitate enhanced cross disciplinary collaboration in the development of safety initiatives to optimize the safety of the delivery of Emergency Medical Services.

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