April 2013

Reducing Ambulance Dispatch Time

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Project Number: IQP MQF-2819

Reducing Ambulance Dispatch Time

An Interactive Qualifying Project

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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MIRAD Laboratory, April 25, 2013

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Abstract

An important marker of quality emergency medical care is measured by meeting the required paramedic response time. . The nature of some highly time sensitive medical situations such as cardiac arrest and bleeding continues to impose a demand to improve the response time of emergency medical care services. It is widely known that t in the United States, the national average of EMS response time is far above the eight-minute standard. This is mainly due to the fact that there are time delays occurring in the communication among 911 callers, Public Safety Answering Points (PSAP), First Responders and road traffic uncertainty. Any one of these delays can lead to an increase in response time The current EMS response system is subjected to time delays involved in communication, transportation and uncertainty factors. These various time delays are largely subjected to technical constraints such as unreliable GPS locating of wireless calls and limited level of traffic preemption, and are further worsened by miscommunications and language barriers. The goal of our project is to understand and identify the critical time delays in the EMS dispatch process and to propose a feasible solution that monitors and optimizes these delays. At the beginning of the project, we conducted extensive research about the components of EMS communication system and data on emergency call volumes is collected and analyzed. Then, a mathematical model was constructed to predict and evaluate the response time of an average ambulance specific to the United States, based on which a computer simulation of the mathematical model were produced and analyzed. Finally, these simulations provide us with the opportunity to locate appropriate time delays required to respond to 911 calls. Key factors influencing EMS response time were presented and an improved EMS response system with a reduced ambulance dispatch time was proposed.

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Acknowledgements

The project team would like to give special thanks to everyone who aided the project development. We would like to thank the Worcester EMS, the Worcester Police Department and the Boston EMS. A special thanks is due to Professor Fofana, whose passion and vision helped us throughout our project. His support, understanding and enthusiasm were invaluable assets to this team.

CHAPTER 1. EMS AND LIFE SAVING PRACTICES

1. Introduction

Emergency Medical Services is a system that provides emergency medical care to the sick and injured and also transports patients to hospitals for extended evaluations by a physician or doctor. They provide out-of-hospital medical care and transport to professional medical care facilities. The increase in population in the world over the last few decades has led to an increasing number of emergency calls. The rising number of emergency calls pertaining to medical situations has resulted in a growing demand of more efficient Emergency Medical Services (EMS). Urgent symptoms such as heart attack, stroke, bleeding and trauma that immediately require first aid could deteriorate into death in a very short period of time. Therefore, quality EMS is imperatively needed and EMS response time is critical to such life-saving practices. However, there still exist gaps in infrastructure due to an uneven distribution of medical resources. As a result, a substantial disparity in EMS response time across regions is present. To meet the growing demand of emergency medical services and to prevent death, it is crucial for EMS care providers to understand the dynamics of the EMS system, to calibrate and reduce the ambulance dispatch time.

The goal of our project is to first understand and improve the EMS system. This includes research into various standards for EMS responders, EMS communication protocols, and EMS equipments. Based on the research, the project locates and classifies the time delays associated with each component of the EMS system. Current EMS dispatch process, EMS traffic preemption and ambulance warning systems are researched. Data of emergency call volumes, information of EMS system in other countries and EMS-associated accidents are collected and analyzed. To quantify the time delays, a mathematical model is formulated. Using control theory, solutions to mathematical models are derived. The solutions serve as a framework to improve the dispatch and response time. Simulation results are presented to show how the model quantifies the delay factors mentioned above and produces a physically accurate prediction of an average ambulance response time. A communication app is also designed. This app provides an opportunity to reduce communication time delays.

The project report consists of four chapters. Chapter 2 provides an elaboration on background research into ambulance communication technology used by EMS systems. Specifically, current technologies involved in initial 911 call processing, Central Medical Emergency Direction (CMED)-directed communication and ambulance warning devices are addressed. The working mechanism of EMS systems are discussed and compared among different countries in the world including Australia, Canada, China, India and the United Kingdom. Chapter 3 presents solutions and suggestions proposed based on the results of our mathematical models. Two apps are presented to reduce the communication delays identified by the mathematical models. The applications seek to improve the rate of communication between 911 callers and Public Safety Answering Points (PSAP). Simulation results of the mathematical models for EMS respone time in Miami and Massachusetts are shown. The influence of traffic density on ambulance dispatch time is explored and peak traffic densities are identified, along with their respective time delays. The effect of distance on ambulance response time in Eastern Massachusetts is also studied. In Chapter 4, we include concluding remarks on the data analysis and model output presented in Chapter 3. This project extends research into the modeling of communication delays using control theory. Some rising technologies and new ideas associated with reducing ambulance dispatch time are discussed. A summary of the work done in this project is also included.

CHAPTER 2. EMS AND PATIENT- CENTRIC QUALITY CARE

2. Introduction

EMS care can be provided in different forms like inpatient treatment, pre- hospital treatment to patients in the case of minor to major injuries or illness. In general there are four levels of emergency care provider; First Responder, Emergency Medical Technician (EMT)-Basic, Advanced EMT (AEMT) and Paramedics. All providers are well-trained to treat the patients in the case of emergency. The EMTs assess and evaluate the patient, recognize the problem and provide interventions to stabilize the condition. Pre-hospital medical services provide transportation of patients to and from places for treatment and acute medical care (also called First Aid). In the past, EMS care used to be provided only by the ground transportation like road ambulance but today the EMS provides emergency medical air transport—air ambulance (helicopter). This has helped the conventional ground ambulance in coping with medical emergencies. EMS communication starts as soon as a person dials 911. 911 is an official emergency telephone number for the North American Numbering Plan (NANP). This number is used to access emergency services, including police, fire and EMS. 911 respond to emergencies regarding circumstances involving on-site illness and injuries. The 911 call protocol has different components which include communication among ambulance dispatcher, EMTs and hospitals which are explained in detail in the sections below. Also there are different official emergency phone number for different countries which is mentioned in sections below. Different countries and states have different protocols and regulations to make the emergency communications flow smoothly between the caller, 911 dispatch center, Emergency Medical Technicians (EMTs), and hospitals.

2.1 Overview of EMS Communication Protocol

In case of an emergency such as fire, traffic accident and crime occurs, people call 911 for immediate help. Based on the contents of the call, the call taker makes a judgment on the nature of the call and directs the information accordingly, to fire or police department. The 911 call protocol can be divided into four components, namely ambulance dispatch, ambulance-to- Central Medical Emergency Direction (CMED) communication, CMED-to-hospital communication, and ambulance-to-hospital communication. Once a 911 call is received the dispatch center identifies the urgency of the call and make decisions on urgency of the call and make decisions on whether an ambulance needs to be dispatched. The communication process is illustrated in Figure 1.

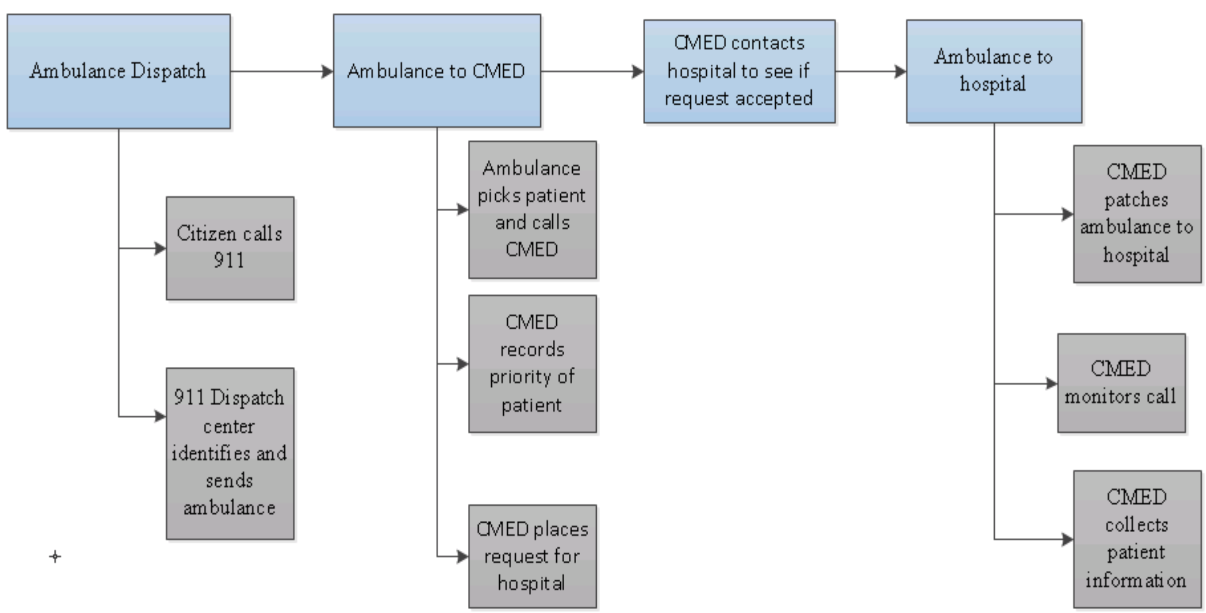


Figure 1: Flow Chart of 911 Call Protocol

Following the initial call filtering in the EMS communication flow is the ambulance-to-CMED communication which constitutes a crucial part of efficient EMS functioning. The ambulance-to-CMED communication is conducted using radio or wired phone. Once the ambulance picks up the patient from the location, EMTs start to contact CMED to relay information of the patients. Judging from the information received, CMED determines the priority status of the patient. At the same time, the ambulance requests communication and connection to hospital from CMED. The CMED-to-hospital communication when the CMED contacts the requested hospital to confirm its acceptance on providing treatment to the incoming patients. This communication is followed by the ambulance-to-hospital communication where CMED functions as a medium through which ambulance and the hospital achieve the sharing and updating of information. Monitoring communication with hospital and ambulance simulataneously, CMED ends the communication once all necessary information information is obtained and delivered.

2.1.1 Standard Operating Procedure for 911 Call Process

This section explains about the standard operating procedure for 911 calls, which is developed by National Emergency Number Association (NENA). The process starts when a 911 call is connected to an emergency dispatch center called Public Safety Answering Point (PSAP). All the phone calls will be answered in order of priority. 1st priority will be the 911 phone and emergency phone lines; 2nd priority will be non-emergency lines and 3rd priority will be the administrative and internal phone lines. If a call is a non-emergency call the telecommuniator at PSAP will direct the caller to a non-emergency line. The telecommunicator will gather the basic information from the caller. This information includes the address or exact location of the address or the exact location of the incident, call back number, type of emergency, time of occurrence and hazards. The telecommuniator will verify the reported addresses with the Automatic Location Identification (ALI) database. This happens in the case of caller calling from the landline phone. On the other hand, if the caller is calling from a wireless phone he is required to provide all the relevant information including physical address and emergency request accurately by means of oral communication. This is the only source of information that the telecommunicator will have to decide on the next step. If there are abandoned calls to 911, then the telecommunicator will attempt to call back once. But if the phone is busy or there is no answer, the additional attempt will not be made. Sometimes may be received by one PSAP which are intended for another PSAP. These calls should be transferred to the right PSAP after informing the caller. If there is a foreign language call then a language translation service should be available to the telecommunicator to assist the translation. These are the basic guidelines and procedures provided by NENA to handle different types of 911 calls. The EMS Call Processing Time is different for different standards and some of them are shown in Table 1.

Table 1: Processing Time Requirements for EMS Events for 911 Call (Kinsley [23])

Standard	**EMS Call Processing Time**	**Standard Number**
NFPA	60 seconds 90% of the time	1221/1710
CPSE	60 seconds	N/A
ASTM	120 seconds maximum	N/A
MCFRS	60 seconds	N/A

2.1.2 911 Procedure for Wireless and Wireline Calls

The 911 calls can be made by different medium i.e. landline phone, wireless phone, business phone, VoIP etc. This section explains about the way the wireless and wireline 911 calls are handled by the telecommunicator. When a caller calls 911 from a landline phone, the E-911 network components operate together in order to deliver a 911 call including caller data to a PSAP. In the wireline 911 call, the call is sent to the local central office that serve specific telephone. The central office recognizes the call as 911 and forwards the call to a specialized switch, referred as a selective router. The selective router routes both the voice and the caller's telephone number, called as Automatic Number Identification (ANI) to the appropriate PSAP. The PSAP's customer Premise Equipment (CPE) used ANI to retrieve the caller's Automatic Location Informatin (ALI) by checking the ALI database. The entire wireline 911 call process is shown in Figure 2.

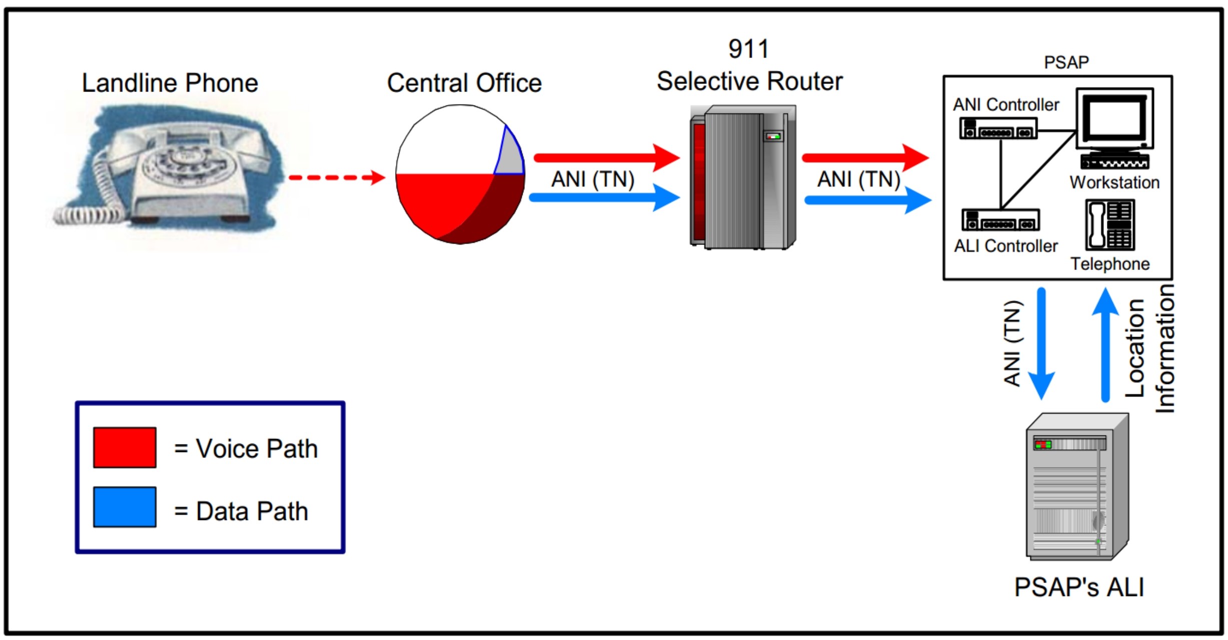


Figure 2: Wireline E-911 Call Environment

When the caller dials 911 from a mobile phone, the caller gets connected to the state police or highway patrol. Since the location cannot be determined immediately by searching through any database system, when a caller calls from wireless phone, the caller must describe the location accurately so that the agency could transfer the call to the nearest emergency service center. Wireless emergency call has been an issue since the patient-dispatcher communication relies solely on verbal communication. Any misuse of a term might result in inaccurate locating of the patient by EMS and possibly a substantial delay that causes severe consequences (Lavigne [47]). In 1996, US Federal Communications Commission (FCC) issued an order requiring wireless carriers to determine and transmit the location of callers who dial 911. They developed Phase 1 and Phase 2 for this transition. Phase 2 is illustrated in Figure 3 below.

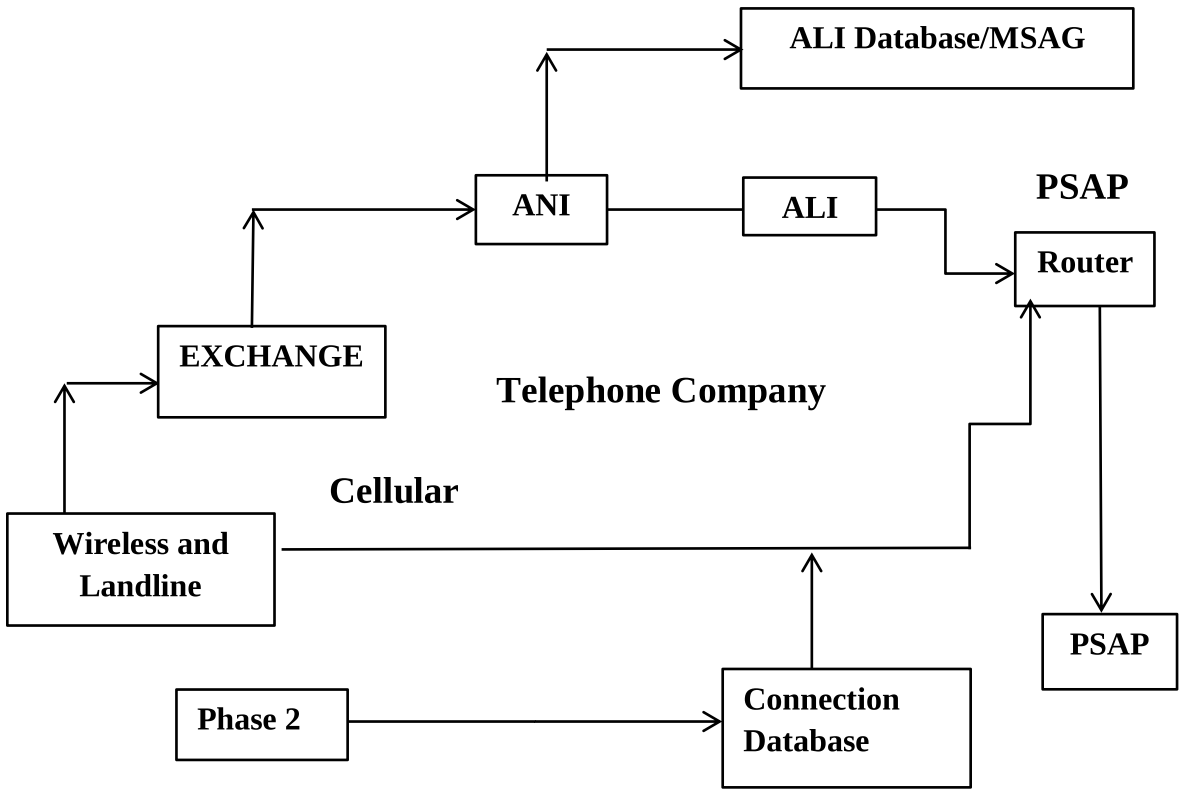


Figure 3: Wireless E-911 Call Procedure for Phase 2 transition

Phase 1 requires caller's phone number and location of the caller to be delivered to PSAP. This is done inorder to call back the caller in the event when the connection is lost. Also the location of the originating cell site and sector would provide a level of location information that would allow delivery of 911 call to the appropriate PSAP. Phase 2 requires caller's nunber and location within a specified accuracy margin be delivered to the call taker in the form of earth co-ordinates (latitude and longitude). Phase 2 call shows name of the wireless carrier, address of cell tower being accessed, sector of the accessed cell tower MDN of wireless phone being used to call 911 and latitude and longitude of caller. Wireless network operators must provide the latitude and longitude of callers within 300 meters and six minutes of a request respectively by a PSAP (Central Mass Emergency Medical Systems Corp [68]). This phase allows a wireless or mobile phone to be located. This is done by two methods. The first method is radiolocation from the cellular network and the other method is Global Positioning System receiver that is built into the phone. Both are described by using radio resource location services protocol which makes use of the radio towers and cellular telephony base stations (Bv911 [56]).

Moreover, the wireless cell sites can either be omnidirectional or sectored. Omnidirectional cells serve a roughly circular coverage area. As the name suggests, the signals are received from all points of the compass around the tower, whereas the sectored cell sites divide the circular area into roughly wedge shaped coverage areas. Omnidirectional cells are well-suited to rural applications where a large coverage area is desirable and call density is low. Sectored cells are well suited to urban environments where a focused coverage area is desirable and call density is high. Each sector in a sectored cell is capable of receiving as many concurrent calls as a single omnidirectional cell, which is important as calling populations become concentrated, resulting in higher call density. An added plus for sectored cells is the ability to determine the direction from which a call came through use of directional antennas. Instead of the call potentially originating in a large circular coverage area around the cell tower, its point of origin is within the limited Coverage area of the sector, which can be directly associated with a compass point (Understanding Wireless Telephone Coverage Areas [42]).

2.1.3 Other Medium of Calling 911

Besides the landline and wireless phone, one can call 911 by using different medium like

VoIP, NG911. This section explains about the other medium of calling 911. The Telematics and Automatic Collision Notification is one of the medium to inform 911 call center about emergency. The calls from OnStar and its telematics clones are primarily voice at present but there is a widespread deployment of IP data connectivity between call centers and PSAPs. Automatic Collision Notification (ACN) can provide impact data, number of occupants' data, and probable type and severity of injury data, as well as countless other types of data that can be enormously useful to first responders and trauma centers. It has been realized that the 911 community needs to implement the public safety network infrastructure, locally and nationally, to take advantage of it.

Voice over internet protocol (VoIP) or voice over internet (VOI), is currently a great concern of attention in 911 call protocol. The 911 provisioning for VOI was initially a huge problem, but the IP technology it uses offers vast potential for providing much more information to the PSAP in Next Generation 911. Both the Association of Public Safety Communications Officials (APCO) and National Emergency Number Association (NENA) have taken pro-active attitude on VoIP, actively seeking workable solutions through cooperation with IP experts since its inception (Federal Communication Commission [81]). NENA and APCO have been exploring innovative ways to call 911. They have been inquiring about the technologies, service offerings, and capabilities which will revolutionize the delivery of all 911 calls. 911 calls and the procedure will virtually cease to exist if these new and improved technologies provide features and integrations that have been dreamed about. One important concept is Next Generation 911 (Del Castillo et al. [26]).

2.1.4 Central Medical Emergency Direction

CMED is an integral part of EMS Communications, and provides specialized communications services to connect EMS personnel to hospitals. The state of Massachusetts is divided into five different Emergency Medical Services regions and each region has its own CMED center. Figure 4 shows the different CMED regions in the state of Massachussetts.Each CMED center is responsible for providing communication support to the ambulances and hospitals of that region. The main job of the CMED is to connect EMTs to the hospital and make the most efficient use of the medical radio channel. CMED also coordinates EMS response in mass casualty incidents and helps EMS in distributing patients from the scene to hospital.CMED operation is a three step process. The first step is ambulance calling CMED, second step is CMED calling hospital and third is CMED connecting ambulance to hospital.

Figure 5 illustrates the entire CMED operation. As we see in the figure, CMED has a network of radio towers placed strategically through its EMS region and dedicated telephone lines controlled by computer operated consoles at CMED. This system is designed to facilitate CMED communication over a large geographic area throughout Massachusetts and reduce radio frequency congestion. Standard ambulance radios operating on Very High Frequency/Ultra High Frequency medical channels can access the system. When an ambulance calls CMED, a CMED operator will ascertain the ambulance's identification, hospital of choice and geographic location. It is important for CMED to take note of the geographic location so that it patches the ambulance to the closest radio tower for clear transmission. Ambulance gives a priority status of its patient on a scale of 1 to 4 with 1 indicating severe injury and 4 indicating minor injuries. This is done so that CMED can connect ambulance to hospital multiple times in case of very critical medical emergencies. CMED of EMS Region IV in city of Boston only facilitates priority 1 calls because Boston receives a high volume of 911 emergency calls (City of Boston [52]). After ambulance requests connection to a hospital, CMED connects it to the hospital, monitors the call, and collects information of the patient and once ambulance has relayed sufficient information to the hospital, CMED disconnects the call.

Proper communication system design and equipment will ensure good use of the medical radio channel and hence better dispatch time.

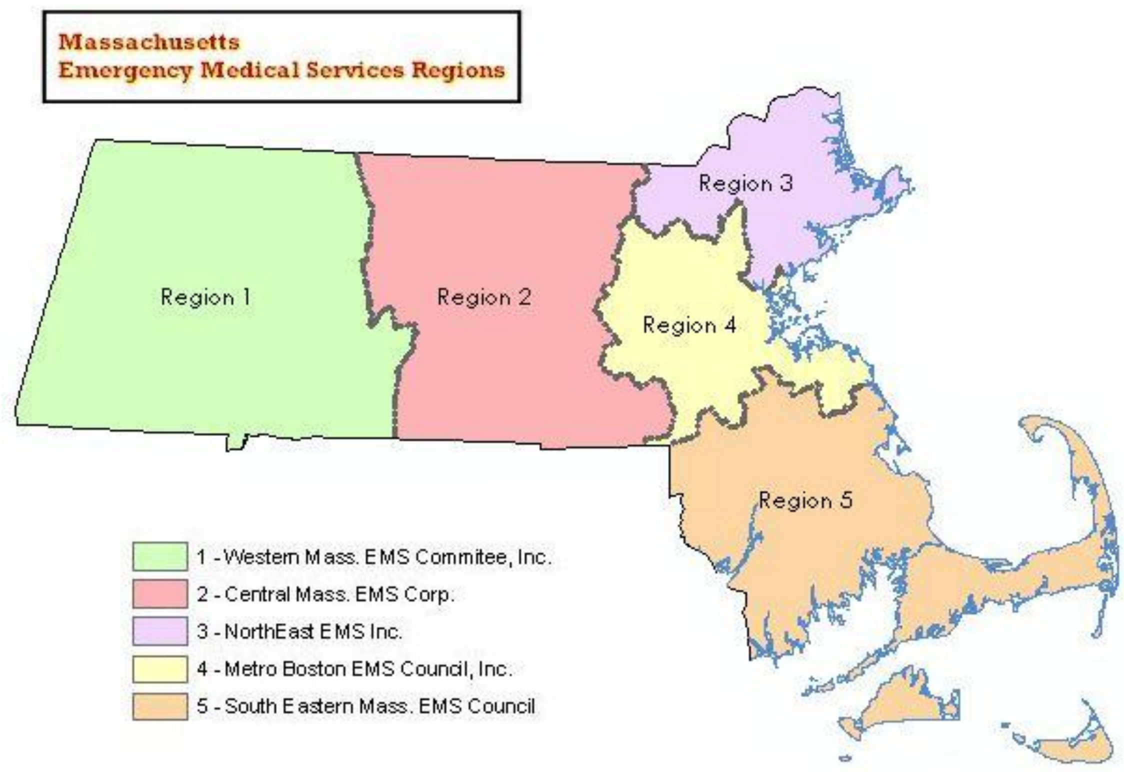


Figure 4: EMS regions in Massachusetts (Mass[50])

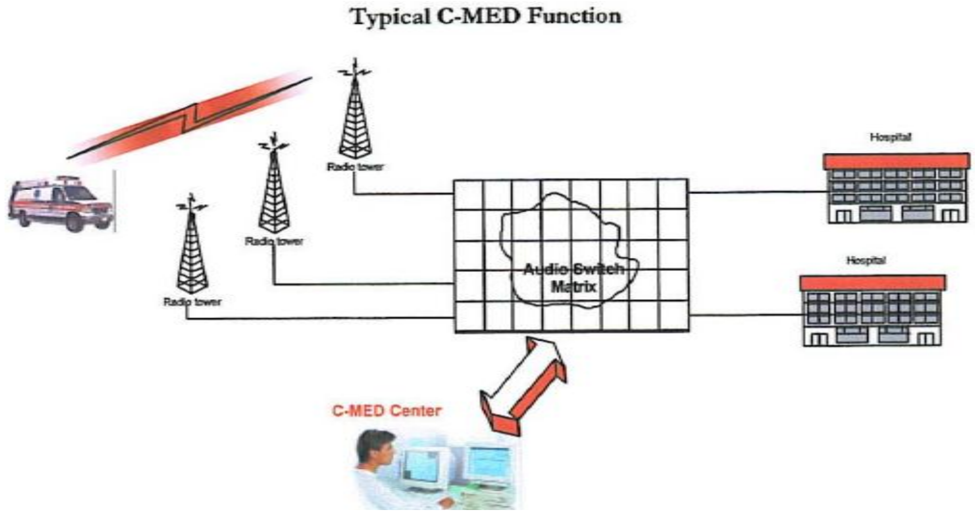


Figure 5: CMED operation (Mass[58])

2.1.5 EMS Equipment and Software

The Massachusetts EMS Radio Communications Plan dictates the standards for the communication equipment and software to be used in Massachusetts emergency medical services (Office of Emergency Medical Services). The legal status of the Radio Communications Plan is that it has the force of regulation and all ambulance services' communications and communications equipment must comply with the standards given by the plan under 105 CMR 170.380(D). The EMS communications infrastructure in Massachusetts and throughout the United States is currently transitioning from wideband to narrowband frequencies following a mandate by the Federal Communications Commission (FCC) to do so by January 1, 2013 [56]. This will improve the quality of EMS radio communication capabilities between ambulance services and CMED centers and hospitals. A visualization of the switch is presented in Figure 4. Wideband channels usually have frequencies of 25 or 30 kHz, while narrowband technology uses a channel spacing, or bandwidth, of 12.5 kHz [52]. This means that once the transition has been made and only narrowband technology is used, the number of channels available will be twice that of the current system (Giorgetti, A., and M.Z.W. 2141). This reduces the extreme shortage of radio spectrum available for public safety use. In Figure 6 below, the bandwidths of the two systems are explained.

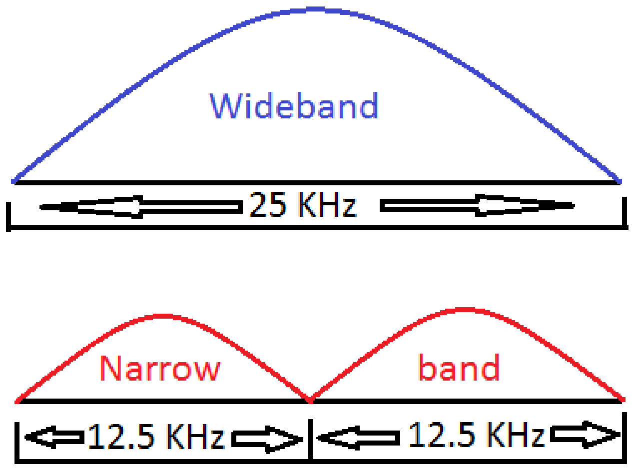


Figure 6: Narrowband and wideband

This makes radio communication more flexible since more channels are available and EMS systems can deliver higher quality care as the communication quality will be improved. The plan mandates ambulances to use Ultra High Frequency (UHF) two-way radios. A typical radio used by EMS features a channel and zone selector.

The communications plan mandates that equipment has to be capable of operating from 450 MHz through 512 MHz without any loss in performance. Radio equipment should have a channel capacity of 200 or greater. Channel capacity refers to the number of preprogrammed radio channels (frequencies) that a two-way radio can hold in memory and be capable of receiving and/or transmitting on these channels. This should not be confused with “Zones and Channels”, which is the name of a method for grouping a set of radio characteristics such as transmit and receive frequency pairs into a memory location to make for easy operation and recall

[48]. This feature is also required by the plan for equipment in use of ambulance-to-hospital communications. The equipment should be capable of storing a minimum of 10 zones in its memory, with each zone containing a minimum of 20 channels.A typical two-way radio is shown in Figure 7 below.

Figure 7: A typical two-way radio as found in UMass ambulances

The Massachusetts EMS Communications Plans also dictates that equipment should be capable of displaying a minimum of 8 characters on its display, including both numbers and letters. This is used for channel and zone naming. All UMass EMS ambulances have to comply with the standards set forth by the communications plan (Office of Emergency Medical Services) [51], therefore it is important to study this document so that future communication innovation proposed in this project will comply with the necessary standards. Radios should also be capable of being programmed on a channel by channel basis and use

different codes for transmitting and receiving (Van) [81]. Equipment should also be able to operate on any of the 38 Electronic Industries Alliance (E.I.A.) standards using Continuous

Tone-Coded Squelch System (C.T.C.S.S) or 83 Digital Coded Squelch (D.C.S) codes. The E.I.A. is a national trade organization that includes the full spectrum of U.S. manufacturers and is accredited by the American National Standards Institute (ANSI). The E.I.A. provides a common ground for the private sector to develop standards and publications in its main technical areas.

The C.T.C.S.S and D.C.S are sub-audible selective signaling methods used in most analog two-way radio systems today. They are signals that are transmitted with the radio frequency carrier wave and are decoded by receivers (Foosaner) [37]. This system is useful because it allows different groups of users on the same radio frequency to operate without interference, even though they are within the range of reception. Further standards by the EMS communications plan require radio equipment to have a maximum transmitter power output between 25 and 50 watts. Equipment also has to conform to the US military standards MIL 810 C, D, E, and F. This kind of equipment is designed and tested to meet the US military standards approval for shock, vibration, rain, and dust. This makes sure that the equipment is durable and can perform in emergency environments (Foosaner) [37]. A dual-control radio system is shown in Figure 8 below. It shows the respective speakers and microphones in the patient compartment and the driver compartment well as the VHF receivers in the form of a block diagram.

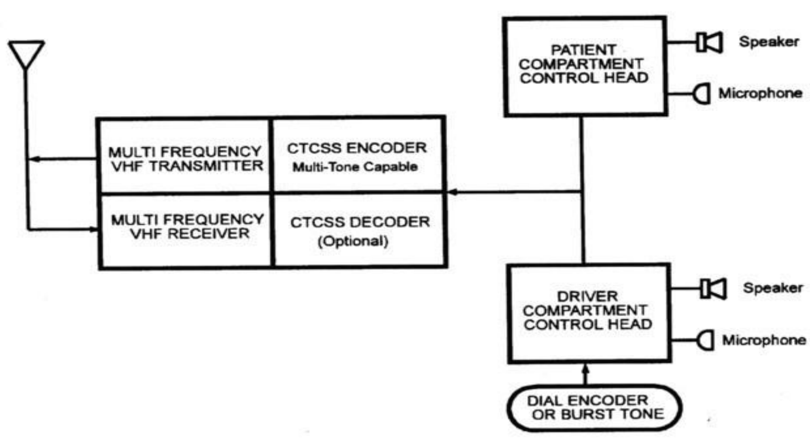


Figure 8: Dual control ambulance mobile radio

The equipment also has to be capable of both wideband and narrowband operation (Rosston) [38]. Radio devices should also have a time-out-timer which automatically turns off the transmitter and alerts the user by emitting a sound once it does so. The device will shut off when a continuous transmission has exceeded the set time limit, which should be set to no more than 90 seconds. Radio equipment should be capable of supporting analog operation and have a minimum receiver audio output of 10 watts. An analog radio processes sounds into patterns of continuously varying electrical signals, which look like sound waves, and then transmit the signal on a single radio frequency carrier wave. This wave is then received and decoded by a receiver within range. Digital radios, on the other hand, process sounds into electrical signals. These signals correspond to one of four levels of frequencies, which resemble digits. The information is then transmitted on a single radio frequency carrier wave and received and processed by a digital receiver within range.

Several additional standards for receivers, transmitters, and other general standards are presented in Table 2.Values for quieting sensitivity, maximum power output, operating temperature,and deviation limits are tabulated.

Table 2: Minimum Technical Performance Specifications as stated by EMS Communication Plan

Minimum Technical Performance Specifications in Massachusetts		
Receiver	**Transmitter**	**General**
20 dB Quieting Sensitivity (25 KHz channel) 0.4µV	R.F. Power Output Max 25-30 W	Operating Temperature -20° F to +135° F
12 dB SINAD Sensitivity (25 KHz channel) 0.3µV	Frequency Stability 2.5 ppm	Power Supply (nominal) 12 Vdc Negative Ground
Intermodulation Rejection 75 dB	Emission (Conducted and Radiated) -70 dBc	Maximum Current Draw 12 Amperes
Spurious Rejection 80 dB	Deviation Limiting (25KHz channel) +/- 5.0 KHz	NA
Selectivity (25 KHz channel) 80 dB	Deviation Limiting (12.5 KHz channel) +/- 2.5 KHz	NA
Selectivity (12.5 KHz channel) 65 dB	NA	NA
Distortion at Audio Output <5%	NA	NA

The CMED Communications Center radio infrastructure is made up of base stations, switch matrices, and communications consoles. These are all similar in technology across CMED Centers but are not necessarily the same. All of the cities in Massachusetts with the exception of Boston use the Motorola Centracom II Communications Consoles. One center using such a communication system is shown in Figure 9.

Figure 9: Motorola Centracom II Communication Consoles (Motorolla) [55]

Boston, the exception, utilizes a united console and switch matrix manufactured by Penta. One communication scheme offered by Penta is shown in Figure 10. It shows how multiple radio towers and PBX stations interact with the Penta PAx communication platform which relays information to the operator’s console from where local or remote dispatch operations can be performed.

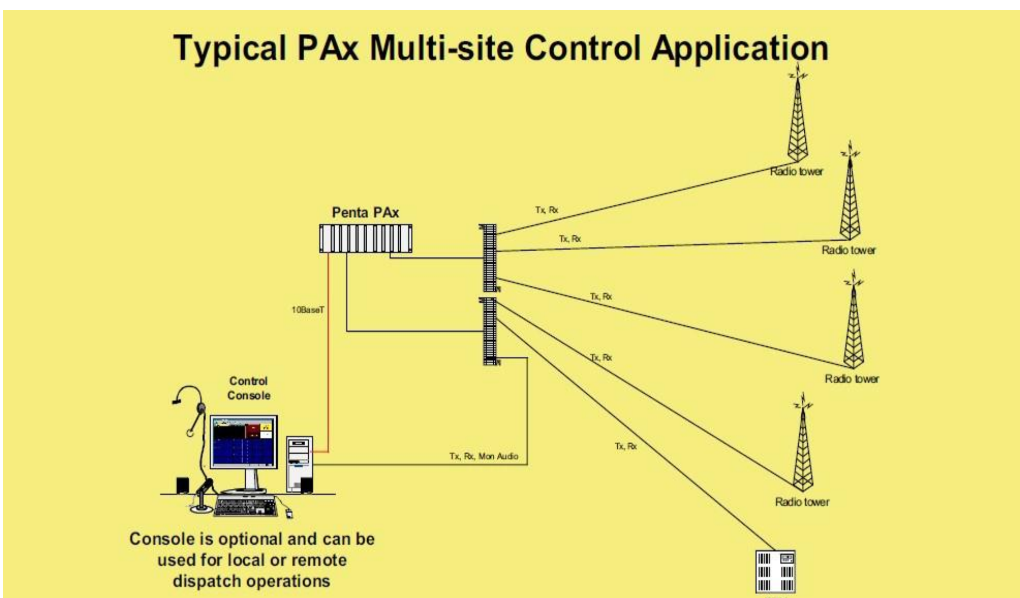


Figure 10: Penta communication console

The guidelines for CMED Operator Position equipment set forth by the EMS Radio Communications Plan is that it should provide for sufficient communications capacity to allow for communication that is free from co-channel interference 80% of the time. Medical communications utilize both Very High Frequency (VHF) and Ultra High Frequency (UHF) radio bandwidths. Systems that are using UHF are required to provide for VHF cross-patching. A system used by hospitals and CMED centers is the Hospital Capacity Website. This is used to capture and report the status of a hospital to EMS systems. The system also shows if beds are available in the hospital. This is of high importance since on a daily basis shortages exist in hospitals, and EMS units have to decide where to transport their patients.

2.1.6 General types of EMS System

The Emergency Medical Services are responsible to provide acute medical care, transport the patient to the definitive care and provide the urgent care to the patients. There are different types of medical services in different countries around the world which provides the medical care. The mode of emergency health care delivery in pre-hospital involves two main models of EMS system since 1970. They are Anglo-American and Franco-German.

This system runs by bringing patients to the hospital with less pre-hospital interventions. This model uses pre-hospital care specialists like emergency medical technicians and paramedics. This system is basically allied with public safety services such as police or fire departments. There are trained paramedics and Emergency Medical Technicians (EMTs) who run the system with a clinical oversight. This system relies on land ambulance and less on aero-medical ambulance. All patients in AAS are transported by EMS personnel to developed Emergency Departments. In this system the patients are treated by the attending crew, and then transported to definitive care. This system is more popular than the Franco-German System (National Center for Biotechnology Information. U.S. National Library of Medicine [71])

In this system paramedics are used to treat the patients assuming that paramedics could be trained to alleviate patients. The other reason for using paramedics involves the financial issue. Doctors are more expensive to educate and to employ compared to the trained staff. Hence, paramedics are preferred. Although paramedics are not as educated as doctor but they are well-trained and equipped with a wide range of treatment options on the basis of their practice. In this system the patients with less severe diseases are treated and transported by First Responder Units (FRU) or EMTs. The Emergency Responder (ER) in AAS is well equipped with modern technology, and physicians. The countries using this system of EMS model are U.S.A, Canada, United Kingdom, Ireland, Australia, Hong Kong, Mexico, South Korea, and Iran (National Center for Biotechnology Information. U.S. National Library of Medicine [71]).The existing prehospital emergency system is illustrated in Figure 11.

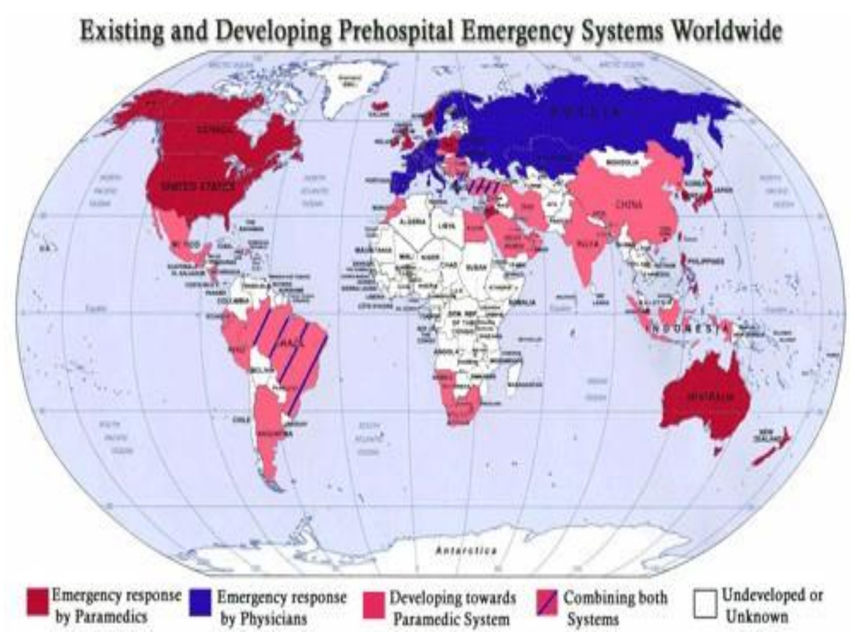


Figure 11: Existing and Developing Prehospital Emergency System (National [71])

The Franco-German model of EMS delivery works by bringing the hospital to the patients. It is usually run by physicians and they have extensive scope of practice with very advanced technology. The principle of the German doctor-based system was introduced in 1938 by the German surgeon, Martin Kirschner. It has been developed further in the 1950's trying to provide adequate medical care, primarily for emergency patients, by a qualified and especially skilled physician. France and Germany developed similar concepts of delivering structured care to patients with life-threatening diseases or injuries in the prehospital setting. The motivation of FGS has always been to treat a patient effectively and efficiently at the scene, during transport and in the hospital by a qualified physician. This model uses many means of transportation to transport the patient. They use the land ambulance and air ambulance. This system is mostly used in European countries. Table 3 shows the comparative differences between AAS and FGS.

Table 3: Franco-German and Anglo-American Model (National Center for Biotechnology

Model	**Franco-German Model**	**Anglo-American model**
Patients	More treated on scene and few transported to hospitals	Few treated on scene and more transported to hospitals
Provider of Care	Medical doctors supported by paramedics	Paramedics with medical oversight
Main motive	Brings the hospital to the patient	Brings the patient to the hospital
Destination for transported patients	Direct transport to hospital wards i.e. by passing EDs	Direct transport to EDs
Overarching Organization	EMS is a part of public health organization	EMS is a part of public safety organization

In Europe, pre-hospital emergency care is almost always provided by emergency physicians. The attending emergency doctors in the field have the authority to make complex clinical judgment and treat patients in their homes or at the scene. This results in many EMS users being treated at the site of incident and less being transported to hospitals. The very few transported patients are usually directly admitted to hospital wards by the attending field emergency medicine physician bypassing the emergency department. The countries using this system are Germany, France, Austria, Russia, Ukraine, Italy, Spain, Poland, Estonia, Hungary, Switzerland, Portugal etc (National Center for BiotechnologyInformation. U.S. National Library of Medicine [71]).

2.2 Comparing EMSs in different countries

The EMS systems around the world can use different protocol and they can vary from each other in different ways. Different countries uses different system of EMS that suites their country and people and on the basis of available resources. Some country follows Franco-German System while some others follow Anglo-American Model (CityNoise [6]). Here is the brief description on Emergency Medical Services of the five main countries of the world i.e. Australia, Canada, China, India and United Kingdom.

2.2.1 Australia

The national emergency number in Australia is 000.When a caller dials this number it rings at the Telstra Global Operations Centre, where an operator determines the caller’s needs and then directs the caller to the appropriate emergency service (police, fire, and ambulance). Then the caller speaks to an operator at a dispatch center, managed by the relevant state ambulance service or may even speak to an individual officer in the case of rural/remote stations. Dispatch technologies, including automated vehicle locating (AVL) and decision-support software are either identical (as with AMPDS) or comparable with those found in North America and Europe (Medical Journal of Australia [43]).

The Australian EMS has many similarities as the United States EMS. However, unlike the U.S., where fire departments have a major role in the provision of EMS, in Australia, the role is fulfilled by ambulance services. Emergency Medical Services in Australia are provided by the state or territory ambulance services, which are a division of each state government. Australia has six states and two territories. Majority of people live in the capital of New South Wales, Sydney followed by the capital of Victoria, Melbourne. The EMS service operates on the Anglo-American EMS service delivery model. There is also a provision of air ambulance in Australia. In majority of South Wales, the ambulance service of South Wales provides the service directly, with the service providing paramedic flight crews and helicopters being provided under a contract with Commercial Helicopter Corporation, CHC helicopters Australia Limited. This started in 2006 with Westpac Life Saving Rescue Helicopter Service which is represented in Figure 12 a. Figure 12 b represents the Australian Capital Territory Land Ambulance (Medical Journal of Australia [43]).

a. Westpac Rescue Helicopter b. Australian Capital Territory Land

Figure 12: Australian EMS Vehicles

In Melbourne the Metropolitan Fire Brigade, (MFB) provides a fully professional Emergency Medical Response (EMR) capability for the City of Melbourne. Under the EMR program, MFB firefighters are simultaneously dispatched with the Ambulance Victoria (AV) paramedics to all “priority 0” (suspected cardiac arrest) emergencies. In 60% of these EMR events, MFB firefighters arrive first on scene and begin initial patient assessment and provide care as required. On arrival, Ambulance Victoria (AV) paramedics take over responsibility for patient care with MFB firefighters then providing assistance as required. As a result of this response, two minutes have been out from the response time to cardiac arrest cases in metropolitan fire district covered by MFB. This program has been providing the Melbourne community with a higher cardiac arrest survival rate other than the other capital cities (FCC [69]).

The Australian ambulance services are facing a challenge of the provision of effective and efficient healthcare to the increasing population across the vast geographical areas. The country has a somewhat unique infrastructure for the delivery of pre-hospital care. With most states and territories having only one agency responsible for EMS, the size of the organization required to deliver this service can be significant. This offers many economies of size, enables uniform communications and control systems, and provides standardized levels of service. There have been recent initiatives that aim to develop pre-hospital care in Australia to maintain a position of best practice that is of an exceptionally high level (Medical Journal of Australia [43]).

2.2.2 Canada

The national emergency number in Canada is 911. Canada is a diverse country, with 13 separate jurisdictions governing EMS operations that no single standard for response time measurement currently exists. Urban areas, such as Toronto, will set standards according to percentiles; in this case the standard is 8 minutes and 59 seconds or less. There is no jurisdiction in Canada that is currently reporting successful achievement of this response time standard and services cite a variety of reasons for this failure, but continue to aspire to the standard. This approach to response time monitoring is accepted in most urban areas of the country; however, there are some jurisdictions which reasonably set a second standard for rural (the majority of the country) response. Such standards can vary from one jurisdiction to the next. Additionally, there are jurisdictions that do not set specific response time objectives, instead simply reporting average response times for emergency calls (EMS Chiefs of Canada [3]).

In Canada, responsibility of Emergency Medical Services has been allocated to the provincial/territorial level of government. Typically, the provincial/territorial government will provide enabling legislation, technical standard, accreditation or licensing, and oversight to a variety of potential system operators, including municipalities, hospitals, or private companies. Municipalities or hospitals may also designate to provide EMS service directly, as a branch of another municipal department, such as the fire department or health department or may contract out this responsibility to a private company. The approaches used for service delivery are governed by what is permitted under the legislation of the individual province or territory, or under the by-laws of a local municipality, when that municipality accepts responsibility for EMS service (EMS Chiefs of Canada [3]).

There are currently major initiatives to improve the standardization of staff training in Canadian EMS. Provinces and territories are also responsible for standards with respect to the dispatching of EMS resources, and some jurisdictions are measuring performance, benchmarking, and setting standards. In addition, initiatives by the EMS Chiefs of Canada organization are working towards improved interoperability and a ‘best practices’ approach to the overall management of EMS systems (SoundJax [12]). Figure 13 a and Figure 13 b represents Air Ambulance and Land Ambulance services in Canada.

a. Air Ambulance b. Land Ambulance

Figure 13: Air and Land Ambulances in Canada (SoundJax [12])

Canadian provinces are also served by air ambulance services. These arrangements may come in a variety of forms, including direct service provision, contracts between private companies and the provincial government, or they may be 'brokerage' arrangements, in which one private company takes the lead on service provision, perhaps even operating some of their own aircraft and providing dispatch services, but subcontracting many of the operations to smaller air charter services (EMS Chiefs of Canada [3]).

2.2.3 China

The development of Emergency Medical Services in China began in 1980. The EMS dispatch in China is centralized. The national emergency number is 120. When the caller calls the emergency number, the call is directed to rescue center and a physician is dispatched. The online radio communication between hospitals and ambulances does not take place. Urban ambulance dispatch or "rescue" centers are staffed by physicians and can provide pre-hospital care, inpatient care and transport home. These centers have been established in order to avoid centralization of ambulances, which may result in increasing response times in less-populated areas. In such situation, there is no extensive or overlap between hospital emergency physicians and ambulance physicians and no-out-of-hospital providers at paramedic or emergency medical technician level exist (EMS Chiefs of Canada [3]). Figure 14 a and Figure 14 b represents certified EMS symbols in China and EMS vehicle respectively.

a. Certified symbol for EMS

b. EMS vehicle

Figure 14: Certified symbol and EMS vehicle in China (Academic Emergency Medicine [21])

There are certain principal systems for EMS but they differ from city to city. These EMS systems are also integrated with fire and police departments. In the cities like Shanghai, Tianjin, Nanjing, Wuhan and Hangzhou there are purely pre hospital care. The average response time in these cities are 10 minutes. There is independent emergency service center in Beijing and

Sheyang which are different than hospitals and are equipped with Emergency Department, ED and Intensive care unit, ICU. The pre hospitals in Chongqing, Chengdu, Qindao and Hailou are supported by general hospitals. There are Unified communications command center in cities like Gangzhou and Shenzen. These centers are responsible for handling urban calls and the calls are forwarded to the nearest appropriate hospital for ambulance dispatch. Table 4 shows the comparison of EMSs between USA and China (Academic Emergency Medicine [21]).

Table 4: Comparison between EMS System Components: USA and China

EMS System Components	**United States**	**China**
Medical direction	Off-Line On-Line	Off-Line
Protocols	Jurisdiction approved on local or state level; standing orders also seen	Formal protocols or standing orders not commonly seen
Financing	Tax-subsidized; fee-for-service	Typically fee-for-service
Education	Primary – EMT, EMT-P; secondary – continuing education	Primary- medical school; secondary some master's level education for physicians
Out-of-hospital transport	BLS; ALS; critical care; aeromedical transport	Transport vans; physician transport; aeromedical transport rare
Dispatch/access to care	Dispatch; 911; enhanced 911	1-2-0 (approx. 80 cities); enhanced 1-2-0 in planning phase
Receiving facilities	Typically hospital EDs	Outpatient clinics; emergency care centers; hospital (ED or other services)
Specialty care units	Cardiac, trauma, pediatric, obstetric, neonatal, burn	Women's, children's hospitals
System review	QA, CQI	Rare
Communication	Dispatch, on-line radio communication	Designated phone dispatch on-line radio uncommon
Staffing/manpower	Physicians extenders- EMT, EMT-P, nurses and physicians	Driver transport with or without physician

2.2.4 India

There is no single system which could play a major role in managing emergency medical services in India. There is fragmented system in different places to attend the emergencies in the country. There are different emergency numbers in India's 28 states and seven Union Territories. Hospitals in India provide different numbers for ambulance services. Clearly, it is understood that there is an improper fragmented health services in this country which terribly needs a drastic improvement compared to the developed countries. It has been found that trauma is one of the major causes of death in India. In order to avoid such preventable deaths, Indian government has planned an effective system that could provide emergency care. To address this problem, the Centralized Accidents and Trauma Services (CATS) were set up by the Delhi Government in 1990s, which was later expanded throughout the country. Unfortunately this attempt failed despite having a toll free number, 102 (BBC News [18]).

Recently, many NGOs and hospitals have started to provide their own EMSs. Other organizations like Emergency Management and Research Institute (EMRI) and American Association of Physicians of India Origin (AAPI)'s EMS are banned by corporates. EMRI is an exception in the otherwise struggling EMS system. EMRI was founded in 2005. EMRI is responsible for medical, police and fire emergencies through 108 emergency services. Initially, its operations were limited to Hyderabad and Andhra Pradesh with an aim of responding to 30 million emergencies and saving 1 million lives a year. EMRI also comprises a research institute, which does medical research, systems research and operations research. Other services that EMRI's includes is free medical advice on phone on another toll free number 104 with access to more than 200 medical doctors and several more paramedics (Emergency Numbers Around the World [31])

In 2007, with the extension of Ambulance Access for All (AAA)'s services, American Association of Physicians of India Origin (AAPI) founded Emergency Medical Services (EMS) for the city, Mumbai. AAPI has collaborated with many other organizations to endorse the growth of the healthcare sector in India, especially in rural areas. Although there are many efforts being implemented in many areas to improve the EMSs but these are the examples of fragmented system. There is lack of common emergency number across the country which is a major hurdle in creating a reliable emergency service (Emergency Numbers Around the World [31]).

In spite of so many efforts implemented to improve the medical service there is still a long way to go before a comprehensive EMS is implemented across the country. From the different data, it has been found that one ambulance is needed to cover a population of 50,000 to 100,000 which is not sufficient to meet the demand. It is seen that India should have more accessible and reliable emergency medical services irrespective of geographical factors. Another important component missing in the current system is that there is a need of a body to regulate the EMS in the country. Hence, it can be said that India needs to improve its medical system in order to provide better services to the Indian population (Emergency Numbers Around the World [31]).

2.2.5 United Kingdom

The national emergency number in United Kingdom is 999. EMS in UK provides immediate care to people with acute illness or injury. The EMS is provided by the four publicly funded health care systems i.e. the National Health Service (for England), Health and Social Care in Northern Ireland, NHS Scotland and NHS Wales. The public ambulance services across the UK are required by law to respond to four types of requests for care, which are: Emergency calls (999), Doctor’s urgent admission requests, High dependency and urgent inter-hospital transfers, and major incidents. Emergency medical services are provided through local ambulance services, known in England and Wales as trusts. In England there are twelve ambulance ‘trusts’ with boundaries generally following those of the regional government offices. Table 5 represents the ambulance service responding to 911 calls.

Table 5: EMS responding to the emergency calls in the given years (Ambulance New [8])

Year	**Emergency Calls**	**Type of Call**
1994/1995	2.61 million	VoIP and Landline
2004/2005	5.62 million	VoIP and Landline/Wireless
2006/2007	6.3 million	VoIP and Landline/ Wireless

The Government targets to reach 75% of Category A (life-threatening) calls – as decided by the computerized AMPDS (Advanced Medical Priority Dispatch System) within 8 minutes. A number of initiatives have been introduced to meet these targets which include Rapid Response Vehicles and Community First Responders. The target in Wales is set by the Welsh Assembly Government (WAG). Currently, WAG requires 65% of category A calls to be reached within 8 minutes (Air Ambulance [46])

Private ambulance services are becoming very common in the UK performing a number of roles like providing medical cover at large event. The most common type of private ambulance provider is in the patient transport role, with many trusts and hospitals choosing to outsource this function to a private company, rather than use the NHS service, although the policy differs from trust to trust. Some companies have been contracted to provide additional emergency crews and vehicles to supplement the core NHS staff at busy times, with a quarter of the UK ambulance trusts contracting private companies to front line work.

Since April 2011, all private ambulance providers operating in England have been required by law to be registered with the Care Quality Commission. These services are represented by the Independent Ambulance Association. The British Association for Immediate Care (BASICS) coordinates voluntary schemes, and individual medical and allied health professionals, providing immediate care throughout the UK BASICS doctors, nurses or paramedics may assist NHS paramedics at the scenes of serious accidents or be on-hand at major sporting event (Ambulance New [8]). Figure 15 a and Figure 15 b represents Air Ambulances and Land Ambulanes in the UK respectively.

a. Air Ambulance in EMS

b. Land Ambulance in EMS

Figure 15: Air Ambulance and Land Ambulance in EMS in UK (Ambulance New [8])

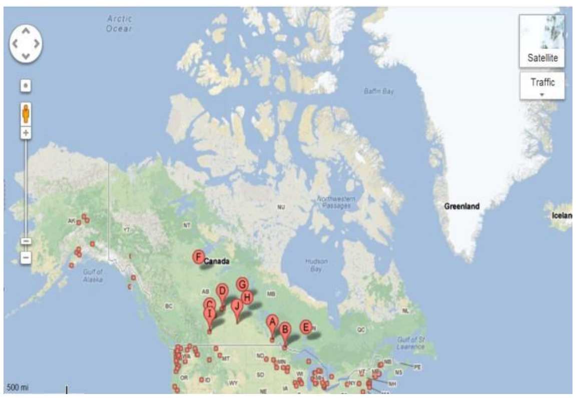
The Northern Ireland Ambulance Service (NIAS) is the ambulance service that serves the whole of Northern Ireland, and was established in 1995 by parliamentary order. As with other ambulance services in the United Kingdom, it does not charge its patients directly for its services, but instead receives funding through general taxation. It responds to medical emergencies in Northern Ireland with the 270 plus ambulances at its disposal. The Service employs approximately 1,044 staff based across 32 stations & sub-stations, four Control Centers and a Regional Training Centre. The data supplied by the HSE (Health Service Executive)

National Ambulance Service show that the ambulance response times fell in 2009 with just 24% of ambulances responding to calls within the internationally accepted time of 8 minutes. Furthermore, at least 15% of ambulances and more than 20% in December alone took longer than 25 minutes to respond to emergency calls. Also an internal review in 2007 found that response times for the delivery of emergency ambulance services in Dublin city and county were considered very low in comparison with similar cities around the UK and Europe (BBC News [48])

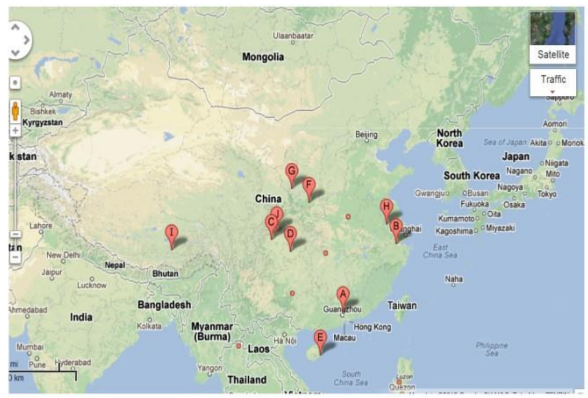
The ambulance services in Dublin are beset by number of problems that are unique to the capital city. The major one is the time it takes to offload patients who arrive by ambulance at emergency departments (EDs). Sources working in the system also claimed that the ambulances spend hours backed up outside EDs in Dublin and that the problem is particularly serious at the other hospitals. There have been many organizations involved in solving this matter. There is also the provision of air ambulances in the UK. Figure 16 shows different EMS regions in different countries of the world and Figure 17 shows emergency numbers around the world (Hinterland [35]).

EMS in United States

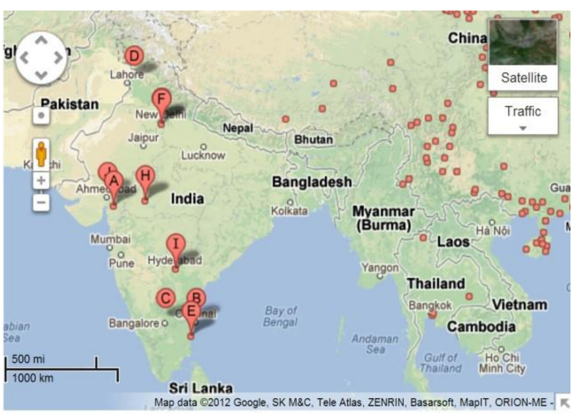
EMS in Australia



EMS in Canada



EMS in China



EMS in India

EMS in United Kingdom

Figure 16: EMS regions in different countries

Figure 17: Emergency Numbers Around the World (Emergency Numbers Around the World [31])

2.3 General Problems during dispatching

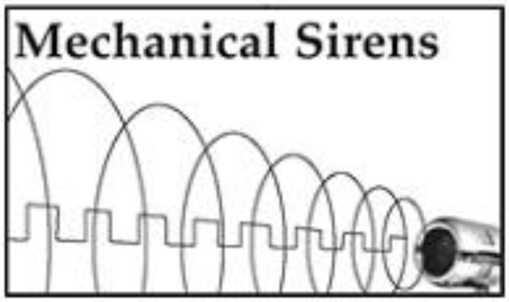
When the dispatch center receives a call from a citizen, then the dispatcher determines the nature of the call. Based on the nature of the call, the call is either filtered or relayed to the next-stage dispatch process. Once a call is identified as emergent in nature, ambulances, along with fire trucks depending on the circumstance, will be dispatched to the locale. This procedure is not as easy as it seems. During the process of dispatching, there might be many obstructions that may defer the patient from receiving the service on time. The delay factors concerning traffic navigation, means of communication, weather and constructions are listed and explained below.

2.3.1 Navigating Through Traffic

To fasten the ambulance response to emergency calls, EMS providers routinely use sirens to warn civilian vehicles of an ambulance's arrival. In order for pedestrians and drivers to yield to emergency vehicle prior to its arrival, it is vital for audio signals to be delivered in time in an effective range of locations. This requires the sound waves produced by sirens to penetrate the soundproof system of vehicles without creating further noise pollution. In order for drivers and pedestrians to identify the direction from which an ambulance is approaching, it is critical for the siren to be highly localizable and sufficiently robust to damping and interference in the time course of its propagation. A desire for robust and noise-devoid sirens has led to the development of sirens with different operating mechanisms and acoustic features. By operating mechanism, current ambulance sirens can be classified into two main categories, namely mechanical sirens and electronic sirens. Figure 18 shows a mechanical siren installed on an ambulance.

Figure 18: Sirens on an ambulance (Dreamstone [11])

Mechanical sirens generate sounds by pumping air. The siren produces wave in a square wave form, resulting in a spiraling form of a sound wave. Since a mechanical siren produces a spiraling wave, the pattern of sound is strong and focused. This not only enables the siren to be localizable but also reduces potential noise pollution. However, mechanical sirens are much more energy-consuming than their electronic counterpart (Timberwolf Sirens [54]). Figure 19 a illustrates the spiraling wave generated by a mechanical siren. Figure 19 b shows the picture of a typical mechanical siren.



a. b.

Figure 19: Mechanical siren (Timberwolf Sirens [54], SignalGuy [74])

Electronic siren, developed and introduced to application in emergency vehicles after mechanical sirens, functions by translating a transistor-generated signal to an electromagnetic driver. Although electronic sirens have made their entry into ambulance business since 1960s and have gradually taken the place of "old-fashioned" mechanical sirens, there still exists a controversy over this replacement. Though more energy-efficient and customizable by nature, electronic sirens are notorious for propagating in multiple directions and for their incapability to penetrate obstructions. Compared to mechanical sirens, electronic sirens create more noise pollution and have dead spots. Figure 20 a illustrates the wave generated by an electronic siren. Figure 20 b is a typical electronic siren.

a. b.

Figure 20: Electronic siren (Timberwolf Sirens [54], Wolo Manufacturing [30])

Acoustically, sirens are capable of generating sound waves of more than one pattern. The advent of electronic sirens made it possible to customize the tone for uses in different circumstances. The typical tones of sirens currently include wail, yelp, phaser, hi-lo, scan, airhorn, and manual, each with a unique frequency and amplitude pattern. Usually, ambulances use tones of different frequencies to signal different level and type of emergency. Figure 21shows a typical sound wave of an ambulance siren.

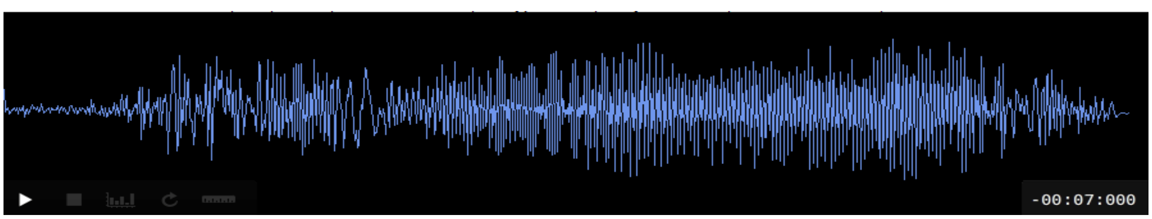


Figure 21: Sound wave of a typical ambulance siren (SoundJax [12])

A major sensory input to a vehicle driver is visual by nature. Hence, light is a crucial part of the warning system. In general, appropriate and effective perception of visual signal is determined by factors of visibility, conspicuity, driver attention, and driver expectancy. (Delorenzo et al [27]). Visibility refers to an object's visual size, luminance, color contrast and glare. Conspicuity includes the amount of associated distractions. Visibility and conspicuity are two critical issues to be taken into account into ambulance design. Among all colors, white is the most visible for warning lights, followed by green, amber and red. While white is effective in attracting attention, it is incapable of distinguishing ambulances from non-emergency vehicles. Green is also considered effective in alerting drivers visually, but lacks widespread use in vehicle lights, to avoid confusion with traffic lights. Yellow and red have been widely used in alerts that signify emergency. However, yellow has been complained to resemble white at threshold level. Similarly, red can often be misidentified in the presence of the tail lamps of other vehicles. Therefore, it is important to combine a range of different colors to achieve an optimal alerting effect. Figure 22 shows multi-functional light used for emergency vehicles.

Figure 22: LED Multi-functional light (TradersCity [7])

There are mainly two light sources, namely strobe light and incandescent light. Generally speaking, each of the two light sources has properties that are beneficial to ambulance warning system. Little evidence has demonstrated a superiority of one to the other. The major downside of strobe light is its brevity of powerful flash, which is likely to be missed by human eyes. Another concern about flashing strobe lights is their potential to induce seizure of photosensitive patients. Encouragingly, no such effects have been testified. Besides lights, different color schemes and markings have also been used to distinguish ambulances from normal vehicles. The most common color and marking designs seen on ambulance are orange-white and red-white stripes, which may vary from countries to countries. Figure 23 a and Figure 23 b are pictures showing different ambulances used in the United States and Germany, respectively.

a. Ambulance in the U.S b. Ambulance in Germany

Figure 23: Ambulance in Germany (Pepperell Fire Department [62], Ambulance Photos [9])

Traffic signal preemption is a type of system that manipulates traffic signals. By artificially interfering with the cycle of traffic signals, preemption devices have been installed in most US cities at main intersections to yield time for a temporary vehicle clearance prior to an emergency vehicle's arrival. An effective signal preemption system has the potential of significantly improving response times and reducing crashes at controlled intersections. Many communities have endorsed this technology by making them standard on traffic signal devices to improve the response time of emergency responders (Olson [60]). Current traffic preemption systems can be classified into sound-based, light-based, GPS-based and radio-based systems.

Systems that rely on the transmission of acoustic signals use an acoustic sensor which can either function by itself or in conjunction with other systems. The waveform of the siren sent from an emergency vehicle will be loaded into and detected by the sensor. Once detected, a preemption request will be generated by the preemption device. The major advantage of this system lies in its comparatively low cost and simple operating mechanism. The system makes use of pre-existing siren of emergency vehicles and requires no installation of additional devices to enable signal emission. However, the downside of the system is its vulnerability to sound wave mitigation in its time course of propagation and possible unauthorized uses due to the simplicity of the mechanism. Figure 24 illustrates generically how sound-based system functions and Figure 25 depicts a preemptive device currently in use.

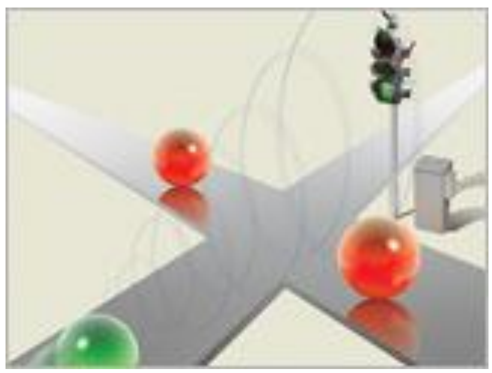


Figure 24: Illustration of a sound-based system (Global Traffic Technologies [59])

Figure 25: A real preemption device (Communication Technology and Device [32])

Systems that use visual signals to control traffic lights require the equipment of an emitter in the front of the vehicles to enable the communication between traffic lights and vehicles. The working mechanism of a light-based system resembles that of a sound-based system. The drawback of the light-based system is its sensitivity to obstructions, bad lighting and inclement weather conditions. Obstructions may include the ramp of road and large size fright trucks, both of which could prevent the signal from traveling towards the traffic light. The effectiveness of the system could also be diminished when the sunlight is too strong. In this case, the sensor implemented in the system is incapable of detecting and differentiating between the natural sunlight and the light sent from emergency vehicles. Furthermore, the detection of light signals depends also on the atmospheric conditions. The light signals could hardly be detected and identified in misty weather conditions, which further constrains the reliability of the system. Figure 26 demonstrates the working mechanism of a light-based preemption system.

Figure 26: Light-based preemption system (US Department of Transportation [80])

The invention and development of Global Positioning System (GPS) has opened a new way of controlling over the timing and sequence of phases of traffic lights. The GPS-based preemption systems, which functions in conjunction with satellites, are capable of determining the location of an emergency vehicle, the direction it is heading towards, and which traffic lights to be manipulated to assist the traveling of emergency vehicles. The advantages of the system include its capability to access the information of the vehicle's location from a much broader and more comprehensive perspective and its potential to coordinate the preemption of several different traffic lights simultaneously. These new features, largely unavailable in the traditional preemption systems, help the system to reduce risk and minimize the interruption of normal traffic operations. The limitations of the system include obstructions, atmospheric conditions and satellite availability. The dense buildings in metropolitan areas and inclement weather conditions could both affect the transmission of satellite signals. While the system functions by coordinating the network of traffic signals, a single failure on the primary system controller can disable all traffic preemption functions within the network, making the GPS-based preemption system particularly vulnerable to discruptions. Figure 27 depicts a demonstration of a GPS-based system.

Figure 27: A GPS-based preemption system (US Department of Transportation [80])

Figure 28 is a diagram illustrating GPS navigation and management system, which demonstrates how GPS navigation and information system can be integrated into the ambulance dispatch process to achieve the synchronization of information and hence the reduction of ambulance dispatch time.

Figure 28: GPS Navigation and Management System (EMS World [41])

Radio-based traffic preemption systems using a local radio signal overcome the weakness of both light-based system and GPS system. Similar to the light-based system, the signal is sent from an emitter installed on the vehicle but in the form of a radio signal. Radio-based systems utilize a receiver with an antenna to detect a radio signal sent from an emergency vehicle (Paniati et al [59]). In these systems, the direction of preemption is selected in the vehicle. Once a radio frequency is detected and the proper direction of travel is determined, the preemption request will be processed. Unlike visual, acoustic or GPS signals, radio signals are not subjected to obstructions, weather conditions or system instability. The cost of a system that uses radio signals may equal or exceeds that of a GPS-based system since the cost averaged to each vehicle involved in the GPS system may be lowered as more vehicles are included. Figure 29 is an actual preemption device installed on a traffic light.

Figure 29: An example of traffic preemption device (US Department of Transportation [80])

The cost of traffic preemption systems may vary significantly depending on the technology selected, the number of units purchased and vehicle conditions. The cost consists of the intersection cost and vehicle cost. Table 6 illustrates the typical costs of traffic preemption systems.

Table 6: Typical costs of traffic preemption systems (Paniati et al [64])

System Component	**Capital Cost (in 2003 dollars)**	**Operation and Maintenance Cost (in 2003 dollars)**
Equipment Required Per Intersection		
Signal Preemption receiver with optional confirmation light	$2000-3000	$250-500
Signal Phase Selector	$2000-5000	No specific maintenance required
Equipment Required Per Vehicle		
Signal Preemption Emitter	$700-2100	Remove and replace the optical emitter upon failure

2.3.2 Locating the Patient and Weather

When an ambulance starts to navigate through the traffic, it first requires to know the exact location of the patient. It has been found that depending on circumstances, locating the exact location of patient could be a serious problem. When a person calls from landline, the exact address including the street number and house number will be automatically mapped to the call and displayed on the computer screen of the dispatcher. However, if a caller calls from wireless media, he or she needs to provide the accurate location to the dispatcher by voice communication. In some cases, when the caller calls from the site of accident through the wireless, he or she might not know the exact address. Hence, the actual location of the caller may be misrepresented to the911 dispatcher. Such inaccurate information to the dispatcher would create a substantial delay in getting ambulance to the patient. On the other hand, to reach the locale, EMTs have to rely on the GPS. However, sometimes GPS does not have the most up-to-date local maps, in which case, ambulance drivers have to depend on paper maps, resulting in a much longer response time. In other cases, depending on the system of GPS, GPS might not be smart enough and could lead the driver to the destination through a longer way than necessary. Both cases of using GPS could create delays pertaining to locating the patient, indicating that locating is one of the critical problems to be resolved in shortening ambulance response time.

Weather and natural disatsers also significantly delay emergency medical services. According to John Nowak, operation supervisor for Medtsar Ambulance Service, ambulance response time increased from an average of four minutes to twenty five minutes during a severe strom in Illinois in March 2008 (Kdsk [33]). Severe weather causes severed transport network, downed power lines near roads and fallen tree branches that block roads. During periods of heavy snowfall from January to March, EMS papramedics in many states have a hard time avoiding ice and snow to get to a patients house. It is also hard for them to push a stretcher carrying a pateint in six inches of snow. Other than delaying reponse time, natural disasters/ weather can pose a threat to the lives of paramedics on their way to help patints. Sustained winds or significant gusts can cause emergency vehilces to be pushed off roadways or traffic or overturn the vehicles. During severe weather there is less EMS staff available to work than during normal days which further compromises service by EMS systems.

2.4 Identifying the Problems

In a complete 911 call processing, many factors could contribute to the delay of an ambulance response. Starting from the initial communication between caller and call taker, delay could be resulted from human miscommunication and technical constraints. Following this communication, the inaccurate locating of the patient and making the way through frequently dense traffic could create yet another delay in delivering effective medical service. Attributed to both the setup of 911 protocol and unreliability of the technology utilized, the delay factors affecting the EMS response time could be classified as communication-based, traffic-based and uncertainty- based. In order to obtain a comprehensive view of the problems critical to reducing ambulance response time, an interview with the director of the Worcester 911 call center is conducted. On the basis of this interview and various valid sources, major problems contributing to the ambulance dispatch delay is identified and some justifications are given to support the claim.

2.4.1 Interview with the director of the Worcester 911 Call Center

On November 13, 2012 an interview was conducted with the director of the Worcester 911 Call Center inside the Headquarter of the Worcester Police Department. The first problem identified in the interview pertains to language barrier in the initial caller- dispatcher communication. He introduced that there are two bilingual call takers currently at the Worcester 911 call center that speak both English and Spanish. However, their abilities are rarely used due to legal implications. According to him, in a situation where the call taker incorrectly translates a 911 call that then leads to an increased delay in service or possibly no service at all, the call taker and the call center could face legal consequences. To prevent such a case from happening, the center subscribes to a language line that detects up to 180 dialects and then makes a legal translation of a 911 call. By so doing, the call center can remove itself from any liability issues.

The second problem he identified is the relay of patient information. Fortunately, considerable inputs have been taken to improve this issue and certain achievements have been made regarding this issue. He believes that the main improvement made in the 911 dispatch process in the last few years is the simultaneity of the ambulance dispatch and caller- dispatcher communicating. Unlike in the past, ambulances are now dispatched while the emergency caller is still on the line. As soon as the call taker identifies the call as an emergency and in need of an ambulance, an ambulance is dispatched. Then as the phone communication proceeds and as the call taker receives more information from the caller, that information is fed to the first responders. This saves a significant amount of time in the dispatch process.

Following the two major problems as identified above, he introduced some working mechanism based on the functioning of Worcester 911 call center. He stated that 911cell phone calls are answered by the state police and then routed back to the Worcester call center. Locations of cell phone calls can be obtained from the billing address or through triangulation of cell phone towers. Some phone carriers such as Verizon also have GPS based phones that give the exact location of the emergency call. Currently at Worcester 911 call center, there are three 8-hour shifts for call takers and the minimum staffing is 9 people per shift. He said that their peak hours are from10:30 AM to 11:00AM and calls stay relatively constant until 2:00 am.. He said there are about 800,000 911 calls and 700,000 seven-digit calls made per year, including multiple emergency calls per incident. He also said that of around 25,000 EMS requests, 22,000 included an EMS transport. He explained that call takers are required to go through 16 hours of 911 training, 50 hours of telecommunications training, and 3 months of training by the Worcester call center before they are put on a shift alone.

Continuing on the problems to be identified, he pointed out that establishing a more efficient emergency call filtering mechanism is potentially important to reducing ambulance dispatch time. Currently, the call volumes received by Worcester 911 call center each day is comparatively large considering the scale of the center and a significant portion of the calls do not require urgent assistance. He recommended a central PSAP for the state that would filter emergency calls. Those calls placed by the public to complain about an issue such as a burst water pipe would be referred to a 7 digit non-emergency number or even transferred to the public health department, depending on the issue. This would decrease the volume of calls that the call center has to answer and would enable employees to focus on emergency calls only. The lower volume of calls would also decrease the stress of the employees and enable them to work more efficiently.

Besides, the efficient emergency call filtering, he indicated that the locating of cellphone calls is still an issue to be tackled. Unlike 911 calls made from landlines whose locations are automatically identified through Automatic Number Identification (ANI), cellphone calls cannot be located this easily. The billing address of the caller is most likely not its current position, therefore other methods have to be used. One option is triangulation using the three nearest cellphone towers. This proves to be difficult when calls are made from high risers, however, since the location of the caller inside the building in terms of height cannot be determined. If the cellphone is a Sprint and a Verizon GPS-based device, the location is automatically passed along to the 911 call taker and its exact location is known. The same difficulties are present with Voice over Internet Protocol (VoIP) services such as Vonage, since the billing address of the caller is often not the same address as the one where the call is placed from.

Regarding the accurate phone call locating, he also stated that he had been talking to FCC commissioner about people texting 911. This would be useful when only limited cellphone connectivity is present and only bursts of connectivity exist. In these conditions a call could not be placed, but text messages can still be sent in one of the brief moments of connectivity. The downside of using text messages would be that the call taker cannot tell the emotional state of the caller and therefore cannot judge the situation as well as if a voice call would be placed. Voice communication is also much faster than text messages. More problems arise from autocorrect services that automatically change words in text messages. If the word “gone” was misspelled as “gon”, the autocorrect service might change the word to “gun”. This could cause confusion with the call taker and add complications and time delays to the dispatch process. Older employees at the call center also are not familiar with text messages and the acronyms commonly used for the technology, this would be another challenge.

Another proposal he made regarding the caller-dispatcher communication is to allow multimedia messages such as videos and pictures. The problem with this idea is that dispatchers generally do not want to view graphic images. There would also be legal consequences since a dispatcher that viewed images and videos would become a witness and might be required to come to court and testify. It would also be a challenge to then route videos and pictures to EMS ambulances and fire trucks.

Another improvement made to the 911 system, as he mentioned, comes from a company called smart 911. It provides a service that people can subscribe to and create their own critical care information in a database. This information is attached to their phone number. Should a subscriber to the smart 911 service place an emergency call, the call center will be able to see all of the information the subscriber has voluntarily given. A challenge with this is that it is up to the subscriber to keep their information updated. In addition, another issue facing the call center in implementing this technology is that sharing information about patients with the hospitals or between fire and ambulatory emergency services is quite restricted due to the Patient

Privacy Act.

Besides all the above problems, he emphasized the importance for 911 call centers to handle various disruptions. He stated that the Worcester 911 call center currently uses a computer-aided dispatch system from PAMET which directly integrates with windows. He also talked about the challenges presented by power outages. He stated that the call center is equipped with a backup generator and will remain functional during an outage. He said that copper based telephone landlines will work during an outage as long as the household has backup power. He also stated that many AT&T owned cellphone towers include back-up batteries which provide only temporary power, whereas Verizon usually includes a backup generator at its cell sites. VoIP services such as Vonage are not functional during power outages since they rely on cable for communication.

2.4.2 Major Problems

As summarized from the interview, the delay factors of EMS system could be classified into communication, traffic and uncertainty-based delay. The EMS communication system consists of two major components, namely the patient-PSAP-dispatcher and the ambulance-CMED-hospital communication. The communication failure of the either system as a result of technology breakdown or human miscommunication could significantly hamper the EMS response efficiency. The traffic-based delay is mainly determined by the effectiveness of ambulance warning and traffic preemption. Uncertainty–based delay factor refers to EMS's vulnerability to inclement weather conditions and unpredictable accidents in general.

Based on the justifications and interview, we identify that the major problems crucial to improving EMS response time in current EMS system remain in improving the accuracy of locating patients and the effectiveness of traffic preemption system. While a fixed line phone has a direct mapping between a telephone number and a physical location, a wireless phone does not. With the rapid growth of cellular phone users, wireless emergency calls have become frequent occurrences. When a wireless emergency call is received, usually it would be connected to state police or highway patrol and requires the caller to specify his exact physical location, based on which, the police will then locate and dispatch the closest emergency responder accordingly. In this case, the time efficiency of the EMS response could be significantly harmed by possible human miscommunication.

Besides the locating of cellular phones, locating VoIP (Voice over Internet Protocol) phone also forms an impediment to reducing dispatch time. VoIP refers to the communication protocols and technologies used in the delivery of voice communications over network, that is, Internet. Due to its inexpensive nature, VoIP service has been enjoying an increasing popularity among phone users. While many have been using VoIP phones to make emergency calls, the fact remains that the nature of VoIP makes it difficult to map a call to an exact physical location. Although a method named VoIP Enhanced 911 (E911 has been set up in the United States to enhance accurate locating, the participation in this service is optional and many customers lack the knowledge of the difference between a nomadic VoIP service that does not support accurate emergency call locating and ones that does. Moreover, VoIP is based on a static table lookup and requires service providers to provide information up to date in order for it to function (Peters et al [66]). Besides, an emergency-supportive VoIP service has not been set up in many other countries other than the United States. Therefore, while VoIP is being promoted as a new and inexpensive communication technology, appropriate knowledge about its limitation needs to be emphasized and certain aspects of the technology itself remain to be improved upon.

Aside from communication, certain delays caused by traffic could also contribute to delays in EMS that lead to severe consequences. Thus, the effectiveness of traffic preemption is also critical to reducing the ambulance dispatch time. Each year, a large number of traffic accidents are associated with clashes between ambulances and civilian vehicles. Frequently when such a crash happens, due to the large speed of the ambulance, the consequences are severe, resulting in additional injury of patients in the ambulance. Most of such accidents take place at intersections and are ascribed to the ineffectiveness and malfunction of preemption devices. Therefore, a complete and functional traffic preemption and ambulance warning system are required for civilian vehicles to be fully aware of the presence of an emergency vehicle and yield the way accordingly. Figure 30 is a picture of an ambulance crash occurred in New York due to ineffective EMS communication.

Figure 30: Ambulance crash (CityNoise [6])

2.4.3 Justifications for major problems

Recently, news reported that a SUV collided with an ambulance and two other vehicles in Los Angeles, California on November 12, 2012. This accident took place in Rolling Hills Estates. The ambulance was transporting a patient on Crenshaw with its lights and siren on. Then the Honda pilot which was heading west on Palos Verdes Drive North struck the emergency vehicle at the intersection. After the SUV hit the ambulance, it flipped and knocked over a light pole and then it landed upright on all four tires. The Honda ended up hitting two other vehicles heading southbound on Crenshaw. After this accident was reported and recorded, the patient was transported to the hospital but there were no injuries caused by this collision (Hedges JR, *et al*. [63]) . Figure 31 shows the area where the accident took place.

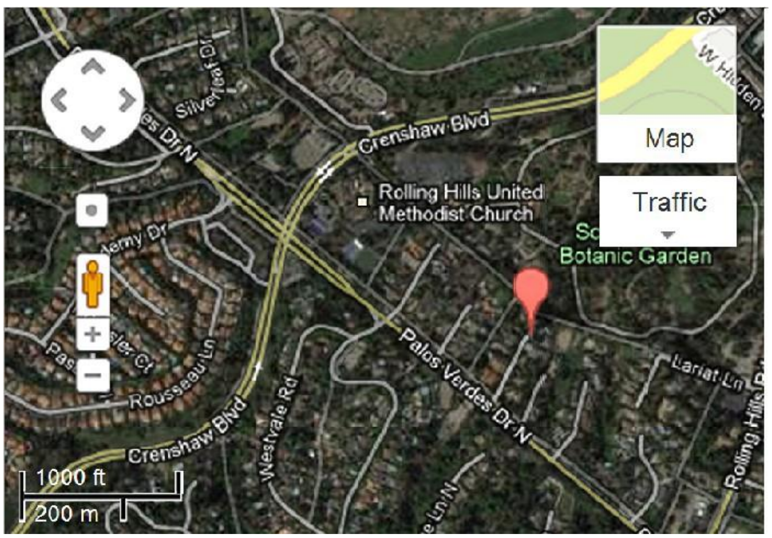


Figure 31: Intersection of Palos Verdes Drive North and Crenshaw (Hedges JR, etal. [63])

A second justification is that on July 29, 2012, an ambulance in Colorado collided with a Dodge Caravan and resulted in eleven injuries. The ambulance crashed into the van when it was carrying a stroke victim along with his wife and other EMTs. According to Utah Highway Patrol, the van was traveling through the intersection of State Road 9 on a green light and began to turn left when the ambulance entered the intersection and hit the van.

All of the three passengers in the van suffered from severe injuries. One of them was transported to University Medical Center in Las Vegas. The passengers in the ambulance also suffered from the consequence of clash, including a dislocated shoulder. Ambulance driver Lizzie Barlow was issued a citation for traffic control signal violation (Utah News [5]). In this incident, if traffic preemption devices had been installed and functioned properly, the ambulance would have gained right-of-way and absolute access to the intersection, in which case, the tragedy could have been completely avoided. Figure 32 shows the intersection where the accident took place.

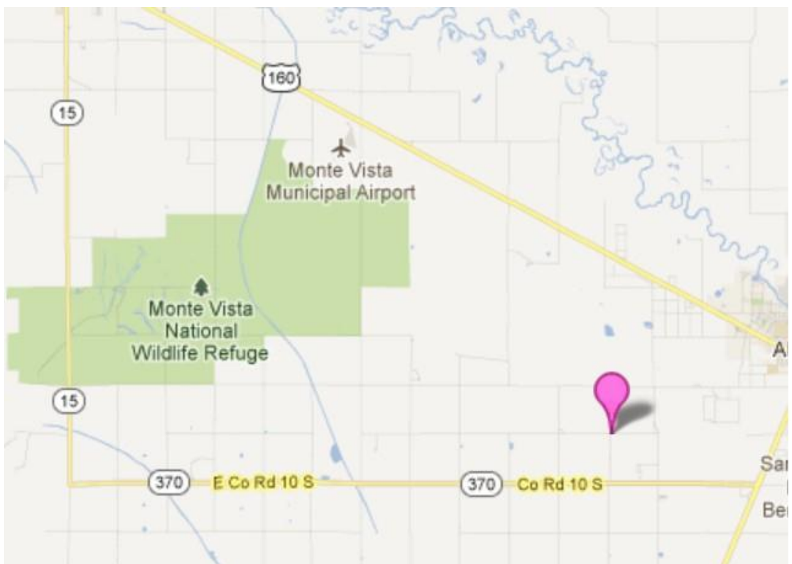


Figure 32: Intersection of StateRoad 9 in Colorado (Utah News [5])

A third justification is that on May 7 2008, an 18-month old toddler in Calgary, Canada, died after it took two ambulances 40 minutes to get to him due to the inaccurate address provided by the VoIP phone which has resulted in one ambulance being dispatched to the wrong city. Elijah Luck went into medical distress and his family made an emergency call for an ambulance. Due to the fact the family used a nomadic VoIP service which does not support accurate physical address locating of emergency calls, wrong address information was shown on the end of emergency dispatcher. As a result, other than in Calgary, an ambulance was dispatched in Mississauga, Ontario, which is more than twenty-five-hundred miles away.

After waiting a half an hour for the ambulance, the parents rang again from a landline and an ambulance arrived six minutes later, though the baby was pronounced dead upon his arrival at Alberta Children's Hospital. Only fixed landlines and VoIP services automatically route an emergency call to the nearest call center. Nomadic VoIP services unfortunately do not always give the correct information. As is seen, it is crucial to educate the general public about the limitation of using VoIP in emergency context before tackling the technical issues to resolve this dilemma (Tom's Hardware [15]).

A fourth justification is that on August 2 2008, Atlanta resident Darelene Dukes called 911 from her cell phone because she was stricken by a heart attack. Suffering from intense pain, she could barely talk to the operator and tell her address. In case of a landline call, the caller's location would have popped up on the operator's computer. The operator misunderstood Dukes, and sent an ambulance to Wells Street in Atlanta, 28 miles from Dukes apartment in Johns Creek, a suburb in the north of Atlanta. The operator did not notice that the cell phone call was made from a tower in North Fulton and not Atlanta. The operator stayed on the phone with Dukes for 25 minutes, waiting for the ambulance to arrive and Duke felt silent 17minutes into the call. John Creeks authorities responded within five minutes once the error was discovered, but by then it was too late. The operator was fired for his mistake, but this incident highlights the need for developing technologies that provide location of wireless 911 calls. The procedure of looking up the location of cellular towers can be tedious and inefficient in stressful situations compared to the procedure of looking up addresses of landline calls which is directly displayed on the computer screen (Hinterland [35]).

2.5 Implemented Solutions

On the basis of problems related to ambulance dispatch as mentioned in the previous section, some solutions that have been already implemented are introduced in this section. This includes the solution to traffic preemption devices, lights, sirens, vehicle colors and patterns, communication technologies and softwares. These solutions have already been implemented and can be experienced in today's day to day life. These solutions are explained in detail in the following subsections.

2.5.1 RescueNet Dispatch and EMS-TIF Software

RescueNet Dispatch is software made by Massachusetts based Company ZOLL Medical Corp. This software has been used by Albuquerque Ambulance Service (AAS), which is the largest provider of emergency medical services in the state of New Mexico. It is a non-profit service and division of Presbyterian Hospital, installed this software called *RescueNet Dispatch Pro*. This software helps EMS staff to predict exactly where ambulances should be placed at any hour. This new technology, along with a new way to analyze data, has dramatically reduced the time to respond to emergency calls. According to statistical data, before using this software, the ambulances used to respond to "priority 1" or life-threatening calls within 10 minutes between 86 percent and 88 percent of time. After using this software, they respond to 96 percent of time. Also the nonlife threatening calls are being responded in 15 minutes (FireRescue [27]).

RescueNet Dispatch Pro brings existing pieces of information in the database together. This software can predict where the next emergency call can come from and hence the ambulance is positioned in that location before the calls have been made. Each call in the 911 center is analyzed and stored in database. Hence, these past calls and information are used to predict the future calls. This software displays the information graphically on the dispatch screen where the next call is going to be. It works by analyzing the past priority 911 calls. For example, the staffs look into all the prior calls for 911 on the night of Wednesday at 10 p.m. and by mapping it out, they will try to predict where the ambulance will need to be in future. This system refreshes every 10 minutes and it has been used since 2009. It has been found that by using this software it saves a minute of each call that the dispatcher responds to. This software works on the theory that "Our life is predictable". This software should be encouraged in other states and countries too (FireRescue [27]). Figure 33 a shows the dispatch call center and Figure 33 b shows the screenshot of the software RescueNet Dispatch Pro used.

a. Dispatch call center b. Data Dispalyed by the RescueNet Dispatch Pro

Figure 33: Data Dispalyed by the RescueNet Dispatch Pro (FireRescue [57])

The other software that plays a significant role in emergency is EMS-TIF. In one of the cities of Canada named Kitchener, the firefighters have started to arrive up to 40 seconds faster at medical emergencies than usual. This is because of the new computer system called EMS-TIF, which stands for Emergency Medical Services Technical Interoperability Framework. This system was installed in June after a year-long pilot project. Basically, this technology links to the provincial ambulance dispatch center in Cambridge with the Kitchener fire dispatch center. When a person calls 911 for a medical emergency, dispatchers in both call centers receive the information at the same time. Previously, the ambulance dispatcher would have to call the fire dispatcher with the information. This process used to increase response times by crucial seconds in life and death situation. The data showed that last year, firefighters went to 9544 calls of which about 5500 were medical incidents. One recent incident that the chief of 911 call center in Ontario talked about was a 911 call about a person who was having difficulty in breathing at Kitchener mall. Because of this system, the call was received by the fire department at the same time and the fire truck reached the scene in five minutes and 49 seconds later. The firefighters stabilized the patient until paramedics arrived. Hence, this technology has been showen to be highly effective in reducing the ambulance dispatch time and efforts should be made to expand the application of this technology to a wider range of emergency responders (FireRescue [27]).

2.5.2 Sirens and Lights

Currently, the ambulance sirens in the market are mainly electronic sirens that combine the classic mechanical tone and air horn. The dual tone feature allows for a large selection of tones and gives the perception of two sirens operating at the same time, optimizing the alerting and warning effect. The sirens are typically equipped with a rotary switch for selecting siren tones and radio, a momentary push button for the air horn and manual siren control, a master on/off switch, a noise-cancelling microphone and a large volume control knob. Figure 41 is a classical mechanical siren used for ambulances. Strobe lights currently used by ambulances feature multiple flashing patterns and typically a total output control allowing the maximum output available to installed strobe heads. Figure 34 a is an example of strobe light used for emergency vehicles. Figure 34 b is an ambulance with its light turned on flashing at night.

a .Classic Mechanical Siren

b. Strobe System

Figure 34: Siren and Lights (Carson Manufacturing Company [77], Strobes N’ More [75])

2.6 Response Time Analysis Mathematical Models

Travel time and velocity of ambulance are key components in reducing ambulance dispatch time. Figure 35 illustrates a whole process of ambulance dispatch where each of the components plays a different role that affects the final response time.

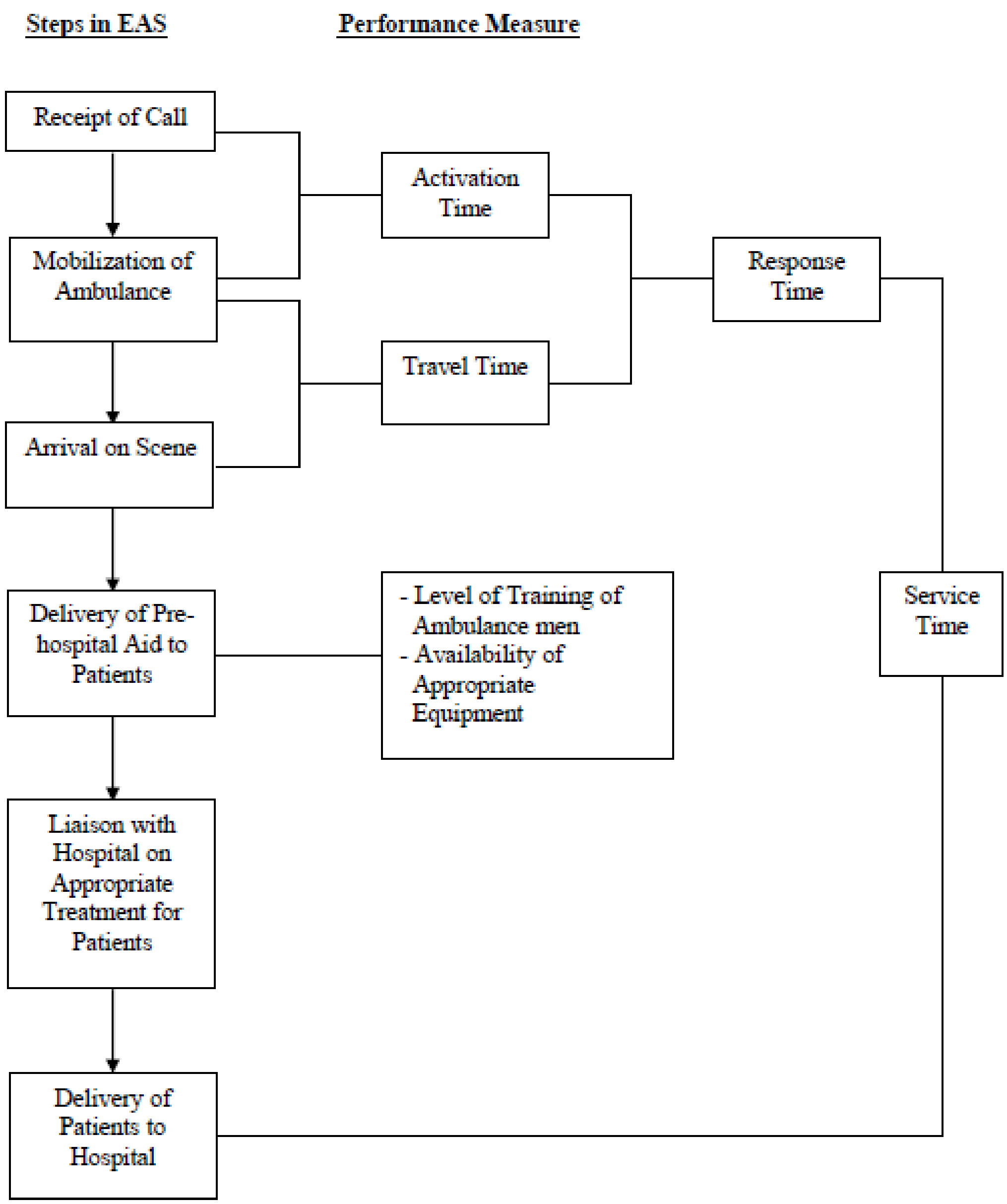


Figure 35: A Flow Chart of Time Delay Analysis (Hong et al [44])

It is therefore critical to establish mathematical models to predict an average ambulance dispatch time. Current mathematical models on predicting ambulance dispatch time mainly include those of stochastic type and differential equations.

2.6.1 Stochastic Model

Given the distribution of medical emergency service demand and the assumed ambulance locations within a region, models of stochastic type estimate the probability that the closest ambulance is within a given response distance when an emergency occurs. The distance is related to time through the distribution of travel velocity of ambulances. The goal of the models of this type is to obtain the probability distribution of response time and evaluate the time efficiency of EMS dispatch system.

Let D be the random variable of response distance for an emergency in a region of area A, in which N ambulances are uniformly and independently distributed. Then assume D satisfies spatial Poisson process. For any response distance d positive, the probability that an ambulance is within this distance is calculated by equation (1).

$$P(d \leq D) = 1 - \exp(-\pi d^2 N/A) \qquad (1)$$

If the region is divided into K sub-regions with equal area and let E_i be the total number of expected emergencies in a sub-region in a given time period, then $Z_i = E_i/A_i$ is the expected demand per unit area. Then the probability density function (PDF) of ambulances in a region with N ambulances P_N can be computed by equation (2).

$$P_N = 1 - 1/\overline{Z_m} \int_0^\infty \bar{z} \exp\{\left[-\pi d^2 N/A\bar{h}(\bar{Z})\right] h(\bar{z})\} g(\bar{z}) d\bar{z} \qquad (2)$$

where, $g(\bar{z})$ is the probability density function of $\bar{Z}$ and $\bar{h}(\bar{Z})$ is the expectation of $h(\bar{Z})$ given by $\int h(\bar{z})\, g(\bar{z}) d\bar{z}$. To relate the response distance with response time, we let T denote the random variable response time. Let V be the random variable representing the average velocity with a density function $f(\bar{v})$. Then the distribution function of response time can be modeled by equation (3) (Scott et al [74]).

$$P_N(T \leq t) = \int P_N(D \leq \bar{v}t)\ f(\bar{v})d\bar{v} \tag{3}$$

The model was first proposed in 1978 and has been tested with large volumes of sample data. This model could be further extended to take into account queuing effect of ambulances, i.e. the situation where the closest ambulance in the region is busy with other requests at the time of service demand.

2.6.2 Differential Equations Model

Models dealing with differential equations are mostly focused on the speed-density relationship, quantifying the relationship between an individual vehicle velocity and traffic flow. Paveri-Fontana established a traffic flow model in 1975 considering each driver has a velocity w and a vehicle distribution function $g(v, w, x, t)$, which denotes the number of vehicles per road interval with instantaneous velocity v, expected velocity w at time t and road position x. The Paveri-Fontana Equation is formulated in equation (4).

$$\frac{\partial g(v,w,x,t)}{\partial t} + v\frac{\partial g(v,w,x,t)}{\partial x} + \frac{\partial}{\partial v}\left(g(v,w,x,t)\frac{w-v}{\tau}\right) =$$

$$f(v,x,t)\int_v^\infty (1-p)\,(v'-v)g(w,v',x,t)dv' - g(w,v,x,t)\int_0^v (1-p)(v-v')f(v',x,t)dv'$$

(4)

where $f(v, x, t)$ is the distribution function corresponding to the number of vehicles per road interval with instantaneous velocity v at time t and road position x (Paveri-Fontana [65]).

Although it is a fairly accurate representation of vehicle velocity, the complete Paveri-Fontana equation has not been solved so far. The equations served as a good starting point of constructing a macroscopic traffic flow model.

CHAPTER 3. TESTING OUR SOLUTIONS

3. Introduction

In this section, we summarize the pros and cons of the warning devices used in current EMS system, namely siren and light. We then discuss the most up-to-date prototype products and technology for EMS warning system. In the next section, we present mathematical models discussed in Chapter 2 in greater details. Three types of mathematical models in literature which have been used to capture EMS communication and ambulance dispatch efficiency are presented and illustrated. These three models are constructed using knowledge of differential equations, control theory and probability respectively. In particular, a modification was applied to the differential equations model to enlarge the scope of the model and to obtain a generic relation between speed and traffic flow rate. Applying the differential equations and probability models, we conduct case studies on different regions in the US by running a series of simulations. By analyzing the results of simulations, we present the actual ambulance response behavior and provide insights into solutions to reducing ambulance response time. In the third section, the concept of texting 911 is discussed including both its history and potentials. Two texting 911 smartphone apps developed by us are then demonstrated. These two apps feature personal medical history, GPS locating, scripted questions and text-sending. The concrete functionality of the apps and the environment in which the apps are developed are both demonstrated in details in each subsection of this section.

3.1 Some Implemented Solutions and Testing

The Emergency Medical Service (EMS) providers use sirens to warn civilian vehicles of approaching emergency vehicles. Sirens are the source for warning and alerting civilians for clearing up the road for the emergency vehicles. There are generally two types of sirens that have been used by the emergency vehicles i.e., mechanical or electronic siren. There has always been controversy between using mechanical or electronic siren to alert the civilians in the best way. Sometimes it is just about the modern versus the old fashioned siren. There are many articles reporting why mechanical sirens are better than electronic sirens or vice-versa. Different minds have different opinions on the basis of their experiences, readings and characteristics of the sirens (Timberwolf Sirens [54]).

The working mechanisms of mechanical and electronic siren have been described in detail in Chapter 2. Electronic Sirens translate a transistor signal to an electronic magnetic driver which pulses a ¾ inch diameter diaphragm back and forth to move the air in a sine wave, creating "Whoo-Whoo" sound. Mechanical Sirens pump air, compressing and accelerating it to more than 130,000 inches per minute (or 124 miles per hour) where a rotor pulses it, off on, off on in a square wave form which spirals at 9,000 revolutions per minute as it expands from the 2 3/4 inch diameter guiding throat.

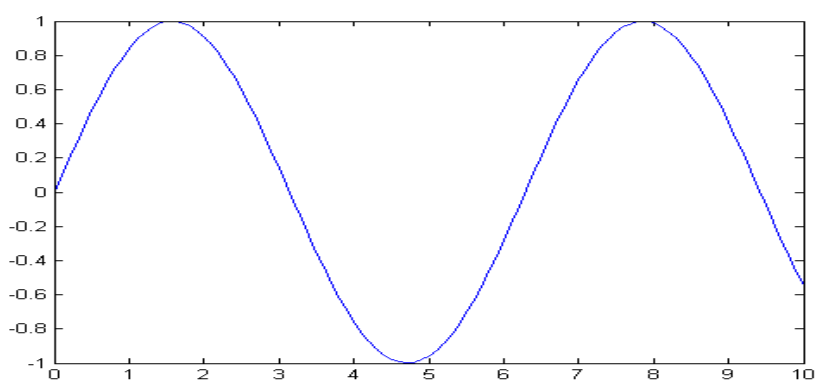


Figure 36: Sine wave used by electronic siren

The Mechanical Siren's spiraling wave is like an ocean's wave curl projected from a short guiding throat, on off on off, making the Whoo sound. The operator controls the volume and the pattern with the foot switch. If the operator wants to create a loud and sharp alerting siren then he presses the foot switch hard. The sine wave created is shown in Figure 36 (Timberwolf Sirens [54]).

In order to know which siren is better to alert civilians on the road about the emergency vehicles coming we asked Neil Blackington, Deputy Superintendent of *Boston EMS*, about it. He told us that people seem to respond to the mechanical siren more than the electronic siren. He also said that it was nothing to do with the sound waves but it was the familiarity that the public has for the mechanical siren which is also addressed as "Federal" siren. The public assumes that there is an emergency vehicle approaching as they hear that distinct siren. Also the electronic siren waves can pass over a vehicle and people can be left with the confusion if there was the fire truck or the ambulance or the police car. On the other hand, because of the penetrating and narrow pattern of the mechanical sirens' wave it is hard to ignore them. The effect of mechanical siren is such that one cannot only hear the approaching siren, but can also recognize the direction it is travelling to or from. He also mentioned that the wave of the electronic siren expands to create noise pollution by penetrating the neighboring homes over a great distance. He also mentioned about the electronic siren called "Q". It is an Electronic Siren which sounds just like a mechanical siren. This digitized signal is played from a special large speaker horn. The mechanism of this siren is that it only moves air by a 3/4 inch diameter diaphragm, pushed and pulled by electro magnets (Timberwolf Sirens [54]).

Figure 37: Q siren (Timberwolf Sirens [54])

This siren "Q-Siren" shown in Figure 37, is the most recognized in the fire industry and this has been used in the fire service for almost more than 50 years. This electro-mechanical siren is a streamlined siren to provide reliability for life-long operation. When "Q-siren" is mounted on emergency vehicles, it delivers 123 decibels warning sound at 10-feet which is more than any other sirens (Timberwolf Sirens [54]).

Next, ambulance lightning will be discussed. On December 4, 2012 our team gave a presentation on emergency warning lights before Neil Blackington, Deputy Superintendent of *Boston EMS*. After the presentation he came up to us and discussed about the popular use of lights in emergency vehicles. He mentioned that nowadays LED-based lightning is becoming very popular than the traditional strobe light and incandescent light in the emergency vehicles. The reasons are LED (Light-emitting diodes) are small, solid state, very power-efficient, long lasting. The best advantage of LED light is that it can be seen very easily even at greater distances and in sunlight. Compared to other lights used in emergency vehicles, LED-based lights use a clear, colorless dome and they can be made very thin which reduces the wind resistance. LED light bars are very reliable and practical to use. The size of the LED lights is smaller compared to the other lights. Because of the smaller size, the fuel used to run the light is less. At the same time, an LED light bar also uses less power but emits maximum lightning. This increases the efficiency of the LED lights and more effective emergency vehicles. LED bars are also capable of using different strobe patterns to better attract attention or communication. Because of these advantages Neil Blackington said LED lights are better than the strobe lights or incandescent lights. Figure 38 shows the LED Light used in emergency services vehicle (Delorenzo et al [27]).

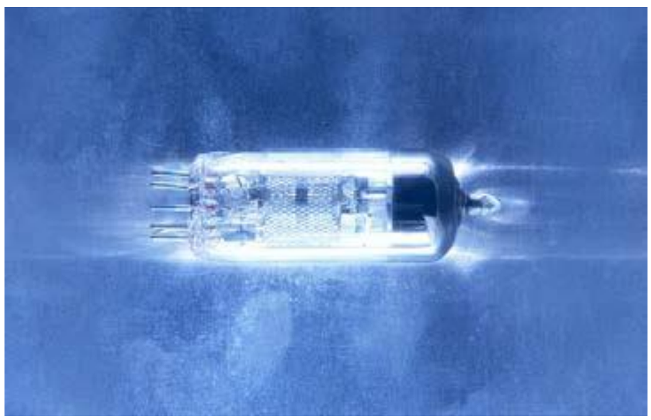


Figure 38: LED Light used in emergency services vehicle (Delorenzo et al [27])

VoIP is one of the intermediate through which a caller can contact 911. But there are many problems when a caller calls 911from VoIP which were mentioned in Chapter 2. FCC has been working on improving calling 911 from VoIP phone. E911 system has been developed which automatically provides emergency service personnel a 911 caller's call back number and location information. The main issue with VoIP phones is to locate the correct location and connect to the right PSAP to provide the best emergency services. It is because the portable interconnected VOIP service allows the users to take the phone almost everywhere and connect to any internet connection. Hence it becomes difficult in order to identify the correct location of the caller.

Certain problems with VoIP phone compared to traditional phone are VoIP 911 calls may not connect to the PSAP, or may improperly ring to the administrative line of PSAP. In such case the line might not be attended by the staff or by trained 911 operators. On the other hand, sometimes VoIP 911 calls may correctly connect to the PSAP, but not automatically transmit the user's phone number and location information. VoIP users may need to provide location or other information to their VoIP providers, and update this information if they change locations, for their VoIP 911 service to function properly. Also the VoIP service depends on the power and internet connection; in case of outage of any of these the VoIP services may not be functional. FCC has been trying to overcome these problems and implement some regulations for the VoIP users. FCC has imposed the requirements like before an interconnected VoIP provider can activate a new customer's service; the provider must obtain from the customer the physical location at which the service will be first used. This is done so that emergency services personnel will be able to locate any customer dialing 911. Also interconnected VoIP providers must transmit all 911 calls, as well as a callback number and the caller's registered physical location, to the appropriate emergency services call center or local emergency authority. Interconnected VoIP providers must obtain confirmatory acknowledgement from all existing customers that they are aware of and understand the limitations of their 911 service. In some areas, emergency service providers are not capable of receiving or processing the location information or call back number that is automatically transmitted with 911 calls. In those areas, interconnected VoIP providers must ensure that a 911 call is routed to the appropriate PSAP. These are the implemented possible warnings that FCC has made to alert customers about limitations of VoIP phone to call emergency number 911 (Federal Communication Commission [81]).

It is definitely true that voice calls are the most efficient means of communicating in case of an emergency but texting has its own benefits especially in the situations where talking can put the victim in danger. It is also useful in the place where there might be disaster and have low signal strength or if the caller has a hearing or speaking disability. Therefore, the FCC has made a decision for implementing texting 911 program soon and have made a deal with U.S.'s four big carrier's Verizon Communications Inc, AT&T Inc., Sprint Nextel Corp. and T-Mobile USA Inc. to allow the customers to send text messages to a 911 call center during an emergency nationwide by 2014. Moreover, FCC is planning on the approach to make sure that texting 911 program is available for customers of other cell carriers, as well as those who use Internet-based texting services (APCO [42]).

In 2009, Iowa's Black hawk County Consolidated Communications Center (BHCCC) had an effort to implement text messaging 911. In order to make texting possible, BHCCC made a network and software which can be compatible with 911 call handling equipment and service provider. The secure IP connectivity was provided through a private network ensuring greater functionality and security. After upgrading the network and software, the county needed a wireless carrier that could provide a mobile signal covering area. This could provide the environment in which 911 text messaging could be monitored, analyzed and evaluated. A message service named short message service (SMS) was used to establish a text conversation directly between the caller and a BHCCC operator. After all the network and services a trial for texting 911 was implemented. When a Black Hawk County resident sends a text message to 911, the SMS is routed into 911 network and prompts the caller to provide the closest city or zip code. Once location is determined, the text is received at the nearest located PSAP. Then the emergency services team is dispatched for the help (City of Durham [36]).

This text solution enables the caller to be located automatically by cell-tower location. The location technology used for this SMS call flow is similar to a voice call flow location technology. Therefore, the text messages are delivered into 911 to the correct PSAP. The Black Hawk County Text to 911 Project was successful because it worked in the targeted areas. Keeping this in mind our team has decided to make an application for the cell phone in order to be able to text 911 and make 911 services better. The ‘911 text messaging app’ is discussed more in detail in the following topics (APCO International [76]).

3.2 Models on EMS communication and ambulance dispatch

To better understand the structural and systematic behavior of the EMS system, various mathematical models on EMS communication protocol and ambulance dispatch time have been proposed. These models extract the central components of EMS protocol affecting EMS response time and capture the relations among different time delays. In the following subsections, three mathematical models in literature will be discussed, namely models using differential equations, probability and control theory.

3.2.1 Differential Equations – Castilo-Benitez Speed-Density Model

One of the most critical parameters needed to determine the response time of an ambulance is the time it takes for the ambulance to reach a certain destination, or alternatively the speed at which the ambulance travels. A very important notion evaluating the time efficiency of ambulance is "speed-density relation", as the traveling speed of a vehicle depends heavily upon the traffic density. Many models on speed-density relation have been proposed before Del Castilo and Benitez. These models, however, are mostly derived based on empirical evidence using simple curve-fitting, which lack theoretical support. Models that are more theoretically well-grounded complicate the mathematics at the same time, making it difficult to solve. In their 1995 paper, Castilo and Benitez proposed the speed-density relation that has since then become the most traditional and classic model on speed-density model used in studies of traffic flow. The model assumes that the speed-density relation is an exponential function and introduces parameters to quantify jam density, free flow speed, kinematic wave speed, etc. The model Castilo and Benitez proposed is formulated in equation (5).

$$v = v_{free}\left\{1 - \exp[\frac{c_m}{v_{free}}(1 - \frac{\rho_{jam}}{\rho})]\right\} \tag{5}$$

where v_{free} is the free flow speed of the vehicle, c_m is the kinematic wave speed under the jam density ρ_{jam}, and ρ is the traffic density (Del Castillo et al [26]). Essentially, traffic density is a quantity representing the number of vehicles per unit length (per kilometer or mile). In some circumstances, instead of traffic density, traffic flow rates are recorded and used to account for the different traffic conditions. Using the relation between traffic density and traffic flow rates, shown in equation (6) , we modified the original Castilo-Benitez model to be a speed-flow rate relation, which can be applied to circumstances where only data on traffic flow rates are available.

$$q = \rho v \tag{6}$$

In equation (6), q is the traffic flow rate. ρ is the traffic density and v is the traveling speed of the vehicles. Notably, as ρ has a unit of number of vehicles per unit length and v has a unit of length per unit time, q naturally takes a unit of number of vehicles per unit time (Del Castillo et al [26]).

With the relation as shown in equation (6), the original Castilo-Benitez Model can be re-written as a relation between velocity v and traffic flow rate q, as is shown below in equation (7). Given enough data on parameters such as v_{free}, c_m and ρ_{jam}, equation (6) suffices us to solve for the corresponding speed of the vehicle v ,under a particular road condition with the parameters provided above.

$$v = v_{free}\left\{1 - \exp[\frac{c_m}{v_{free}}(1 - \frac{v\rho_{jam}}{q})]\right\} \tag{7}$$

The Castilo-Benitez model, though established upon the assumption of an exponential speed-density relation, is capable of roughly capturing the empirical data obtained for vehicle speed and traffic density. Most importantly, it also preserves the mathematical simplicity required for computation. Since ambulance by nature enjoys many privileges in gaining the access to road, models on speed-density relation specific to ambulance have been constructed with some modifications to the original Castilo-Benitez speed-density model. Weighting coefficients and piecewise functions have been incorporated to account for many privileges of ambulance including the right to use the opposite lanes and not to stop when traffic lights turn red. However, the model is further complicated and within the scope of this paper, the original Castilo-Benitez model is chosen to predict the ambulance velocity for simplicity.

3.2.2 Probability – Scott-Factor-Gorry Model

Besides the traffic flow model focused on the behavior of a single vehicle, mathematical models predicting the overall performance of a system of ambulances have also been derived using knowledge of probability. To capture the distribution of response distance and time, these models consider the entire spatial distribution of ambulance base services and account for the rate and spatial demand of emergency request. Scott et al. derived a classic model on ambulance distribution first in 1978 that captures the relation among number of ambulances available, ambulance response distance and response time within a region. Assuming a roughly circular urban region with no prominent barriers to travel within it, their model estimates the probability that when an emergency occurs, the closest ambulance is within a given Euclidean distance (i.e. the response distance) of an emergency.

The basic model of response distance in Scott, Factor and Gorry's paper can be represented in equation (8) as shown below.

$$\mathrm{P(D \leq d)} = 1 - \exp\left(-\frac{\pi d^2 \mathrm{N}}{\mathrm{A}}\right) \tag{8}$$

where D is the random variable of response distance for an emergency in a region of A, in which N ambulances are uniformly and independently distributed. D is assumed to approximately follow the spatial Poisson process. $P(D \leq d)$ is the probability that an ambulance is present within a given region for any response distance $d \geq 0$ (Scott et al [69]). Queuing effect is also considered in the original model of Scott et al., but ignored here for the sake of mathematical simplicity. The computation of response time is based on the simple time-velocity relation $T = D/V$ where D is distance and V is velocity. The distribution of response time is computed using equation (9).

$$P_N(T \leq t) = P_N\left(\frac{D}{V} \leq t\right) = \int P_N(D \leq \bar{v}t)\, f(\bar{v}) d\bar{v} \quad (9)$$

where $f(\bar{v})$ is the probability density function for the ambulance velocity.

In Scott et al. paper, a case study is done on Houston for which the distribution of ambulance response time is simulated and compared against real data. In the case of Houston, the distribution of response distance, instead of being modeled as an exponential function, is chosen to be equation (10).

$$P_n(D \leq d) = 1 - (1 + \pi d^2 n/A)^{-2} \quad (10)$$

Based on equation (10), the distribution of response time can be approximated by equation (11). The distribution of average ambulance velocity in Houston is obtained from the measured distances between ambulance station and pick-up locations from a random sample of 104 of 3,936 runs. An estimate of the mean velocity is computed based on this sample. The average ambulance velocity computed in Houston is 22.5 mph.

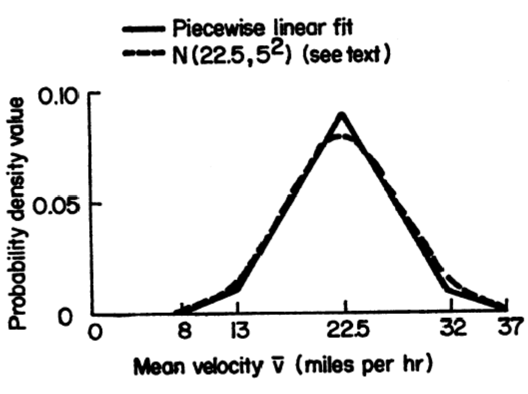


Figure 39: PDF for mean ambulance velocity in Houston (Scott et al [74])

Based on the data collected, an ambulance probability density function is obtained and fitted with a piecewise linear function shown in Figure 39 (Scott et al [74]).

$$P_n(T \leq t) = 1 - \frac{1}{2}\sum_{i=1}^{m}\left[\frac{b_i\bar{v} - a_i/f}{1 + f\bar{v}^2} + \frac{b_i}{f^{\frac{1}{2}}}\arctan(f^{\frac{1}{2}}\bar{v})\right] \tag{11}$$

where $f(\overline{v})$ is the probability density function of ambulance velocity and a_i, b_i are coefficients obtained by fitting this probability density function.

3.2.3 Control Theory – Fofana Model

An emergency call flow model capturing the time delay involved in the EMS call protocol has been proposed by our advisor Professor Fofana. This model, based on the concept of control theory, predicts the speed at which 911 calls are being processed and controlled. Let $x(t)$, $y(t)$, and $z(t)$ represent amount of calls entering PSAP, total amount of calls made by callers and amount of calls controlled in the control loop respectively. The following equations have been derived to keep track of the number of calls received and processed, and the time delays involved.

$$\begin{cases} \dot{x}\,(t) = -\beta_1[(1-\beta_2)x(t) - y(t)] \\ \dot{y}\,(t) = \mu_1 x(t) + \beta_3 y(t) - \gamma_1 z(t) + \varepsilon g(x,y,z,\mu) \\ \dot{z}\,(t) = -\gamma_2 z(t) + \mu_2[y(t-\tau_h) - x(t)] + \mu_3\left(x\left(t-\tau_p\right) - y(t)\right) + \varepsilon h(x,y,z,\mu) \end{cases} \tag{12}$$

In equation (12), $g(x,y,z,\mu)$ and $h(x,y,z,\mu)$ are two disturbance functions representing time delays caused by some random factors. τ_h and τ_p represent the delay of sampling time and controller respectively.

If the two system disturbance functions $g(x, y, z, \mu)$ and $h(x, y, z, \mu)$ are ignored here for simplicity, the system of equations can be simplified to a linear system and written in the following matrix notation. An analytic solution can be obtained by computing the determinant of the matrices, as is shown in equation (13).

$$\begin{pmatrix} \dot{x}\ (t) \\ \dot{y}\ (t) \\ \dot{z}\ (t) \end{pmatrix} = \begin{pmatrix} -\beta_1(1-\beta_2) & \beta_1 & 0 \\ \mu_1 & \beta_3 & -\gamma_1 \\ -\mu_2 & -\mu_3 & -\gamma_2 \end{pmatrix} \begin{pmatrix} x(t) \\ y(t) \\ z(t) \end{pmatrix} + \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \mu_3 & \mu_2 & 0 \end{pmatrix} \begin{pmatrix} x(t-\tau) \\ y(t-\tau_h) \\ z(t-\tau_p) \end{pmatrix} \tag{13}$$

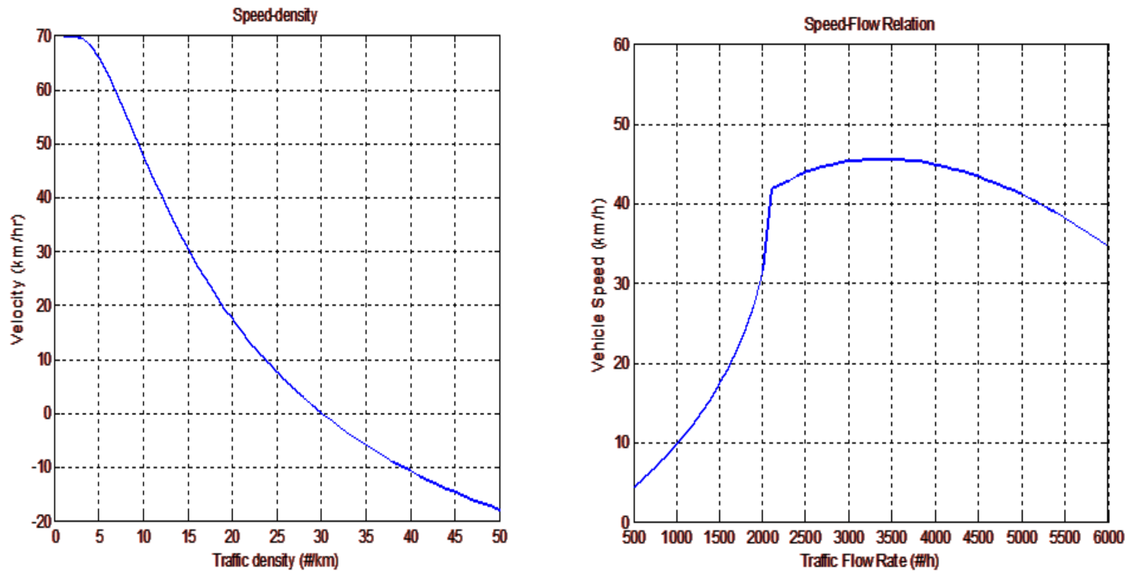
The model looks at the emergency call flow as a whole and captures the interaction and interplay among different sectors of the EMS communication control loop. While solving this model is somewhat computationally expensive, this model, however, opens up a new perspective looking at EMS communication delay and has the potential of providing some new insights into modeling the time delays involved in EMS communication.

3.3 Simulations using MATLAB

To apply the mathematical models to our study on ambulance dispatch delays, we ran a series of simulations based on the data collected in specific regions in the United States. In the following subsections, we present simulations of Castilo-Benitez model and our case study of ambulance velocity in Dade County near Miami and Orange County near Orlando. We also present simulations of Scott-Factor-Gorry probability model and case study of ambulance response efficiency in Eastern Massachusetts.

3.3.1 Simulations using Castilo-Benitez Model

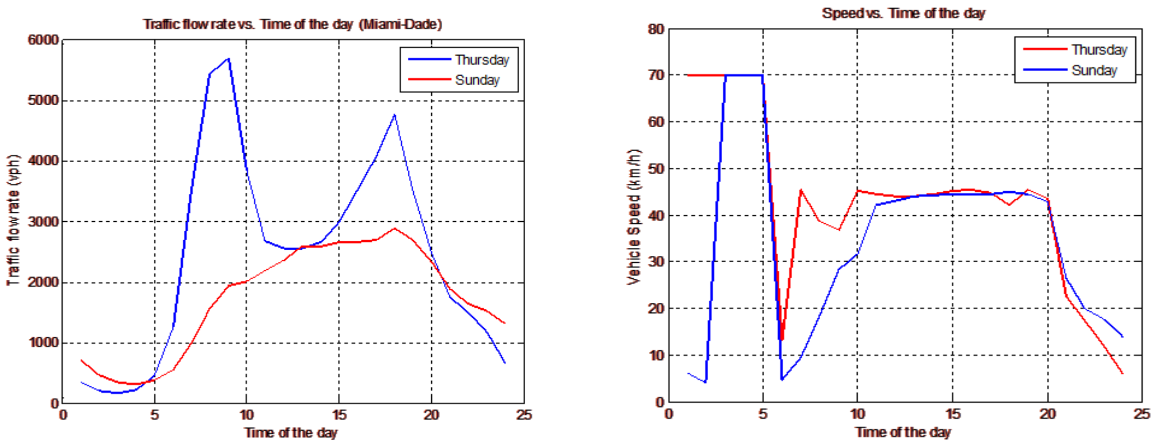
Applying the original Castilo-Benitez Model on the speed-density relation, we obtain a generic speed-density curve shown in Figure 40 a. Applying the modified speed – flow relation and solving for the relation between traffic flow rate and velocity, we obtain a generic speed vs. traffic flow rate graph as demonstrated in Figure 40 b.



a. Speed density curve b. Speed flow curve

Figure 40: Speed-density and speed-flow curves

In this section, we collect data on traffic flow rates measured at Counter 0267 on Turnpike in Mimia-Dade County, near Miami and analyze the data using the modified Castilo-Benitez Model (My Florida [74]). The traffic flow rates in North bound Miami-Dade county at different times of the day are plotted in Figure 41 a. Historical data of a typical Thursday and Sunday in January are chosen in particular to compare the traffic flow fluctuation between weekdays and weekends. Applying the modified Castilo-Benitez Model, we are able to simulate the vehicle traveling speed at different times of a typical weekday and weekend in Miami-Dade, Florida. The predicted vehicle speed is demonstrated in Figure 41b. Parameters chosen in the computation are illustrated in Table 7.



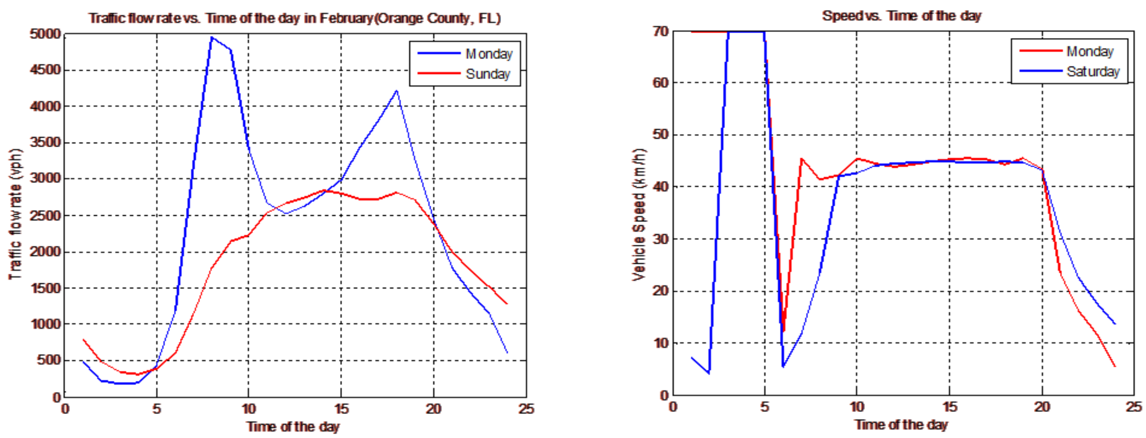
a. Traffic flow rate b. Vehicle speed

Figure 41: Traffic flow and vehicle speed simulation

Table 7: Table of Parameters (Scott et al [69])

Parameter Meaning	Notation	Value
Free speed, i.e. the speed at which vehicle moves when there traffic density is zero	v_{free}	48 *km/h* (city environment)
Kinematic wave speed, a parameter associated with the kinetic wave properties of the flow	c_m	40 *km/h*
Jam density, i.e. the maximum density when traffic is jammed	ρ_{jam}	30 *vehicles/km*

Similarly, we apply the same simulation to the traffic flow data collected at Counter 0130 on I-4 in Orange County, near Orlando (My Florida [79]). The data of traffic flow rate is demonstrated in Figure 42 a. Historical data of a typical Thursday and Sunday in January is chosen. Same parameter set is chosen for the computation of vehicle speed. The predicted vehicle speed based on the traffic flow rates is shown in Figure 42 b.



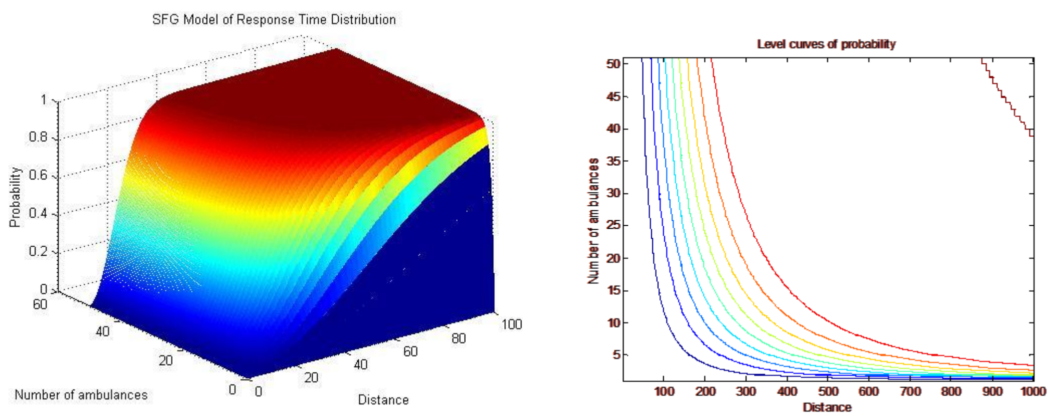
a. Traffic Flow Rate   b.Vehicle Speed

Figure 42: Traffic flow rate and vehicle speed simulation

As can be seen from the data and simulations above, there exists a significant difference in the pattern of traffic flow rates and hence the vehicle speed at different times of the day between weekdays and weekends. Noticeably, much higher traffic flow rates are observed from 5:00 AM to 10:00 AM and from 3:00 PM to 8:00 PM on a weekday than on a weekend day. Correspondingly, a lower vehicle speed can be observed during these times. One can also notice that these are also the times when traffic flow rates are much higher compared to other times on a weekday. Presumably, these are the rush hours where people drive to work and come back home on a typical weekday. As a consequence, any ambulances dispatched during these "peak" hours will be affected by the relatively large traffic density. Enhanced traffic preemptions must be carried out to ensure the time efficiency and safety of ambulances. To avoid any partiality of data specific to Miami-Dade County, a separate data set on Orange County near Orlando is collected and analyzed using same approach. Particularly, traffic flow rate data on a typical Monday and Sunday in February is chosen as opposed to Thursday and Sunday in January as chosen for Miami-Dade. The simulation shown in Figure 3.4 demonstrates a somewhat similar pattern of traffic flow of Orange County with Miami-Dade County on a weekday and weekend day. Same analysis procedure is carried out and the results obtained show that our simulation does yield an authentic and generalized vehicle speed prediction.

3.3.2. Simulations of Scott-Factor-Gory Model

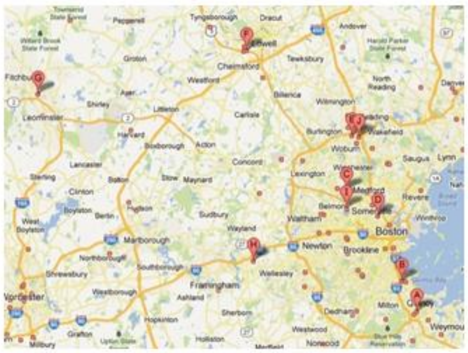
Applying the SFG Model, we plot the generic response time distribution as shown in Figure 43 a. Figure 43 b is the plot of level curves of probability.



a. Generic plot of SFG Model b. Level curves of Probability

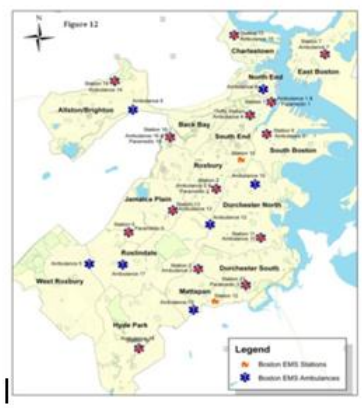
Figure 43: Plot of SFG model

Applying the SFG Model, we did a case study of distribution of ambulance response in Massachusetts. In this section, we present the result of our analysis on ambulance service distribution. Figure 44 a shows the distribution of major ambulance stations in Massachusetts. Since these EMS care providers are densely located near East of Massachusetts, we focus our study on Eastern Massachusetts, viewing Boston as the center of our region of interest, as demonstrated in Figure 44 b and c.



a. Distribution of ambulance stations

b. Region of our interest



c. Distribution of ambulance service station in Boston (City of Boston [19])

Figure 44: Ambulance service stations in region of our interest

We applied the SFG probability model to simulate the distribution of response distance and response time of Eastern Massachusetts. Within the range of Eastern Massachusetts as shown in Figure 44 b, data specific to Massachusetts used in our simulation includes the area of the region of our interest and the number of ambulances available in that region. In this simulation, area is computed using the area formula of a circle where the radius is chosen to be the distance between Boston, MA and Burlington, MA. Using Google Map, we obtain the distance d = 51.3 miles, which is taken to be d = 50 miles for simplicity. Within this region, we observe that there are approximately 26 service stations and of these 26 stations, 7 appear to be relatively larger service stations as marked in Figure 53b. Of the 7 ambulance service providers, Armstrong Ambulance Service is reported to have more than 90 vehicles in the fleet. Accounting for the size of the service station and correspondingly the size of the fleet, we estimate the total number of ambulances within the region of our interest to be $N = 90 \times 13$ = 1170, based on the number of ambulance stations in Boston shown in Figure 53c. The probability density function for ambulance velocity is assumed to be the same with the one obtained for Houston, and so is the mean ambulance velocity. Same parameters are chosen for the fitting function.

Using the parameters specific to Massachusetts estimated above, we apply the SFG model to find the distribution of ambulance response behavior in Eastern Massachusetts. The curves for distribution of response distance and distribution of response time of Eastern Massachusetts are obtained and shown in Figure 45 a and Figure 45 b.

Figure 54a. Distribution of response distance

Figure 54b.Distribution of response time

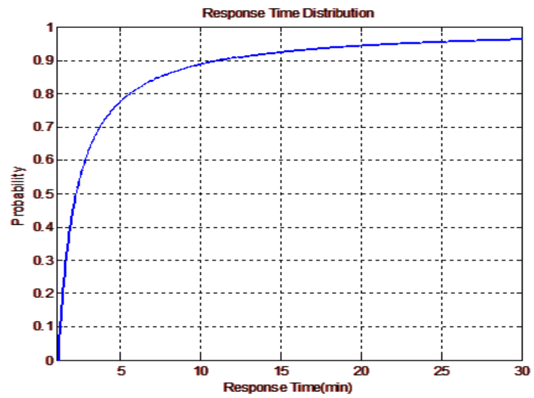


Figure 45: Response Time Distributions

Table 8 is the data cited from Boston EMS Annual Report in 2010. The data verifies the accuracy of prediction made by our model.

Table 8: Median Response Time of Boston EMS in 2010 (City of Boston [19])

Priority Level	Priority 1	Priority 2	Priority 3
Median Response	5.3 minutes	7.0 minutes	7.1 minutes

The distribution of response distance measures the probability that an ambulance is available within a given distance and the distribution of response time measures the probability that an ambulance reaches a pick-up location within a given time. As can be observed from our simulation, within two miles of an emergency request, the probability that an ambulance is present reaches 100%. In other words, an emergency responder is guaranteed to be present within a range of at most two miles from the center of Boston. From the graph of distribution of response time, the probability that an ambulance arrives at its destination within 5 minutes reaches almost 80% and the probability that a pick-up is completed within 10 minutes is around 90%. The probability that an ambulance arrives at the pick-up location within 20 minutes almost approaches 100%. As can be seen, the prediction made by our simulation demonstrates a fairly authentic EMS response behavior, compared to the data provided by Boston EMS in Table 11.

3.4 Smart Phone App for Texting 911

Texting 911 technology was introduced by Next Generation 911(NG 911), an initiative by National Emergency Number Association (NENA) to update 911 infrastructures in order to accommodate modern wireless communication technologies like transmitting wireless calls, texting, images and videos. NG 911 kicked off in 2001 when the FCC mandated mobile carriers to identify a wireless caller's location by using methods like GPS . NG 911 turned its attention to receiving text messages after the tragic shootout in Virginia Tech in 2007 which left thirty three people dead. Dozens of students and staff from the university were desperately trying to reach 911 quietly by sending texts for help. The need for texting 911 is apparent as texting via cell phones is an important form of communication in modern society. According to Pew Research Center's Internet and American Life Project survey, 83 % of Americans own cell phones, and out of the 83 % three quarters of them send and receive texts (Pew [13]). However, texting 911 is a developing technology and has its pros and cons. In this section we discuss the technology of texting 911 and design a 911 texting app which will make texting 911 an effective method of contacting 911 for help and reduce the delay associated with texting technology.

3.4.1 Text-to 911 Technology

Presently most 911 centers in United Sates cannot receive text messages. On December 2012 Federal Communications Commission announced that 911 centers across the country will soon start accepting text messages. The top four wireless carriers in the US, AT&T, Verizon, Sprint and T-Mobile, have agreed to accelerate the availability of 911 texting facility to their users with major deployments expected in 2013 and complete implementation of the technology expected in May 2014. The four carriers have filed voluntary commitment in an agreement with the National Emergency Number Association (NENA) and Association of Public Safety Communications Officials (APCO), and have also agreed to provide automatic bounce back messages across their networks by June 2013. While texting 911 facilities will be available to 90% of the cell phone users in the United States, it will not be uniformly available to everyone. . Hence the cell phone carriers are implementing the bounce back message notification to reduce confusion due to the non-uniformity of the texting service.

911 texting technology provides numerous benefits in certain situations. It will be a big help to millions of people with hearing or speaking disabilities who presently use a Text Telephone (TTY) device with help of a relay service which reads out their messages to the receivers. TTY calls take much longer than an average phone call and have 5-6 % spelling error rate (Captions [82]). Another useful application of texting 911 is that callers can silently contact 911 when placing a call may endanger the caller. Texting also works in low cellular network unlike calling. FCC's approach to text-to-911 technology is based on the belief that consumers in emergency situations should be able to communicate using the text applications they are more familiar with from every day. Currently short messaging is the most commonly used texting technology, but the rapid increase in usage of smart phones have led to people shifting to IP based text applications from short message service. FCC's goal is to expand its infrastructure and provide emergency communications in all types of texting technologies out there in the market.

Texts to 911 technologies have been implemented in several counties across the nation on a trial basis. The texting service was first implemented in Black hawk County, Iowa in 2009, followed by Durham county,North Carolina in 2011 and then by Williston PSAP in Vermont in 2012. Many other counties have followed North Carolina and Vermont ever since. During the trial period, the county police were able to help domestic violence victims, child abuse victims and people with suicidal tendencies. Although the general consensus among the emergency communications officials have been that texting 911 is a valuable asset, Association of Public-Safety Communications Officials or APCO has published a white paper called 'Text messages in a PSAP Enviornment' which includes some disadvantages of the texting technology based on the experience from various trials. According to the APCO paper, some of the major disadvantages of text-to-911 technology are that text messages are not real time, and its delivery time varies from few seconds to minutes. Messages can come out of order due to the limit if 160 characters on every message and messages do not have location information. Moreover, during texting, the 911 telecommunicator cannot actively interact with the caller and cannot hear background noise or tone of voice to gain additional information. Cell phone users commonly use abbreviations while texting which can confuse 911 telecommunicators. APCO emphasizes the need for developing process that adequately deal with protocol driven interrogation and developing human friendly interfaces between systems that receive Next Generation 911 (APCO [75]).

3.4.2 Case Study, City of Durham

The city of Durham in North Carolina implemented a six month trail of texting 911 in collaboration with Verizon Wireless and Intrado. Intrado, which is an emergency communications technology provider, has installed next generation 911 software that enables text messaging in the Durham Emergency Communication Center. The software costs $103,500 , and was funded by 911 Surcharge Revenue Fund. [28] Since Verizon is the only service provider participating in the trail, only Verizon Wireless customers will be able to send a text message to 911; all other wireless customers have to still call 911. The trail period lasted from August 2011 to January 2012. According to the Durham Emergency Communication Center experts, the textting 911 trial is designed for two emergency situations. One for people who are hearing and speaking impaired.

Secondly, for potential victims who do not want themselves to be heard while contacting 911. After gauging the effectiveness of text-to-911 for a year, the Durham Communications Center and Verizon Wireless have decided to continue offering the technology to their customers. Communication Center, is the first center in North Carolina to implement text-to-911 technology and second center in the nation to do so.

James Soukup, the director of Durham Emergency Communications Center, gave some feedback based on the trial. According to Soukup, customers should use texting option only when calling 911 is not an option as it takes longer to receive a text message. Someone has to enter a text for help, the text goes through the system and then a 911 telecommunicator reads the text and texts back. Unlike a telephone call, texting is not instantaneous which is critical in a life threating situation. Moreover, people texting 911 should avoid using abbreviations or slang as that leads to confusion. Text messages to 911 have a limit of 169 characters same as other texts.

3.4.3 Survey by Emergency Access Advisory Committee

According to the Twenty-First Century Communications and Video Accessibility Act of 2010(CVAA), FCC has to take actions to ensure that people with disabilities have access to emergency communications technologies in the twenty first century. In accordance to the CVAA, FCC established an Emergency Access Advisory Committee to collect data through a national survey of people with disabilities. EAAC received and analyzed 3,149 fully completed surveys. These fully completed surveys in addition to partially completed surveys, gave EAAC access to survey results of 12,766 people (FCC [68]) . The survey results of EAAC give some excellent insights about the needs and preference of disabled people, and help tremendously to design our 911 texting smart phone app. This section discusses some of the survey highlights.

Majority of the survey respondents were in the age group of 25-55, spoke English as their first language, and suffered from hearing disabilities. 60.2 % of survey respondents suffered from hearing disabilities and 4.3 % suffered from speaking disabilities. In response to questions on assistive and communications technologies used by the survey respondents, 62.9 % of respondents said they use wireless phones every day, 77.5 % said they used computer based TTY devices every day and 77 % said they used E-Mail for sending text messages daily. Presently the respondents are mainly using computers to send text messages to 911, but the answers to questions on preference for emergency calling in future shows that texting 911 through cell phone is a promising technology. The bar graph from the EAAC report in Figure 55 shows the preference of respondents for texting 911. 48.1% people responded that they will prefer texting 911 as opposed to sending video, artificial speech, and braille messages. And, 45.1 % of the respondents prefer to use SMS for texting 911 for help. Moreover, when asked about using new mobile devices that have additional functions for contacting 911, 34 % responders answered that they have a smart phone app and would be willing to install a 911 app. In addition, 26 % of responders answered that they would be willing to buy a smart phone and then install a 911 app (see pie chart Figure 47). Finally, on being asked what is important to them while texting, 54.1% people said they would like to text in both direction which is similar to SMS in cell phones, and 53.8 % said they would like the dispatcher to see their message while they are typing it like in instant messaging. Figure 46 shows the bar graph of the response to the question.

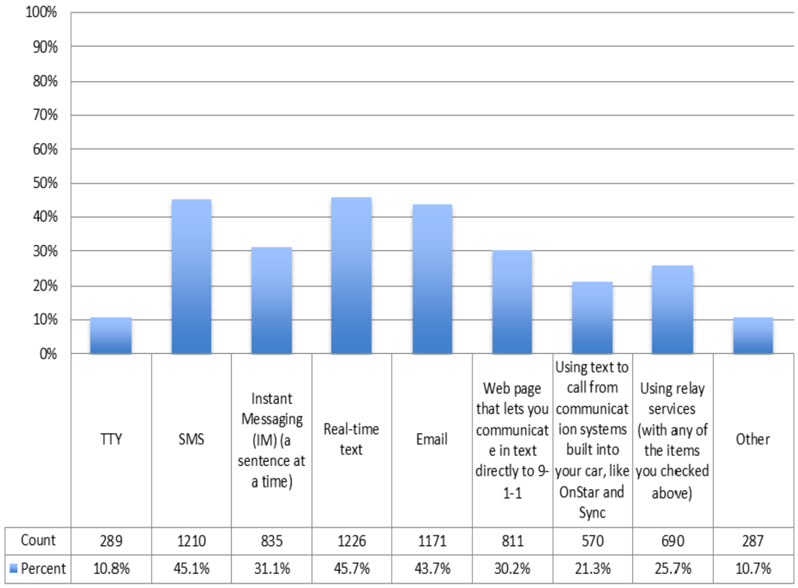


Figure 46: A bar graph of the response to texting options used by survey respondents (FCC [68])

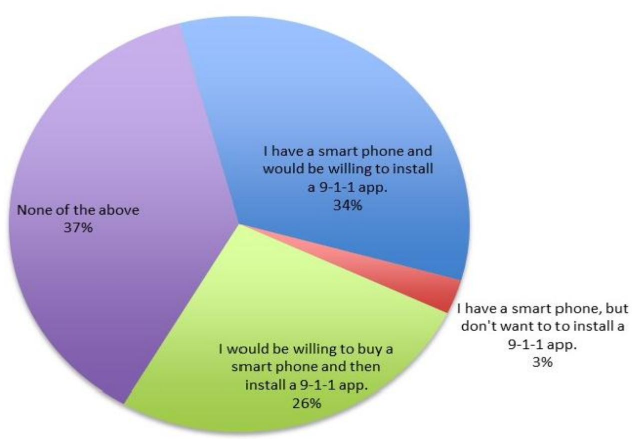


Figure 47: Texting preferences of respondents (FCC [68])

The next bar graph, Figure 48, depicts the percentage of users that responded to the questions in the survey about texting 911. Five options were given to the survey taker, varying from strongly demanding to text 911 to none of the above.

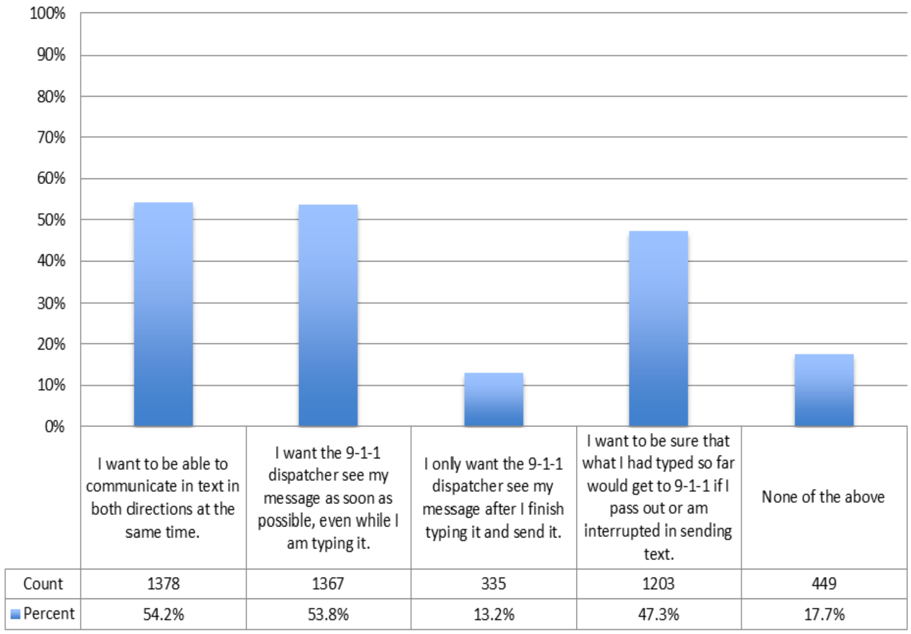


Figure 48: Survey about texting 911 (FCC [68])

3.4.4 Developing Smart Phone App for texting 911

In APCO's white paper on 'Text Message in a PSAP Environment', APCO officials express the need for adapting processes to adequately deal with protocol driven interrogation and developing human friendly interfaces between the systems that receive next generation calls. Our Smart phone app designed for NG 911 can incorporate the above features into NG 911 calls. Smart Phone apps are increasingly becoming popular to customize phone and play games. Smart phone users can download apps from app stores and the most popular app store is Apple with 100000 apps, followed by Android Market with 10000+ apps. Results from EAAC survey discussed in the previous section shows that smart phone apps are very popular with people with disabilities as well. Smart phones apps popularity can be attributed to their user friendly nature and their widespread applications in everyday tasks. Consequently, many Android and Apple apps have been developed for emergency communications which forms a very vital part of our everyday life.

There are many smart phone apps out there in the market which send video, text or voice messages to 911 in case someone wants to quietly send a request for help. These apps also provide GPS location to help the first responders reach the caller as soon as possible. Most prominent among these apps in terms of reviews and downloads is Apple's Advanced 911 App which sends text, photos and GPS address to PSAP centers. Additional features of the app include sending medical history of the caller and saving emergency contacts. Figure 49 displays the screen shots of the app. However, in spite of its many features, texts sent through these smart phone apps may not provide enough information. 911 telecommunicators ask several questions to properly understand the emergency at hand and send adequate help to the caller. First set of questions is common to all medical emergency calls and include questions about location and vital signs of the patient. A second set of questions depends on the nature of medical emergency. 911 call protocol is an important part of the dispatch process and APCO officials emphasize the need of protocol driven processes for NG 911 to depart adequate information to 911 dispatchers. Our smart phone app integrates 911 call protocol with other features like GPS location and medical history of current 911 smart phone apps . Our app is user friendly and provides more information to 911. Moreover, people will be less likely to use abbreviations used in everyday long text conversations while answering short questions about medical emergencies in our app . During an interview with the director of the Worcester 911 call center, we learned that text abbreviations is a big source of confusion for telecommunicators In the next section of the chapter we talk about the features and implementation of our app in details.

Figure 49: Screen shots for Advanced 911(itunes [85])

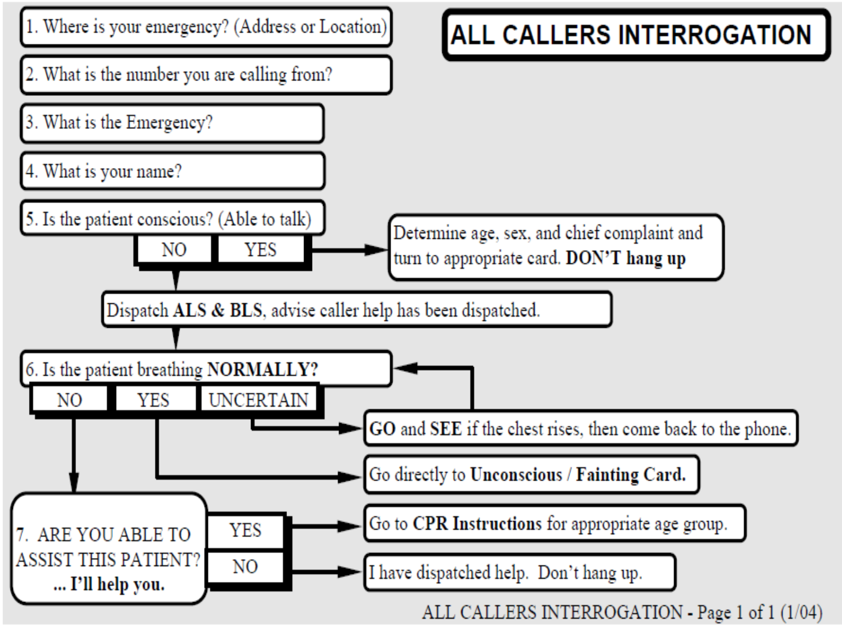


Figure 50: All calls interrogation questions from New Jersey 911 call guide(Emergency office New Jersey [86])

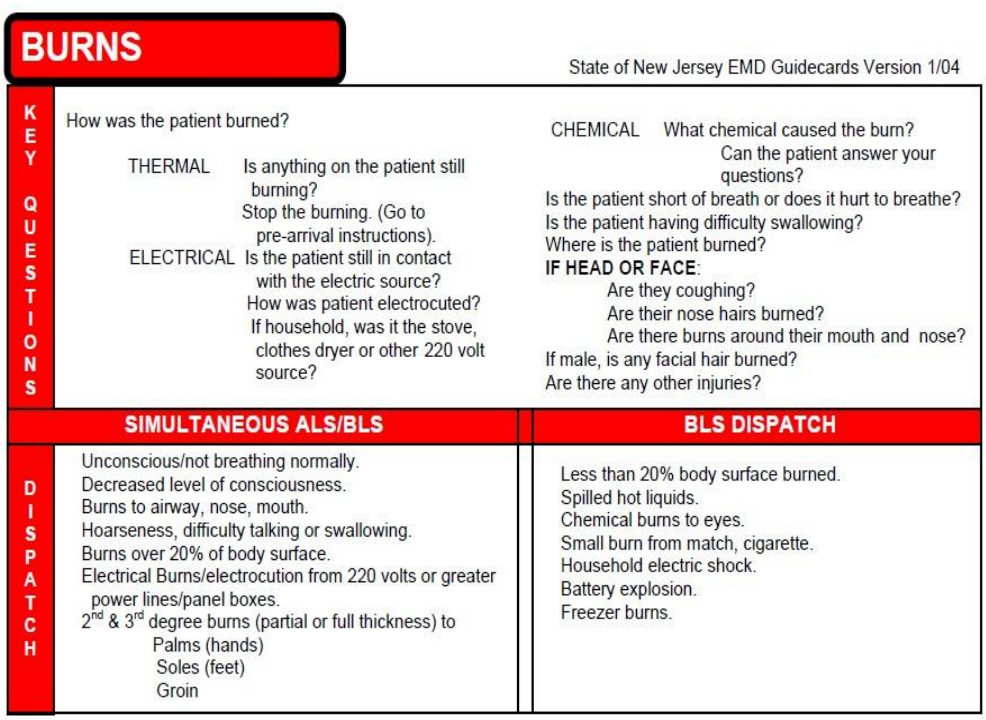


Figure 51: New Jersey 911 call guide card for burns (Emergency office New Jersey [86])

3.4.5 Implementing ‘Text 911’

We use EAAC survey response and APCO white paper on ‘Text messages in a PSAP Enviornment’ to outline features of ‘Text 911’. Another good source of information is 911 guide card of the state of New Jersey. Some of the main features of our smart phone app ‘Text 911’ include the following:

- Option to choose nature of emergency-fire, police, EMS or car accident
- Series of questions similar to 911 guide cards to send most information to 911 dispatchers
- GPS information to help paramedics easily locate caller

First two features of ‘Text 911’ are similar to 911 call protocol. When a caller calls 911, first question posed by the telecommunicator is what kind of help is required. Is it a crime scenario where police needs to be dispatched? Or is it a medical emergency where paramedics need to be sent or a car accident and so forth. Depending on the answer to the question, telecommunicator asks other questions to gather more information. Since our project is about EMS communications, we focus on building a smart phone app for medical emergencies. We refer to 911 guide card for the state of New Jersey to frame questions of our smart phone app. Our first set of questions is about

- What is name of the patient?
- What phone number is he texting from?
- What is the medical emergency situation?
- Is the patient conscious?
- Is the patient is breathing?

Building a database of questions for every medical scenario is beyond the scope of our project, however for our testing prototype we include a second set of questions for callers who are victims of anima bites. For second round of questions, our software asks

- What kind of animal bit the patient?
- Is the animal contained?
- Is the patient short of breath or does it hurt to breathe?
- What part of body was bitten?
- How long ago did he receive the bite?

After outlining features of our app, we start programming. To build our smart phone app 'Text 911', we use Google's app developing software *App Inventor*. App Inventor develops applications for Android phones using a web browser and either a connected phone or emulator which simulates a cell phone environment. App inventor servers store the apps created by programmers and help them keep track of their progress. In App Inventor, apps are built using *App Inventor Designer* and *App Inventor Blocks Editor*. Figure 61 shows various windows of App Inventor. Designer window is where programmers select components for their app. Blocks Editor is a java program where programmers assemble program blocks which specify how components should behave. Advantage of App Inventor is that programs assemble visually, like fitting pieces of puzzle together, which makes it easy to learn and program App Inventor. System requirements for App Inventor are Java 7, App Inventor Setup software and Gmail account.

Text 911 consists of four screens as seen in Figure 52. Screen 1 has two buttons. One button to contact 911, and other button to update medical profile. In this section we discuss how we programmed 'Contact 911'. Programming code for 'updating medical profile' is discussed in subsequent sections. Function of screen 1 is to take user to screen 2 which begins a series of questions similar to 911 call protocols. Programming blocks for screen 1 in our App Inventor project are ‘Button.click’ and ‘Open another screen’.

Figure 52: Screen shots for 'Text 911'

Figure 53 shows blocks for screen 1. As name suggests, these programming blocks open a new screen when user clicks on the button. Programming an app is event driven programming. When the event of clicking button occurs, software opens a new screen. Similarly, we program the other screens which consist of questions and text boxes to answer the questions.

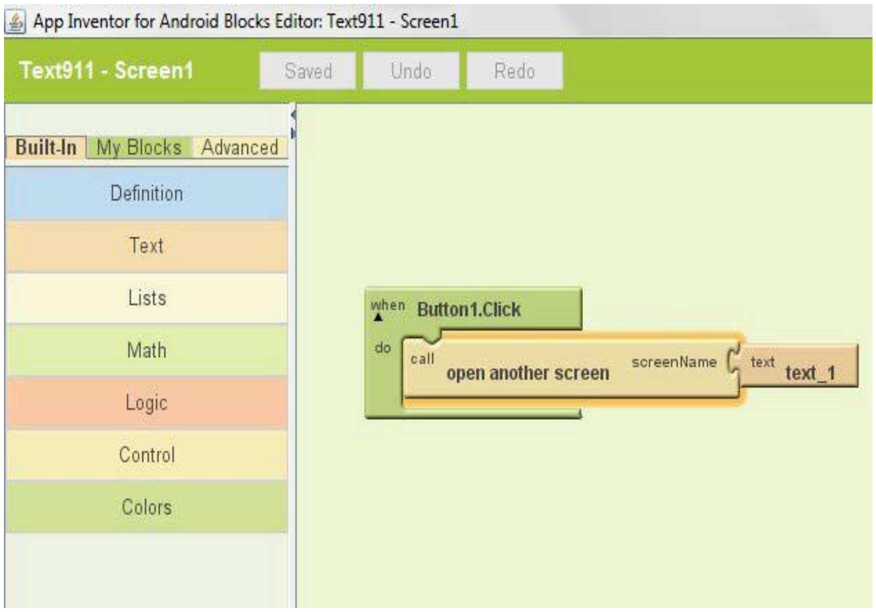


Figure 53: Designer blocks for screen 1

3.4.6 911 Emergency App for Android OS

An application was developed for the android operating system in order to facilitate communication between the emergency caller and the call taker at the 911 call center. The android operating system was chosen in particular because over half a billion of devices are running on the operating system. These devices include smartphones and tablets, all having interconnectivity through either cell service or wireless internet.However, since it is a relatively new technology that launched on the first mobile phone only a few years ago, it is lacking behind in the availabilites of applications (or “apps”) in comparison to apple’s app store. As a result, there are no comprehensive 911 emergency apps available on the market today. Another benefit of the android operating system is that it is an open source software, meaning that its source code has been released and is freely available online. This makes it extremely simple for companies wishing to enter into the android market to modify the software to their preferences and load a customized version on their devices should they wish to do so. It also eliminates the barrier to market entry in terms of financial investment since there is no developer fee and no need to pay for licenses in order to run the operating system. This will enable the created emergency app to be flexible and possibly run on non-native systems such as medical devices or even laptops.

The application was developed using the Java programming language, which is the standard computer language for android apps. Combined with Extensible Markup Language, or in short XML, that defined the layouts of each page (or "activity") in the app, the finished app with the user interface was produced. It contains a total of 6 pages which the user can access through a series of buttons both on the smartphone or tablet screens as well physical hardware buttons part of the device. The storage space that is required to install the application on a user device is roughly 180 megabytes, and then some storage memory is required to hold variables put in by the user. In the following pages, the reader is presented with a walkthrough of the app combined with explanations of the various functionalities. Upon opening the software from the android device, the user will be presented with the screen shown in Figure 54.

Figure 54: Main user interface upon start

The application is entitled “MIRAD Laboratory 911 Software” and is displayed at the top of the screen. The user is presented with an editable textfield, easily identifiable by the “Send 911 Request” text in gray letters. The application user can press on this field via the touchscreen and can then enter any message he or she would like to send to 911 in the case of an emergency. The user simply has to press the “Send” button. By clicking the large red 911 button with black lettering and automated text message will be sent to 911 containing user variables. This user data can be entered into the software by clicking on the “Update Information” button with red lettering. The third button in the app’s main user interface is the “Jogging Mode” button, which will be explained in further detail later in this section. Upon pressing the “Update Information” button, the user is guided to a view where he or she should enter their allergy information as shown by Figure 55.

Figure 55: Screen enabling input of user allergies

The user is prompted to update their records and can do so by selecting "yes" for the various radio buttons. The "yes" and "no" radio buttons are each grouped together so that only one can be selected (or checked) at the same time. This information can be very valuable to first responders and other medical staff since allergies against medicines and drugs that the first responder might administer could be detrimental to the patient's health. In rare cases it could even prove to be fatal. Therefore, in order to improve patient care and reduce the risks associated with administering drugs without knowing how the patient will react to those drugs; a database of user allergies was included in the app. The options for the various allergies include penicillin, sulfonamides, and cephalosporin, which are all three antibiotics and therefore obviously prevalent in the medical world, especially in emergency care. Other options include Aspirin, Ibuprofen, and Naproxen, which are all pain soothing medicines and an ambulance is certain to have at least one of the aforementioned drugs. The allergy questionnaire is shown in Figure 56.

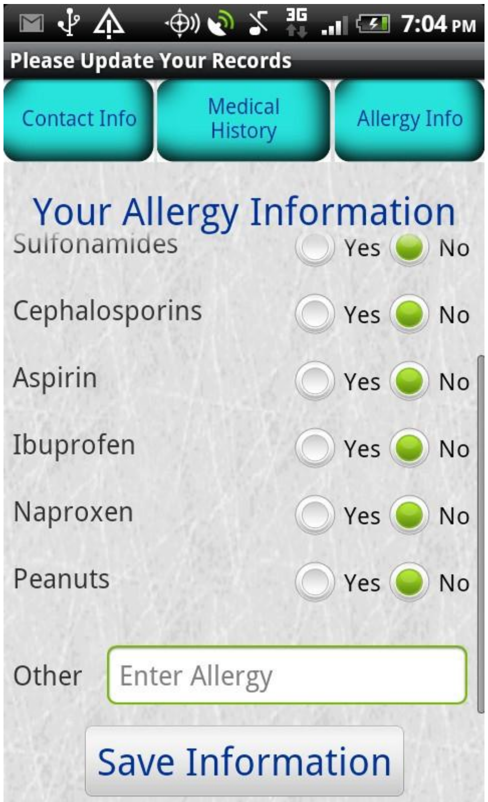


Figure 56: Allergy input screen scrolled to the bottom

The radio button groups with the "yes" or "no" choices and the corresponding text with the names of the various allergies are all part of what is called a scroll container in the android java class. The editable text field to the right of "Other" is part of this scroll container as well. The user can enter a custom allergy that he or she might be subjected to in order to give first responders as much information as possible about the user's health conditions. At the top of the layout are three buttons entitled with "Contact Info", "Medical History", and "Allergy Info". The user can use these to navigate between the three different pages. The bottom of the page contains a button entitled "Save Information" in blue writing. When the user presses this button the selected radio buttons and any text input into the custom allergy field by the user will be saved.

Upon pressing this button, a message will be displayed as shown by Figure 57.

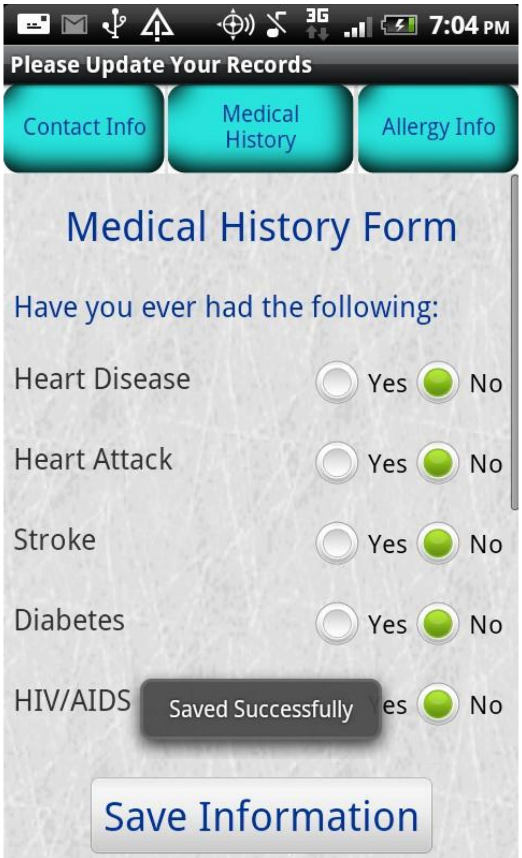


Figure 57: The medical history form's user interface is shown

The user receives positive feedback by the display of a short message. This assures the users that their input is indeed being saved and that in case of an emergency their information is on file. The data is stored on the user's phone or tablet memory in the form of string variables. These string variables can then be recalled at any time by the software, such as in the event of an emergency when the user attempts to send an emergency text. The "Saved Successfully" message is a temporary message and is only visible for about three seconds on the user interface.

The emergency application that was developed also contains a Medical History form that is integrated into the user interface, as shown in Figure 58. The user can navigate to this page simply by pressing the "Medical History" tab located at the top center of the page in the form of a turquoise colored button.

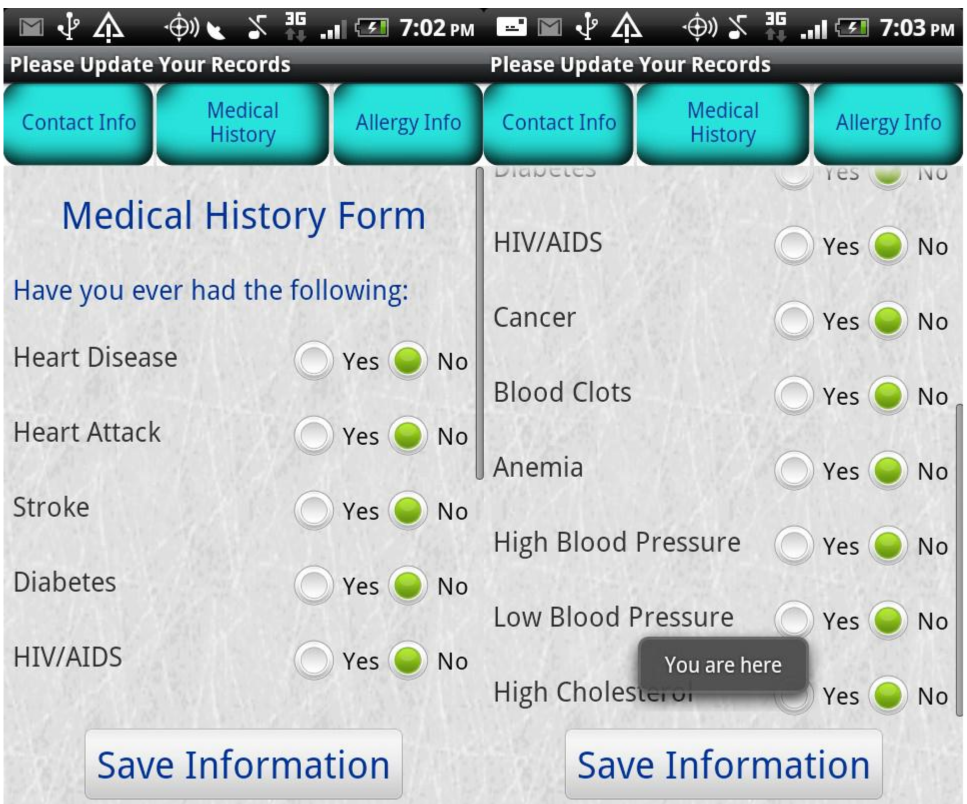


Figure 58: The integrated medical history form

It enables the user to provide their preexisting medical conditions to the application, which the application then relay to the 911 call center and first responders in the form of a text message or several text messages. The software does this by loading the user string variables that were saved onto the device at an earlier time. Some of the most important preexisting conditions include heart disease and heart attack as well as stroke , diabetes, and HIV/AIDS. If first responders know that the patient is at risk for a heart attack they will take special precautions in their treatment of the patients and they can prepare themselves at the possibility of cardiac problems. It also allows the 911 text receiver to make a more informed decision. For example, dispatchers might be tempted to send out a Basic Life Support, or BLS, ambulance because Advanced Life Support, or ALS, ambulances are in short supply. However, if the dispatcher knows that the patient has had a history of heart attack the chance is there that a similar cardiac problem might occur, therefore he or she can send out an Advanced Life Support ambulance ingood conscience, knowing that the case is likely to be serious and therefore ALS is, indeed, appropriate.This leads directly to the next screen- the contact information. It is important for first responders to know the patient's home address if the patient needs help there, as well as the patient's age and gender. The contact information form is shown in Figure 59.

Figure 59: The contact information screen in the emergency application

It includes an editable text field for the name of the owner of the smartphone or tablet as well as their phone number in plain number format. It also includes a dropdown spinner with the options of selecting either “Male” or “Female” as the user’s gender. All of the information entered or selected will be stored, just as in all previous screens. The only difference is that the selection of the dropdown spinners is stored in the form of integer values, since the index of the spinner is returned by the java code. For example, in the male and female dropdown options, “Female” is the first choice and has an index of 0 while “Male” is the second choice and has an index of “1”. These indices are then stored in integer variables and are accessible at a later time.

The contact information form is embedded inside a scroll container just as the user allergy form and the medical history form shown by the previous figures. The scroll container is shown in Figure 60 as fully scrolled to the bottom, revealing the dropdown spinners for the birthmonth, birthday, and birthyear.

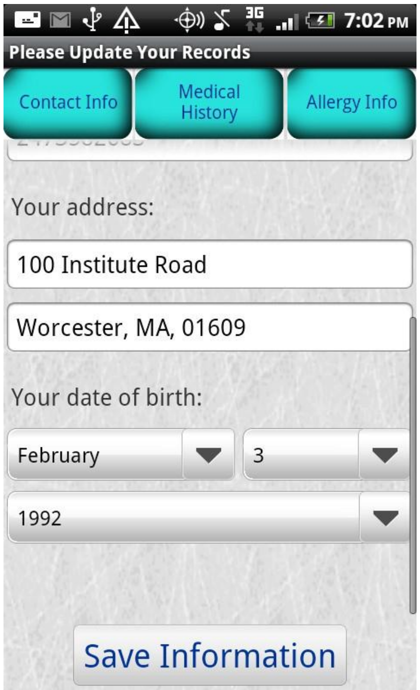


Figure 60: The contact information screen when scrolled to the bottom

The information for the spinner values that yield the date of birth is stored in the same manner as the gender value was stored: in the form of integer variables that represent the respective indices. For example, the year spinner starts at the year 1900. Therefore 1900 represents index 0 in the year spinner. Since the year 1992 is selected, the index of the spinner would be 92, and that is the integer value that is stored on the user's smartphone.

A special feature of the 911 emergency app is the "Safe Jogging Mode". It can be accessed by the user through the main user interface through the blue "Jogging Mode" button right below the major red 911 graphic. The screen that appears is shown in Figure 61.

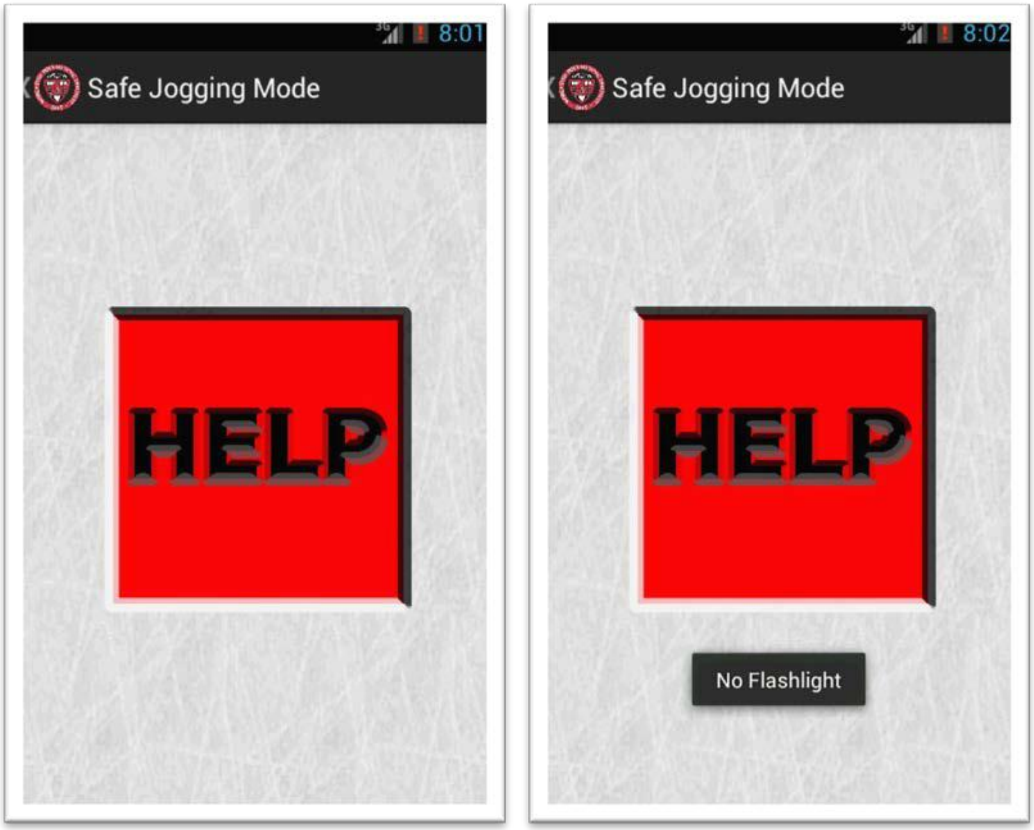


Figure 61: The safe jogging mode feature

The user is presented with a large red square which has “help” spelled out in capital letters. This feature is intended to be used in situations or environments where the user feels insecure, generally frightened, or threatened by the environment. The user can open the 911 emergency application to this screen when he or she feels the previously mentioned. One scenario is if the user would go jogging after work, and it was already dark outside such as is the case in many states during the winter months. Then the jogger could simply open the application to the appropriate screen and feel more secure knowing that at a click of a button they will receive help. The functionality of the button was considered carefully. When this specific feature was programmed, the usability of the resulting product was taken into account. The conclusion was made that in most instances, an attack such as a robbery only lasts a minute and often just several seconds. Therefore creating a help button that would call and text 911 or a similar functionality would not be effective in aiding the victim (the user) in the case of an attack. Another consideration was that while the user is jogging or performing a similar activity the likelihood that he or she accidentally presses the help button is high. If 911 would be contacted each time this would occur, an emergency vehicle would be dispatched and remove valuable resources from the fleet of available vehicles. This could delay the emergency response for a patient that might be in dire need of help after an accident or a similar event. Obviously this should be prevented at all costs, since the goal of this application is to improve emergency care and not diminish it. The final design included three features. First, an alarm sound is played when the user initiates the help button. This will surprise the attacker and freeze his thought process, momentarily halting his actions. Secondly, the LED light from the device's camera is activated. It is then deactivated and reactivated in quick succession, giving the impression of a strobe light. If the user is in a dark environment this will blind the attacker and surprise him. Combined with the flashing LED lights, this proves to be an effective defense. The third feature is that the screen itself starts blinking upon activation of the help button, which is an additional visual effect. These three features, when combined, make for an extremely effective method in fending off attackers. The reaction is immediate; there is no five minute delay between the initiation of the action and the response, such as an ambulance or a police station. Not only does the attacker become surprised and intimidated, but the flashing light, the alarm sound, and the blinking of the screen will increase the visibility of the user and possibly attract the attention of other people who can the come to the user's aid. In the rare event that the user does not have a camera flash, a message will be displayed notifying the user that he has no camera flash. This is shown in Figure 71 in the image on the right hand side. The message "No Flashlight" will be displayed for about three seconds. While this removes the strobe light effect from the "Safe

Jogging” feature, all the other features are still available an alarm sound will still play. While this is not as effective as when all features are available, it could still improve effective in promoting the user’s safety. It is recommended, however, that the user purchase a device that supports the camera flash functionality.

In the event that a user of the 911 emergency application starts the app through the device’s user interface and does not have GPS (Global Positioning System) enabled on his or her smartphone or tablet, a popup will appear asking the user to enable his or her GPS. It is important that the user do so since this is the most reliable method in automatically identifying the location of a user. By automatically locating a user’s position, the application can communicate the user’s coordinates to the 911 call center in the form of a text message. This can prove crucial in situations where the user might not know his or her location, such as a natural environment like a large forest or a desert. There are no street signs or similar location markers by which the user could identify his or her position. Therefore, in the case of an emergency, the device user could not communicate his position with 911 call operators. This causes immense delay in the emergency dispatch. The pop-up screen the user is presented with is displayed in Figure 62.

Figure 62: Pop-up screen when GPS is disabled on the user's device

The user is prompted to enable GPS in the settings of his or her smartphone or tablet. It will allow the app to locate the user and store the user's longitude and latitude coordinates. The two options presented by the notification menu are the "Settings" and the "Cancel" buttons. Upon pressing the "Cancel" button the user is returned to the main user interface of the application. This is not recommended in the least since this will not allow the application to have access to the user's longitude and latitude data and therefore cannot accurately position the user. If the user is serious about his or her safety, he or she should press the "Settings" button upon which the user will be directed to the screen displayed in Figure 63.

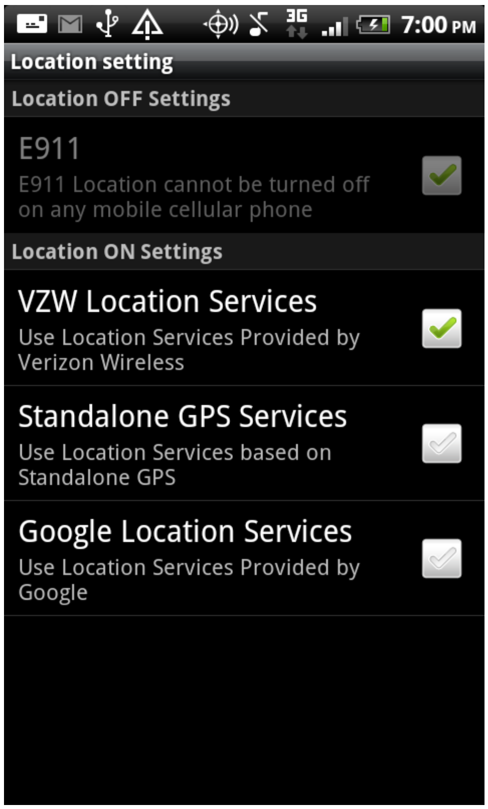


Figure 63: Settings screen on the user's android device

From this screen the user will then be able to enable the Global Positioning System on his or her device by pressing on the "Standalone GPS Services" checkmark. There are other options available that can be used to locate the user, however, none of them are as accurate as the GPS. These include location services provided by the cell service provider (in the example in the figure, it is Verizon). The rough location of the device can be found by triangulation of the nearest cell service towers. As already mentioned this is quite inaccurate and is not useful in locating the potential patient since the distance can be off by several miles, especially in rural areas with limited number of cellphone towers. The third service that could be used to find the location of the device are location services provided by Google. This works in a similar fashion as the cellphone tower triangulation method, except that the wireless internet signals are interpolated. The service uses location data of nearby wireless access points to estimate the location of the device. The drawback from this method is that it is only functional in areas where wireless internet is available, which means there is limited support in urban areas. When the user selects the Standalone GPS Services option, he or she will be presented with a prompt as shown on the left hand side of Figure 64.

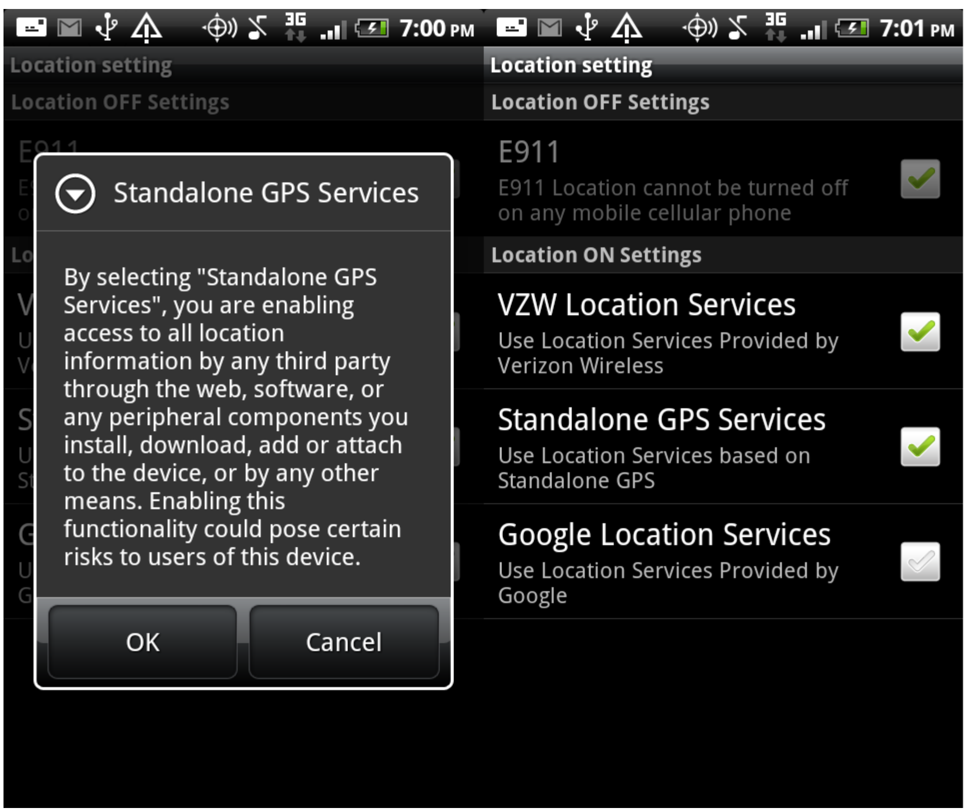


Figure 64: GPS warning message and enabled GPS settings screen

The user is asked if he or she understands the potential privacy infringements that enabling GPS could mean, and can press the “OK” button if they agree or the “Cancel” button if they would rather not enable this service. Again, it is highly recommended that the user presses “OK” for best performance. The enabled GPS services checkbox can be seen on the right side of the graphic. However, the user should be aware of these possibly privacy infringements and make intelligent choices when installing apps. The 911 Emergency App only reads and sends the user’s GPS coordinates in the case of an emergency where the user contacts 911 through the user interface. The user should be aware that other applications might have different policies and should therefore take extreme caution when installing apps that ask for permission to use location services. The permissions that 911 Emergency App requires are shown in Figure 65.

```
<?xml version="1.0" encoding="utf-8"?>
<manifest
xmlns:android="http://schemas.android.com/apk/res/android"
    package="com.merlin.myfirstapp"
    android:versionCode="1"
    android:versionName="1.0" >

    <uses-sdk
        android:minSdkVersion="8"
        android:targetSdkVersion="17" />

    <uses-permission
android:name="android.permission.CAMERA" />
    <uses-permission
android:name="android.permission.SEND_SMS" />
    <uses-permission
android:name="android.permission.RECEIVE_SMS" />
    <uses-permission
android:name="android.permission.ACCESS_COARSE_LOCATION" />
    <uses-permission
android:name="android.permission.ACCESS_FINE_LOCATION" />
    <uses-permission
android:name="android.permission.INTERNET" />
    <uses-permission
android:name="android.permission.ACCESS_MOCK_LOCATION" />
    <permission android:name="android.permission.FLASHLIGHT"
             android:permissionGroup="android.permission-
group.HARDWARE_CONTROLS"
             android:protectionLevel="normal"/>
```

Figure 65: The manifest file of the android application

The Extended Markup Language (XML) document shown is the manifest of the application. In it all permissions that the user grants the application upon installation are explicitly stated. It can be seen that the application makes use of the hardware camera, the send and receive text messages options, as well as access to the internet and fine and coarse location services. The camera permission is needed for the jogging mode feature in which the camera's LED flash lights are repeatedly turned on and off to yield a strobe light effect. The send and receive text messages permissions are needed to provide communication between 911 services and the user in the form of text messages. The fine location services means that the application has access to the device's GPS system (a fine location service) as well as to cellphone tower triangulation (a coarse location service). Overall, this application will be very useful in increasing the safety of the user and it is recommended that every android user should install this application on his or her system.

CHAPTER 4. CONCLUDING REMARKS

The goal of the project is to reduce EMS ambulance dispatch time by improving EMS Communications. Today in United States today, a person calls 911 to ask help for medical emergencies and the 911center coordinates with EMS to send an ambulance to the patient. The industry standard for EMS response time is 8 minutes and 59 seconds, but there is a wide variation in ambulance response time from city to city, state to state and from country to country. Better ambulance response time will result in better medical services around the world, improved health index and efficient use of medical resources. For our project we did a thorough background research and literature review on EMS communication protocols of various countries. We then interviewed the director of the Worcester 911 Center, and went through case studies on ambulance accidents to identify major problems in the ambulance dispatch process. Two problems identified were heavy traffic that slows ambulance and disadvantages associated with the newly developing texting technology for 911. Finally we studied previously implemented solutions on the identified problems.

We worked on three solutions for the problems we identified in EMS communications. Firstly we simulated mathematical models on ambulance speed and ambulance distribution. Del Castilo and Benitez proposed a mathematical model which relates vehicle speed to traffic density. Castilo-Benitez model differs from previously proposed models in its sound theoretical proof to the mathematical equation on traffic density and vehicle speed. We changed the model to relate traffic flow rate to vehicle speed. We used our modified version of the Castilo-Benitez model to plot ambulance speeds in Miami, Florida and Orange county near Orlando, Florida during different times of day using MATLAB. It was concluded that maximum traffic and hence slow vehicle speeds are observed between 5AM to 10 AM and 3 PM to 8 PM. These are rush hours when people get to work in morning and get back from work in the evening. Ambulances travelling during peak hours will be affected by large traffic density and hence will have to employ enhanced traffic preemption to ensure timely and safe arrival at the emergency scene and from emergency scene to hospital. In addition to Castilo-Benitez model, we simulated SGF probability model in MATLAB. SFG model is a relation between number of ambulances available, ambulance response time and ambulance response distance within a region. Applying SFG model we did a case study of distribution of ambulance response in Massachusetts focusing on Boston. The curves for distribution of ambulance response time and distance are verified with response time data from Boston EMC Annual report.

Our second and third solutions are texting apps for 911. Texting 911 can be very helpful in certain situations. For example, if a person does not want to speak because of a danger, communicating with people who have hearing and speaking disabilities and in situations when cell phone connection is weak. However, text messages can be confusing as abbreviations are commonly used in text messages and autocorrect dictionary can change the intended word of the user. Additionally, people may not provide all necessary information required by EMS to provide best medical services. Hence we built 'Text 911', a texting app for 911, which asks a series of questions similar to 911 call protocol and compiles all that information as a text and sends it to 911. Although texts are not real time like calls, but texts sent through 'text 911' contain same information as a 911 call.

Our final solution is also a smart phone app for 911. The app has two options in the main screen. One is to *Update information* and the other one is the *Jogging mode*. *Update information* records personal information and medical history of the user. This information is sent as a text to the 911 telecommunicator. The app also popups a message asking user to enable GPS and sends the user's location to 911 as a text. *Jogging mode* is useful for emergency situations when user cannot contact 911. In Jogging mode cell phone sets off an alarm and flashes light to surprise the person causing danger and to attract attention to the user. Features of Emergency 911 App will provide useful information to 911 to better help a caller. For future work we can include more questions on medical emergencies from 911 guide card into our smart phone app 'Text 911'. We can combine both smart phone apps 'Text 911' and '911 Emergency App' to make one smart phone app that will have all features of both the apps, and will provide more information to 911 dispatchers to assist callers for medical emergencies.

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APPENDIX

Interview Transcript

The following interview was conducted on November 13, 2012 at a local 911 Call Center:

Question: What is your name, job title, email address and/or phone number?

Reply: My name is undisclosed, I am the Director of the call center. I can be reached at undisclosed email and undisclosed number.

Question: Do you have call takers with multilingual abilities? How are such calls handled?

Reply: We have two bilingual call takers that speak English and Spanish. We don't like using them though if a call is made in a different language because of legal implications. Should a call taker translate a caller incorrectly and send an ambulance to the wrong location or not at all, the call center could face legal consequences. Therefore we subscribe to a language line that automatically detects 180 dialects, and then brings the appropriate person fluent in that dialect on the line. This person then makes a legal translation for us so that the liability falls to the PSAP language line.

Question: What improvements to the 911 call and dispatch process have been made in the last few years?

Reply: We started this center seven years ago and relied on UMass hospital services. The call takers were not trained as well and the call taker went through the interview process ‘till the very end. This lost time because the ambulance was not dispatched until after the call was completed. This already caused a minute delay, and then adding on the delay of the actual dispatching of the vehicle made this very inefficient; it was a waste of resources and fuel. So the improvements that we made were that if an easy identifiable emergency call is made, such as someone calling who is having a heart attack, someone calling about a head-on car accident, or industrial accidents such as someone getting their arm caught in a machine, an emergency vehicle is immediately dispatched while the call is still active and then the call taker feeds more information to emergency transponders as more information is received. Fire trucks and ambulances are also dispatched at the same time, and if fire services arrive at the scene first, they analyze the situation and call the ambulance over radio to give them more info. When UMass medical services have no more ambulances available, a private EMS service is contacted. UMass EMS has generally higher standards than private companies, however.

Question: How are cell phone calls handled?

Reply: When emergency calls from cell lines are made, they go directly to the state police. From there they're routed back to Worcester police.

Question: What kind of shift system do you use?

Reply: We have three 8-hour shifts. The minimum staffing of the call center is 9 people. If more people are on vacation or away from work this is achieved through over time. The call center can also have 12-13 people working at the same time; it all depends on vacation and sick days.

Question: What information do you have related to the volume, number, and types of emergency calls made?

Reply: Our peaks hours are at about 10:30/11:00 am, and calls stay relatively constant until 2:00 am, then calls decrease until 7:00 am. I don't have specific data, but more detailed information can be found on the website mass.gov/e911. You can also send me an email for call data, peak times, incidents, etc. What I do know is that there are usually 80,000 911 calls and 700,000 seven-digit calls made per year. Keep in mind that the same emergency can generate multiple 911-calls though. If there is an accident on I-290, ten or more emergency calls can be made for the same accident. It is impossible to identify those multiple calls for the same incident because minor changes in details cause the 911-system to file it as a different incident, there are too many variables. Last year there were about 25,000 EMS requests, and 22,000 EMS transports.

Question: What kinds of training do emergency call takers receive before they are put on the job?

Response: Call takers go through sixteen hours of 911 training from the state, then through 40 hours of basic telecommunications, and then 3 months of training by the Worcester call center before they're put on a shift alone.

Question: Have there been cases of hearing loss caused by the sirens of emergency vehicles?

Reply: The siren is actually not that loud from inside the vehicle, it's worse for people on the outside. I have never heard of any kind of hearing loss associated with sirens.

Question: What are improvements that can be made to the 911 call process?

Reply: Lots of improvements can be made in the IP based phone system, since it's difficult to locate callers that call 911 from VoIP services. Also a central PSAP for the state would be good for the public just to complain- about burst water pipes and such. If the call is not an emergency call the caller will be referred to the 7 digit non-emergency number or the call will be disconnected. Calls could also be transferred to the public health department from there. This would decrease the call volume that this call center has to answer and therefore employees can focus on emergency calls and not have to deal with complaints etc. We've also been talking to the FCC commissioner about people wanting to text to 911, but voice is always better because then you can tell the emotional state of the caller and judge the situation better opposed to text messages. Voice communication is also faster. Then there are also such issues as autocorrect, if a word was changed from “gone” to “gun” it adds complications to the call. Things such as videos and pictures are also considered to be added to ways that 911 can be reached. But then problems arise with the dispatchers, they generally don't want to view videos and pictures since they would be graphic. There are also legal issues since once those videos or pictures are viewed the dispatcher becomes a witness and has to come to court to testify. It would also be difficult to route those videos and pictures to EMS ambulances and fire trucks. Then also a lot of older dispatchers are not as familiar with technology such as texting and also

would not know the short hand such as "LOL" etc. Also we're working with such things as trap calls where a call number goes in and then a caller ID comes back. The location of cellphone calls through triangulation can also be improved, and the method gives problems in high rises. It's easier with Verizon GPS based phones that include the exact location. A location can sometimes be obtained

from the phone records of the cellphone, but the address is not necessarily the location of the call. We're working with a company called smart 911 and the RS232 cable. It uses a record that is associated with a phone number and assigned to that number. It is voluntary information provided by the subscribers, a nd it is up to the people that keep that information updated. Sometimes there are also problems with sharing information about a patient with the hospital or communicating between fire and ambulatory emergency services; mainly because of the Health Insurance Patient Privacy Act.

Question: Would it be helpful to train the public better in the 911 calling process? Reply:

It has been my experience that you can't train the public to behave a certain way during crisis situations. That was proven during the bird flu (H1N1) epidemic, once vaccination shots were offered everyone lined up to receive one, even the low-risk group.

Question: Do you use a computer aided dispatch system?

Reply: Yes, we do, it is called PAMET and the company is based out of New Jersey. There is a local location in Hudson. The program is windows based and therefore directly integrates with our computer system.

Question: How are 911 calls affected during power outages?

Reply: When there is no power, only cell phones and cell sites will work because most cell sites have back-up battery power. The Worcester call center has a backup generator, so calls can still be taken. All cable systems do not work without power. So Vonage, for example, a VoIP service, cannot be used for 911 calls during power outages since it relies on cable. AT&T installs battery back-up in its cell sites while Verizon includes a back-up generator at its sites. The copper based telephone landlines will still work without power as long as the home has power.

Question: What kind of record is kept of 911 calls?

Reply: Audio recordings and data recordings of the last 3 years are stored. The number of the emergency caller can be looked up in the system to pull up a specific incident.