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FINAL REPORT

Highway Safety Performance Metrics and Emergency Response in an Advanced Transportation Environment

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16. Abstract

Traditional highway safety performance metrics have been largely based on fatal crashes and more recently serious injury crashes. In the near future however, there may be less severe motor vehicle crashes due to advances in driver assistance systems, infrastructure and vehicle based communication technologies, active traffic management systems, and vehicle design. To understand the impact that these technologies will have on highway safety, emergency response, and performance metrics this paper evaluates the state of the art practices and technologies that will transform future transportation systems. In addition, event scenarios in which crashes or safety critical events could still occur are examined. Finally, alternative highway safety performance measures and response are identified.

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MOTIVATION

In the not too distant future, sensor-rich vehicles operating on smart roadways will automatically exchange safety information with other vehicles and with the roadway. Active sensing and ranging systems such as radar, laser scanners and ultrasonic sensors, will be fused with passive systems such as computer vision, to provide redundant sensing and prevent crashes, even in poor weather. Some level of vehicle automation will be established and short range communications between vehicles will support cooperative adaptive cruise control, enabling smaller longitudinal gaps between vehicles and increasing the capacity of existing roadways. Infrastructure-based radar, a key technology in 'active' traffic management, will help stabilize vehicle flows in a way that is automated and adaptive to road network conditions.

If all the components in these systems were completely reliable, and all roads and vehicles were controlled, we might reasonably expect no crashes to occur. However, experience teaches that a perfect, fail-safe system is an ideal that is never fully realized. On rare occasions, fully autonomous vehicles will still have collisions, even if all sensors, vehicle components and algorithms function as designed[1]. Furthermore, since implementation of an advanced transportation system will occur incrementally, transition paths must be considered which accommodate mixed traffic (i.e., smart vehicles on the same roadway as traditional vehicles). 'Managed' lanes will reduce conflicts between smart and traditional vehicles, but they will not completely eliminate them. Incidents which require time-critical emergency response will still occur. These might come from occasional failures of sensors or technologies, unexpected maneuvers made by traditional vehicles, sensor performance lapses related to severe weather or unexpected interference with power or communications that in some way compromises system performance. Moreover, there will always be non-crash related personal injuries and illnesses which require ambulance transport. NHTSA estimates that there are approximately 37 million ambulance responses each year[2]. Based on a 2013 sample of 4.5M of these responses, only 11% of ambulance calls were from traffic accidents[3]. Therefore, in spite of reduced numbers of crashes, we anticipate the continued need for emergency responders of all types to operate on the nation's roadways addressing injuries, illness and infrastructure disruptions.

With the above in mind, this paper considers how one might best leverage and use emerging technologies to enhance emergency response. (Here we focus mostly on emergency medical response but many of the same arguments apply to police, fire, etc.). Careful selection and incorporation of smart technologies into emergency medical response protocols would not only benefit patients, but could also help convince the public that there are advantages to adopting advanced transportation technologies. Public support will be crucial to establish the business case for continued development and expansion of this revolutionary new system of transportation[4]. We therefore suggest that how emergency events are handled, especially during the transition period, can do much to color public perception regarding automated roadway systems and partially (or even fully) autonomous vehicles.

One vision for an advanced, smart emergency response and management system includes automatic dispatch when an emergency event is detected, and implementation of various smart support systems which integrate real-time sensor data and computer vision with augmented reality to provide enhanced situational awareness for responders. This vision (for the year 2030) was described in a previous paper[5]. The purpose of this paper is to examine both the in-vehicle and infrastructure-based technologies and systems which are emerging in the *next five to eight years* and assess how these technologies might impact the operations of Emergency Medical Services (EMS). Technical aspects of various technologies developed by vehicle manufacturers and government programs are reviewed (but cost, availability or institutional issues are not addressed here).We also consider whether protocols need to be modified when EMS are responding to an emergency along a route where platoons or autonomous vehicles are operating. Finally, we examine how the types of emergencies on the roadways may change in the future and describe event scenarios (or use cases) which may help guide planning.

Finally, starting with MAP-21, there has been greater emphasis on developing performance measures to justify roadway safety improvements. The reliance on safety measures which only address traffic fatalities often result in incomplete or inadequate measures. In response to MAP-21 legislation recommending that states comply with the reporting requirements of the Highway Safety Improvement Program (HSIP), state DOT's current safety programs are beginning to incorporate serious injury crashes in order to develop more robust measures. As previously mentioned however, through the advancement of vehicle design and intelligent transportation systems (ITS), there may be even fewer fatal and serious injury motor vehicle crashes. Therefore it is imperative to develop alternative metrics which could be used to assess the performance and safety of highways.

BACKGROUND

In recent years, the U.S. Department of Transportation (USDOT) has actively pursued research to create and deploy an advanced transportation system based on 'Connected Vehicles.' Their intent is to reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmissions which support driver advisories, driver warnings and vehicle or infrastructure controls. In a connected vehicle world, data would be wirelessly transmitted via the Dedicated Short Range Communication (DSRC) system (5.9 GHz; 1000 meters range). Key attributes of DSRC include low latency (only 0.02 second delays in opening/closing connections), high reliability, tolerance to multipath transmissions, privacy, and security. DSRC is also robust in the face of radio interference and is capable of strong performance during adverse weather and at high vehicle speeds[6,7].

The Vehicle Infrastructure Integration (VII) Program provided the basis for the earliest discussions of a V2V/V2I deployment strategy. Over one hundred potential VII applications were proposed[8]. Of these, five were related to emergency vehicle response:

- Emergency Vehicle Signal Preemption

- Approaching Emergency Vehicle Warning
- Emergency Vehicle at Scene Warning
- Emergency Vehicle Initiated Traffic Pattern Change
- Emergency Vehicle Video Relay (for the deaf)

Early in the VII effort (2006), the USDOT developed detailed ‘use cases’ which describe the requirements and main flow of events which would enable various applications to effectively use V2I and V2V communication. These ‘use cases’ focused largely on applications related to traffic management, winter maintenance, traveler weather information and electronic toll payments[9]. With regard to emergency response, other than references to the Transportation Operations Center ‘receiving incident notification from public safety’ or the ‘vehicle presenting relevant incident notification to the driver’, there was little initial focus on making plans for upgrading future emergency response and enabling it to operate effectively within the advanced transportation environment.

More recently, some attention has been given to emergency response applications as part of the Dynamic Mobility Applications (DMA) initiative led by the Office of the Assistant Secretary for Research and Technology at USDOT (formerly known as RITA)[6]. One DMA activity included the ‘R.E.S.C.U.M.E.’ set of applications, shown below:

- Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
- Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
- Emergency Communications and Evacuation (EVAC)
- Advanced Automated Crash Notification Relay (AACN–RELAY)

Thus far, the Phase 1 Concept of Operations for R.E.S.C.U.M.E has been completed. Prototypes are currently being developed for the first two items and architecture definition for the third[10].

Other efforts have been pursued at the state level. In June 2011, the American Association of State Highway Transportation Officials (AASHTO) assessed which connected vehicle infrastructure components and systems would be practical for initial deployment[11]. Highlighted as part of this assessment, was a signal preemption application for emergency vehicles[12]. Emergency vehicle preemption (EVP) can currently be provided in a number of ways including strobe or infrared-based devices, GPS and radio communications from vehicles, pushbuttons in a fire station or by detecting the siren of an approaching emergency vehicle. Equipment is required at the intersection and on the ambulance. Each approach has limitations including line-of-sight, obstruction and weather issues. Another approach (which avoids some of these issues) is an EVP system that uses the DSRC-enabled Signal Phase and Timing (SPaT) message[11]. With this type of preemption, the intersection-mounted roadside unit (RSU) would verify that the request was made by an authorized source (e.g., from equipment on-board ambulance) and then alter the traffic signal to provide a green light to the emergency vehicle.

As noted by AASHTO, emergency vehicles provide a strong opportunity for deploying Connected Vehicle applications in part because they are high-value assets that also tend to be highly customized. It is anticipated that emergency vehicles will use most of the applications developed for light vehicles and some developed for commercial or transit vehicles[11]. Expected benefits to EMS might include reduced response time and faster transport of patients to a medical facility, crash avoidance during EMS travels, reduced secondary crashes that may occur at the scene or during EMS response and support to enable automated functions in other vehicles to respond properly to an approaching ambulance. Future integration with operations centers may also support dynamic routing of ambulances around congestion.

NHTSA recently released a notice of proposed rule-making to mandate factory-installed DSRC on passenger vehicles[13]. Such equipment will likely first appear in the 2020 model year. However, AASHTO recommends that state and local agencies *not* wait for DSRC to appear on passenger vehicles, but rather focus on deployment applications that meet the needs of potential early deployers, such as commercial vehicles, transit vehicles, and emergency and public safety vehicles, since these fleets are controlled by a private entity or separate agency[11]. This would help promote near-term deployment of DSRC in both vehicles *and* roadside infrastructure.

EVALUIATION AND FINIDINGS

In order to properly assess transportation related safety resources and technologies will present a summary of the state of the art technologies currently deployed or under development for near term implementation and report on their potential utility to emergency responders, traffic managers and planners, as well as the general driving public. In particular we will asses Vehicle-Based Technologies and the Automation Continuum, Advanced Driver Assistance Systems, Autonomous Vehicles / Self-Driving Cars, Infrastructure-Based Technologies and Active Traffic Management, Automation and Connection of Vehicles and Infrastructure, Emergency Event Scenarios, and Safety Performance Metrics.

Vehicle-Based Technologies and the Automation Continuum

This section describes in-vehicle sensor technologies. Understanding the operational strengths and weaknesses of each sensor type helps clarify technology limitations and suggests where *redundan*t sensors may be needed. Key capabilities of the active and passive sensing technologies used in vehicles have been well described in a recent report contained within 'USDOT's 'Connected Vehicle Insights' series[14]. Selected information from this report are summarized here as background before considering the utility for EMS.

Active Sensors

Active sensor systems infer the speed, bearing, altitude and range of a selected object by generating a signal and using a receiver to analyze the return signal reflected or scattered off the object. Radar emits radio waves, LIDAR emits light rays (UV or Near IR) and short range ultrasound generates a shock wave.

There are two classes of vehicular radar: Long Range Radar (LRR) (detection range > 150m) and Short Range Radar (SRR) (detection range <50m). LRR is mature, reliable, low cost and performs well even in poor visibility and bad weather. LRR can detect vehicles but does not do well at detecting pedestrians, bicyclists, debris or roadside barriers. SRR operates well in detecting other vehicles in close proximity, but again, *not* pedestrians[14].

LIDAR transmits laser pulses in the eye-safe range of 850-950 nanometers. There are two types of vehicle-based LIDAR. A narrow FOV sensor (typically mounted in front of vehicle) has an arc sweep of 40 to 80 degrees. The second, more expensive type is mounted on the side or top of a vehicle and provides 180 to 360 degrees of coverage. LIDAR can detect, classify and assess range and speed of objects *and pedestrians*[14]. However, unlike radar, LIDAR is adversely affected by mud, snow, dust and dirt which can block the sensor.

Short range ultrasound is another type of 'active' sensor which uses an acoustic pulse. Ultrasonic detectors are small, easy to install and have high resolution. However, they have a slower detection response and can only sense objects no more than two to four meters away. Still, they are useful for vehicle applications which operate at low speed and in close-quarters such as maneuvering around parked vehicles and pedestrians. However, accumulations of mud, dust or snow can block sound waves[14].

Although limited in their range and FOV, active sensing systems such as radar and LIDAR are ideal for measuring vehicle presence, speed and traffic flow; however, such systems cannot receive messages or "warnings" from vehicles or pedestrians or traffic control devices[14]. Here V2V and V2I can provide support. V2V systems are designed to send warning messages as well as speed, braking information and GPS location (using DSRC protocol) to receivers in other similarly-equipped vehicles. Development of V2V communications capabilities which will complement emerging vehicle-based safety technologies is an active area of research[15].

Passive Sensors

'Computer vision' is a passive sensor system which uses a camera to capture images and a computer to analyze the acquired images to extract information (e.g., detect objects that pose a safety risk). Although some application environments can be challenging, in general it is non-intrusive, relatively inexpensive and easily installed either in vehicles or in roadside elements. Furthermore, the range of computer vision extends beyond that of active radar[16].

GPS satellite navigation is another passive system which can be used to infer speed, bearing and range; however, it requires line-of-sight to at least 3 satellites and assumes exchange of coordinates with other vehicles via V2V communication.

Both computer vision and satellite navigation are limited in their ability to support crash avoidance. Computer vision typically requires abundant light (unless infrared imagers are incorporated for night use) and can be affected by variable illumination such as shadows that obscure features. Satellite-based navigation requires a clear view of the sky with limited blockage from buildings, mountains, etc. [16].

To overcome the limitations of computer vision, data from other sensors (e.g., radar) can be 'fused' with the computer vision results. In addition, 'machine learning' (use of algorithms that enable computers to learn from experience) is an approach being researched to create more robust computer vision systems.

Advanced Driver Assistance Systems

In recent years, various implementations of active and passive sensing technologies have been combined with other data available in the vehicle to create various driver support tools that fall into the category of "Advanced Driver Assistance Systems (ADAS)". ADAS technologies are intended to address driver error and/or ease driver workload. An ADAS typically senses the environment, assesses conflicts, plans solutions and executes a response. The response can take the form of driver warnings, evasive maneuvers (either driver-assisted or automated), deploying countermeasures for occupant protection (air bags) or even effecting changes in traffic control devices[14].

Some ADAS technologies focus strictly on crash prevention. Examples include *Forward Crash Prevention* technology (which uses LRR), *Blind Spot Detection* and *Lane Change A*ssist technologies (which both use SRR). Other ADAS, categorized as safety technologies, include *Lane Departure Warning* and *Backup Camera* technologies (which use Computer Vision), as well as *Pedestrian Detection Systems*[17,18]. Ultrasonic sensors are used in those ADAS which operate at low speed and in close quarters such as *Intelligent Parking Assist* to automate parallel parking. ADAS are implemented differently by each vehicle manufacturer; variables include operating condition thresholds (daytime only or below certain speeds), or different driver interfaces and alert modes[14].

Technology and the EMS Driving Environment

Before implementing ADAS in an ambulance, it is important to consider the EMS driving environment, since the 'rules-of-the-road' governing an ambulance are different from those of the driving public. The driver of an emergency vehicle may typically do the following[19]*:*

- Exceed the prima facie speed limits as long as life or property is not endangered. (In some states, ambulances may only go 10 mph over the posted speed limit).
- Proceed past a red stop signal or stop sign, but only after slowing down as may be necessary for safe operation. (Must be using siren and/or flashing red or blue emergency lights).
- Disregard regulations governing direction of movement or turning in a specified direction.
- Park or stand irrespective of ordinances and police regulations of the city.

Drivers of other (non-emergency) vehicles must pull over and stop - not just slow down expecting the ambulance to pass.

For EMS, the issues that must be considered when using ADAS relate to both the functionality of the technology as well as how warnings or alerts generated by the technology are communicated to the driver. The ambulance environment is clearly different from other vehicles. Flashing lights and a wailing siren provide a sensory background that is not typical of the normal driving environment. Audio warnings from ADAS may not be heard over a siren and reflections from external flashing lights may reduce the effectiveness of warning lights inside the vehicle. Given this, key questions that we consider here are:

- Which technologies should be given the *highest priority* for incorporating into emergency vehicles?
- Are there technologies that might be counterproductive in some circumstances?
- What is most effective way to provide warning information to the driver of the ambulance?
- Are there laws or policies that should be changed regarding how others on the road (operating in a semi or fully autonomous manner) should respond to an ambulance?
- Are there policies that should be changed which govern how an ambulance equipped with ADAS and other technologies, should operate?

Although these questions will not be fully answered here, our goal is to begin the conversation.

Emerging ADAS Technologies and Utility for EMS

Table 1 lists fifteen emerging ADAS technologies, including the sensors or information sources used by that technology and a brief description. The top and middle sections list ADAS that are solely in-vehicle technologies while the bottom section lists those that are DSRC-enabled and acquire information (via V2V communication) from other vehicles. The last two columns of Table 1 list potential benefits or impact the technology might have on EMS followed by a qualitative ranking or utility (shown as ’High’, ‘Mid’, ‘Low’ or ‘Mixed’) for its incorporation into ambulances.

Many ADAS technologies would clearly benefit EMS, but others might need to be modified given that an ambulance can violate normal ‘rules-of-the-road’. Some ADAS may have mixed utility, providing benefits in rural driving but perhaps be less effective (and possibly counterproductive) in urban environments. For example, warnings from *’Lane Keeping Assist’* may be helpful when an ambulance is negotiating curves at speed on rural roads, but be very distracting when an ambulance in urban traffic is weaving around stopped vehicles or going into an opposing lane. The option to ‘turn off‘ a warning system should be provided. *Intelligent Parking Assist’* is given a low priority since an ambulance can violate parking ordinances. However, a *modified* (or EMS-specific) version may be useful if it could automatically position the ambulance to better load patients (perhaps turning around so rear door is facing proper direction), thereby freeing driver to immediately respond to patient needs.

If all vehicles were equipped with DSRC and if V2V communications were freely exchanged, some of the alerts in Table 1 (such as *Blind Spot Warning*) would be available via exchange of vehicle GPS position, without requiring independent radars or computer vision sensors on the ambulance. There is some movement in this direction as illustrated by NHTSA's recent issuance of an advance notice of proposed rulemaking to require V2V communication in passenger cars and light trucks[13]. However, as V2V is not available yet, many car manufacturers are working to develop in-vehicle technology that can provide other ways of acquiring critical safety information independently. With regard to warning mechanisms, haptic (vibration-based) warnings, or alerts conveyed via a Heads-Up-Display (HUD) will likely be more effective than audio alarms or warning lights in an ambulance environment.

Table 1. ADAS for Crash Avoidance and Steady State Driver Assistance

Technology	Source	Description / Response	EMS Benefits or Impact	Utility
ADAS for Crash Avoidance Using In-Vehicle Sensors (No Communication)				
Forward Collision Warning (FCW) *-Brake Assist (BA)* *-Collision Imminent Braking (CIB)* *-Automated Braking (AB)*	Long Range Radar (LRR)	-Driver in control of brake initiation; automated braking-assist thereafter. -If crash imminent, vehicle brakes automatically to reduce impact - Meant to avoid crash all together. Only at low speeds. (e.g., Citysafe)	Many ambulances have poor ratings for crashworthiness of patient compartment. Preventing even minor crashes is critical.	High
Blind Spot Detection (Lane Change Assist)	Short Range Radar (SRR), CV	Visible alert when a car enters the blind spot while driver is switching lanes.	Good safety measure given ambulance frequently changes lanes going around traffic. Haptic or HUD* alert likely	High
ADAS to Improve Safety or Ease Driver Workload Using In-Vehicle Sensors				
Adaptive Cruise Control (ACC)	Radar (LRR and SRR).	ACC designed for highway speeds; eases driver workload.	Can enable ambulance to travel in 'fast' platoon as managed lanes become available.	Mid
Stop & Go Adaptive Cruise Control	Radar (SRR)	Ease driver workload in lower speed, stop & go congested conditions. Driver must still steer.	Ambulance has authority to go around traffic in any lane. Normal 'rules of road' do not apply so likely not very effective.	Low

Technology	Source	Description / Response	EMS Benefits or Impact	Utility
Lane Keeping Assist or Lane Departure Warning (*if no turn signal)*	Computer Vision (CV), LIDAR	CV & LIDAR detect lane markings, road, straight lines, vanishing points. LIDAR also detects curbs, berms. Requires daylight, good weather.	Ambulance often intentionally violates lane or goes into opposing lane to get around stopped vehicles. Low urban utility but useful on rural road curves.	Mixed
Traffic Jam Assist	Radar (SRR), LIDAR, CV	Combines Stop & Go Adaptive Cruise Control with Lane Keeping Assist.	Ambulance weaves around traffic. May accept tight gaps or drive on shoulder which would be rejected by software.	Low
Pedestrian Detection Safety System	Computer Vision &/or LIDAR	Detects and warns if pedestrian in path of vehicle.	Ambulance has right of way; however, pedestrians with headphones may not hear siren. High payoff if crash prevented	High
Backup Camera System	CCD Camera	CCD Camera with wide FOV (100 deg)	Ambulances moving through crowds or parking lots to a scene may need to back up if tight corner (& back up to ER door.)	High
Intelligent Parking Assist / Self valet Park	Computer Vision &/or Ultrasonic	Assists driver with parallel or perpendicular park. Can also park without driver. Audi Piloted Parking	Ambulance parks without regard for city ordinances. (But *modified* EMS version to auto-position may help in loading.)	Low
ADAS with DSRC Enabled Technology (V2V)				
Emergency Vehicle at Scene Warning	DSRC/V2V	-Emergency vehicle broadcasts identification message to vehicles in immediate area.	Announcing ambulance presence to other vehicles approaching scene is particularly useful if poor visibility	High
Incident Scene / Work Zone Alerts		Warns driver approaching scene at unsafe speeds and warns scene responders of approaching vehicle.	Two way warning of unsafe speed has benefits.	High
Emergency Electronic Brake Lights (EEBL)	DSRC/V2V	Vehicle broadcasts self-generated emergency brake event. Following vehicles receive braking alert from broadcasting vehicle -possibly several vehicles ahead & out of view	Braking alert broadcast by other vehicles in response to approaching ambulance provides no new information to ambulance driver. But, emergency braking by ambulance with alert to following vehicles may have benefit.	Mixed
Do Not Pass Warnings (DNPW)	DSRC/V2V	Warns that passing zone occupied by vehicle in opposite direction of travel on single lane road.	Warns ambulance going around a stopped vehicle in poor visibility that another vehicle in opposing lane.	High

Technology	Source	Description / Response	EMS Benefits or Impact	Utility
Control Loss Warning (CLW)	DSRC/V2V	Warning of impending maneuver (sudden braking, rollover, hydro-planing).Events not detected by road sensors communicated via DSRC	Provides warning to approaching ambulance that hazardous area ahead.	High
Cooperative Adaptive Cruise Control (CACC)	Radar or LIDAR and DSRC/V2V	Enables longitudinal automated vehicle control. Radar gives range to vehicle ahead & preceding vehicle provides acceleration to following.	Will enable ambulance to fully participate in managed lanes, platoons, etc. on highway portion of travel.	High

Autonomous Vehicles / Self-Driving Cars

There have been several recent advancements that clearly demonstrate that with an appropriately designed suite of in-vehicle sensors acquiring real-time vehicle performance and other safety-related information, a vehicle can be programmed to drive autonomously *without* communicating with other vehicles or with the roadway infrastructure. Google has developed just such a driverless car on a Toyota Prius platform and has been testing it on public roads since 2010. Information gathered from Google Street View is combined with input from sensors on the vehicle including radar on the front of the vehicle, a roof-mounted LIDAR, multiple video cameras and a GPS position sensor attached to one of the rear wheels[20]. Google Street View provides pre-built navigation maps which contain static infrastructure (telephone poles, crosswalks, traffic lights, etc.). The roof-mounted LIDAR system contains 64 lasers in a spinning 360-degree turret, creating a high-resolution point cloud map accurate to about 11 centimeters.

The auto-drive function is considered by Google to be safe, i.e., not perfect, not crash-proof, but safer than a human driver. Google further maintains that a car’s manufacturer would be at fault if the car caused a crash, based on existing product liability laws[21]. When the inevitable crashes occur, the data that the autonomous cars collect (in order to navigate) will provide an accurate picture of exactly what happened in the crash. Since the introduction of the Google self-driving car, California, Nevada, Florida and now Michigan have adjusted their laws to allow tests of self-driving cars on public roads.

Nissan is developing a driverless car on a Leaf electric vehicle platform with six laser scanners (in corner body panels and on rear passenger doors), three radars (one in front, two in back), five cameras (to read speed limit, stop signs, etc.) and twelve sonar[22]. Neither Google nor Nissan use V2V or V2I communication, largely because they believe it will take years to fully penetrate the vehicle fleet and the roadway infrastructure.

Scientists at Oxford University in the UK have also developed a self-driving car system on a Nissan Leaf that can function in inclement weather and can be fitted to existing cars[23]. They use

3D laser scanning coupled to computer storage to build a map of its surroundings accurate to a few centimeters. The plan is to extend the map by downloading data from passing cars (would require V2V) or downloading over the internet via 3G and 4G connections to a central system.

Many of the major car manufacturers are now developing autonomous driving technology (Audi, BMW, GM, Nissan, Toyota, Volkswagen and Volvo). Some will have V2V/V2I communications, some not. The latter design raises the question as to how autonomous vehicles without communications will recognize and respond to emergency vehicles.

NHTSA Policy on Automated Vehicles / Self-Driving Cars

NHTSA has acknowledged that there are three distinct but related streams of technological development occurring simultaneously[24].

- In-vehicle crash avoidance systems developed by vehicle manufacturers that provide warnings and/or limited automated control of safety functions.
- V2V communications that support various crash avoidance applications.
- Self-driving vehicles that operate independently without use of V2V or V2I communication. (e.g., Google, Nissan)

There has been some confusion regarding how these three streams of innovation will interface. To alleviate this confusion, NHTSA recently developed a framework that views these emerging technologies as part of a *continuum of vehicle control automation*. This continuum goes from vehicles with no active control systems to vehicles with full automation and self-driving capability[24]. In the NHTSA framework, vehicles that provide forward crash warning or have V2V technology that provides a safety warning message, are not considered automated. Rather, 'automated vehicles' are defined as those in which some aspects of safety-critical control (steering, throttle, braking) occur without direct driver input. NHTSA defines five levels of automation summarized in Table 2.

Table 2. NHTSA's Five Levels of Vehicle Automation

Level	Definition	Example
Level 0 – No Automation of Control Systems	Driver is in complete and sole control of the primary vehicle controls (braking, steering, throttle) & solely responsible for safe operation	Forward collision warning, lane departure warning, blind spot monitoring) as well as systems providing automated secondary controls (wipers, headlights, turn signals, hazard lights, etc.)

Level	Definition	Example
Level 1 - Function-Specific Automation	One or more automated control functions operating independently of each other: 1) Driver can cede limited authority over a primary control 2) Vehicle can automatically assume limited authority or 3) Automated system can provide added control to aid driver. However, there can be no combination of vehicle control systems working in unison. Driver is still responsible.	1.Adaptive Cruise Control 2. Electronic Stability Control (mandatory on new light vehicles since 2011) 3. Dynamic brake support in emergency
Level 2 – Combined Function Automation	Automation of at least two primary control functions working in unison. Shared authority with driver. Driver can have hands off steering wheel *and* foot off pedal at same time but driver must be available for control at all times and at short notice.	Adaptive cruise control combined with lane centering (i.e., Stop & Go Adaptive Cruise Control with Lane Keeping Assist = Traffic Jam Assist or GM Supercruise)
Level 3 – Limited Self Driving Automation	Vehicle enables driver to cede full control under certain traffic or environmental conditions. Driver must be available for occasional control but with comfortable transition time. Driver is NOT expected to constantly monitor the roadway.	Automated self-driving car that can determine need to relinquish control back to driver (e.g., when approaching a construction area.)
Level 4 – Full Self Driving Automation	Vehicle performs all driving functions and monitors roadway for entire trip. 'Driver' just provides destination or navigation input but not expected to be available (or even present).	Automated self-driving car that does not require human in the loop.

Transition to Driverless Cars and Implications for EMS

Widespread adoption of autonomous driving technology could increase highway lane capacity two to three-fold[25]. During the transition from few – to some – to many, partially or fully automated (driverless) cars on the nation's highways, some thought must be given to revised protocols for emergency vehicles. As automated cars become more prevalent (with vehicles in managed lanes providing safer, but more tightly packed traffic), there will be less maneuvering room and/or no space for vehicles to 'pull over' and stop. EMS vehicles will still have the right-of-way, however, rather than requiring other vehicles to stop, it may be more efficient (and faster) on multi-lane roads, to give EMS priority entry into the 'managed lane', putting a hold on other vehicles entering the same lane, (and possibly asking some vehicles to exit the managed lane) and then modifying the speed in the lane to whatever is appropriate for the ambulance. (This of course assumes the ambulance has the technology to safely operate in the managed lane). This approach could well result in faster transit of the ambulance and less disruption of the transportation system. For this to be successfully implemented, EMS vehicles must be equipped with the latest required technology so that the public has confidence that every ambulance operates in the same way and it is clear what the public response should be. It also suggests that infrastructure (roadway) based technologies supporting active traffic management must play a role. These technologies are discussed in the next section.

Infrastructure-Based Technologies and Active Traffic Management

We now discuss infrastructure-based technologies including radars implemented at intersections and on ramps, as well as sensor and communication systems at intersections and those contained in RSUs supporting V2I communications. V2I enables the use of 'Active Traffic Management' (ATM) defined by FHWA as dynamic management of recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions. It includes automation of dynamic deployment strategies to optimize performance quickly without the delays that occur when operators must deploy operational strategies manually[26]. A single ATM strategy can be deployed to address a specific need or multiple strategies can be combined to meet a system-wide need for congestion management. Table 3 lists ATM strategies which use infrastructure radar and other technologies and further identifies issues and considerations for EMS. Again, "High', 'Mid" and 'Low" indicate an initial qualitative ranking of utility/priority for EMS.

It is likely that widespread implementation of ATM will be complex and expensive. This is all the more reason to consider EMS needs while planning is still in progress. Different adaptive ATM applications may also need to adjust signals and other traffic control devices on different time scales (daily, hourly, per minute) and in reaction to different events or activity thresholds[14].

Table 3. Active Traffic Management Using Infrastructure Radar and Other Applications

Technology	Source	Description / Response	Benefits or Impact	Utility
Infrastructure Radars	Dual beam radars side-fire mode oriented 90º to lanes of traffic	-Provide traffic speed, flow & classification of vehicle length. Enables Traffic Management Center (TMC) to send congestion alerts to Variable Message Signs (VMS), radio, internet.	-Guidance from TMC can help route ambulance through congested areas. Likely only at selected intersections.	Mid
CICAS: Cooperative Intersection Collision Avoidance System • Traffic Signal Adaptation (CICAS-TSA) • Stop Sign Assist (CICAS-SSA) • Left TurnAssist (CICAS-LTA)	Intersection radar Infrastructure radars, DSRC.V2I Intersection radars, DSRC.V2I	-Intersection radar dynamically calculates 'dilemma zones' (speed through yellow light or brake aggressively?). Traffic signal phase & timing is modified based on traffic flow. Red phase held longer for opposing traffic if an (approaching) high speed vehicle is detected. -Infrastructure radar detects speed of vehicles on rural expressway; alerts driver at non-signalized intersection if 'turn gap' sufficient -Intersection radar at conventional signalized intersections detect turn gap for left turn	-A variation on this technology is Emergency Vehicle Preemption which is described below. -May help ambulance safely turn onto high speed road in poor visibility conditions -Helps ambulance safely execute left turn	High

Technology	Source	Description / Response	Benefits or Impact	Utility
Intersection Movement Assistance (IMA)	Intersection cameras, DSRC/V2V/ V2I	-Warns drivers approaching intersection of red light or stop sign infringement, or hazardous turn-off maneuvers at intersection.	- Warns ambulance of hazards *prior* to arrival at intersection.	High
Adv. Autom Crash Notification Relay (AACN-RELAY):	In-vehicle Accelerometers, DSRC (V2I/V2V)	-Transmit crash event data (via other vehicles or roadside hot spot) on crash location, severity, likelihood of injury, commercial truck contents.	-Data provides crash-specific information to EMS. Info on *number of injured* is desired.	High
Dynamic Shoulder Lanes (Hard Shoulder Running)	Radar, TMC	-Use of shoulder as traffic lane during congested periods based on real time and anticipated congestion levels.	-Benefit if ambulance able to use shoulder. Impediment if other traffic using shoulder.	Mixed
Emergency Vehicle Signal Preemption	DSRC (V2I)	-Detects when ambulance nearing controlled intersection & ensures ambulance has green light. Uses DSRC to send SPaT message.	-Important technology for EMS. Can be accomplished via optical, strobes or DSRC	High
Approaching Emergency Vehicle Warning	DSRC (V2I & V2V)	-Warning broadcast (from infrastructure and ambulance) to vehicles in area that ambulance approaching.	-Improves situation awareness of vehicles near ambulance, enhancing safety	High
Emergency Comm. & Evac (EVAC):		-Provide dynamic route guidance, conditions and food/fuel/ lodging options to evacuees.	-Not directed at EMS but high value for other drivers	Low
Weather Responsive Speed Limits	RWIS, VSLS	-Based on atmospheric, visibility or pavement sensors, adjust speed limits dynamically using variable speed limit signs (VSLS).	-Real time, location specific weather data improves safety for ambulance.	High
Adaptive Ramp Metering	Radar Loop Detectors, Infrastructure radars	-Entry & exit from corridor managed by ramp metering; queue measured by loop detectors. Uses traffic responsive/adaptive algorithms.	-Slow or stop entry of additional vehicles onto highway until approaching ambulance passes.	Mid
Adaptive Traffic Signal Control	Infrastructure radars, radar loop detectors, SPaT.	-Monitors arterial traffic conditions including upstream queuing at intersections. Dynamically adjusts signal phase & timing (SPaT)	-For ambulance, function is superseded by Emergency Vehicle Preemption.	Low
Incident Scene Staging Guidance (RESP-STG)	GPS, Google Earth, NWS	-Provide information to responders en route including routing and scene staging guidance, satellite imagery, weather data, etc.	-EMS specific technology. Improves situation awareness of responders prior to arrival.	High
Cooperative Adaptive Cruise Control (CACC)	DSRC/ V2V /TMC	-Uses preceding vehicle's acceleration or deceleration (from cooperative awareness messages transmitted via DSRC) to adjust gap.	-Assumes ambulance in platoon with lead vehicle setting best speed for EMS.	High

Technology	Source	Description / Response	Benefits or Impact	Utility
Dynamic Lane Use & Lane Reversal	Radar, TMC	-Dynamic closing or opening of lane to safely merge traffic in adjoining lanes. Dynamic reversal of lane direction to allocate capacity	-Reversal of lane may be used to provide clear pathway for ambulance.	Mid
Speed Harmonization	Radar, TMC	-Minimize variations of all drivers from average speed on roadway to prevent crashes. -Post speed via dynamic speed limit signs/VMS	-Dynamic posting of speed limit can control traffic around ambulance; aid highway entry	Mid
Coupled Platoon Groups	Radar, TMC	-Active Traffic Management from a TMC	-Ambulance merges into platoon & dictates speed, etc.	High

Automation and Connection of Vehicles and Infrastructure

It is expected that in 6 to 8 years we will see automated vehicles on the road[27]. The quality (and cost) of these vehicles is expected to be high although the quantity low. One question which was the subject of a recent debate is should these automated vehicles operate without communications[4]. By separating the vehicle from the infrastructure and operating autonomously on the roads that already exist, these smart vehicles could well deliver benefits without waiting for the development of a V2I smart roadway infrastructure with DSRC. The latter will likely take many more years and may not be available on all roads.

However, it can also be argued that there are shortcomings in sensors on cars and V2V/V2I communications (in connected vehicles) can help make up for some of these sensor shortcomings. Cars already communicate and by utilizing and expanding this communication, some of the cost of sensors in vehicles might eventually be reduced. In this scenario, the system that evolves is not expected to be 'connected automation', but rather 'automation that is connected'[4]. In particular, communications can handle the 'exceptions' which will always occur, which in turn will enhance safety. It is also anticipated that cellular (4G LTE) communication between vehicles and infrastructure could be as beneficial as DSRC and may be lower cost[4]. Regardless, the software used in these vehicles will need exhaustive testing.

Public perceptions of the value provided by these vehicle and infrastructure technologies could well affect the public's willingness to accept and pay for these safety and automation features. To gain broad public acceptance, the transition from traditional to automated roadways must be handled well, particularly for emergency events as these attract public attention. However, given that urban drivers currently spend 30% of their driving time in traffic jams, the time savings provided as automation frees drivers to do other things may be a more compelling argument than safety for obtaining widespread public acceptance[4]. Certainly, older drivers and disabled drivers will likely embrace the automation.

Emergency Event Scenarios

Given the new operating environment created by the emerging vehicle and infrastructure technologies described above, there is a need to consider what type of emergency events will likely occur as well as how the response to emergency events on our roadways might be different.

One significant benefit of increased automation with communication is that the number of motor vehicle crashes will greatly decrease. Increased automation will also support much smaller longitudinal separation between vehicles, which will greatly increase road capacity. Furthermore, the lower risk of crashing is expected to lead to new vehicle crashworthiness designs which can potentially make the vehicles lighter in weight, thereby improving gas mileage. These benefits may have some unintended consequences however. Smaller separations between vehicles could mean that if a crash happened, it will involve more vehicles and lighter weight vehicles might provide less protection in a crash. As a result, the nature and type of injuries to occupants in the future fleet of vehicles is likely to be different that those seen today. However, the expected improvements in safety and large reduction in deaths and serious injuries will still outweigh these potential negatives. That said, efforts should be made to ensure that if a crash does happen, response is rapid and effective.

There is clearly great potential for using V2V and V2I communications in concert with other sensor networks (expected to be ubiquitous in the future) to support *all types* of emergency response services. These services include public safety, EMS and highway maintenance as well as power and communications support. Following the 'use case' approach used by USDOT for V2I/V2V system planning, **Table 4** provides a few example scenarios of events which might occur in an advanced transportation system which would require an emergency response. Both injury and non-injury events are included. All scenarios require a time critical response either for reasons related to safety (injuries) or mobility (congestion and gridlock). One of the critical tasks will be to review and refine the scenarios using the best available information on the capabilities, performance and potential failure modes of the advanced transportation system.

Some of the event scenarios requiring emergency response listed in **Table 4** are the traditional vehicle or pedestrian injury crashes which require EMS response. Incidents related to natural disasters will also always occur as will medical emergencies and non-crash-related injury events. However, other events are less traditional but could well become more common given the increasing dependence on communications and software. These other types of events will require emergency response from police or IT specialists rather than EMS. For example, intentional or unintentional jamming of GPS signals created by transmission of a noise signal across one or more GPS frequencies, can interfere with the system's capacity to lock onto a GPS signal. There have already been instances of interference from small jammers (which disrupt the GPS signal for a mile or more when plugged into a cigarette lighter) being used by car thieves, those trying to avoid tolls and commercial drivers trying to hide from their management or conceal the fact that they are driving long hours[28].

Besides interference with navigation, other forms of attacks can affect the V2V and V2I communication network. Cyber attacks can involve malicious software including viruses, worms, Trojan horses or attacks causing modification and dissemination of correct and incorrect information. Cyber attacks can cause drivers to make poor decisions resulting in an accident, can cause congestion or rerouting of a driver and generally reduce drivers' faith in the system as messages become unreliable or unavailable. Attacks on the communication system can also lead to threats to privacy (e.g., tracking location or driving route of a particular person). Thus, emergency response planning must include consideration of these types of event scenarios.

Table 4. Emergency Event Scenarios in an Advanced Transportation System

Scenario	Examples or Description	Emergency Services	Progression of Events as Incident Unfolds	Examples of In-Vehicle & Infrastructure Technologies Utilized
1. Multi-vehicle crash occurs on highway after loss of control by a vehicle operating with small longitudinal gap.	Vehicle in platoon skids on icy road Sensor failure occurs in Cooperative Adaptive Cruise Control system. Vehicle from unmanaged lane drifts into managed lane.	Fire, EMS / HEMS, police, Towing service, Hwy repair if infrastructure damage occurs.	-Control Loss Warning (CLW) alert issued and Collision-Imminent braking (CIB) activated on vehicle losing control. - Vehicle broadcasts emergency braking event (Emergency Electronic Brake Lights) to following vehicles. -Crash occurs; AACN sends automatic crash message via cell, V2I alert to RSU V2V multi-hop forwarding of message.	-*Emergency Vehicle Signal Preemption* (EVP) invoked by ambulance -Ambulance broadcasts *Approaching Emergency Vehicle Warning* alert. -*Adaptive Ramp Metering* on freeway portion of EMS route limits entry of additional traffic until ambulance passes -Ambulance with *Cooperative Adaptive Cruise Control* given immediate entry into high speed platoon in managed lane & rapidly escorted to required exit (or scene) while maintaining traffic flow. -*Incident Scene Pre-Arrival Staging Guidance* given to EMS. -*Emergency Vehicle at Scene Warning* broadcast by ambulance to alert approaching vehicles of stopped ambulance ahead.
2. Pedestrian hit on city street in bad weather.	-Computer vision & LIDAR impacted by weather & shuts down.	First responders, EMS, police	- Pedestrian Detection Safety System obscured by weather and fails -Collision with pedestrian occurs. - AACN sends crash message. -Weather Responsive Speed Limits (due to poor visibility) broadcast reduced speed limit as result of accident.	- *Emergency Vehicle Signal Preemption* (EVP) invoked by ambulance -Infrastructure-based radars help TMC monitor traffic & broadcast directives to aid in clearing path for EMS -*Hard Shoulder Running* provides additional path for EMS. -*Incident Scene Pre-Arrival Staging Guidance* given to EMS. -*Emergency Vehicle at Scene Warning* broadcast by ambulance to alert approaching vehicles of stopped ambulance ahead.
3. Intentional or un-intentional GPS jamming disrupts vehicle functions.	Transmission of noise signal across one or more GPS frequencies cause a loss of lock	Police	-Navigation systems fail in all vehicles within x meter radius of jammer. -Vehicle notifies driver that navigation features disabled & alerts police.	-Police use last position of reporting vehicles to narrow jammer location -Jamming detection equipment in police vehicle used to locate source. -Police deactivate jammer.

Scenario	Examples or Description	Emergency Services	Progression of Events as Incident Unfolds	Examples of In-Vehicle & Infrastructure Technologies Utilized
4. System error or other sensing failure leads to traffic jam.	-Ramp metering errors allow too many vehicles to enter corridor.	Police, IT system maintenance	-TMC observes congestion building (via infrastructure radar); attempts to change ramp access rate; sends IT maintenance & police to manually control ramp access	- Traffic Management Center (TMC) sends congestion alerts to Variable Message Signs (VMS), radio, internet. -*Hard Shoulder Running* & *Dynamic Lane Reversal* used to get IT technicians and police to congested area & source of system failure.
5. Natural or man-made disasters cause full or partial impasse on roadways.	-Snow storm downs trees, power lines; -Flash flood, mud slide blocks highway. -Terrorist attack closes bridge or tunnel	Fire, police, EMS, utility services, hwy maintenance, Comm./ IT support.	-Notification of emergency sent via V2V/V2I or cellular communications. -TMC observes congestion building (via cameras or infrastructure radar) in area of blockage. -TMC broadcasts alert to drivers with location of blockage.	-TMC uses *Adaptive Ramp Metering* to close entry to damaged or blocked roads. -TMC or telematics service (e.g. OnStar) provides dynamic routing around hazard (EVAC) - Technologies in scenarios above utilized by EMS to expedite travel to scene.
6.Cyber attack or other RF interference.	Communications disrupted by denial of services (DOS), Sybil attacks, Worm Hole, etc.	Fire, Police, EMS, HWY Dept., Comm/IT	-DOS attack degrades performance -Misleading or false messages could lead to inappropriate responses or crashes. -Vehicles *may* be able to detect anomalous performance and warn drivers of possible system compromise.	-Alert EMS of cyber attack in area & warn that *Emergency Vehicle Preemption* and other technologies may not be working properly and drivers may not be aware of ambulance approach -Protocols for travel when V2V/V2I compromised must be used. -EMS must maintain redundant/backup communications pathways

Safety Performance Metrics

In an advanced transportation system , taking advantage of the systems previously described, it is likely that there will be fewer fatal and serious injury crashes. Traditional assessments of safety or efficiency however often use measures associated with these previously mentioned crashes to support or reject roadway improvement projects. In the future, transportation systems will still not be one hundred percent safe or efficient, will still have occurrences of safety critical events and congestion, and will still need maintenance and improvement. Therefore it is imperative to develop alternative metrics which could be used to assess the performance and safety of highways.

One such alternative metric could be the through the monitoring and classification of near crash events. Near crash events are normally defined as the exceedance of accepted thresholds for various vehicle kinematics such as lateral/longitudinal acceleration/deceleration, forward or rear 'time to collision' (as measured by radar), and yaw rates. Many of today's vehicles contain the sensors required to measure these kinematics, and can be reported via the Data Acquisition System (DAS). In addition, NHTSA now requires that all new vehicles contain event data recorders (EDR) that will store vehicle kinematic data. Furthermore, connected vehicle technologies in the future will also allow for the communication of these events to state and federal transportation agencies for archival. In the near term however, data from the second Strategic Highway Research Program (SHRP 2) Naturalistic Driving Study (NDS) can be utilized to identify new metrics and demonstrate their proof of concept.

SHRP 2 NDS data was collected at six sites throughout the U.S. to characterize the behavior of the driving public. Driver's cars were instrumented with a suite of sensors to gather information about the performance of their vehicles as well as their behavior over a period of one to two years. In all 3,247 drivers were recruited for the programs, generating approximately 5.4 million trips and 49.7 million vehicle miles travelled (VMT)[29]. For examination purposes this project focused on the New York test site (Erie County, NY) which had 772 drivers, approximately 1.3 million trips and 8.0 million VMT[29]. A comparison of the crash rates for Erie County as provided by NYS DOT[30] in 2013 and the observed crash rates in the SHRP 2 NDS program as provided by the SHRP 2 NDS InSight[31] website is provided in Table 5.

Table 5. Comparison of Crash Rates with SHRP 2 NDS Data

Erie County 2013 (NYS DOT)	Count	Rate 1M VMT (5,036 M)	Erie County 2011-2013 (SHRP2 NDS)	Count	Rate 1M VMT (8 M)
(K) Fatal	54	1.07	(I) Most Severe	22	275.00
(A) Incapacitating Injury	632	12.55	(II) Police-reportable Crash	46	575.00
(B) Non Incapacitating Injury	1,116	22.16	(III) Minor Crash	120	1,500.00
(C) Possible Injury	5,577	110.74	(IV) Low-risk Tire Strike	111	1,387.50
(O) Property Damage Only	14,883	295.53	Near Crash	489	6,112.50
Total	22,262	442.06	Total	788	9,850.00

It is important to note the significant differences between the rates in Table 5. Two factors confound this comparison. First, the crash rates when compared between the data sourced from the NYS DOT and SHRP 2 NDS are based on drastically different exposure levels. NYS DOT estimated 5,036 million VMT in Erie County, NY in 2013and just over 8 million VMT was estimated from the SHRP 2 NDS trip data for the New York test site. Second, there is not a one-to-one mapping of crash severity between the two data sets and in particular, the SHRP 2 NDS data includes many more less severe events. These two factors along with the qualified definitions of the crash types make direct comparisons difficult.

Motor vehicle crashes are relatively rare events due to high exposure levels therefore transportation safety research has a long history of identifying alternative ways to asses safety. These alternatives have included conflicts[32,33] and near crashes[34]. Another way to asses driving performance across the transportation system is quantifying surrogates for crashes, near crashes, or conflicts; namely the identification of safety critical events. Table 6 provides a summary of kinematic data associated with trips within the SHRP 2 NDS NY to aid in the identification of safety critical events.

Table 6. Selected Vehicle Kinematics from SHRP 2 NDS New York Site Trips

Maximum Deceleration			**Maximum Lateral Acceleration**			**Maximum Turn Rate**		
Gs	Trips	%	Gs	Trips	%	Deg/Sec	Trips	%
>= 0.0	20,394	1.55%	< 0.0	13,180	1.00%	< 0.0	5,188	0.40%
-0.1 - 0.0	41,219	3.14%	0.0 - 0.1	62,989	4.80%	0.0 - 5.0	80,514	6.14%
-0.2 - -0.1	55,695	4.25%	0.1 - 0.2	46,322	3.53%	5.0 - 10.0	17,577	1.34%
-0.3 - -0.2	426,287	32.49%	0.2 - 0.3	138,391	10.55%	10.0 - 15.0	21,502	1.64%
-0.4 - -0.3	562,732	42.89%	0.3 - 0.4	380,944	29.04%	15.0 - 20.0	57,292	4.37%
-0.5 - -0.4	160,377	12.22%	0.4 - 0.5	440,440	33.57%	20.0 - 25.0	230,963	17.60%
-0.6 - -0.5	29,139	2.22%	0.5 - 0.6	176,847	13.48%	25.0 - 30.0	465,231	35.46%
-0.7 - -0.6	7,177	0.55%	0.6 - 0.7	38,781	2.96%	30.0 - 35.0	273,483	20.85%
< -0.7	3,495	0.27%	>= 0.7	8,620	0.66%	>= 35.0	98,300	7.49%
NULL	5,456	0.42%	NULL	5,457	0.42%	NULL	61,921	4.72%
Total	1,311,971	100.00%	Total	1,311,971	100.00%	Total	1,311,971	100.00%
Headway 0.0-0.5s (Time/Trips)			**Traction Control Activation**			**ABS Activation**		
Minutes	Trips	%	Number	Trips	%	Number	Trips	%
0.0 - 1.0	1,053,770	80.32%	0	358,475	27.32%	0	588,451	44.85%
1.0 - 2.0	4,720	0.36%	1	3,517	0.27%	1	24,931	1.90%
2.0 - 3.0	1,452	0.11%	2	756	0.06%	2	4,153	0.32%
3.0 - 4.0	660	0.05%	3	351	0.03%	3	1,249	0.10%
4.0 - 5.0	330	0.03%	4	195	0.01%	4	534	0.04%
5.0 - 6.0	152	0.01%	5	118	0.01%	5	276	0.02%
6.0 - 7.0	89	0.01%	6	78	0.01%	6	176	0.01%
7.0 - 8.0	63	0.00%	7	65	0.00%	7	111	0.01%
>= 8.0	104	0.01%	>= 8	258	0.02%	>= 8	286	0.02%
NULL	250,631	19.10%	NULL	948,158	72.27%	NULL	691,804	52.73%
Total	1,311,971	100.00%	Total	1,311,971	100.00%	Total	1,311,971	100.00%

For the purpose of defining safety critical events in this project we identified six vehicle kinematics that were readily accessible from the SHRP 2 NDS InSight data and will also be available from currently deployed EDRs. These kinematics include maximum deceleration in gravitational units, maximum lateral deceleration in gravitational units, maximum turn rate in degrees per second, vehicle headway in time spent at 0.0-0.5seconds, the number of traction control activations, and the number of automated braking (ABS) activations.

For passenger vehicles, past research has indicated that maximum deceleration and maximum lateral acceleration values drivers are willing to subject themselves to in crash type situations falls in the range of 0.3 to 0.53 g's[35] therefore values exceeding 0.5g's may indicate safety critical events in both deceleration and lateral acceleration. An empirical examination of maximum turn rates revealed that approximately two-thirds of trips had turn rates below thirty degrees per second. For the purposes of this study we have identified turn rates as greater than thirty degrees per second as perhaps indicative of an evasive maneuver. In general, the commonly accepted practice of allowing two seconds of headway between vehicles headway, based on drivers reaction times, is viewed as a safe practice[36]. As a conservative measure, this study identified trips where headway was indicated as 0.0 to 0.5 seconds (the smallest increment reported in SHRP 2 NDS InSight data). The number of traction control and ABS activations are not especially useful on their own but could potentially provide verification of deceleration and turn rates. This study identified any positive activation as an indication that a safety critical event may have occurred.

Unfortunately due to data sharing restrictions and privacy issues, the above kinematics cannot be extracted for individual trips and therefore it is not possible to statistically infer relationships between these variables or correlate them with particular roadway segments. In addition, the events table on InSight, that contains all crash and near crash events does not contain the above referenced kinematic data therefore conclusions cannot be drawn between the exceedance of the thresholds and the likelihood of a crash or near crash occurring. The data to support these analyses does exist however, and is now becoming available through access to the raw SHRP 2 NDS time series data. Future work intends to access this raw data through an appropriate data use agreement.

CONCLUSIONS

If automation proceeds as expected, the changes will be revolutionary. The role of the driver will be modified (perhaps even eliminated) as in-vehicle and roadside technologies become more advanced. Motor vehicle crashes will be greatly reduced, longitudinal separation between vehicles will decrease and the capacity of roads will increase. The lower risk of crashing means vehicles can be constructed with lighter weight materials resulting in significant improvements in gas mileage. Yet smaller separations between vehicles could mean that if a crash did happen, it will likely involve more vehicles and lighter weight vehicles might provide less protection and/or result in different types of injuries. Nonetheless, the large reduction in deaths and serious injuries from fewer crashes and the expected improvements in congestion relief still outweigh these potential negatives. Other types of emergency scenarios will likely increase as adverse events involving sensor, software or communication failures are added to the mix. A variety of event scenarios (or use cases) which may help guide planning have been provided (Table 4).

In-vehicle automated technologies will clearly provide a greater margin of safety and ease driver workloads. However, careful thought must precede implementation of some of these technologies in emergency vehicles since automated systems that are appropriate for the typical driver, may not be appropriate for emergency vehicles.

This paper examined both the in-vehicle and infrastructure-based technologies which are emerging in the *next five to eight years* to assess how these technologies might impact emergency responders, particularly EMS. A qualitative score was assigned (in Tables 1 and 3) as a way of ranking technologies to identify those which might be considered a priority for incorporating into emergency vehicles, as well as identifying those with marginal utility for EMS. Examples of technologies which were assigned a High priority included *Forward Collision Warning, Intersection Movement Assistance, Do Not Pass Warnings* and *Emergency Vehicle Signal Preemption.* Examples of those assigned a Low score included *Stop and Go Cruise Control* and *Traffic Jam Assist*, since ambulances intentionally violate many of the normal rules-of-the-road (and such violations would trigger repeated warnings to the driver). Still other technologies *(Hard Shoulder Running, Lane Departure Warning),* earned a mixed rating since their benefits for EMS were situation dependent.

There will clearly be a transition period during which automated and traditional vehicles are operating on the same roadways. Policies must therefore be developed which govern how these two fleets will share roadway resources. In considering next steps, topics which require further study include the design of standards and protocols which will govern operation of (and response to) emergency vehicles in this new transportation environment. Key topics might include:

- Ambulance Right-of-Way. As semi and fully-automated cars become more prevalent (with vehicles in managed lanes providing safer, but more tightly packed traffic), there will be less maneuvering room and/or no space for vehicles to ‘pull over and stop’ to allow an ambulance to pass. This is an especially difficult issue if *Hard Shoulder Running* is used to relieve congestion during peak periods. Protocols to address this situation need to be defined.
- Ambulance in Platoon. Key questions here include how should EMS operate when responding to an emergency along a route with platoons of vehicles? Will ambulances equipped with CACC join platoons and then have authority to govern subsequent speed of that platoon?
- Autonomous Vehicles. What requirements should be placed on autonomous vehicles (operating without V2V or V2I communications) so that they recognize and respond to emergency vehicles?

Proper handling of emergency vehicles (and emergencies incidents on our roadways) is an important issue since it could be a key factor in giving the public the confidence needed to accept and support automation - and embrace the changes ahead.

Finally, safety critical events as defined by vehicle kinematics can provide meaningful safety performance metrics and will be more widely available in the future. The results of this project provide transportation safety analysts with insights into *potential sources* of safety critical events and the frequency of their occurrence, and their relationship to property damage only, injury, and fatal crashes. Furthermore, continued investigation of these safety critical events could help to evaluate pre-crash and pre-near crash contributing factors, and the types of evasive maneuvers that make crashes avoidable.

REFERENCES

1. Goodall, Nathan, "Ethical Decision Making During Automated Vehicle Crashes", Proceedings 93rd Annual TRB Conference, #14-4227, Washington, D.C., 2014.
2. NHTSA, "The Facts", http://www.nhtsa.gov/nhtsa/Safety1nNum3ers/may2014/ems/S1N_May14_EMS_3.html
3. NEMSIS 2013, https://reports.nemsis.org/Reports/Pages/Report.aspx?ItemPath=%2fNEMSIS+Version+2%2fNational+Reports%2fEMS+Agency%2fPatient+Complaint+Reported+by+Dispatch
4. Denaro B, Kornhauser A., Capp J, Shladover S, Misener J, "Road Vehicle Automation (Debate)", 93rd Annual TRB Conference, Session 871, Washington, D.C., 2014.
5. Flanigan M, Blatt A, Russell M, Batta R, Lee K, "Emergency Response Technology and the Integrated Active Transportation System (IATS); State of the Art and Vision for the Future", *Transportation Research Record*, No. 2189, 2010, pp.26-36.
6. Hill, Christopher, "ITS e-Primer, Module 13: Connected Vehicles", 9/2013, http://www.pcb.its.dot.gov/eprimer/module13.aspx#sthash.hIA1Q93l.dpuf
7. Fehr, Walton "DSRC: The Future of Safer Driving", 12/4/2013, http://www.its.dot.gov/factsheets/dsrc_factsheet.htm
8. Booz-Allen-Hamilton, FHWA Vehicle Infrastructure Integration (VII) Concept of Operations. Vers1.2, 9/2006, http://www.itsdocs.fhwa.dot.gov/research_docs/pdf/42concept-operations.pdf
9. Booz-Allen-Hamilton, VII USDOT Day-1 Use Case Descriptions, 5/2006, http://www.itsdocs.fhwa.dot.gov/research_docs/pdf/44USDOT-UseCases.pdf
10. Dodge L, R.E.S.C.U.M.E., NRITS Conference , 8/2013, http://nritsconference.org/downloads/Presentations13/Dodge_D1.pdf Accessed 7/29/14.
11. 11) AASHTO, "Connected Vehicle Infrastructure Deployment Analysis", FHWA-JPO-11-090, USDOT, 2011
12. Saleem F, Nodes S, *Arizona Emergency VII (E-VII) Program Overview and Focus Areas*, 2/2008, http://www.u.arizona.edu/~heqing/jjs_files/az-overview-Feb08.pdf
13. FMVSS: Vehicle-to-Vehicle Communications, Federal Register, Vol. 79, No. 161, 8/20/2014, Proposed Rules 49CFR Part 571.
14. Bayless S, Guan A, et.,al., "Connected Vehicle Insights: Trends in Roadway Domain Active Sensing", FHWA JPO-13-086, USDOT, 8/14/2013, http://ntl.bts.gov/lib/50000/50600/50696/Trends_in_Active_Sensing_JPO_format_Aug_23_2013__FHWA-JPO-13-086_.pdf
15. USDOT, "Connected Vehicle Research" http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm
16. Guan A, et. al. "Connected Vehicle Insights-Trends in Computer Vision:" FHWA JPO-12-026, 5/2011, http://www.its.dot.gov/research/pdf/TechScan%20computervision%20ITSA.pdf
17. Iteris News, "Iteris' Lane Departure Warning System to be Integrated into Two Passenger Vehicle Models with Another OEM Customer", 9/22/2010, http://www.iteris.com/about/news/2010/09/22/iteris-lane-departure-warning-system-to-be-integrated-into-two-passenger-vehicle-models-with-another-oem-customer
18. Dollar P, et. al, "Pedestrian Detection: A Benchmark", CVPR 2009 http://www.vision.caltech.edu/publications/dollarCVPR09pedestrians.pdf
19. North Dakota, Chapter 39010, General Rules of the Road, http://www.legis.nd.gov/cencode/t39c10.pdf?20140220131035
20. Rahtod, S, "An autonomous driverless car: an idea to overcome the urban road challenges", Journal of Information Engineering and Applications, Vol.3, No.13, 2013, p.34-38. http://www.iiste.org/Journals/index.php/JIEA/article/viewFile/9752/9960

21. Simonite T, “Data Shows Google’s Robot Cars Are Smoother, Safer Drivers Than You or I”, MIT Technology Review, 10/25/2013. http://www.technologyreview.com/news/520746/data-shows-googles-robot-cars-are-smoother-safer-drivers-than-you-or-i/
22. Berman B, “How Nissan Will Roll Out Self-Driving Cars: Fricking Lasers”, ReadWriteDrive, 9/23/2013. http://readwrite.com/2013/09/23/nissan-strategy-self-driving-vehicles-3d-laser-scanners#awesm=~ousNx3xjJ2WQot
23. Arthur C, “New self-driving car system tested on UK roads”, The Guardian, 2/14/2013, UK http://www.theguardian.com/technology/2013/feb/14/self-driving-car-system-uk
24. NHTSA, “Preliminary Statement of Policy Concerning Automated Vehicles”, 5/20/13, http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf
25. Shladover S, “PATH at 20; History and Major Milestones” IEEE Transactions on ITS, VOL.8, NO.4, 2007, 584-592 http://people.csail.mit.edu/albert/reading/ieeeits/04358931.pdf.
26. FHWA, “Definition of Active Traffic Management” http://ops.fhwa.dot.gov/atdm/approaches/atm.htm
27. MacKinnon B, Edmunds Inc., Six Car Technologies that will Revolutionize Driving in 10 years, 10/8/13, http://www.edmunds.com/car-technology/6-car-technologies-that-will-revolutionize-driving-in-10-years.html
28. Coffed J. “ The Threat of GPS Jamming”, Exelis, 2/201 http://www.exelisinc.com/solutions/signalsentry/Documents/ThreatOfGPSJamming_February2014.pdf
29. Blatt A, et al. *Naturalistic Driving Study: Field Data Collection*. No. SHRP 2 Report S2-S07-RW-1. 2015. ISBN 9780309273930
30. New York State Department of Transportation Accident Location Information System (ALIS). https://www.dot.ny.gov/divisions/operating/osss/highway/alis
31. SHRP 2 Naturalistic Driving Study InSight. https://insight.shrp2nds.us
32. Perkins, S.R., Harris, J.I., (1968). Traffic conflict characteristics: Accident potential at intersections. Highway Research Record, 225, 45-143.a
33. Parker, Jr., M.R., & Zegeer, C.V. (1989). Traffic conflict techniques for safety and operations: Observers manual. U.S. Department of Transportation, Federal Highway Administration.
34. Guo, F., Klauer, S.G., McGill, M.T., & Dingus, T.A. (2010). Evaluating the Relationship Between NearCrashes and Crashes: Can NearCrashes Serve as a Surrogate Safety Metric for Crashes? (Contract No. DOT HS 811 382). Washington, DC: National Highway Traffic Safety Administration.
35. “An Assessment of the National Highway Traffic Safety Administration's Rating System for Rollover Resistance: Special Report 265” (2002).
36. Lamm, R., Psarianos, B. & Mailaender, T. (1999). Highway design and traffic safety engineering handbook. McGraw-Hill, New York.