



First Responders Group

Improving Communication Between Ambulances
and the Hearing Impaired

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Improving Communication between Ambulances and the Hearing-Impaired

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Executive Summary

Emergency Medical Services (EMS) providers face high rates of injuries and fatalities. There is a need to ensure that drivers are accurately warned of the presence of an ambulance so that they can quickly remove themselves from the ambulance's path and reduce the probability of injury to themselves, EMS workers, and patients. One population that particularly faces challenges in recognizing an ambulance's presence is the hearing-impaired. Over 38 million people (12 percent of the population) in the United States have a significant hearing loss (Center for Hearing Loss and Communication, 2013). The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group (FRG), in partnership with the S&T Resilient Systems Division (RSD), sponsored an effort to explore the challenges faced by the hearing-impaired in detecting and localizing an ambulance in the area and identify technologies that could address these challenges.

A team comprised of BMT Designers & Planners (D&P) and Carlow International used information gathered from literature reviews, interviews, and surveys to examine hearing-impaired drivers' needs in responding to ambulances and potential technology to meet said needs. A set of high-level research objectives and considerations were developed to explore the issue of ambulance communication with hearing-impaired drivers. These included:

- What characteristics of warning devices would be most effective in communicating ambulance presence and location to hearing-impaired drivers? This would include single modalities like visual or tactile/haptic as well as combined modalities.
- How effective the warning devices are with respect to improving hearing-impaired driver situation awareness and responses.

This report describes the research approach and results in detail.

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Acronyms

CDS	Crashworthiness Data System
D&P	BMT Designers & Planners
DHS	U.S. Department of Homeland Security
EAR	Emergency Alert Receiver
EAT	Emergency Alert Transmitter
EMS	Emergency Medical Services
E.V.A.D.E.	Emergency Vehicle Alert DEvice
E-VIEWS	Emergency Vehicle Early Warning Safety System
FEMA	Federal Emergency Management Agency
FRG	First Responders Group
GPS	Global Positioning System
LED	Light-Emitting Diode
LOI	Letter of Intent
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
PND	Personal Navigation Devices
RSD	Resilient Systems Division
S&T	Science and Technology Directorate
SART	Situation Awareness Rating Technique
SWS	Safety Warning System
SCS	Smart Care System
TLX	Task Load Index

1.0 Introduction

1.1 Background

Approximately 6,500 ambulance collisions occur every year, injuring about 10 people per day and resulting in an estimated two fatalities per week (Maguire, 2002). Due to high rates of injuries and fatalities among emergency medical services (EMS) providers, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group (FRG) and the S&T Resilient Systems Division (RSD) partnered with the National Institute of Standards and Technology (NIST), National Institute for Occupational Safety and Health (NIOSH), BMT Designers & Planners (D&P), and Carlow International to develop design guidance for ambulance patient compartments that address crashworthiness, patient safety, and EMS provider safety and performance. During the development of this design guidance, D&P identified several issues associated with accident avoidance. One of the issues identified was communicating the presence of an ambulance to deaf or hearing-impaired drivers and pedestrians. Hearing impairment, for the purposes of this task, includes: 1) those who suffer from congenital hearing loss or acquired hearing loss, and 2) those who experience temporary hearing loss due to loud ambient background noise from radios or devices such as headphones/ear buds as well as distractions resulting from environmental conditions such as a loud construction zone or voice and phone conversations in vehicles. Since the identification of this issue, DHS S&T has been working with a Federal Emergency Management Agency's (FEMA) Disability Integration Specialist, who has requested S&T's support in the research effort. This includes researching alternate approaches to focusing the driver's attention on the imminent presence of an oncoming ambulance, helping to provide an immediate understanding of the direction from which the ambulance is approaching, and supporting the driver's decision-making about an effective avoidance response. To help DHS better understand this issue, D&P was tasked with performing a literature review to analyze the issue, identifying and ranking candidate solutions, and developing an initial research plan to investigate those solutions that seem the most promising.

1.2 Objective of Report

The objective of this report is to provide a summary of key research issues associated with ambulance communication with hearing-impaired drivers. These research issues are based on literature review findings, identification and ranking of potential solutions to improve the communication between ambulances and deaf/hearing-impaired drivers and pedestrians, and descriptions of approaches to explore the feasibility of these solutions.

2.0 Defining Communication Issues between the Hearing-Impaired and Ambulances

To develop an understanding of the communication issues between hearing-impaired drivers and ambulances, D&P conducted literature reviews, informal interviews with hearing-impaired individuals as well as EMS providers, and research into emergency vehicle warning systems.

2.1 Literature Review

2.1.1 Accident Rates and the Hearing-Impaired

To the extent that the researchers could determine, limited research has been conducted on the driving capability of hearing-impaired individuals. The research that has been undertaken is largely anecdotal and historical. Finesilver (1962) compared the driving records of 100 deaf drivers with two groups of 100 hearing drivers in Colorado. The control groups consisted of 100 drivers randomly chosen from the Department of Motor Vehicles registry and placed in either group A or B. The deaf drivers were selected from a list of 128 deaf participants in a driver improvement program. Finesilver found that the deaf drivers had fewer moving violations than control group A (54 percent fewer) and control group B (113 percent fewer). They also had significantly fewer accidents (control group A, 18 percent fewer; control group B, 31 percent fewer). However, Lee (1998) identifies several problems with the Finesilver study. The records from the deaf drivers were obtained from a driver-improvement program while the hearing drivers' records were selected at random from state driving records. The deaf drivers were individuals who were already interested in improving their driving capability and may have been more conscientious than the control group drivers. The average age of the deaf drivers was significantly higher than the hearing drivers. Consequentially, they may have had more experience behind the wheel and been better at avoiding accidents. Additionally, there was no indication of the experience level of either driver groups or the type of terrain they drove on. As Lee indicates, the higher performance of the deaf drivers could be a reflection of being older, more experienced, and more conscientious.

Henderson and Burg (1973) examined hearing loss and accident rates for truck and bus drivers. They performed audiograms on 236 commercial vehicle operators. They analyzed the correlation of data between hearing level and accident history for each driver. Hearing loss was associated with a better driving record. However, the level of hearing loss recorded was low, so it cannot necessarily be inferred that a totally deaf driver would have a better driving record than a hearing driver. The study is also confounded by the fact that the drivers with the most hearing loss were also older, so they may simply be better drivers due to more experience.

Contradictorily, Coppin and Peck (1963) examined driving records over a three-year period for 721 deaf and 94,935 hearing drivers. Deaf drivers' accident rate was nearly twice that of hearing drivers. Drivers were compared across age, gender, occupation, and annual mileage. Significant differences were found for annual mileage, occupation, and age. Deaf drivers were older, drove more miles annually, and were employed in more skilled and semi-skilled positions. These factors could have influenced the accident rate. Deaf drivers were older with more time behind the wheel and therefore had more opportunities to be in an accident. They conducted a subsequent study in 1964 in which they matched 453 deaf drivers with 453 hearing drivers on gender, age, annual mileage, and occupation. Deaf males still had nearly twice as many accidents as hearing males. No significant difference in accident rate was found between deaf and hearing female drivers.

Cook (1974) examined the Wisconsin driving records of 81 deaf drivers with 100 hearing drivers. Hearing-impaired drivers were found to have 1.82 times higher the number of accidents as non-hearing-impaired drivers. Additional studies have been conducted to examine the influence of hearing devices on driving. McCloskey, Koepsell, Wolf, and Buchner (1994) performed a case study in which older drivers involved in an injury-related accident in the previous two years were matched with other older drivers who had not been in any injury-related accidents. Participants were matched according to gender, age, and county of

residence. They found that drivers who wore hearing aids while driving had a 2.1 times higher risk of an accident compared to other drivers. This risk rate included drivers who indicated they were hearing-impaired but did not own a hearing aid. It can be inferred that receiving auditory information from the hearing aid was more of a hindrance than a help for these drivers. However, Foley, Wallace, and Eberhard (1995) also examined accident risk and hearing aids among elderly drivers and found no significant effect of hearing aids on accident risk. Overall, the data reviewed is largely inconclusive on whether deaf drivers' performance is significantly different than that of their hearing counterparts.

2.1.2 Distracted Drivers

In addition to the challenges deaf and hard-of-hearing drivers face in recognizing approaching ambulances, hearing drivers can also experience difficulty. Hearing drivers can experience temporary hearing loss when faced with distractions such as making calls or listening to music while driving. Young and Regan (2007) define distracted driving as "occurring when a driver's attention is, voluntarily or involuntarily, diverted away from the driving task by an event or object to the extent that the driver is no longer able to perform the driving task adequately or safely." The current trend toward developing "quiet cars" may also inhibit communication between ambulances and surrounding civilian vehicles. While research about accident rates for the deaf and hard-of-hearing drivers is contradictory, research has consistently indicated that distracted drivers are more prone to accidents.

Various researchers have examined the influence of vehicle distractors on accidents. Redelmeier and Tibshirani (1997) investigated cell phone usage while driving and accident occurrence as well as whether hands-free devices reduced accident occurrence. They obtained billing records of 699 drivers who were involved in accidents that caused considerable property damage but resulted in no physical injuries. Call records for the day of the accident and week preceding it were reviewed. The time of the accident was determined through reviewing police records and emergency vehicle logs. A total of 26,798 cellular-telephone calls were examined during the 14-month study. Redelmeier and Tibshirani (1997) found that drivers had four times the risk of being in an accident while talking on the phone. Laberge-Nadeau and colleagues (2003) also examined the correlation between mobile phone use and vehicle crash risk. They surveyed 36,078 drivers on driving habits, detrimental driving activities over the previous two years, and mobile phone use. They found that male drivers who used a cell phone while driving had 1.11 times higher crash risk and female drivers had 1.2 times higher risk than those who did not use a phone while driving. Male and female cell phone users had a 38 percent higher risk for collision. Stutts, Reinfurt, Staplin, and Rodgman (2001) investigated vehicle crashes from the Crashworthiness Data System (CDS) gathered between 1995 and 1999. They found that 8.3 percent of crashes were due to driver distraction. Stutts et al. (2001) also examined what types of distractions drivers attributed to crashes. Distractions outside the vehicle (police presence or road construction) were attributed to 29.4 percent of crashes; adjusting the radio, cassette, or CD player were the cause of 11.4 percent of crashes; and presence of other passengers in the vehicle accounted for 10.9 percent. Using or dialing a mobile phone was reported by only 1.5 percent of drivers. This is contradictory to previous research which found a strong link to cell phone usage and crashes. Young and Regan (2007) attribute this low figure to underreporting by drivers because cell phone usage while driving is restricted or banned in many states. Identifying technologies that can help deaf and hard-of-hearing drivers recognize ambulances also has implications for helping temporarily hearing-impaired drivers recognize and respond to ambulances.

2.2 Interviews and Surveys with Drivers and EMS Providers

2.2.1 Interviews and Surveys with Hearing-Impaired Drivers

Based on the findings from the literature review, informal, non-structured interviews and surveys were conducted with 10 deaf and hard-of-hearing individuals contacted through the National Hearing Loss Association of America, the Association of Late Deafened Adults, and the Deaf and Hard of Hearing Consumer Advocacy Network (See Appendix A). The topics addressed through these interviews and surveys include:

- The listening devices they currently use;
- Their ability to recognize the presence, location, and orientation (approach or recession) of an ambulance using lights and sirens while driving;
- The factors that hinder their ability to recognize an ambulance using lights and sirens while driving;
- The factors that hinder their ability while walking to recognize an ambulance using lights and sirens; and
- The feasibility of proposed solutions for drivers and pedestrians.

The respondents included equal numbers of male and female participants. When asked to identify what aids they typically use to hear, 30 percent of participants indicated they rely on a hearing aid, 20 percent use a cochlear implant, and 20 percent use hearing aids and a cochlear implant or assistive listening device. Forty percent of participants rated their hearing loss as moderate, another 30 percent rated their hearing loss as profound, 10 percent rated their hearing loss as mild, and 10 percent rated their hearing loss as severe. Fifty percent of participants had experienced hearing loss since birth, 40 percent had experienced hearing loss for 10 years or more, and 10 percent had only been deaf for six months.

Twenty percent of respondents indicated they could not recognize an ambulance and its distance, direction, and orientation while driving and 30 percent indicated difficulty in recognizing an ambulance while walking. Of the remaining respondents, 50 percent indicated they relied on seeing the ambulance's lights and other cars' reactions while driving and 40 percent relied on seeing ambulances' flashing lights while walking. A lack of lights on the ambulance was indicated as the greatest difficulty in recognizing ambulances while driving or walking. When queried about potential solutions, adding additional ambulance lighting received the highest rating for increasing ambulance recognition while walking. Providing an in-vehicle display with light-emitting diode (LED) lights or text warnings received the highest rating for increasing ambulance recognition while driving (See 2.3.4).

2.2.2 Interviews with EMS providers

D&P was also tasked with identifying best practices for ambulance drivers. As part of the interview process to obtain this information, EMS providers were queried about their experiences with hearing-impaired drivers and ways to improve communication with these drivers. The majority of drivers indicated no awareness of any encounter with a hearing-impaired driver. When asked about suggestions for technologies, two EMS providers mentioned they had heard about the Rumbler, a vibration-emitting siren. Other suggestions included adding brighter lights to the ambulance, improving the way lights are arranged on the vehicle, and using an air horn.

2.3 Emergency Vehicle Warning Systems

In the literature review, several solutions were proposed to improve deaf or hard-of-hearing drivers and pedestrians' ability to quickly discern the presence of an emergency vehicle and respond. These devices include single as well as multiple modality devices including: LED lights or text messages through in-vehicle displays to visually notify drivers, vibration-emitting sirens, vibration delivered to the user's body, or combinations of the above.

Jenkins (1999) indicates that there are three components of the emergency vehicle communications system: the source of the message, how it is transmitted, and how it is received. Typically, emergency vehicles such as ambulances use sirens to provide audible warnings and flashing lights to signify their presence to surrounding drivers and pedestrians. Jenkins indicates five criteria for effective emergency vehicle sirens:

- The siren must be audible to the driver
- The sound level must not jeopardize the driver
- The siren should not overly alarm the driver
- The siren should not prevent the driver from operating the vehicle
- The siren should be meaningful for the driver

For the deaf/hearing-impaired as well as distracted drivers, an auditory-focused warning is insufficient to adequately inform them of an ambulance's presence. Jenkins outlined several ways emergency vehicle signals can be enhanced to meet these criteria. One solution would be increasing the sound level of the siren. However, this would not be helpful to totally deaf individuals and could create more accidents as hearing-impaired and distracted drivers could be startled and lose control of the vehicle. Another solution is to add an artificially intelligent receiver on vehicle dashboards that detects the emergency vehicle siren and provides a visual cue to drivers such as a flashing red light. Other solutions include using a one-way radio to communicate the presence of an emergency vehicle or a radar transmission that emits a light and tone when an emergency vehicle is detected. Several recently developed technologies include these capabilities.

2.3.1 In-vehicle Warning Systems

One adaptive system is the Safety Warning System (SWS). SWS was developed by Georgia Tech Research Institute at the Georgia Institute of Technology (Georgia Tech) on a project sponsored by the radar detector industry. It consists of a transmitter and a radar detector receiver or stand-alone receiver/display system (see Figure 1). Low fidelity detectors have a LED light that will communicate whether the perceived emergency vehicle is moving or stationary through its flashing pattern. For higher fidelity models, a verbal warning is emitted as well as either flashing LED lights or an alphanumeric message on a display. The system can send 64 different messages. It is comprised of a radar mode, time mode, continuous transmit, and contact closure mode. In the radar mode, the SWS will monitor the surrounding area every .5 seconds and can alert the driver of an approaching emergency vehicle from half a mile to one mile distance, depending on terrain. There is also a time mode that allows the user to set four independent turn-on, turn-off times during any 24-hour period. The continuous transmit mode can be used to repeat the warning. The contact closure mode uses sensor arrays to detect other traffic issues like fog and emit warnings accordingly. The transmitter can be mounted on police cars, emergency vehicles, utility vehicles, highway repair vehicles, and on stationary structures at fixed locations along the highway (Braun, 1997). The system is no longer being produced.



Figure 1. SWS Receiver Prototype

Emergency Vehicle Alert is another in-vehicle system. Similarly to SWS, it consists of a transmitter and receiver mounted to the dashboard of a vehicle. When the transmitter is activated by an emergency vehicle, the receiver emits a LED light and an auditory tone. The current prototype is planned for incorporation as a vehicle component but the developer ultimately plans to create a portable version, which can be used to alert persons through visual and auditory modes as well as vibration.

Another LED light-based in-vehicle system prototype to alert drivers to the presence of a car horn or police whistle was developed by Mohammadi and Mesgarha (2011). The device will mount to the dashboard and consists of three LED lights indicating if the sound picked up by the microphone and sound sensor is of a low, middle, or high frequency and the direction of the sound (see Figure 2). It also includes specific LED lights for police sirens and car horns which turn green whenever either is identified. At this point, the device is still a prototype. Some advantages of the system are its ability to provide visual warnings to drivers and to help drivers localize the frequency that is being emitted by the approaching vehicle and its direction. A

limitation of this device noted by the developers is that it currently has difficulty in discriminating warning sounds from noise in the surrounding area. Also, there is no specific indicator that an ambulance or fire engine is approaching. The driver would have to be trained to know which frequencies are emitted by vehicle sirens and act accordingly when that frequency level is received by the device.



Figure 2. LED-Based Warning System

Kuwahara, Morimoto, Kozuki, and Kawamura (2008) proposed a warning system that uses LED lights and vibrations to alert deaf drivers to the presence of an emergency vehicle. The system will use microphones to determine the type of emergency vehicle and its direction based on its frequency and sound waves. The system then sends a vibration to the driver's antebrachial region (forearm) and LED lights flash on the dashboard indicating the type of emergency vehicle detected and its direction. They have conducted initial lab tests on the effect and driver response to the placement of the LED monitor at different distances from the driver's viewpoint. However, they have not examined the vibration component or the suitability of combining it with the LED lights.

Guinn, Logan, Nelson, and Watson (2010) proposed a system for improving recognition of emergency vehicles called the Emergency Vehicle Alert DEvice (E.V.A.D.E.). The system is composed of two modules, the Emergency Alert Transmitter (EAT) and the Emergency Alert Receiver (EAR). The EAT would be located on the emergency vehicle and incorporated into the vehicle lighting system. When the warning lights on an emergency vehicle are activated, the EAT broadcasts a signal with information such as the type of emergency vehicle, its position, and its orientation. The signal is then picked up by the EAR. The EAR examines the information transmitted and compares it with the driver's own location and direction using a compass and Global Positioning System (GPS) microchip. An audible warning message, which can be transmitted in English or Spanish, is sent through the vehicle's pre-existing speakers. A visual warning is sent to an external display installed in the dashboard. A flashing LED will be used to draw attention to the message appearing on the visual display and to show the direction of the emergency vehicle. The LEDs are arranged to refer to the eight possible directions transmitted (north, south, east, west, northeast, northwest, southeast, southwest) and the appropriate corresponding light will be activated (see Figure 3).



Figure 3. E.V.A.D.E.

Another in-vehicle display system is 911ETA. 911ETA provides notification of an approaching emergency vehicle to smartphones, Personal Navigation Devices (PNDs), or in-dash GPS displays. It can be downloaded as a software application to these devices. The system provides visual, auditory, and vibration alerts. As shown in Figure 4, it consists of a map highlighting the current direction of the approaching emergency vehicle (indicated by the fire truck icon) in reference to the user's location (indicated by the red dot). It also emits auditory warnings and a 30-second vibration to indicate the emergency vehicle's approach. The in-vehicle version is still under development but will ultimately have the ability to lower the volume on the radio, lower the air conditioner speed/noise, and possibly roll down the windows. It is currently developed to provide warnings when an emergency vehicle is 900 feet away, but this can be tailored to the needs of the jurisdiction (B&C Electronic Engineering Inc., 2011).



Figure 4. Screen Capture of 911ETA

2.3.2 External Warning Systems

In addition to in-vehicle warning systems, technologies have also been developed to help ambulances provide widespread alerts to drivers in addition to the traditional lights and sirens. These technologies can potentially benefit hearing-impaired and non-hearing-impaired alike.

One external warning system is the Emergency Vehicle Early Warning Safety System (E-VIEWS). E-VIEWS is comprised of three modules that direct traffic flow in the presence of emergency vehicles (NASA Spinoff, 2002). The first module (E-COMM) informs drivers and pedestrians that emergency vehicles are approaching an intersection. Using microwave transmissions from an approaching emergency vehicle, it provides a green light to the approaching emergency vehicle and changes lights in the opposite direction to red. The second module establishes an intelligent two-way communication network (E-MITT) between response agencies such as police, fire, medical, and road maintenance units. The third module (E-VIEWS) uses LED displays placed above the center of the intersection to inform drivers of the approaching emergency vehicle's direction. The visual displays can be designed to include detour directions, maintenance and traffic safety information.

The E-VIEWS system has been used on the West Coast in Monrovia, California since 2001 along 10 intersections. Twenty police cars and 10 fire emergency vehicles have been equipped with transponders to communicate their approach to the intersection. Emergency vehicle responders have indicated reduced response time, reduced job stress, and increased safety for themselves and other drivers. They also indicated that drivers seem more aware and responsive to emergency vehicles' approach (NASA Spinoff, 2002).

When an emergency vehicle is within 3,500 feet of the traffic signal, the first responder activates the vehicle's transponder, causing the traffic lights at the intersection to automatically turn to yellow, and then red, for cross-traffic and oncoming traffic. The first responder then receives a message that a priority to pass through the intersection has been approved by the system. At the intersection, the visual warning display signs are activated. An icon in the shape of an emergency vehicle flashes brightly, indicating the vehicle's direction of approach and departure (see Figure 5). The icons appear to move in step with the

actual movement of the emergency vehicle as it passes through the intersection. Each emergency vehicle's contact with the traffic light signal is recorded and stored in memory for later download (NASA Spinoff, 2002).



Figure 5. E-VIEWS

Another external warning system is the Rumbler. The Rumbler is a siren system emergency workers activate to inform drivers and pedestrians of an approaching emergency vehicle by creating a vibration. Kanable (2008) indicates that the Rumbler is currently used by approximately 60 law enforcement agencies, with most located in metropolitan areas on the East Coast. Rumlbers operate at 110 decibels, less than the traditional primary siren (119 decibels). Rumlbers are particularly useful at dangerous intersections and in heavy traffic that requires vehicles to move aside to create a path for the emergency vehicle to pass. Maddern, Privopoulos, and Howard (2011) compared the Rumbler with traditional police, ambulance, and other commonly-used sirens. The Rumbler was found to be easily heard and rated easiest to localize within vehicles. It also was effective at counteracting masking from other background noises and the effects of signal shadowing (fluctuations in sound due to the presence of barriers such as buildings). A noise pollution newsletter, [NoiseOFF](#) (n.d.), identified some concerns about the disturbance of the siren. The newsletter indicated the siren can be heard and felt from a distance up to 200 feet away. It easily penetrates into nearby homes and apartments even with windows closed. However, a representative from Federal Signal Corporation, which distributes the Rumbler, indicated it could only be felt by individuals in the immediate vicinity of the siren (Joseph Bader, Federal Signal Corporation, personal communication, March 11, 2013). [NoiseOFF](#) also suggests that exposure to the Rumbler could lead to involuntary stress responses resulting in increased adrenaline, increased cardio-respiratory rates, muscle tension, and elevated blood pressure.

2.3.3 Portable Warning Systems

Initial development has also begun on portable warning systems that hearing-impaired pedestrians can use while walking to alert them of the presence of an emergency vehicle. Of 10,376 deaf and hard-of-hearing individuals surveyed by the Royal National Institute for the Deaf (now known as Action on Hearing Loss), 60 percent indicated that they use a cell phone on a weekly basis. Vibe, a mobile phone which uses multiple modalities to alert users, is an attempt to modify this technology for emergency messaging. Vibe will feature an always-on microphone which will detect cues in the surrounding environment such as ambulance sirens. The device will then use different types of vibration to alert the user. The alert will be further confirmed by visual icons and sound. Ravid and Cairns (2008) conducted a feasibility study and initial usability study examining the usability of the menus for the phone prototype and groupings of alerts and alarms. Respondents provided positive feedback on menu design and alarm categories. However, no testing of the phone in an actual environment where they would be exposed to an approaching emergency

vehicle took place. One limitation noted of this device is that the battery will be easily drained as the use of the phone to detect loud noises in the environment requires the microphone to remain on. Some proposed solutions include a separate Loud Noise Alert function so that users can extend battery life when the capability is not required or to develop an algorithm that keeps the system on standby until a noise requiring an alert is detected. In the interim, the device would have to be charged each night. Other concerns raised were the sensitivity of the Loud Noise Alert, propensity for false alarms, and the ability of deaf or hearing-impaired seniors to use the device. The majority of individuals with hearing loss are over 65 and the capability to use this device will continue to be an issue as the deaf and hearing-impaired age.

Moneual recently developed the Smart Care System (SCS) (Moneual, 2013). SCS is a watch that can be used to provide emergency vehicle alerts by displaying visual messages on its LCD screen and providing an accompanying vibration alert (see Figure 6). In the outdoor mode, it can detect emergency sirens and other loud noises. It also includes an emergency mode, which can be used to call 9-1-1 and obtain emergency services support. This technology provides a portable way for hearing-impaired drivers and pedestrians to maintain awareness of ambulances in their surroundings.



Figure 6. Smart Care System

2.3.4 Ratings of Technologies

Based on feedback from the deaf and hard-of-hearing survey and interview respondents, technologies that build upon currently available tools and provide visual cues about the presence, direction, and orientation of ambulances are preferred. Participants rated how effective they felt eight proposed technologies would be in increasing their ability to perceive an ambulance on a scale from 1-8. As indicated in Table 1, in-vehicle technologies received the highest rating for potential solutions. In-vehicle displays that use flashing LED lights to provide warnings had the highest average rating ($M = 6.78$) followed by in-vehicle displays with text warning messages ($M=5.67$).

Table 1. Deaf and Hard-of-Hearing Technology Ratings

Proposed Technology	Mean Rating
In-vehicle display with text warning messages (ex. GPS)	5.67
In-vehicle display with flashing LED lights	6.78
In-vehicle seat vibration	4.78
Cell phone/PDA text warning messages	2.7
Cell phone/PDA vibration	2.4
Increased ambulance lighting	4.2
Ambulance emitted vibration	2.7
Wristwatch with visual alert and vibration	3.2

Based on this feedback, 911ETA seems to be the most feasible of the technologies explored. It can currently be downloaded on mobile phones and its developers ultimately plan to integrate it into vehicle navigation systems. The remaining in-vehicle systems, although intriguing, are largely still in prototype form and would need additional funding before they are available for testing. The Rumbler and E-VIEWS warning technologies are external to the vehicle and are also possible solutions. These technologies are both in limited use and although some positive feedback has been indicated by emergency workers and

initial research, there has previously been little research on their effectiveness in alerting drivers. Hearing-impaired respondents indicated that the Rumbler vibration may not be strong enough or that experiencing the vibration while driving could be disconcerting and increase accidents. They also expressed concerns about being able to see E-VIEWS in inclement weather or if they were behind a truck or sports utility vehicle. One respondent indicated that many of the intersections he crossed did not have traffic lights which are where E-VIEWS would be mounted. The Vibe mobile phone and the Smart Care System seem to be viable portable tools to alert pedestrians of approaching emergency vehicles, but they are currently still in development. Some hearing-impaired interviewees indicated that they liked being able to have a portable warning system; however, they felt having the alerts come through a cell phone would be distracting while driving and they worried that if it alerted them through vibrations, they might dismiss it as a call while driving or walking and not immediately heed it. They also expressed reluctance at having to purchase a watch to monitor emergency vehicles.

3.0 Research Proposal

3.1 Research Objectives and Considerations

As a result of the literature reviews, interviews, and surveys, several research topics were identified for further exploration. These topics can be divided into two foci: identifying characteristics of the warning systems and examining their effects on drivers.

3.1.1 Characteristics of Warning Devices

The first research focus is to examine the characteristics of the warning devices themselves. Of the technologies reviewed above, some rely on multiple modalities to alert hearing-impaired drivers while others rely on one modality, usually vision. Further research is needed to determine whether one modality or multiple modalities increase responsiveness. If one modality is believed to be sufficient, the one deemed to be most effective should be explored. If multiple modalities are more effective, the combination of modalities needed should be explored. This could be examined using many different experimental design approaches, but the most effective might be using a driving simulation. Deaf and hard-of-hearing drivers would be recruited to participate. Once they are familiarized with driving in the simulator, they would conduct a simulated drive. During the course of the drive, the warning devices would periodically be activated and participants would have to respond by moving the vehicle to the shoulder of the simulated roadway. They would be exposed to various warning modalities including: visual alert, auditory alert, vibration, visual and auditory, visual and vibration, auditory and vibration, and visual, auditory, and vibration. Presentation of conditions would be counterbalanced across participants to avoid order effects. Driver performance measures collected by the simulator as well as human factors engineers' observations, participants' survey responses, and interview responses would be used to determine the effectiveness of the modalities. This information would be useful to developers so that they know how to develop their products to gain maximum effectiveness for the hearing-impaired community. Some benefits of using a driving simulator are that it provides a realistic representation of the driving experience and collects accurate and timely measures of performance. A difficulty with driving simulations is that the workload on the driver in the simulation may not approach the actual workload experienced in an actual driving situation. The presence and proximity of other vehicles and pedestrians, ambient noise level, traffic conditions, tempo of stop and go traffic, traffic signals, etc., would need to be controlled to approximate the workloads placed on actual drivers.

Within this same vein, another area of research is to identify what requirements are needed for an alert to be sufficiently noticeable to warn drivers. The alert should be distinguishable enough that drivers can localize it and discriminate it from other visual, auditory, or vibration signals. The type of color and level of brightness and frequency can be modified to help drivers maintain awareness of the severity of warning system alerts. Implementing too strong or too weak a warning could increase the possibility of collision with other individuals or the approaching ambulance. Further research is needed to determine the warning thresholds of the technology reviewed. Human factors engineers would determine these thresholds using human factors standards and psychophysical experimental methods such as the method of limits. For this

methodology, participants would be exposed to lights, sound, and vibration below threshold (the lower limit). The stimuli would then be increased and participants would indicate whether or not they can perceive it until the stimuli reaches the upper limit. The threshold is determined as the midpoint between the last "No" response and the first "Yes."

The type of information that needs to be provided to hearing-impaired drivers/pedestrians is another research objective. The effectiveness of informing hearing-impaired drivers/pedestrians of the presence of an ambulance or the presence and location of one should be explored. Driver simulator performance measures collected by the simulator as well as human factors engineers' observations, participants' survey responses, and interview responses would be used to determine the effectiveness of various levels of information provided. Research is also needed to determine what types of hearing-impaired driver/pedestrian behaviors require an alert. Accident databases could be examined to determine if there is any commonality in civilian drivers'/pedestrians' behaviors preceding an accident. Any near-misses that occurred during driving simulation could also be used to identify behaviors that precede an accident with an ambulance. This information could be used by warning system developers to ensure that the systems provide a warning if these behaviors are detected.

3.1.2 Effects of Warning Systems

Another research focus is the effectiveness of in-vehicle, portable, and external tools. Their ability to improve decision making and accident avoidance for deaf/hard-of-hearing/distracted drivers and pedestrians should be examined. Additionally, the impact on driver workload, situation awareness, and performance from interacting with an in-vehicle device should be explored. The in-vehicle devices reviewed require drivers to maintain attention to the primary task of driving their vehicle but also to be cognizant of visual, verbal, and/or vibration alerts signaling the presence of an emergency vehicle and to be ready to respond appropriately. This divided focus could increase the workload currently experienced by drivers and lead to more accidents. This is particularly true for totally deaf drivers. As they cannot receive information about the driving environment through auditory means, they are largely reliant on their visual ability. Having to visually monitor the surrounding traffic as well as the warning device display could significantly increase the workload these drivers encounter and impact their situation awareness and driving performance. These objectives can best be explored through simulated driving experiments where participants would be exposed to each device with the presentations of devices counterbalanced. The driving simulator and human factors engineer observations would be used to measure performance, decision making, and accident avoidance. Participants would also complete workload and situational awareness and usability measures. Additionally, human factors engineers would evaluate the usability of each device based on human factors principles such as consistency and simplicity of design, design for human error tolerance, and design to accommodate the full range of human capabilities and physiology. E-VIEWS could be challenging to evaluate in a simulated environment. E-VIEWS is implemented by mounting it to a traffic light and during the interviews of hearing impaired individuals, they expressed concerns with viewing E-VIEWS such as the ability to see it in inclement weather or when driving behind a truck or sports utility vehicle. These conditions would be difficult to address realistically in a simulation. However, this system is currently in limited use. Surveys and interviews could be conducted in the communities where it is already implemented to supplement data collected in a simulated environment and obtain further insight into its impact on driver performance, situation awareness, and workload.

A second consideration is the infrastructure impacts (costs and logistics) of these tools. Research should be conducted to determine the cost thresholds of the technology identified. Techniques should be identified that can reduce the cost but maintain the viability of the tools. Human factors engineers would conduct a cost benefits analysis and use this information and the results from the simulator study to determine which tools can effectively warn participants without reducing driver performance or being too difficult to implement.

Additionally, research is needed to identify techniques to reduce the panic, confusion, or distraction associated with alerts. In researching the Rumbler, one concern that was identified was fear and confusion that surrounding drivers and pedestrians could experience. Interviewees also expressed concern that feeling the vibration from the Rumbler or from an in-vehicle warning system could be disconcerting and

increase the possibility of them having an accident. Even the visual warnings provided by in-vehicle systems or the E-VIEWS system could lead to confusion and distraction in hearing-impaired drivers. Techniques can be identified to reduce these challenges. Human factors engineers would develop a training program to teach these techniques. The program would be piloted with warning system users and then the effectiveness of the program would be examined through user surveys, interviews, and performance. Based on the feedback received, the program would be further modified as needed.

3.1.3 General Methodology

To examine many of the research objectives mentioned above, participants from the deaf and hard-of-hearing community will need to be recruited to participate. Attempts should be taken to ensure that a representative sample is included. Efforts should be made to include participants of different ages, genders, and levels of hearing impairment. All participants will have to sign an informed consent form that describes the study procedure, benefits and risks associated with participating, and assurances that participation is voluntary and all data collected will be kept confidential. Interpreter services should be budgeted into the project to assist deaf participants in understanding the procedures and presenting any questions and concerns to the researcher. Ethical standards will be maintained throughout the implementation of experiments, surveys, and interviews.

4.0 Expected Implications

This research has important implications for improving the communication between deaf, hard-of-hearing, and distracted drivers and ambulances. Though focused on ambulance research, the challenges experienced and technologies explored have implications for improving communication with all emergency vehicles. The amount of literature on deaf and hard-of-hearing drivers is limited and largely historical. Further research would provide more up-to-date information on challenges these drivers face and the tools to resolve them. It would provide information on the effectiveness of using these tools as well as characteristics that should be considered in their design. Based on the results of this research, the hearing-impaired community and product developers will have an increased understanding of these tools and how they can be effectively designed and implemented.

A multi-tiered research project could be implemented. Characteristics of each warning system could be examined to determine the most effective warning features. Developers could use this information to modify their system as needed. Then, research on the effectiveness of each technology on driver performance, situation awareness, and workload could be conducted.

Many of the warning systems discussed are still in the prototype phase. The Rumbler and E-VIEWS are in limited use on the East Coast and West Coast, respectively. This would be the optimal time to obtain further insight into these tools and the ways they can be maximized so that any necessary modifications can be identified before it becomes too costly and time-consuming to implement them. Identifying effective warning systems will further increase the safety of EMS workers, their patients, and the greater community, particularly those who are deaf and hard-of-hearing.

5.0 References

- B&C Electronic Engineering Inc. (2011). *Information Paper on Technology for Citizen Notification of Responding Emergency Vehicles*, Retrieved February 10, 2013 from <http://www.911eta.com/911ETA-White-Paper-w-cover.pdf>.
- Braun, A. E. (1 August,1997). Intelligent Transportation Systems: Mirage or Reality?, *Microwave Journal*, 8, 1-9.
- Center for Hearing and Communication (2013). *Facts about hearing loss*, March 18, 2013 from <http://www.chchearing.org/about-hearing-loss/facts-about-hearing-loss>.
- Cook, J. J. (1974). *Hearing-impaired survey* (Monograph Series - Program Accountability in Special Education No. 3). Madison, WI: Wisconsin Department of Public Instruction.
- Coppin, R. S., and Peck, R. C. (1963). *The totally deaf driver in California, Part I*. Sacramento, CA: State of California Department of Motor Vehicles.
- Coppin, R. S., and Peck, R. C. (1964). *The totally deaf driver in California, Part II*. Sacramento: State of California Department of Motor Vehicles.
- Finesilver, S. G. (1962). They can't hear . . . but they get the message. *The California News*, 77, 1-5.
- Foley, D. J., Wallace, R. B., and Eberhard, J. (1995). Risk factors for motor vehicle crashes among older drivers in a rural community. *Journal of the American Geriatrics Society*, 43, 776-781.
- Guinn, J., Logan, C., Nelson, D.J., & Watson, S. (2010). *Emergency Vehicle Alert Device (E.V.A.D.E.)*, Unpublished senior thesis, University of Central Florida, Orlando, FL.
- Hart, S. G. & Staveland, L. E. (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.). *Human Mental Workload*. Amsterdam: North Holland Press.
- Henderson, R. L., & Burg, A. (December, 1973). *The role of vision and audition in truck and bus driving* (Final Report PB-230 776). Washington, DC: Federal Highway Administration.
- Jenkins, J. (1999). *Suitability of optical radio, and radar technologies as potential emergency vehicle siren system enhancements* (SWUTC/99/472840-00003-4), College Station, Texas, Texas Transportation Institute, Retrieved January 10,2013 from <http://trid.trb.org/view.aspx?id=653423>.
- Kanable, R. (2008). Rumbler Rattles Motorists Alert, *Law Enforcement Technology*, 35, 116-119.
- Kuwahara, N.; Morimoto, K.; Kozuki, K.; & Kawamura, T. (2008). Emergency Vehicle Alarm System for Deaf Drivers by using LEDs and Vibration Devices, *Journal of Light & Visual Environment*, 32, 226-229.
- Laberge-Nadeau, C., Maag, U., Bellavance, F., Lapierre, S.D., Desjardins, D., Messier, S., & Saidi, A. (2003). Wireless telephones and the risk of road crashes. *Accident, Analysis and Prevention*, 35, 649-660.
- Maddern, A. J., Privopoulos, E. P., Howard, C. Q. (2011). *Emergency Vehicle Auditory Warning Signals: Physical and Psychoacoustic Considerations*, Proceedings from Acoustics, Gold Coast, Australia.
- Maguire B.J., Hunting K.L., Smith G.S., & Levick N.R. (2002). Occupational Fatalities in Emergency Medical Services: A Hidden Crisis. *Annals of Emergency Medicine*, 40, 625-632.

McCloskey, L. W., Koepsell, T. D., Wolf, M. E., and Buchner, D. M. (1994). Motor vehicle collision injuries and sensory impairments of older drivers. *Age and Ageing*, 23, 267-273.

Mohammadi, S., & Mesgarha, S. G. (2011). Horn Detection System for Deaf Drivers By Tensity and Directions, World Academy of Science, *Engineering and Technology*, 76, 913-915.

Moneual (2013). *Awards and Recognition 2013*. Retrieved January 30, 2013 from <http://www.moneualusa.com/mrusa>.

NASA Spinoff (2002). *Proceeding with Caution*. Retrieved January 20, 2013 from http://spinoff.nasa.gov/spinoff2002/ps_5.html.

NoiseOff (n.d.) *Rumbler*. Retrieved February 5, 2013 from <http://www.noiseoff.org/rumbler.php>.

Ravid, U. & Cairns, P. (2004). *The design development of a mobile alert for the deaf and the hard of hearing*. Poster presented at 2AD, Second International Conference on Appliance Design.

Redelmeier, D.A., & Tibshirani, R.J. (1997). Association between Cellular Telephone Calls and Motor Vehicle Collisions. *The New England Journal of Medicine*, 336, 453-458.

Stutts, J.C., Reinfurt, D.W., Staplin, L., & Rodgman, E.A. (2001). *The role of driver distraction in traffic crashes*. Washington, DC: AAA Foundation for Traffic Safety.

Taylor, R.M, (1990). Situational Awareness Rating Technique (SART): The development of a tool for aircrew systems design. In *Situational Awareness in Aerospace Operations* (AGARD-CP-478),1-17, Neuilly Sur Seine, France: NATO-AGARD.

Young, K. & Regan, M. (2007). Driver distraction: A review of the literature. In: I.J. Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter & J.D. Irwin (Eds.). *Distracted driving*. Sydney, NSW: Australasian College of Road Safety. 379-405.

Appendix A: Interview Questions for Deaf/Hard-of-Hearing Drivers and Pedestrians

Deaf/Hard-of-Hearing Drivers/Pedestrians Communication with Ambulances Interview

Introduction

The Department of Homeland Security Science and Technology Directorate's Resilient Systems Division is teaming with Carlow International and BMT Designers and Planners (D&P) to improve communication between ambulances and the deaf or hard of hearing. In conjunction with that goal, this survey will collect information on the current issues deaf and hard of hearing individuals face in receiving information from ambulances and some potential methods to improve that communication.

All information you provide will be combined with information from other respondents for research and reporting purposes. Your individual responses will not be released.

Demographic information

Please tell us a bit about your background. The following questions will be used for categorizing your responses only. Place an X by the answer that corresponds to your response.

1. Gender
 1. Male _____
 2. Female _____

2. Age
 1. 18-24 _____
 2. 25-34 _____
 3. 35-44 _____
 4. 45-54 _____
 5. 55-64 _____
 6. Over 64 _____

3. Do you use any hearing devices? (Select all that apply.)
 1. Hearing aid _____
 2. Cochlear implant _____
 3. Portable assistive listening device _____
 4. Other _____ (please specify) _____

4. Rate your level of hearing loss with hearing devices.
 1. Mild (sounds such as a faucet dripping, birds chirping, and some speech sounds may not be heard) _____
 2. Moderate (most speech and sounds such as a clock ticking or a vacuum cleaner may not be heard) _____
 3. Severe (most speech will not be understood, and other loud sounds such as a phone ringing or a dog barking may be missed) _____
 4. Profound (very loud sounds such as an airplane flying overhead or a lawnmower will not be detected) _____

5. How long have you been deaf/hard of hearing?
 1. 1-3 years _____
 2. 4-6 years _____

3. 7-9 years _____
4. 10 or more years _____
5. From birth _____

Experiences with Ambulances

Please tell us about your experiences with ambulances.

6. Can you recognize an ambulance is approaching and its distance, direction, and orientation while driving? If yes, how?
7. Can you recognize an ambulance is approaching and its distance, direction, and orientation while walking? If yes, how?
8. What makes it difficult to recognize the presence of an ambulance while driving?
9. On a scale from 1 to 8, with 1 being the factor that causes the least difficulty in recognizing an ambulance while driving and 8 being the factor that causes the greatest difficulty, rate EACH of the factors below.
 1. Weather _____
 2. Other drivers _____
 3. Lack of lights on the ambulance _____
 4. Driver fatigue _____
 5. Distractions _____
 6. Presence of passengers in the vehicle _____
 7. Lack of training _____
 8. Other (please specify) _____
10. What makes it difficult to recognize the presence of an ambulance while walking?
11. On a scale from 1 to 7 with 1 being the factor that causes the least difficulty in recognizing an ambulance while walking and 7 being the factor that causes the greatest difficulty, rate EACH of the factors below.
 1. Weather _____
 2. Other vehicles _____
 3. Lack of lights on the ambulance _____
 4. Distractions _____
 5. Walker fatigue _____
 6. Lack of training _____
 7. Other (please specify) _____
12. Below is a list of technologies that are being explored to increase deaf/hard of hearing individuals' awareness of ambulances' presence. On a scale from 1 to 8, rate how effective (in your opinion) each would be at increasing your awareness of an ambulance's presence and location (with respect to your location) while driving. For the scale, 1 is highly ineffective and 8 is highly effective.
 1. In-vehicle display with text warning messages (ex. GPS) _____

- 2. In-vehicle display with flashing LED lights _____
- 3. In-vehicle seat vibration _____
- 4. Cell phone/PDA text warning messages _____
- 5. Cell phone/PDA vibration _____
- 6. Increased ambulance lighting _____
- 7. Ambulance emitted vibration _____
- 8. Wristwatch with visual alert and vibration _____

13. Rate how effective (in your opinion) each of the following technologies would be at increasing your awareness of an ambulance's presence as a pedestrian. For the scale, 1 is least effective and 5 is most effective.

- 1. Cell phone/PDA text warning messages _____
- 2. Cell phone/PDA vibration _____
- 3. Increased ambulance lighting _____
- 4. Ambulance emitted vibration _____
- 5. Wristwatch with visual alert and vibration _____

14. Do you have any other suggestions for tools/technology that might make it easier for you to detect an ambulance as a driver and/or pedestrian?