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EMS Communications IQP

by

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# Abstract

The purpose of this project is to research communication techniques utilized by emergency medical services, identify areas for improvement, and implement creative solutions with the goal of improving response time, reducing emergency vehicle collisions, and ultimately saving lives. To focus on these goals, our group is concentrating on improving communication on the road between emergency vehicles and civilian drivers.

The first step is to identify the problem. We analyze emergency vehicle collisions that have occurred in the past 18 months by determining what caused the accidents, trends common to these accidents, and factors that could help drivers make decisions to avoid similar scenarios in the future. Next, we identify past and present communication methods. These include emergency protocols established by the state of Massachusetts, tools used by ambulance companies such as UMass Emergency Medical Services, and patents filed for new ideas that may not currently be available. Third, we compile this information to devise a more effective means of communication. At this time, we determine two possible concepts that we will test.

The first concept is a wireless transceiver system that uses radios to alert drivers of approaching emergency vehicles. A proof of concept using two software defined radios and MATLAB is used to demonstrate the idea and its potential. The second concept regards the way existing sirens are operated. Based on our research, our group hypothesizes that different types of sirens are more effective on different types of roads. To test this, we record the time en route when responding to several calls when using both mechanical and electronic sirens. Despite our lack of a budget and short time frame to conduct our tests, we are able to collect data from both experiments, particularly thanks to the help of the Worcester Fire Department.

After months of research, planning, and testing, we have a functioning proof of concept that demonstrates a wireless alert system and data that helps support our hypothesis. Our results show that using mechanical sirens on urban roads can increase the average vehicle speed and thus improve response time.

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# Acknowledgements

Our IQP group would like to extend a special thanks to UMass Memorial Emergency Medical Services for helping us with our initial research and providing guidance for our project. After explaining the need for improved communications on the road, we had a clear direction to focus our project. After months of research, we hypothesized that mechanical sirens might be more effective than electronic sirens. Thanks to the Worcester Fire Department and the fire fighters at Engine 4, Engine 6, Engine 12, Ladder 1, and Ladder 7, we were able to test our research and gather valuable data that will hopefully form the framework for future experiments. This project would have not been possible without their time, valuable experience, and generous help. Thanks to everyone’s cooperation, this project was a success.

# Chapter 1: EMS Communications

The purpose of this report is to investigate emergency communication methods so as to improve emergency vehicle response time while maintaining safety. To accomplish this goal, we complete research to justify the problem before considering any solutions. Once our group gathered sufficient information, we began devising several potential solutions and pursuing the most promising ones. In the final month of our project, we test our hypotheses and determine final conclusions.

This report first discusses our initial research and states our justification for the need of our project. In Chapter 2, we present information on existing patents pertaining to wireless warning devices, research on color effectiveness and pattern applications, as well as siren types. This section discusses the current technology in terms of emergency vehicle warning systems and tools. After establishing existing technologies, we present the justification for our project. Recent articles regarding emergency vehicle accidents are collected from across the United States; in each of the accidents, civilian drivers are unable to see or hear an emergency vehicle, and several of the accidents result in fatalities.

In Chapter 3, we discuss our testing procedure, how we collect data, and our results. Our initial plan was to improve the effectiveness of the colors and patterns used on ambulances. Based on our research from Chapter 2, we form a combination of colors and patterns we believe to be the most conspicuous. Our plan was to test this combination against a traditional ambulance and see which one of the combinations has the lowest response time over a period of several calls. Unfortunately, patient privacy laws prevent us from performing these tests because non-medical staff are prohibited from riding in an ambulance when responding to a call. From this point, we focus our attention to the effectiveness of sirens. We contact the Worcester Fire Department and establish meeting times to test our theories about mechanical versus electronic sirens. Once we have our data, we formulate conclusions based on the analysis of the average speed of the fire truck on certain types of roads using different kinds of sirens. In Chapter 4, we state the final analysis of our data as well as our concluding remarks about all of the problems and constraints we encounter while trying to accomplish our final goal. We discuss our recommendations for further research and development of effective and applicable emergency vehicle warning technology.

Our goal is to lower response time and increase safety of emergency vehicles. While we may have had constraints and unforeseeable problems, we overcame them to produce important data that we use to formulate applicable data. The data generated can be applied to determine which siren is most effective in specific environments. Given a longer testing period, more applicable data could be generated. For example, running tests over the course of a year instead of several weeks could yield seasonal data that depicts trends based on weather conditions and traffic around schools. Extending the testing period might benefit fire fighters and give them an idea of which sirens would be more effective at certain times of the year. With more time, we could also further develop the transceiver radio warning system. For this project we were only able to accomplish a working model as a proof of concept. Further research and more time would yield a more precise system that could slowly be implemented in automobiles to help improve safety for drivers and decrease response time for emergency vehicles. The following chapter will introduce our research and justification for our project

# Chapter 2: Background, Problem Justification, and Existing Solutions

## 2.1 Massachusetts EMS Protocols

The state of Massachusetts has many guidelines and regulations established to make emergency communication flow smoothly between patient, 911-dispatch, EMTs, and hospitals. Without such guidelines, there would be no available bandwidth and communication would be impossible. To understand the current protocols and procedures, the following is an abridged version of the EMS Radio Communications Plan.

### 2.1.1 Overview

EMS communication begins when a civilian calls a 911-dispatch center. If the call regards a medical emergency, the dispatch center will dispatch an ambulance and any other emergency services (Office of Emergency Medical Services [10]). Dispatching ambulances varies between regions; for example in Central Massachusetts, 911 calls are routed to Framingham and then to Worcester police department. Worcester PD then dispatches an ambulance from one of any available third-party ambulance companies, such as those provided by UMASS Memorial Hospital. Other areas may have designated federally funded ambulance companies that provide service for the city or region.

Once the ambulance receives the call, they leave the dispatch center to pick up the patient. Once the EMTs arrive at their destination, they determine the severity of the patient's condition and classify it on a priority scale of one to three. Priority level one is immediate life threatening, such as cardiac arrest or major head injuries. Priority level two is life threatening including strokes or unstable trauma, and joint dislocations. Priority level three is non-life threatening such as minor fractures. EMTs relay the patient's priority level to CMED who then directs their communication to a hospital through a dedicated channel while still monitoring communication (ER/Trauma Center [6]).

Once connected with the appropriate hospital, the EMTs will relay critical information about the patient including age, sex, date, time, primary complaint, and the priority of the situation. Once the necessary data is acquired, CMED terminates communication and the hospital can prepare for the incoming patient. Figure 1(Office of Emergency Medical Services [10]) shows a flowchart that outlines this process.

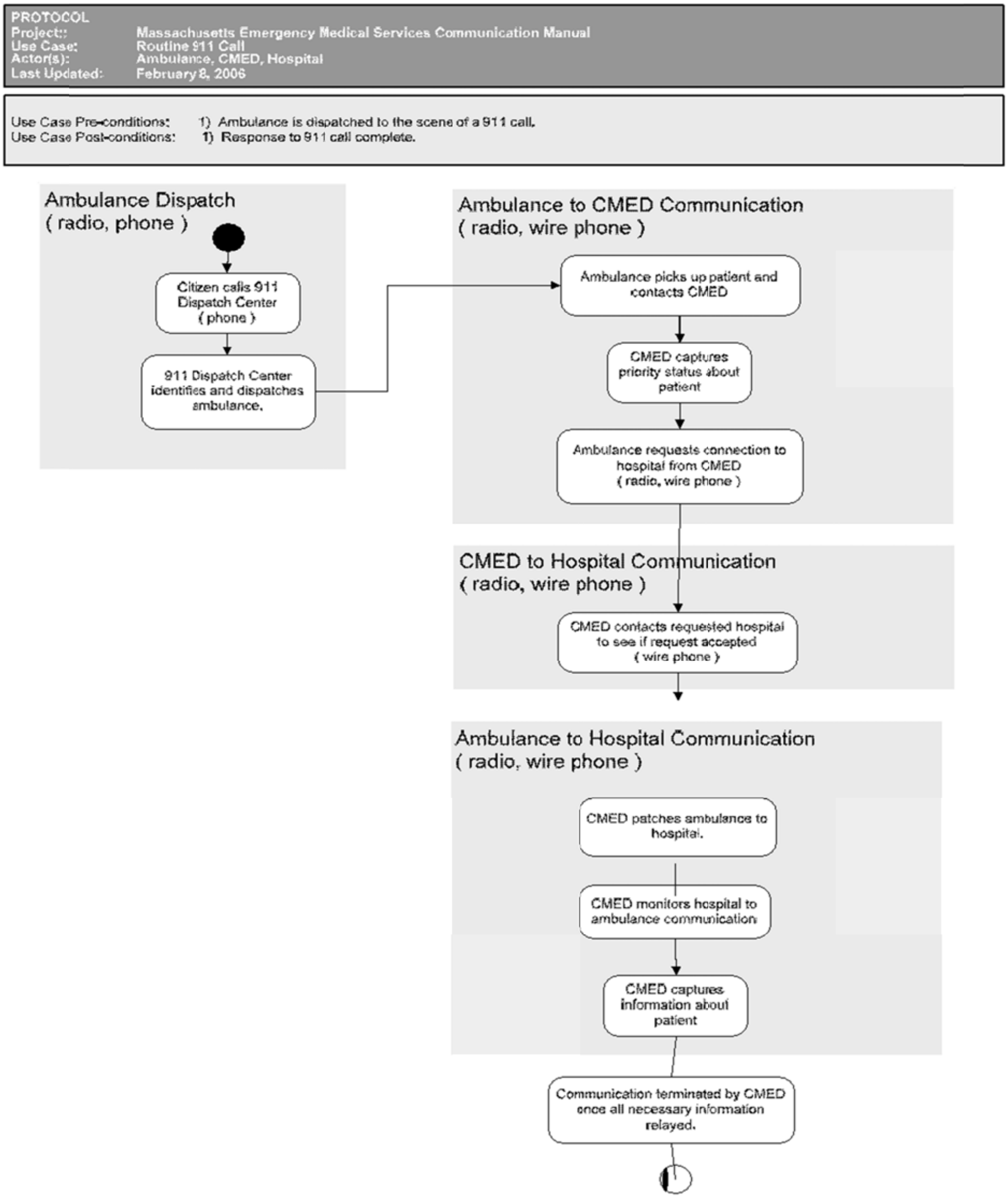


*Figure 1: 911 Call Protocol Flow Diagram*

### 2.1.2 Communication Equipment

Ambulances currently use a mix of wideband (25 kHz bandwidth) and narrowband radios (12.5 kHz bandwidth) as the primary means of communicating with CMED, hospitals, and dispatch centers. They must operate without performance degradation at 450-512 MHz (UHF) and have a channel capacity of at least 200 (Office of Emergency Medical Services [10]).

The state of Massachusetts is transitioning from wideband radio receivers to narrowband, per order of the FCC. These new regulations are designed to help relieve “the severe shortage of radio spectrum allocated to public safety use”. Beginning January 2011, no new wideband radios can be installed in ambulances and beginning January 2013 all wideband ambulance communications will cease. As part of the new requirements, the FCC has allocated a spectrum of frequency below 800 MHz as part of the Private Land Mobile Radio (PLMR) spectrum.

### 2.1.3 CMED

Central Medical Emergency Direction (CMED) serves as a communications link between all dispatched ambulances and all hospitals in its designated region. The primary purpose of CMED is to assist EMS personnel with communication during emergencies. Routing communication from the ambulance through CMED before it reaches the hospital helps to maintain a clear procedure for EMS communication and helps reduce frequency congestion by controlling the use of medical radio channels.

CMED was established in Massachusetts in the 1970s to help better organize the EMS system for the entire state since each city runs its emergency services differently. For example, Worcester dispatches its ambulances through the police department where Boston’s EMS system operates within the fire department. Furthermore, the ambulance services themselves are run differently. For example, some cities such as Millbury use third-party companies like AMR and UMASS while other towns, such as Natick, use public ambulances.

The state of Massachusetts is divided into five different regions each with their own CMED station (Figure 2). Each regional CMED has several UHF and VHF channels to provide adequate coverage over the entire geographic region while also maximizing the available frequencies (Region II Communication System [11]).

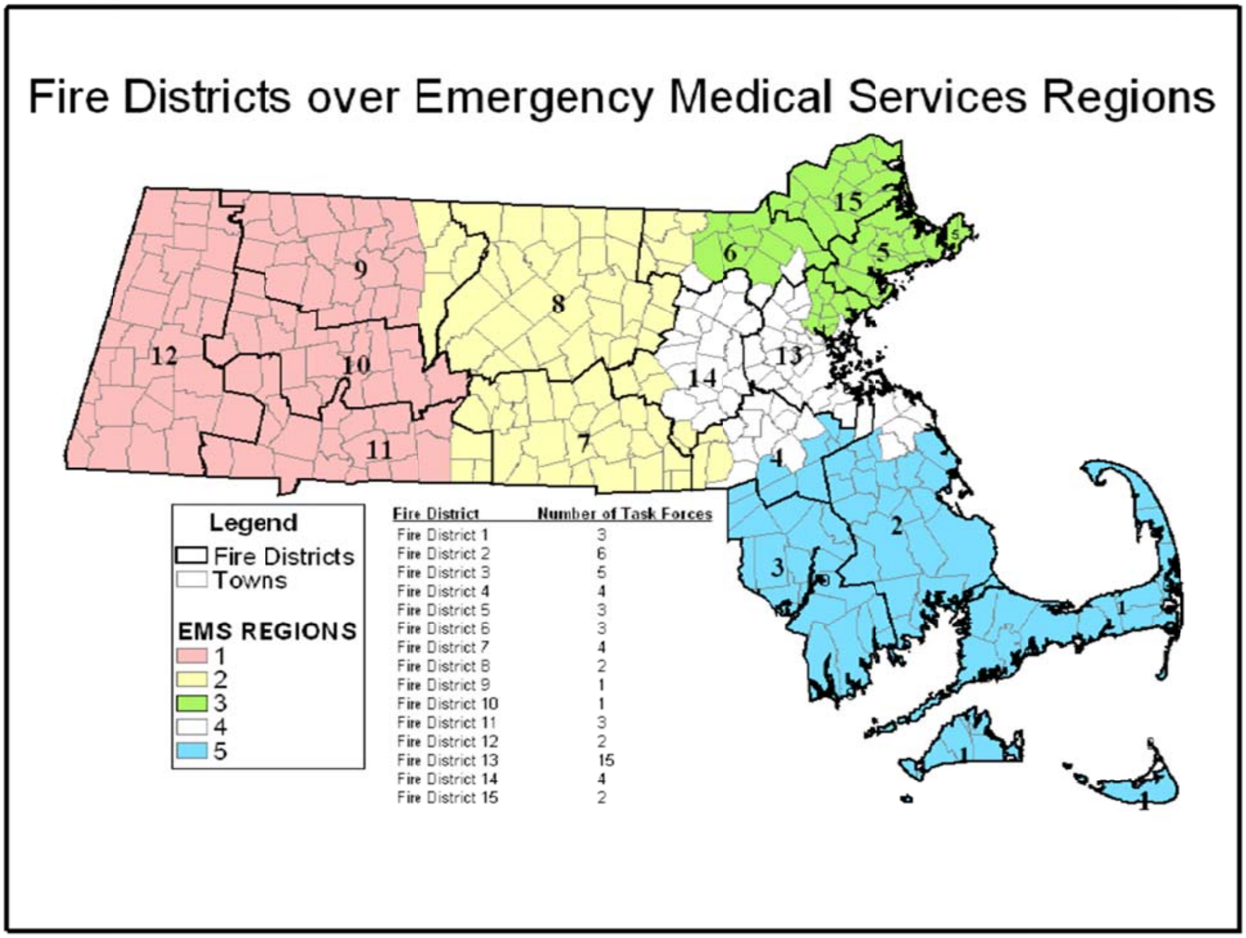


*Figure 2: Massachusetts EMS Regions*

When the EMTs pick up a patient, they request entry and a communications link to a hospital through CMED. The hospital they are directed to depends on the chief complaint of the patient, the current location of the ambulance, and possibly the patient's personal preference. The chief complaint is important in the decision process since not all hospitals have the capacity to treat certain patients: different hospitals specialize in treating trauma, stroke, and pediatric emergencies. The location of the ambulance is also critical because a closer hospital may have a better chance of saving a dying patient in an emergency.

Once the EMTs request a hospital, CMED will patch them through a dedicated channel. The EMTs relay the critical information about the patient including age, sex, chief complaint, and estimated time of arrival (ETA). With this information, the emergency department at the hospital can properly prepare for the incoming patient. Although this is a general process for using CMED, the specific procedures vary by region.

Within the city of Boston (Region IV), CMED is only notified of priority level one patients (those that are dying). This helps to increase the range of available frequencies in order to facilitate the very high volume of calls. Less urban regions such as the Central Massachusetts Region (Region II) require all priority levels be passed through CMED before being redirected to the hospital.

The use of CMED is particularly critical during a mass-casualty incident. CMED is responsible for locating hospitals within its region as well as those in neighboring regions to facilitate the large number of patients. Furthermore, CMED will be responsible for dispatching the state's Ambulance Task Force.

### 2.1.4 Policies

Every state is different in setting laws governing how drivers should react to the presence of an approaching emergency vehicle. In this section, we will discuss a few laws currently implemented in Massachusetts General Legislature which outline procedures drivers must take when an emergency vehicle approaches. All laws found are in Part I (Administration of the Government), Title XIV (Public Ways and Works), Chapter 89 (Law of the Road)

Chapter 89 Section 7 of Massachusetts legislature is entitled "Right of way of fire engines, patrol vehicles and ambulances; obstruction; penalties." It states that whoever willfully obstructs or retards the passage of an emergency vehicle going to the scene of an emergency or an ambulance transporting a sick or injured to a hospital shall be punished. For the first offense a penalty there is a fine of up to fifty dollars. The second offense can carry a fine of up to five hundred dollars or imprisonment of up to one year. The third offense is identical to the second except that the Registry of Motor Vehicles may suspend the license of the violator if it deems necessary and force the violator to return to a driving school (*General Laws Chapter 89, Section 7* [15]).

Chapter 89 Section 7A of Massachusetts legislature states drivers must maneuver the "vehicle as far as possible toward the right-hand curb", hence "pull to the right and stop". This section does not specify whether a vehicle in front of an oncoming emergency vehicle must be parallel to the curb (and not diagonally driven into the curb like some people on the road do in the presence of an emergency vehicle). It states that no civilian vehicle shall follow within three hundred feet of an emergency vehicle in response to a disaster. Vehicles that hinder fire response vehicles may be towed even if parked legally (*General Laws Chapter 89, Section 7A* [16]).

Chapter 89 Section 7B describes the operation of an emergency vehicle when there is an immediate emergency, such as transporting a priority level one patient to a hospital. Drivers of any emergency vehicle responding to an emergency may exceed the speed limit and drive through intersections and other road crossings with disregard to posted traffic signs and traffic lights only when proceeding with caution unless otherwise instructed by a police officer directing traffic. The only exclusion to this law is the interaction between emergency vehicles and school buses; emergency vehicles must yield to school buses with activated flashing lights (*General Laws Chapter 89, Section 7B* [17]).

Chapter 89 Section 7C states that when the operator of a civilian vehicle is approaching an emergency apparatus on the side of a highway or road while stationary as well as road repair crews, the driver must slow down and change lanes (if possible) to avoid any sort of incident at the scene of any road repair or emergency in progress on the side of a road or highway (*General Laws Chapter 89, Section 7C* [18]).

For states that do not have laws outlined as specifically as Massachusetts, the National Safety Commission's website provides some suggestions for how a driver should respond to the presence of an emergency vehicle. These guidelines are very similar to those specified by Massachusetts General, specifically to pull to the closest curb and stop. It also states that following emergency vehicles within five hundred feet is prohibited in many states (*The National Safety Commission Alerts* [19]).

## 2.2 Potential System Problems

Our most important task to complete before meeting with the EMTs at UMASS was to come up with a substantial list of problems we thought might cause delays for the EMTs based on our background research. These problems were related to CMED, the use of radios, interaction with other drivers on the road, navigation through traffic, finding patients, and determining which hospital to send them.

Because we initially were unfamiliar with CMED and its purpose, we decided to do some background research. We learned CMED is used to relay information about the patient from the ambulance and EMTs to the appropriate hospital in order to allow the hospital to prepare the necessary personnel and equipment for the incoming patient. We figured in some cases this would be helpful but in most cases would be somewhat redundant. We assumed it would be simpler to eliminate CMED altogether and have the EMTs simply call the hospital they are going to and notify them of their needs. Next, we thought using radios might be more complicated than cell phones. In addition, the audio quality of radios is usually less than that of cell phones. We felt that simply using a cell phone to communicate with the appropriate parties might be easier and more efficient than using radios. A more obvious issue we thought EMTs might have while on call is dealing with other drivers on the road. Sometimes people know how to act and where to pull over, however, there are times when people assume the best thing to do is stop or just turn to the side. Otherwise the EMT may not know the driver's intentions and the obstacle creates an additional delay.

### 2.2.1 Navigating Traffic

Based on our analysis of the system, traveling from the dispatch location to the patient and to the hospital appears to require more time than any other part of the process. Travelling through traffic, particularly on narrow streets and during rush hour, can be slow because of many obstacles. Although measures have been taken to help improve the commute such as traffic preemption devices and laws requiring drivers to pull over to the side of the road, commuting still appears to cause the most delay.

### 2.2.2 Locating Patient

Before an ambulance even navigates through traffic, it first needs to know where to go. We figured finding exactly where a patient is might easily cause problems. For example, the actual location of a patient may differ from where they told the 911 dispatcher they were. If someone calls for an ambulance and does not know their location, they could give inaccurate information which would create delays in getting to the patient. If the EMT does not know how to get to the location, they will may have to rely on a GPS system to get them there. We thought there could easily be problems with inputting the address into the GPS system as well as the reliability of the system.

## 2.3 Identifying the Problem

In this section of our report, we will outline what we learned from our interview with the paramedics at UMass Memorial, a fire department in McAllen, Texas, and a police station in Worcester, Massachusetts.

### 2.3.1 UMASS Memorial EMT Interview

The first topic we asked the EMTs at UMass Memorial was about the 911 phone call that starts the communications process. After researching the communications flowchart for

Massachusetts, directing the caller through regional and local dispatchers appeared to be a cumbersome process that needed simplification. The paramedics disagreed and said there are no major problems with the current communication system in place and that it allows them to efficiently perform their jobs.  We learned that each ambulance was fitted with a GPS system that automatically downloads patient information and a route whenever they service a 911 call.

After finding no significant problems with the 911 system, we proceeded to ask the paramedics about what improvements they thought could be made to the CMED communications process.  We suggested that maybe using cell phones instead of radios to contact CMED might be a better approach. The EMTs explained that cellphones actually could be used just as easily, but the radios generally have better signal reception and regularly using radios keeps them familiar with the process.

One thing they stressed is the abuse of the EMS system. For example, one may call 911 to report a stubbed their toe, a headache, or ask for a free ride home because they are drunk. Whenever someone abuses the system, it wastes time, resources, and radio frequencies that could be used for helping someone actually in an emergency. Although abuse is a major problem, it is not within the scope of this project and will not be addressed.

Next, we asked if they have any problems getting to their destination, either the patient or the hospital. We discovered that cars that do not pull over create a major hassle for the ambulance in transit. For example, some drivers panic and others cannot decide the best course of action to take when an emergency vehicle approaches. Due to possible inadequate driving education, drivers do not know to move completely to the side of the road.

### 2.3.2 McAllen, Texas Fire Department Interview

Using the information gained from the UMASS interview, most of the questions regarded communicating with drivers during transit from the fire station to the site. The firemen we interviewed also mentioned issues with the local 911 dispatch center.

In the state of Texas, pull over to the right is not a law. Emergency vehicles must abide by all traffic laws and if they approach an intersection with a red light, they do not have the right of way and must receive “permission” to cross the intersection. This is often achieved by cautiously entering the intersection with different siren sounds. As a city on the border with Mexico, there are many international drivers that aren’t very familiar with Texas laws and protocols. In Mexico, there is no standard procedure for moving over when an ambulance is approaching and thus many drivers don't know to pull to the right or stop for emergency vehicles when they are in the United States. In this case, a driver education policy for international commuters may help to resolve this issue.

One of the firemen also mentioned that the use of sirens is not always effective because many new vehicles are resistant to outside noise and drivers are often distracted with mobile devices such as cell phones, car stereos, and GPS receivers. In Texas, a law was passed in August 2009 that prohibits the use of cell phones in moving vehicles driving through reduced speed school zones. In addition, newly licensed drivers under the age of 18 are prohibited from using cell phones for the first six months after receiving a license. This new law was established to help reduce fatal collisions, especially in school zones, but could also help drivers become more aware of approaching emergency vehicles.

To attract the attention of the other distracted drivers, some of the firemen mentioned that noticeable improvement in driver response on the road when the Q2 siren is used instead of the electronic one. A Q2 siren is a mechanical siren with a distinctive sound similar to the air raid sirens used during World War II. These mechanical sirens have a larger range of frequencies. Lower frequencies are more effective at dispersion, propagation and penetration than higher frequencies. As a result, drivers of sound resistant vehicles have an improved chance of hearing the siren and locating the direction from which it originated. The Q2 siren's effectiveness is similar to that of a vehicle playing low bass music; the low frequencies can propagate through sound resistant vehicles from even several blocks away.

The only issue the firemen mentioned regarding the local dispatch center is the person that receives the call must route a report to the appropriate emergency service, e.g. police, fire department, or EMTs. Sometimes the reports do not have enough details and the firemen are required to call the dispatcher back or even in some cases, the original caller, in order to get the necessary information. However this problem is primarily just due to human error, not a flaw in the dispatch system. As a result of the interview, we concluded that transiting to a call and communicating with the drivers en route is again the most serious issue.

### 2.3.3 Police Interview

One of our group members, Connor, recently had a dead battery and asked a police officer for a jump. While waiting for a charge he struck up a conversation about emergency vehicles navigating through traffic to get his opinion on it. First Connor asked him if it is a justified idea. The police officer said that he encounters trouble with other drivers on the road incredibly often.  There are several causes for the trouble he encounters.  He said he has dealt with drivers who do not know where he is coming from, cannot hear his siren, or sometimes make assumptions about his direction of travel.

The police officer made it very clear that the most common problem with other drivers is the inability to hear his siren because of loud music, sound proof cars, or cell phone conversations.  The police officer cited examples where this has recently happened.  In a recent call involving a child unable to breathe, two police officers were dispatched and driving towards the scene in tandem.  A driver going in the same direction as the police officers slowed down to let the first officer pass then quickly moved back into his lane and directly into the second officers car.  This created another scene in which the original two police officers dispatched now had to tend to their own accident then request additional police officers to respond to the original call.

Obviously, this is a problem that could have been avoided.  The police officer Connor spoke with came up with his own remedy for this risk.  When driving in tandem with another police car, the officer always uses a different siren to let drivers know that there is more than one vehicle approaching.  He admitted that this only remedies instances when a driver that is able to hear him could avoid hitting an emergency vehicle.  He stressed that far too often there are drivers with their music playing at a volume so loud it covers the siren.  The police officer stated that a method of turning down the volume in the car or otherwise alerting a driver who cannot hear the siren is a very important problem to pursue.

### 2.3.4 The Most Serious Problems

From the previous section, we can confidently say that navigating through traffic is by far the biggest problem.  Although the abuse of the system is a serious problem, it is not within the scope of our project. Therefore, we will focus on developing a new or improved method of communicating with drivers.

### 2.3.5 Communicating with Drivers

The EMT's at UMass proposed capturing the driver's attention would be a "huge step" towards improving the commute. Communicating with drivers is critical because cellphones and loud music prevent drivers from hearing their siren. With this, we proposed a type of warning system that could alert drivers of an approaching emergency vehicle. The EMTs stressed the importance of a simple device that allows the driver to make a quick and effective decision without distracting them from driving.

## 2.4 Justification

### 2.4.1 Justification 1

On February 10, 2011, a pickup truck ran into an ambulance at an intersection in Ocala, Florida (Miller [9]). According to the article, an ambulance with lights and sirens on approached the intersection of U.S. 441 and County Rd. 326. One driver stopped and motioned the ambulance to continue north on U.S. 441; however, the driver of the truck, continuing westbound on 326, did not see the ambulance and collided in the intersection. Figure 3 shows the direction of travel of the truck (blue arrow) and the ambulance (red arrow).


*Figure 3: Intersection of U.S. 441 and County Rd. 326*

As shown in Figure 3, this is an intersection of two divided highways. The red arrow represents the ambulance and the blue arrow represents the pickup truck. The close-up in Figure 4 shows that the distance from the westbound lane of 326 to the northbound lane of 441 is about 150 feet. As shown above, the westbound lane of Highway 326 (direction of the pickup truck) is over 100 feet from where the ambulance would have first entered the intersection. For a vehicle with the radio and air conditioner running, the maximum propagation of a siren is approximately 100 feet. According to Florida Department of Transportation Intersection Design guidelines, an intersecting rural road such as this is designed for speeds in the range of 30 – 50 mph. If the ambulance was cautiously traversing the intersection at 15 mph and the truck was driving at the maximum assumed speed limit of 50 mph, the truck would have been approximately 415 feet away when the ambulance began to enter the intersection.

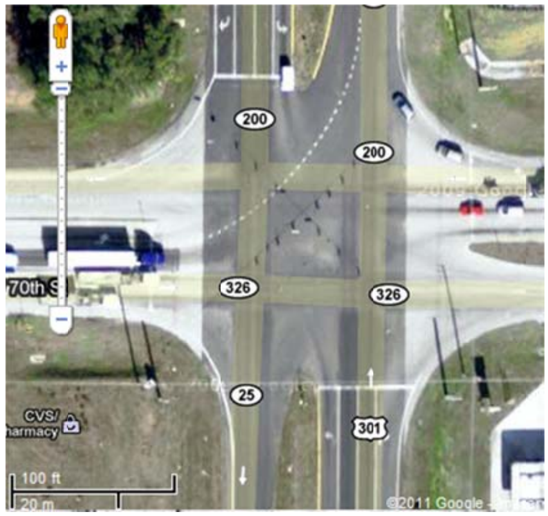


*Figure 4: Enlarged satellite image of the intersection*

Figure 5 shows the extent of the damage caused to the ambulance. The momentum of the large pickup truck and horse trailer caused the ambulance to roll over. Fortunately the patient and paramedics inside only sustained minor injuries.


*Figure 5: Extent of the damage to the ambulance*

According to a research study conducted by Dr. Robert DeLorenzo for the *Annals of Emergency Medicine,* a vehicle traveling at about 40 mph with no radio or air conditioner will cancel the sound of the siren until it is within 330 feet of the source; with the air conditioner and radio on, this distance is reduced to 100 feet (DeLorenzo [4]). According to these rough estimations, the driver of the truck most likely would not have heard the siren.

### 2.4.2 Justification 2

On December 15, 2010, a car crashed into an ambulance responding to a call in Bethesda, Maryland (Donaghue [5]). Fortunately it was a minor collision and no one was seriously injured. It is not clear exactly what caused the collision but the woman driving the car was found to be at fault. The ambulance driver mentioned in the article that it is important for drivers to pull to the right and stop whenever they see an emergency vehicle.

Regardless of what caused the incident it is clear the woman did not know what appropriate action to take. In the event that she saw the ambulance coming, perhaps she did not know which direction of the road to pull to or whether it would have been in the ambulance's benefit for her to simply stop or keep driving, thus to keep traffic flowing. Another possibility is that she heard the siren but couldn't locate where it was coming from. In the panic of trying to locate the vehicle in order to get out of the way, she crashes into it. A third case is that she neither saw nor heard the ambulance and made no effort to move out of the way because she is unaware of its presence in the first place. In all of these situations, it would be beneficial to both civilians and EMTs for a warning mechanism that alerts drivers of the presence of an emergency vehicle.

### 2.4.3 Justification 3

On November 19, 2010, an ambulance collided with a car turning onto a highway in Henry County, Georgia (*Channel 2 Action News* [2]). The serious collision killed a passenger in the car and seriously injured four others, including a mother and her child in the ambulance. The car turning left onto the highway failed to yield to oncoming traffic, in this case the ambulance. According to investigators, the ambulance was not in emergency mode so lights and sirens did not help to make the ambulance more visible. This particular colission is of particular interest to our project because it shows how the cholor scheme of an ambulance greatly influences its visibility to drivers on the road. Figure 6a and 6b show the ambulance that was in the colission. As shown in 6a, the rear of the ambulance is dark blue which may provide high contrast during the day but relatively little contrast at night, which is when the colission took place. The white front provides some contrast but it isn't very reflective in comparison to the 'star of life' logo, as shown in 6b.

As shown in 6a, the color scheme of the rear of the Upson Regional Medical Center ambulance is dark blue with few reflective surfaces that provides little contrast during night driving. In 6b, the front of the ambulance is white which helps improve contrast and visibility but the only reflective surface is the small 'star of life' insignia. 6c shows the extent of head-on damage to the ambulance and in 6d, the passenger side the Chevrolet MonteCarlo thrown across Highway 1941. The front passenger was killed instantly.


*6a*


*6b*

*6c*

*6d*

*Figure 6: Monte Carlo wreck*

This particular accident could have happened with any vehicle. Howerver, this case shows that the distinctive exterior markings of Upson Regional ambulances are not sufficient to increase ambulance visibility to drivers in night conditions. Even when not in emergency mode (no lights or sirens), an emergency vehicle should be more visible than a civilian vehicle. In the event a vehicle receives a call while driving not in emergency mode, drivers need to be alert to its presence in order to take appropriate action.

### 2.4.4 Justification 4

Recently in California an accident involving an ambulance occurred that ended with the patient in the ambulance dying. The accident involved a car driving through an intersection (Figure 7) and crashing into the ambulance, flipping it on its side. The patient was pronounced dead at the scene soon after the crash. The firefighters and EMT riding in the ambulance were sent to the hospital with minor injuries.


*Figure 7: Site of ambulance crash*

This accident exposes many problems that ambulances face. Currently, ambulances are permitted to proceed with caution through intersections. This accident involved a driver who had a green light that failed to notice the ambulance cautiously moving through the intersection with lights and sirens blaring. Ambulances now have to worry about distracted drivers or sound-proof cars that will put the ambulances at a higher risk for a collision. Even though the driver of the car didn't see the ambulance, he is obligated to yield to the ambulance.

The accident itself caused harm that could have been prevented. The EMTs and Firefighters in the back of the ambulance rarely wear seatbelts while working on a patient. In this case, the patient was suffering from cardiac arrest which means an extra level of vital work for the EMTs and Firefighters. Any accident involving an ambulance carrying a patient will cause harm to anyone with the patient because they will likely be without a seatbelt and susceptible to more harm. As for the patient, who is already in some degree of harm, an accident could turn their condition from non-life threatening to life threatening. Unfortunately for this case, the patient was already in life-threatening condition and shortly passed away after the accident. This sort of death could have easily been avoided if the ambulance was able to warn drivers of its presence and direction.

### 2.4.5 Justification 5

An accident involving an ambulance and a fire truck recently occurred in Arizona. The accident happened when both the ambulance and fire truck were responding to a call with lights and sirens blaring when an oblivious driver came off of the highway and collided with the ambulance.  Injuries sustained were minor to severe but all are supposed to fully recover.


*Figure 8: Damage to side of ambulance from impact*

This accident appeared to be minor from the outside of the ambulance (Figure 8) but the EMTs and firefighters in the truck are not always securely fastened in a seat belt.  This shows that an ambulance wreck does not have to be catastrophic for it to cause serious harm.  EMTs and firefighters are simply unable to work to their fullest extent if they are securely buckled in.

In addition to harm caused to the firefighters and EMTs, an overall lag in the response to their call occurred.  This can be the difference between life and death for the people they are trying to help.  Once the ambulance was in a wreck, the fire truck had to stop to make sure everything was ok.  Once conditions were stabilized, additional ambulances and fire trucks were requested to both respond to the original call as well as to the accident involving the ambulance.

### 2.4.6 Justification 6

Michigan may be prone to bad weather this time of year, yet not all accidents can be blamed on the snow and ice.  A recent accident occurred in Michigan where a driver (Figure 9, blue arrow) failed to yield to an ambulance (Figure 9, red arrow) and collided with it. The driver of the ambulance had minor injuries while the driver of the car sustained serious injuries and was immediately rushed to the hospital. The patient in the ambulance appeared to have sustained no additional injuries.

These injuries and delays could have easily been avoided had the driver of the car been able to tell there was an ambulance entering the intersection he was approaching. These injuries are at times, and in this case, life threatening and are preventable. The delays have potential to be catastrophic in certain cases where there is no room for lag.


*Figure 9: The red arrow indicates the ambulance and the blue arrow indicates the civilian vehicle*

### 2.4.7 Justification 7

On the night of February 7, 2011, a large semi-truck collided with an ambulance on Highway 30 in Carroll County, Iowa. The ambulance was transporting a patient to the hospital when the semi-truck shifted to the left lane to make a wide right turn. When the ambulance attempted to get around the semi, the truck moved back into the right lane. Because the ambulance was proceeding at approximately 90 mph, the driver did not have enough time to stop before the collision. As a result, both the patient and the other paramedic on board were killed. The driver was put on probation for his reckless driving.

The cause for this incident can be narrowed down to a lack of communication between both drivers since neither knew the others intention. The semi driver was not able to realize he was creating an obstruction to the ambulance's path until he was already in the middle of the highway, about to make a turn. Had the ambulance known that the semi was planning to move back to the right hand side, he might have been able to slow down the ambulance. By the same token if the semi driver knew the ambulance was planning on taking the opening in the lane to pass the truck, he may not have decided to move over. If a warning system could have notified the semi driver of the oncoming ambulance far in advance, he would not have changed lanes in the first place and the ambulance would have passed on the left without incident.

### 2.4.8 Justification 8

On February 15, 2011, a Toyota crashed into an ambulance transporting a stroke patient to Brackenridge Hospital in Austin, TX (Sadeghi [12]). The ambulance had lights and sirens on but was crossing a red light at the intersection of I-35 Frontage Rd. and 15$^{th}$ street when the Toyota proceeded through the green light, as shown in Figure 10. An ambulance heading to Brackenridge Hospital collided head on with the black Toyota at the intersection of I-35 Frontage Rd. and 15$^{th}$ Street. Althoug the ambulance had a red light, the driver proceeded cautiously through the intersection but the black car did not see the ambulance. Officials stated the stroke victim's condition did not worsen as a result of the collision but sent two paramedics, a firefighter, and the driver of the car to the hospital.  The driver was initially in critical condition but she later died on February 22.


*Figure 10: Austin, TX collision*

Recall that in the state of Texas, emergency vehicles do not have the right of way at a red light. They may proceed with caution if other drivers identify them and come to a stop however the driver of the civilian vehicle had the right of way. Unfortunately this was not enough to prevent a serious accident and her death. It is unclear to investigators why she proceeded through the intersection but it is most likely that she simply did not hear the sirens or see the lights or the yellow ambulance. Although several intersections in the Austin area are equipped with traffic preemption devices, this intersection is not.

Of the incidents provided in this documentation five occurred at intersections when a civilian driver did not yield to an ambulance. An available solution that has been proven to effectively reduce the occurrence of similar incidents is a traffic preemption device. Traffic preemption devices are installed on the traffic signals at intersections and allow emergency vehicles to change the lights so they have the right of way. A joint study conducted by the U.S. Department of Transportation, Federal Highway Administration, and the National Highway Traffic Safety Administration found that traffic preemption devices installed in Plano, Texas, Fairfax, Virginia, and St. Paul, Minnesota have helped to reduce the average number of collisions with emergency vehicles at those intersections (U.S. Department of Transportation [13]).

We have observed that the primary cause for wrecks at collisions is because of a lack of communication with the emergency vehicle that makes the driver uncertain of what to do. Perhaps because of the terrain or layout of the intersection, as in Ocala, Florida, the driver cannot see the ambulance approaching. Or perhaps as in Austin, Texas, the driver simply did not hear the ambulance's sirens. Whatever the cause may be, traffic preemption devices help to drastically reduce the confusion factor: if the light is red, stop and if it's green then it's safe to go. Figure 11 provides a simple explanation for a traffic preemption system.

The black box represents an intersection, the blue arrows are civilian vehicles, and the red arrow is an ambulance. The color of the lights for each lane of traffic is depicted within the intersection. Only the lane where the ambulance is traveling will be green so that the vehicle can easily make a right or left turn without risk of collision with other cars coming from the opposite direction (Global Traffic Technologies [8]).

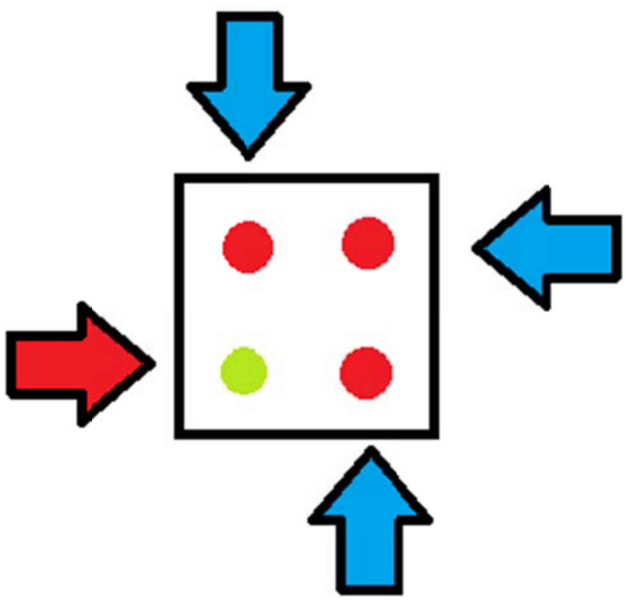

*Figure 11: Traffic preemption diagram*

## 2.5 Implemented Solutions

This section discusses different solutions that have already been implemented in society including traffic preemption devices, lights, sirens, and distinctive vehicle colors, markings, and patterns.

### 2.5.1 Traffic Preemption Devices

The first implemented solution we will discuss are traffic preemption devices. Traffic preemption is the changing of a traffic light signal in order to give a specific user the right-of-way at an intersection. Traffic preemption systems are utilized across the country by emergency vehicles and public transportation systems such as light rails and buses (U.S. Department of Transportation [13]). This retrofitted device requires some sort of transmitter in the emergency vehicle and a receiver at the traffic light.

#### 2.5.1.1 Types

One of the most common types of preemption devices is an infrared (or in some cases visible) strobe light that when set to the correct frequency will trigger a receiver on the traffic signal and thus change the light from red to green. Although an effective device, there have been records of civilians illegally changing the lights because of its simple operating mechanism (U.S. Department of Transportation [13]). However newer models have transmitters programmed with unique strobe patterns for each vehicle that record which vehicle passed through the intersection and helps prevent illegal use. Infrared and visible light signals, as opposed to radio signals, require line of sight access to the intersection. As a consequence, if the vehicle is travelling up a hill, along a curved road, or through dense foliage, the device may not function properly. Yet on straight stretches of road the receiver can detect pulses up to 750 meters away. A receiver must be mounted on each traffic signal arm to determine from where the emergency vehicle is approaching.

One of the main differences between sound systems and light systems is that individual transmitters installed on each vehicle are not required for operation. Instead directional microphones and signal processors detect the siren waveform and change the traffic signal based on the location of the source of the siren. Another difference is that line of sight communication is not required since sound can propagate and reflect off of surfaces.

A radio transmission is sent from the emergency vehicle to a single omnidirectional receiver at the intersection. Because there is only one receiver, the direction for preemption is determined by the transmission; the driver of the emergency vehicle must send different signals depending on the direction of approach. Like the sound systems, radio transmissions do not require line of site communications nor are they affected by adverse weather such as rain or fog.

Another variation created by 3M is the Opticom™ GPS System; this achieves the same function but uses GPS receivers installed on emergency vehicles to change the traffic lights as the vehicle approaches. This system has increased functionality since it can change several lights on the vehicle's designated path, not just the closest intersection. Furthermore, it uses a more secure channel preventing unauthorized users from preempting the signal. It is also the most robust since its performance is not hindered by adverse weather, line of site limitations, or electronic noise interference (Global Traffic Technologies [8]).

#### 2.5.1.2 Benefits

Traffic preemption devices can improve the response time of emergency vehicles. These devices are particularly effective in urban environments where there is a high level of traffic congestion on the roads. When the signal is changed from red to green up to several blocks away, the vehicles currently stopped can have the opportunity to begin moving and clear a path for the emergency vehicle. Without preemption, an ambulance would have to a) wait for the drivers stopped at the intersection to first cautiously and dangerously navigate through a red light and then b) wait for approaching drivers with green lights to stop and yield. Preemption helps resolve this issue by changing several lights on the emergency vehicle's path so that traffic moves continuously with the ambulance with fewer stops at intersections.

Another important benefit is they reduce the number of emergency vehicle collisions at intersections. According to National Highway Traffic Safety Administration fatality statistics, 25% of emergency vehicle accidents happen at intersections with a traffic signal. When the preemption device changes the traffic signal to red for other intersecting lanes, drivers know to stop whether or not they are aware of an approaching ambulance. This is particularly beneficial at intersections where the terrain, foliage, buildings, or adverse weather can inhibit drivers' views of approaching traffic.

Although initially expensive to retrofit several intersections with this technology, it has life-saving benefits. Improving the response time for fire departments and ambulances can reduce the number of necessary stations by increasing their service radius (U.S. Department of Transportation [13]). Faster fire response times means improved fire suppression and reduced fire insurance premiums on public and private property, a factor that affects city growth and development. Faster ambulance response times means saved lives; for cardiac arrest patients, chances of survival are reduced by as much as 10% every minute until defibrillation.

### 2.5.1.3 Case Study

In 2006, the Bureau of Transportation Statistics from the U.S. Department of Transportation conducted research on the effectiveness of traffic preemption devices in three U.S. cities utilizing the system: Fairfax, VA; Plano, TX; and St. Paul, MN. *In Fairfax, emergency vehicles were able to travel through high-volume intersections at an average of 30-45 seconds faster than without the device. In Plano, the number of emergency vehicle collisions was reduced from approximately 2.3 per year to less than one every five years. Emergency vehicle crashes in St. Paul were also greatly reduced after implementing the system.*

#### *2.5.1.3.1 Fairfax County, Virginia*

Traffic preemption devices were first installed in Fairfax county in the 1980s; throughout the 90's, receivers were installed on the busiest intersections and those more prone to accidents. However progress stalled in 1997 because Virginia Department of Transportation was initiating the North Virginia Smart Traffic Signal System that would allow for preemption in public transportation corridors while still benefitting emergency responders. Eventually VDOT won support from key stakeholders to conduct research on a 1.3 mile stretch of US 1 in Alexandria which had high rush hour traffic congestion and also served as a major artery for the busiest fire station in Fairfax County, which receives nearly 90,000 emergency calls each year. When it was determined in 2003 that joint preemption from public transportation and emergency responders could successfully be implemented, receivers were installed on the additional 13 miles of US 1.

Once the preemption devices were all installed and operational in 2004, emergency vehicle drivers nearly always identified time savings from a few seconds to a few minutes during the drive with savings of up to 45 seconds at a single busy intersection. According to traffic flow studies conducted by Virginia Tech, the average time from preempting an intersection to deactivation is 25 seconds and the delays caused on artery intersections was minimal and typically resolved after the first signal after the emergency vehicle left.

Fairfax County was responsible for purchasing and maintaining the preemption devices since they are owned by Virginia Department of Transportation. The average cost per intersection ranged from $4.000 to $6.000 and annual maintenance costs are not expected to exceed $500 each year. The cost per intersection depended on whether the intersection was retrofitted with new equipment, whether new equipment altogether was installed, and the number of receivers installed. In some cases, only two receivers were installed for the busiest directions of the artery.

#### *2.5.1.3.2 Plano, Texas*

Plano, Texas, a suburb of Dallas, began installing traffic preemption devices in 1984 following an analysis of emergency vehicle crashes from 1980 to 1983. Of the 22 crashes, nearly 1/3 occurred at lighted intersections. With the city's population and total land area expected to quintuple of the next 30 years (16 square miles, 50,000 people in 1980; 74 square miles, 220,000 people in 2004), the fire chief pushed for 100% preemption at all lighted intersections within the city. By 1987, all the lighted intersections were retrofitted and each new intersection added had preemption devices installed.

Adding preemption capabilities to new intersections adds up to $8,000 to the bill, about 8% to the total cost. This can quickly add up, especially when up to 17 new signals are added each year. However cost analysis has shown addition of preemption capabilities has in fact saved the city of Plano millions of dollars. Because of preemption, responders can travel from the station to the site faster and hence travel further in a similar amount of time. So even as the city grew, the number of EMS and fire stations didn't have to increase since their service area was improved from 5.6 square miles to 7.5 square miles. As a result, 3 less stations needed to be built, saving Plano approximately $9 million for the sites and an estimated operating cost of $7.5 million annually.

Traffic patterns in Plano are erratic; there are influxes of traffic to and from Dallas during rush hour but there are also peaks in traffic during other times of day as well. Multilane queues of over 22 vehicles at intersections are common, in part due to the long transition time of signals at busy intersections, 160 seconds. As a result, each signal in the city receives an average of one preemption request a day; signals closer to dispatch stations receive as many as 15 a day. Because of the high volume of traffic at major intersections, it can take up to 20 minutes for traffic flow to resume to normal after preemption. However the city receives very few public complaints about the system because of its benefits and public awareness of the system.

These devices have helped emergency services to meet a city wide transit time goal of under 7 minutes. The number of collisions at intersections has been drastically reduced since the installation of preemption devices. During 1980 to 1983, there were 7 crashes at intersections; in the 20 years since their installation, there have only been 4 crashes, 3 of which resulted because drivers failed to stop at the red light. That is an average of 2.3 crashes a year down to 0.2 per year.

##### *2.5.1.3.3 St. Paul, Minnesota*

In the early 1970s, St. Paul, Minnesota began to retrofit all of its traffic signals with preemption devices. Originally the city was only planning to retrofit the two busiest approaches of each signal but this plan was changed following a fatal crash in 1972. After the retrofitting process, all new intersections included preemption capabilities. St. Paul is unique in that all emergency services including the police utilize the system; in most other cities it is only used by fire and paramedic services. The city averages 70 fire and EMS calls in addition to 720 police calls daily. As a result each preemption device across the city is used much more often but intersections near hospitals and dispatch stations experience the heaviest use and are accessed more than five times a day.

Traffic signal cycles are shorter than in Plano with a maximum of 120 seconds. This helps to offset the increased maximum range of the receivers, 2300 feet. This greater distance helps to maximize effectiveness for police vehicles which typically have faster speeds and quicker acceleration than fire and EMS responders. As a result of preemption, response time is often reduced to as little as 3 minutes. After the addition of preemption capabilities, crashes were reduced from 8 to about 3 annually, even despite increases in traffic volume and higher emergency call rate.

#### 2.5.1.4 Conclusions

This study shows that driver confusion is a contributing factor to emergency vehicle collisions at intersections. Directing traffic with signal lights helps to reduce the risk of accidents and improves response times. If reducing driver confusion at intersections helps improve safety and speed, it might also work on the road where traffic signals are not present. In addition to safety, preemption devices can yield long term savings for cities because it can improve the effective range of responders and thus reduce the number of required stations.

### 2.5.2 Lights

There are already multiple warning devices used by emergency vehicles.  One of the more important devices is the implementation of lights.  Traditionally, emergency vehicle lights have been colored incandescent light bulbs (or normal bulbs behind colored lenses) that have rotating mirrors around their base to produce a “flashing” effect.

*Figure 12: Old style light bars with large, bulbous covers for the lights in various combinations*

As seen in Figure 12, these lights are usually large to accommodate the light bulb and mirror inner workings and use a substantial amount of power. While these setups may be traditional and simple, they are not as effective as alternative lighting methods.

The spotlight of emergency vehicle lighting is now focusing on LED technology. LED light bars are far more practical than the older incandescent bulb light bars. With these light bars, there is a large increase in practicality and reliability. First off, as seen in figure 13, the size is much smaller. While this may not seem terribly important compared to the older models, it does play a factor. The smaller and lighter light bar means a slightly lighter and more aerodynamic car. Over the long run, this saves fuel on several vehicles that will be utilizing these light bars.

*Figure 13: A common LED light bar with three different colors.  Note the overall size versus old style light bars*

In addition to saving fuel and being lighter, LED lights can be placed in smaller areas than incandescent bulbs lights as seen in Figure 14.  This allows for greater visibility of the emergency vehicle while still keeping overall power consumption and weight low.  Utilizing maximum lighting creates a much safer emergency vehicle for both the operator of the vehicle and the drivers on the road.

*Figure 14: A police car with concealed LED lights*

From this, we can move to the discussion of power. LEDs require only a fraction of the electricity required for an incandescent bulb. The power consumption is less even if there are several hundred LEDs versus a few incandescent bulbs. With less power required, more lighting can be utilized to achieve maximum lighting. This improves efficiency while also increasing safety creating a more effective emergency vehicle.

In addition to being more practical and more reliable, LED light bars are highly customizable. This customization is very effective for directional lighting as well as color choice. Directional lighting is very effective if an emergency vehicle is parked and does not want to cause glare working the scene while still making its presence known. These light bars are also capable of using different strobe patterns to better attract attention or communicate a purpose.

Strobe lights are vital to emergency vehicle safety. A study conducted by Loughborough University in the United Kingdom found that strobe lights have a shorter reaction time when compared to standard, non-strobe lights. They also found that the faster the strobe, the quicker the reaction time. This supports the use of strobe lights on emergency vehicles and reinforces the importance of their implementation.

Loughborough University went further in their study to investigate the reaction time of different colors as strobes in order to see which color light had the lowest reaction time. In their experiment, they studied blue, red, and amber, the three colors that are most commonly used in emergency vehicle lighting. Both red and blue lights have lower detection times versus amber colored lights in both day and night conditions (Cook [3]). Amber only had a better detection time than red and blue lights when all were held at a constant intensity as seen in Figure 15. This is beneficial for construction and towing vehicles because red and blue lighting is almost exclusively used on emergency vehicles.

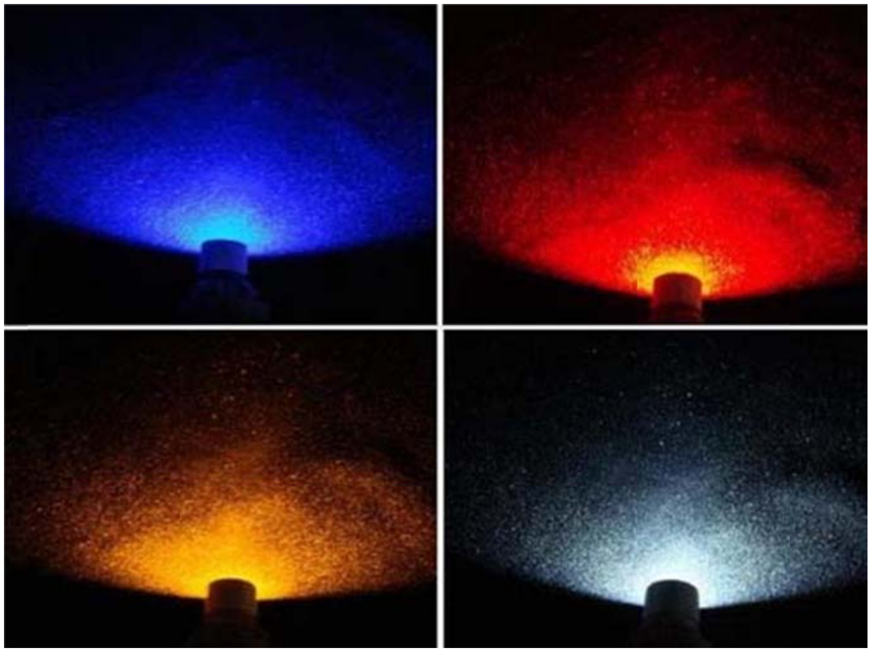

*Figure 15: Light colors used by emergency vehicles in the United States*

Red and blue lights were found to consistently have less glare than amber colored lights. Reducing glare towards other drivers is very important because it can reduce the ability to see and even occasionally blinds drivers. This makes things more dangerous for both the driver and the emergency vehicle and has a high potential to cause another accident. A similar reaction to emergency vehicle lighting is phototaxis which has been called a “moth to flame” effect. This is when a driver is drawn towards the lights and is therefore not paying attention to the road ahead of them (Cook [3]). This is incredibly dangerous for any other drivers or emergency vehicles on the road.

### 2.5.3 Sirens

In our evaluation of currently implemented solutions, we looked at the effectiveness of different types of sirens in use, particularly electronic and mechanical sirens.

Mechanical sirens were the first sirens to be used by emergency vehicles and are capable of producing a loud siren noise with variable pitch. They operate by using a rotating apparatus with small holes that cause alternating pressure differentials to produce a tone. One disadvantage to the original mechanical sirens is that they consumed a massive amount of electricity, up to 300 amps in some cases (Mechanical Sirens [14]). Over time, however, they have become much more efficient. There are 123 dB mechanical sirens currently in production that are currently used on emergency vehicles that draw only 28 amps of current. A strong advantage of the mechanical siren is that it produces a spiraling square wave which is directional in nature thus making it easy to identify where the siren is coming from. As a result, mechanical sirens do not greatly contribute to noise pollution. Furthermore, the circulating square wave can penetrate through sound resistant vehicles to effectively alert drivers (DeLorenzo [4]). In conclusion, mechanical sirens can effectively communicate with drivers and reduce noise pollution but at the expense of high power consumption.

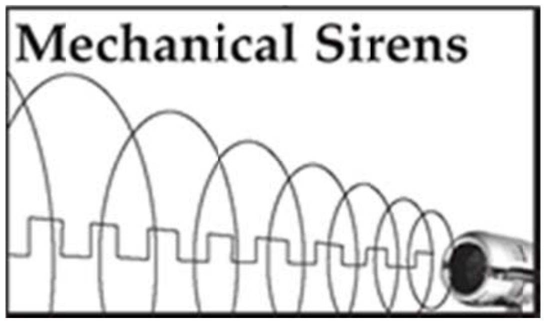


*Figure 16: This illustration shows the square waves and directional propagation produced by mechanical sirens*

Electronic sirens do not require as much energy as mechanical sirens. Also it is possible to quickly change the signal pattern with any preprogrammed sound, a feat impossible for mechanical sirens which can only produce a single signal. However electronic sirens produce sinusoid waves which propagate in several directions and are not as focused as their mechanical counterparts. As a result, contribute to noise pollution and are less likely to penetrate through vehicles to alert drivers of the presence of an oncoming emergency vehicle. In conclusion, electronic sirens are more power efficient but lack the ability to effectively penetrate vehicles.

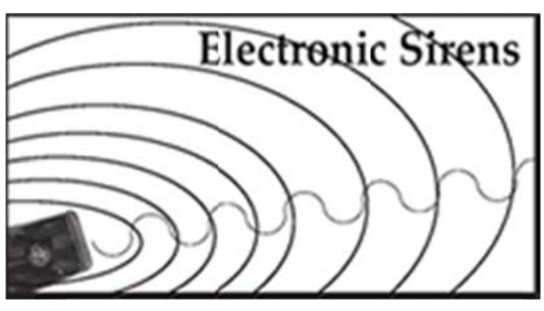


*Figure 17: This illustration shows the sine waves and omnidirectional propagation produced by electronic sirens*

### 2.5.4 Passive Communication

This section discusses different methods of passive communication, techniques which are fixed or static and do not require power. Examples that will be covered include vehicle color, reflective surfaces, markings, and patterns.

While the color of lights on emergency vehicles is very important for both attracting attention and determining the type of vehicle, the color of the cars themselves is also very important. Each state has regulations that dictate the required colors for various emergency vehicles but only apply to federally owned and operated vehicles. This may not be an issue for fire trucks or police cars but there are several ambulances that are privately owned and operated that are in no way bound by these regulations. Figure 18 shows the difference between a government operated ambulance, A, and a privately owned ambulance, B.


*(18 A)*


*(18 B)*

*Figure 18: (18 A)—A government owned and operated ambulance with the regulation markings and colors. (18 B)—A privately owned and operated ambulance with its own exterior design and light configuration*

Most emergency vehicles that are not bound by regulation for color selection simply follow tradition. Fire trucks are primarily red because they have traditionally been red and people recognize fire trucks as being red. Police cars can vary greatly because each station is allowed to determine their own color scheme with their available budget. As long as the police car is not supposed to be an “unmarked” car, the car must state where the police car is from. Ambulances run by the government must employ a red-orange stripe around the ambulance with retro-reflective signs saying “AMBULANCE” on the sides accompanied by the “star of life” and “ECNALUBMA” (“AMBULANCE” backwards) or “YCNEGREME” (“EMERGENCY” backwards) as seen in Figure 19 (Breitrose [1]).


*Figure 19: A classic ambulance color scheme with backwards writing*

The red-orange stripe can vary slightly depending on what each hospital decides to do in addition to the regulation marking. The “star of life” is simply a symbol associated with ambulances and medicine which helps further identify the vehicles purpose. The “ECNALUBMA” and “YCNEGREME” on the front of the vehicles are for potential drivers in front of them who will read the sign in a mirror thus making the sign legible through the mirror.

The “star of life” and “AMBULANCE” markings are mostly all made of a retro-reflective material to help better make the presence of the ambulance known as a passive communication to other drivers. Retro-reflective materials have the ability to reflect light back at its source rather than diffuse it or reflect it at a different angle, like in other materials. This is valuable for emergency vehicles because if a driver approaches the emergency vehicles at night and the emergency vehicle has its lights off, the driver will still be able to see the emergency vehicle because the retro-reflective materials on the emergency vehicle will appear to be shining back at the driver. It acts as a secondary communication that requires no power at all. Figure 20 shows the difference between day and night on a police car utilizing retro-reflective tape.


*Figure 20: The effectiveness of retro-reflective tape. Note the use of text, symbols, colors, and patterns to clearly profile the car*

It is easy to see the importance of retro-reflective tape in low light conditions. It is important to note that retro-reflective material can simply be colors but could also incorporate numbers, letters, and even department emblems and symbols to help determine the denomination of the vehicle. This material is vital because it allows drivers to see emergency vehicles more easily which increases safety of both the driver and the emergency vehicles.

Emergency vehicles are beginning to investigate more attention attracting colors and patterns for their vehicles as a safety precaution for themselves and for other drivers on the road. One color in particular that is the most effective is called “Chartreuse”. It is a yellow green color that excites the most rods and cones in the human eye thus making it more noticeable (Cook [3]). This is obviously important to emergency vehicles because it makes them more noticeable. As seen in Figure 21, some emergency vehicles have begun to incorporate chartreuse into their color scheme over their traditional colors.


*(21 A)*


*(21 B)*

*Figure 21: (21 A) — A fire truck utilizing a chartreuse color scheme instead of the traditional red. (21 B) — An ambulance utilizing chartreuse instead of the traditional red-orange colored stripes*

Some emergency vehicles have gone a step further in passive communication, where the exterior design is not regulated, and incorporated certain patterns to help increase the visibility of their vehicle and creating a safer environment for both the emergency vehicle and the drivers on the road. The most popular patterns used are “Battenberg” and multiple chevrons. The Battenberg pattern is comprised of chartreuse and a contrasting darker color. The large contrast of these colors mixed with the checkered Battenberg pattern greatly increases conspicuity of the emergency vehicle and makes it nearly impossible to miss. Chevrons are also utilized by many emergency vehicles to make them more noticeable. Similar to the checker of the Battenberg pattern, the chevrons will alternate in color between chartreuse and another contrasting color. In Europe where these patterns are more widely used, the non-chartreuse color is often used to signify the purpose of the emergency vehicle to help quickly distinguish one type from another. It is important to note that the Battenberg pattern is primarily used to designate the side of an emergency vehicle while the chevrons are used to designate the front and back of a vehicle as seen in figure 22.


*Figure 22: An American paramedic's car utilizing the Battenberg and chevron patterns*

## 2.6 Possible Solutions Not Currently Implemented

This section discusses proposed ideas that have not been implemented for use in the emergency medical field. Topics that will be covered include patents, Sound LASERS, and radio transmissions.

### 2.6.1 Patents

Most of the patents described in this section have not made it past the drawing board. However, it is important to highlight these ideas since each is slightly different and could contribute to future solutions.

**Emergency Vehicle Traffic Controller**

Patent Number: 3881169

Filing Date: 06/01/1973

Publication Date: 04/29/1975

Inventor: Malach, Henry G. (Beaumont, TX)

This invention is an early traffic preemption device that utilized the siren already present on many emergency vehicles to trigger a sensor installed on an intersection light. The system checks for two specific frequencies between 600 and 900 Hz that are typically present in most emergency vehicle sirens. If both frequencies are present for approximately 2 seconds, the system will initiate emergency control of the traffic signal.

**Emergency Vehicle Alert System**

Patent Number: 5307060

Filing Date: 03/17/1992

Publication Date: 04/26/1994

Inventor(s): Prevulsky, Sy (16 Deer Creek La., Laguna Hills, CA, 92653)

Griego, Tony (4500 Campus Dr., Ste. 131, Newport Beach, CA, 92660)

This emergency vehicle alert system utilizes a transceiver module that allows different emergency vehicle to communicate with each other as well as civilian vehicles. The primary purpose of this invention is to alert drivers when traditional lights and sirens fail, particularly because vehicles are resistant to outside noises and internal noises such as the radio or air conditioner distract the driver. Assuming the driver can be alerted of the presence of an emergency vehicle, hopefully traffic congestion near an accident can be prevented. If a driver can be alerted of a nearby accident, hopefully traffic could also move faster.

The patent does not include any electrical schematics however a block-diagram schematic does explain some of the major components that would be necessary for operation. In addition a flow-chart describes the algorithms that would be implemented, possibly via a programmable microcontroller or FPGA.

**Emergency Vehicle Alert System**

Patent Number: 6252521

Filing Date: 11/08/2000

Publication Date: 06/26/2001
Inventor(s): Griffin, Willie J. (2327 22nd St., S., St. Petersburg, FL, 33712)
Griffin, Anita F. (2327 22nd St., S., St. Petersburg, FL, 33712)

The emergency vehicle alert system comprises of a transmitter located in an emergency vehicle and a receiver placed on the dashboard of a civilian vehicle. The transmitter will broadcast in all directions at a predetermined frequency and at a constant signal strength. The receiving unit includes a speaker and array of LEDs; the power supplied to these two components increases as the strength of the received signal increases (Figure 23). As a result, an increase in volume and an increase in the number of illuminated LEDs indicates the emergency vehicle is approaching the civilian vehicle.

According to the patent description, there is no indication that the device is actually functional because no schematic for either the transmitter or receiver is included. It is merely a design of a possible dashboard alert system. It does not explain the technical characteristics of the assumed transmitter in the ambulance or this receiver. Furthermore, the receiver's method of power spectral sensing and power detection to determine signal strength is also omitted.

The concept of this patent may be a viable solution to our problem. If we could create a functional version of this design it would help emergency vehicle drivers to alert their presence to drivers.

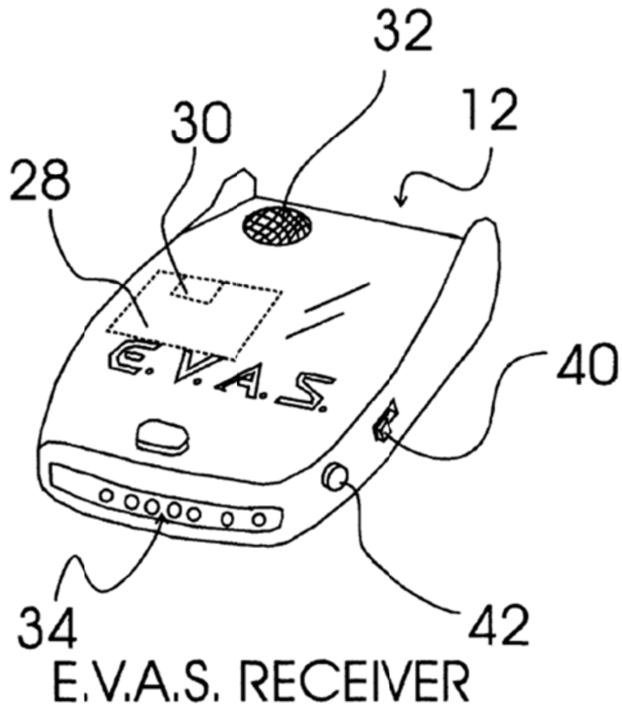


*Figure 23: Proposed design for a dashboard receiver, Patent No. 6252521*

**Emergency Vehicle Warning System**

Patent Number: 7061402

Filing Date: 09/20/2004

Publication Date: 06/13/2006

Inventor(s): Lawson, Robert (1203 N. Bautista La., Colton, CA, US)

The emergency vehicle warning system consists of a transmitter located in the emergency vehicle and a receiver in the civilian vehicle. The receiver will produce an audible alert and display the relative location of the emergency vehicle upon receiving an activation signal of designated frequency from the emergency vehicle; the receiver is also activated by the sound of a siren. The receiver includes both highly directional microphones to detect the siren and highly direction RF antennas to detect the activation signal from the transmitter on the emergency vehicle. The flow chart for this design is shown in Figure 24.

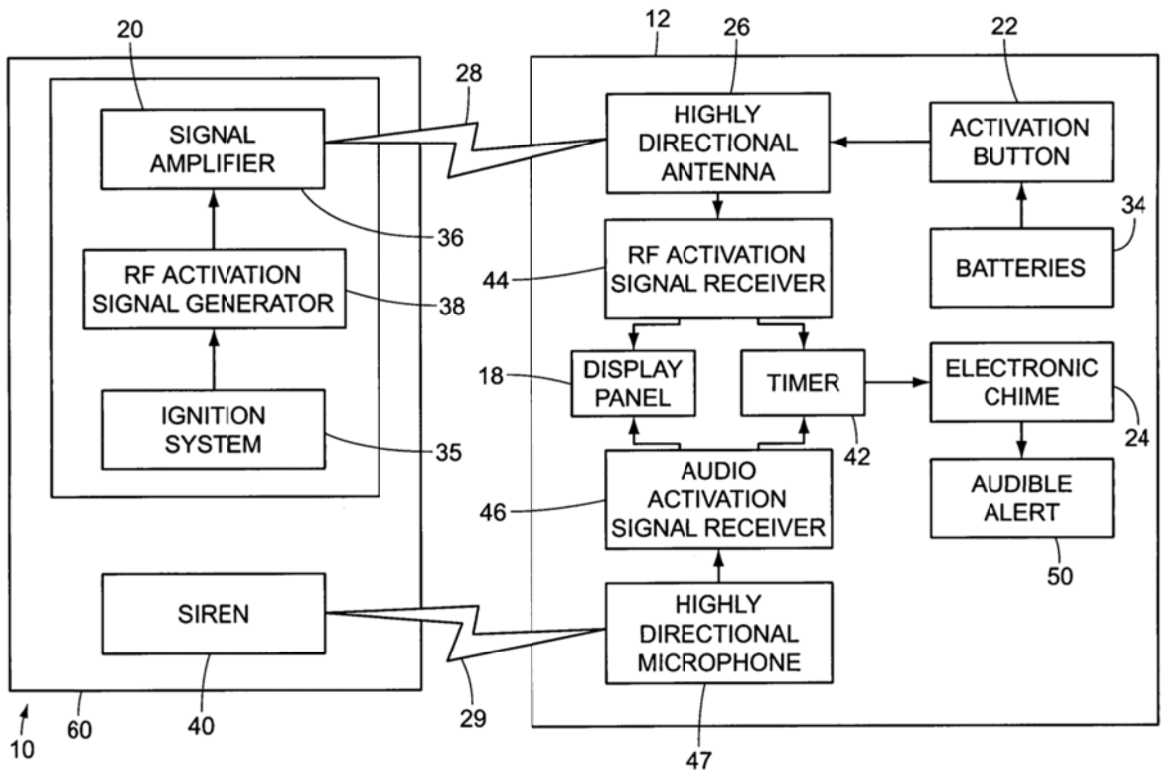


*Figure 24: Emergency Vehicle Warning System flowchart, Patent No. 7061402*

An important feature mentioned in this patent that we would want to consider in our design is identifying the location of the emergency vehicle relative to the driver. This information is critical in helping the driver take appropriate actions such as where to pull over or whether to stop or continue driving if approaching an intersection. However, this patent fails to describe how the direction is acquired. Based on the vague description of using “highly directional” microphones and receivers, an entire array would be necessary, each pointed in a different direction in a radial pattern.

According to the dashboard system as shown in Figure 25, a compass with eight lights would indicate the relative direction of the emergency vehicle. This would mean at least eight receivers and eight microphones would be necessary (unless the system rotates like a RADAR receiver). The patent does not specify if either of these is correct. Another flaw is detecting the “sound waves of a frequency characteristic of the siren.” This statement implies that the device is a digital radio, not analog, and will hence require complex real time digital signal processing (DSP) equipment to detect and identify any one of many different sirens.

Given these requirements, the system will be large, unnecessarily complex, and very expensive. It would not be practical or cost efficient by any means to install such a receiver on the majority of civilian vehicles. Nonetheless, determining the location of the ambulance is an important feature that should be implemented if our group decides a dashboard receiver device is the best solution.

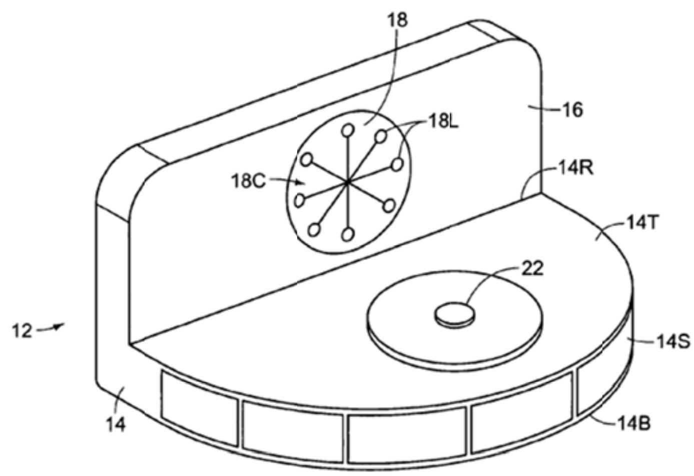


*Figure 25: Emergency Vehicle Warning System dashboard module, Patent No. 7061402*

**Emergency vehicle proximity warning and communication system**

Patent Number: 5825304

Filing Date: 9/18/1996

Publication Date: 10/20/1998

Inventor(s): Marin, Renzo T. (25 Semrado Rancho, Santa Margarita, CA, 92688)

This device also utilizes a transmitter and receiver pair but operates specifically using citizen band (CB), approximately 27 MHz. In this system, the emergency vehicle would broadcast one of several pre-recorded messages that would provide directions to drivers on the road. An additional feature is it can be connected to play through the car's audio system.

This patent is more of a system than an invention. Although smaller handheld radios ("walkie-talkies") using the Family Radio Service (FRS) in the UHF band are more popular for short-range communication, CB radios are still largely used with truckers. The technology is reliable and may even be a successful platform if more civilians had CB radios in their vehicles.

The advantage to CB radio is that anyone can transmit without FCC regulations. This is also its disadvantage. If EMTs began using a public channel, it could quickly become congested. Eventually, a dedicated channel provided by the FCC would be necessary. Initially using CB radios would eliminate much of red-tape and legislation required to get the system approved.

One important benefit is that the EMTs can explicitly tell drivers what to do by giving specific directions. Other systems rely on the driver to decide the best course of action, granted they know where the ambulance is. At the same time, the ambulance may not want to give the same directions to everyone on the road. In this case, the system may prove even more confusing than without it. An improved method would be to transmit different instructions to drivers depending on where they are in relation to the ambulance. This would need to be automated, however, in order to relieve the EMTs of any further distractions that would hinder their driving.

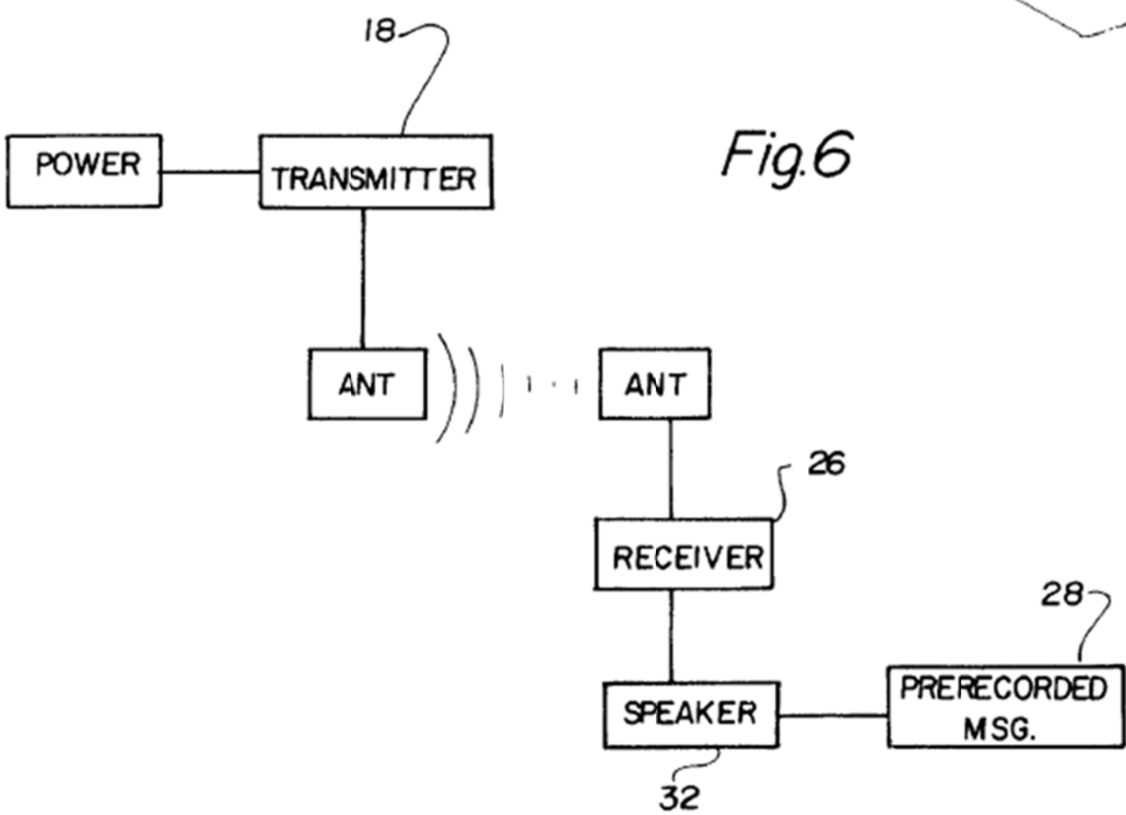


*Figure 26: Flow diagram for a Citizen Band radio alert system, Patent No. 5825304*

**Emergency Vehicle Alert Apparatus**

Patent Number: 5808560

Filing Date: 06/17/1996

Publication Date: 09/15/1998

Inventor: Mulanax, Michael L. (Las Vegas, NV)

This patent uses a digital transmission sent from an emergency vehicle to receiving units installed in nearby vehicles. The transmitter has a fixed message also known at the receiving end (similar to a preamble). If the receiver detects the same correct transmission two or more times sequentially, it will trigger an audible alert in the form of a prerecorded message.

As shown in Figure 27, the top diagram shows flow diagram for the transmitter module installed in an emergency vehicle. The bottom diagram shows a flow diagram for the receiver module installed in civilian vehicles. The programmed data code is correlated with the received data and checks for two sequential transmissions.

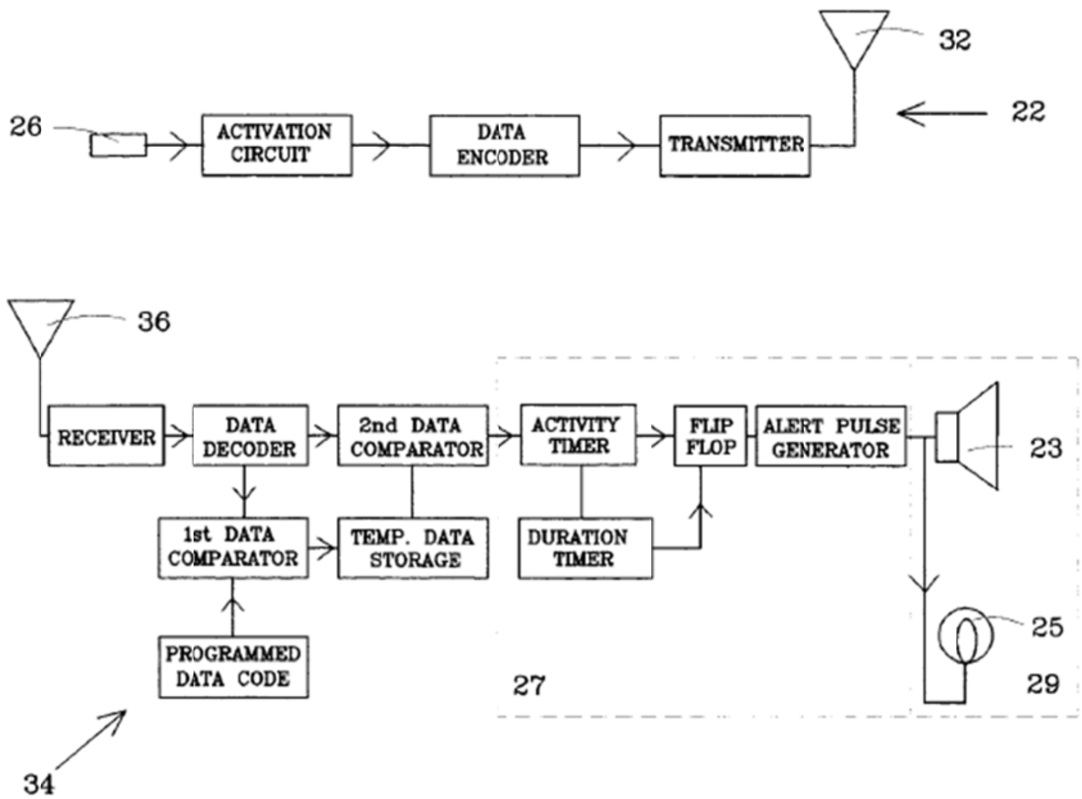


*Figure 27: Transmitter and receiver modules for Patent No. 5808560*

**Emergency Vehicle Alert System**

Patent Number: 6958707

Filing Date: 01/06/2003

Publication Date: 10/25/2005

Inventor: Siegel, Michael Aaron (303 N. Maple Dr., Beverly Hills, CA, US)

Slightly different from the normal transmitter/receiver, this patent incorporates traffic preemption with emergency vehicle dashboard notifications. The transmitter sends data incorporating multiple items including speed, location, and direction of travel to the car's dashboard as well as to traffic lights allowing for traffic preemption. The signal would originate from either a transmitter installed in the emergency vehicle or through existing wireless communications towers, which would receive pertinent data from a central server located at the ambulance's dispatch center.

This design has several flaws that would make it impractical for implementation. Due to the complexity of the system, all of the individual components soon become very expensive. Based on the description, this would be very similar to new cell phone network but in some ways even more complex. Compliance with major companies such as AT&T or Verizon would be necessary to be able to use their equipment, towers, and dedicated frequency spectrum allocation. Next, GPS or some other form of triangulation would be required to identify the emergency vehicle and the commuter vehicles within its vicinity. This becomes exponentially more complex as the number of emergency vehicles in an area increases. Lastly, the receivers that would be installed in each commuter vehicle would be about as expensive both in product and service charges as a cell phone, a cost drivers would have to pay for unless subsidized by the government or incentives provided by insurance companies.

Although this is clearly not the most efficient, cost-effective, or overall practical solution, there are some important features that would be useful. Providing the driver with information regarding the emergency vehicle (or vehicles) in the vicinity could help the driver make the correct decision. However, it is important to note that providing too much information increases driver confusion and distracts from the most important task of driving. Critical information may include from where the vehicle is approaching, but not necessarily the exact distance. The proposed dashboard system, as shown in Figure 28, shows more information than what is critical to the driver. The proposed dashboard system provides too much information for a quick glance from the driver. Long text messages make it difficult to interpret the vital information, in this case, that there is an emergency vehicle to the left. However, the use of graphical representation is nice feature and could possibly replace the text display altogether.

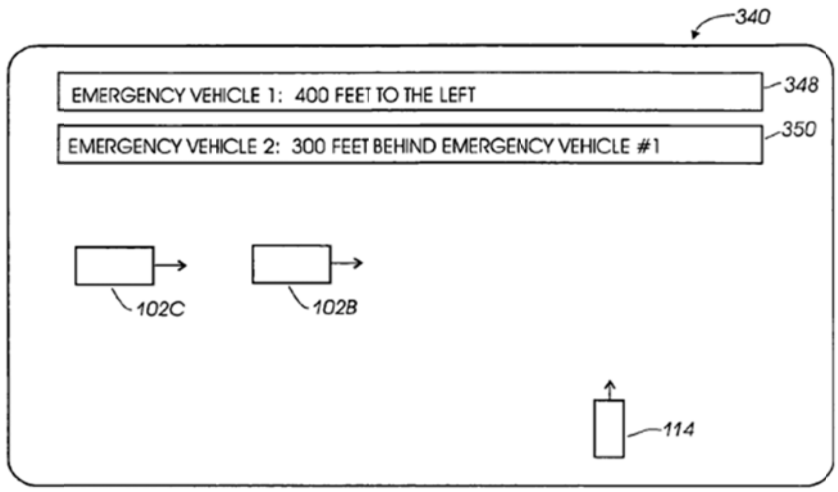


*Figure 28: Dashboard display module*

**Emergency Vehicle Alert System**

Patent Number: 6339382

Filing Date: 12/07/2000

Publication Date: 01/15/2002

Inventors: Arbinger, Donald A. (Neenah, WI)

Bergin, Dennis R. (Appleton, WI)

Pieper, Shane M. (New Berlin, WI)

Sander, Scott T. (Greenfield, WI)

This patent utilizes GPS as well as a broadcasted signal. The emergency vehicle will have a GPS unit and continuously broadcast it's coordinates over some designated frequency. The passenger vehicle will have a GPS receiver and an RF receiver; using the coordinates of the ambulance, the device in the car will compare the two locations. If they are within some given proximity, a warning message displays the location of the emergency vehicle relative to the driver; if not it remains idle. The transmitting and receiving units are shown in Figures 29 and 30, respectively.

As with Patent No. 6958707, this system displays the location of the approaching emergency vehicle, information important for the driver to take appropriate actions. However, this system is not very efficient because of its redundancy. The only purpose of incorporating GPS receivers is to compare the location of the two vehicles and display their difference. However, there are other methods of detecting the direction of a transmission without necessarily sending the coordinates. One method used in aircraft navigation when flying under Visual Flight Rules (VFR) is an Automatic Direction Finder (ADF), a device that determines the relative location of a transmission based the intensity of the signal received by the two antennas. This method is established, reliable, and not nearly as complex. In addition, the required equipment would be cheaper since GPS receivers would not be necessary for operation.

As shown in Figure 29, coordinates are retrieved from a GPS receiver and the longitude and latitude are sent over the RF channel to vehicles within its proximity. In Figure 30, a GPS receiver identifies the driver's current longitude and latitude. The RF receiver acquires a transmission from an emergency vehicle and compares the two coordinates.

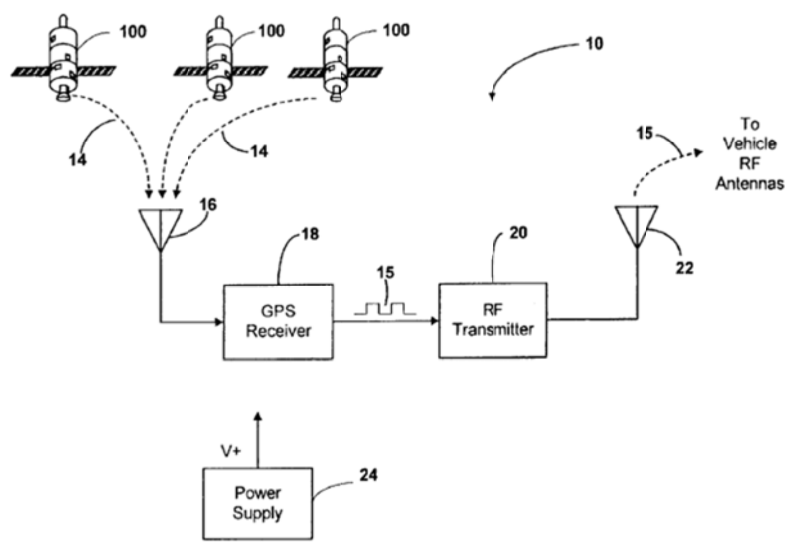


*Figure 29: The transmitting unit installed on the ambulance*

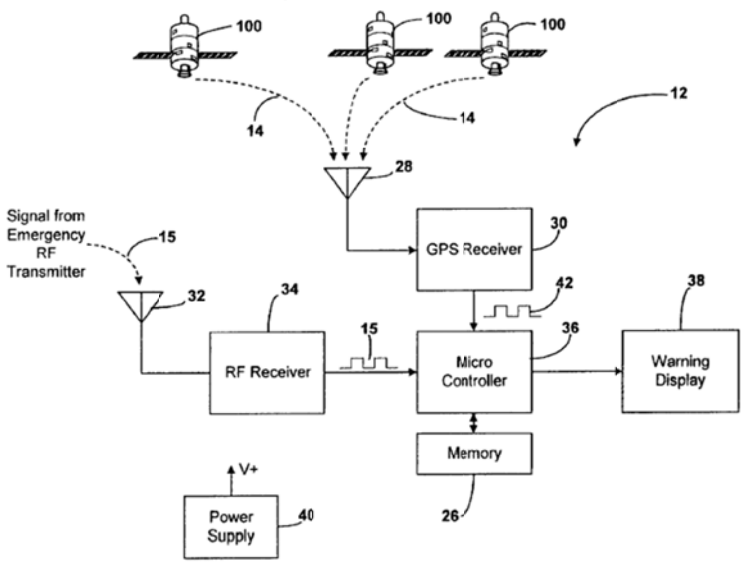


*Figure 30: The receiving unit installed on the commuter vehicle*

**Emergency Vehicle Detection System**

Patent Number: 6778101

Filing Date: 11/27/2002

Publication Date: 08/17/2004

Inventors: Turbeville, Terry A. (Goshen, KY)

Majka, John R. (Louisville, KY)

This system similar to others also incorporates a transmitter/receiver pair with transmissions from the emergency vehicle and the receiver located in the commuter vehicle. The transmitter sends a sinusoid over a designated frequency and the receiver oscillates a warning signal (possibly through a speaker) proportional to the intensity of the received signal. In other words, if the emergency vehicle is far away, the warning speaker would oscillate slowly but as the vehicle comes nearer the rate increases. The primary difference with this device and several other patents is that it aims for a simple and inexpensive yet reliable system.

Compared to other consumer transmitters that operate in VHF running on 6 volts, this transmitter should have an approximate range of about 50 meters, an ideal distance for communicating between emergency vehicles and other drivers on the road. Also since these radios are built almost entirely out of analog components such as resistors, capacitors, and transistors, the end product will be much less expensive than similar proposed systems that require complex real time signal processing equipment that can cost as much as several hundred dollars. Cost is a very important factor to consider for successful implementation since a receiver needs to be installed in the majority of commuter vehicles. This cost will fall on the drivers, the state or local government that will have to subsidize the mandated equipment, or possibly insurance agencies that offer incentives for the product.

### 2.6.2 SASERs

The word “laser” is actually an acronym for “Light Amplification by Stimulated Emission of Radiation”. Basically, a laser is a focused beam of light. A “saser” is the same sort of thing, but instead of light it uses sound. The technology of sasers is very new and is still being improved upon. Like a laser, a saser is a very focused and potentially harmful beam. While lasers are incredibly bright, sasers are similarly loud. The military recently heard of this new technology and contracted American Technology Corporation, or ATC, to produce a saser powerful enough to be used in the field. ATC developed the MRAD (Medium Range Acoustic Device) and LRAD (Long Range Acoustic Device) sasers as seen in Figure 31.


(a)


(b)

*Figure 31: (a) Medium Range Acoustic Device produced by American Technology Corporation. (b) Long Range Acoustic Device produced by American Technology Corporation*

LRAD has now become its own company and produces several types of sasers for security, public safety, military, and renewable energy sources. The smallest saser produced by LRAD is roughly the size of an electric siren utilized by emergency vehicles already. The purpose of looking into installing a saser on emergency vehicles is an attempt at solving the problem of drivers with loud music playing who cannot hear approaching emergency vehicles. The smallest model, as seen in figure 32, is all that would be required because the sasers produced by LRAD are quite powerful in that they are primarily used for military and public safety situations.


*Figure 32: The LRAD-X 100X, the smallest saser produced by LRAD-X*

We have interviewed several emergency personnel and each person interviewed agreed that drivers with loud music or sound proof cars were a hassle to deal with. Using a saser would allow emergency vehicles to be especially loud at a pinpoint location in order to get certain cars attention and make them move. While the saser would be effective for this use, it may be too effective. Sasers have a very long range and usually make sounds around the 120dB range, or about the volume of a jet engine. This is potentially harmful over prolonged exposure although it would be intended for very limited use in short bursts only, like a car horn.

Thankfully, a saser has a very concentrated beam like a laser and unless someone is in the beam's width, they will hear very little or nothing at all. The MRAD and LRAD systems were originally designed for the military and are already used for riot control. It would be possible to weaken the saser, although a weakened saser would still be a weakened riot control device. Overall, the saser could be a viable solution if it had some tweaking. As it stands now, the saser is too powerful for a wide range use on several emergency vehicles with the possibility of accidental discharge in crowded downtown areas and sound reflection being too much of a risk.

### 2.6.3 OnStar and Related Systems

One system that is being incorporated into many cars currently is the OnStar system. The system is already programmed to notify OnStar when a crash has occurred and allows an operator to talk to the driver immediately after the occurrence of an incident who can then dispatch police, fire, and/or an ambulance to the scene of the crash. Additionally, OnStar allows the driver to talk to an operator with simply the push of a button. OnStar is listed in this section of the report because there is a possibility that the OnStar system can be manipulated to notify the driver in some way of an approaching emergency vehicle to prevent any incident and allow the emergency vehicle to pass by easily without having to reduce its speed significantly.

One possibility for implementing this system is to have an OnStar operator call the driver in the car who is approaching an ambulance to notify the driver of the approaching ambulance and give them a heads up of where the ambulance is coming from and the driver's best course of action to stay out of the ambulance's way. One issue evaluated with implementing this as a solution is that the underlying technology of the OnStar system is a cell phone. This means that for every driver with OnStar in their vehicle that is within close proximity to an emergency vehicle, a cell phone call will need to be placed to warn those drivers of the approaching emergency vehicle. This will result in many calls being placed in a very short amount of time for every time an emergency vehicle flicks its lights and sirens on to get where it needs to be. In large cities where emergency vehicles are always crossing from place to place, not only would this overload the cell phone network, but it would also become a huge annoyance for drivers with OnStar and would consequently make the system less attractive for potential buyers of cars with OnStar installed.

### 2.6.4 Radio Broadcast Overlay

British fireman and inventor, James Hutchinson, proposed a design for a device called the 'Warn-Tone', a transmitter to be used by emergency responders to communicate with drivers through their car radios. Warn-Tone would scan the seven strongest radio stations in the area and transmit a preprogrammed warning message on each channel cycling once per minute. Using a low power directional antenna the signal would hopefully only be sent to vehicles directly in front of the ambulance or fire engine. However, the inventor has not had the opportunity to test the invention because Radio Authority of the United Kingdom will not provide a test license; they are convinced that the radio waves would propagate up to several kilometers thus interfering with radio communications across the area, not just the proposed 100 meter stretch of road ahead.

This device would be most useful for gaining attention of drivers distracted by music while driving, particularly those with sound resistant vehicles. In this case, drivers would be able to hear a siren much earlier than through conventional means and possibly take appropriate action before the ambulance or fire engine arrives. And unlike many of the proposed patents, this device utilizes existing car radios and doesn't require the retrofitting of new receiver units. However until it can be shown that the device would not interfere with other radio transmissions, progress will remain at a standstill.

# Chapter 3: Testing our Solutions

In Chapter 2, we identified several existing solutions available that could potentially help improve communication between EMTs and civilian drivers. This chapter will discuss the most viable solutions that could most easily be implemented into society

## 3.1 Introduction

All of the solutions mentioned previously have strengths and weaknesses. Based on the number of patents, the concept for a dashboard mounted emergency vehicle alert system has clearly been widely considered; however, a system has yet to actually be implemented. The biggest challenge for such a system is incorporating the device into every vehicle on the road. A receiver module would need to be installed and operational in the vast majority of civilian vehicles in order to be effective. Because such a mass overhaul would be very expensive, EMS companies are not willing to invest in such a program without subsidized support from the government or incentives from insurance agencies.

A more effective and efficient approach is to improve the communications only on the emergency vehicle, not civilian vehicles. This greatly reduces the number of required units and hence the cost of implementation. Through our research, we have identified passive and active communication methods.  Passive communication is static, conspicuous in nature, and requires no power; examples include the color of the vehicle and reflective materials. Active communication methods are designed to harness attention by changing state and often require power; examples include flashing or rotating lights and sirens.

### 3.1.1 Wireless Transmissions

Although a wireless transmitter and receiver system has yet to be implemented in society, our group has not completely ruled it out as possible solution in the future. For example, if automobile manufacturers included a receiver in the dashboard, implementation would become much simpler. To show how a such a system could work if it were ever implemented, we will devise a simple proof of concept using two Universal Software Radio Peripheral (USRP2) software defined radios to simulate a transmitter located on an ambulance or other emergency vehicle and a receiver located on a civilian vehicle.

### 3.1.2 Passive Communications

The possibility of testing our hypotheses with UMASS was declined because of patient privacy laws and regulations.  We were informed that these were not just UMASS' regulations and that any ambulance company we contacted would tell us the same thing.  This meant that any testing involving the effectiveness of colors and patterns on ambulances would be very difficult or not possible.  The only additional information UMASS could give us was that blue lights were being added to some ambulances for their conspicuity and reputation of marking a real emergency.

### 3.1.3 Active Communications

Our research has not identified many differences in the effectiveness of types of lights. Most ambulances and police cars have switched to light emitting diode (LED) bars because they are cheaper, smaller, use less power, and are brighter than traditional rotating incandescent bulbs. Many fire engines still use the rotating bulbs but there is little evidence to suggest that they are either better or worse at communicating with other drivers on the road.

Different siren types, however, might prove differently. Mechanical and electrical sirens produce unique sound waves which propagate differently. As mentioned in Chapter 2, electronic sirens produce sinusoids which easily disperse over large areas. Mechanical sirens produce a more directional square wave which in theory allows drivers to more effectively locate the source. To determine if different siren types are more effective in certain traffic conditions, we will ride with the fire department on several runs alternating between using electronic and mechanical sirens. The effectiveness of each will be determined by the trial that yields a higher average speed.

## 3.2 Wireless Transmissions

In this section, we will first provide an overview of wireless communications and basic signal processing. Next, we will explain how it is applied in simulation using MATLAB and Simulink. Finally, we will describe the actual implementation and results of testing using the USRP2 software defined radio.

### 3.2.1 Signals Processing: an Overview

One must have a broad understanding of some signal fundamentals in order to understand our process. We will first describe analog and digital signals, sampling, then switching between the frequency and time domains using the Fourier Transform, and finally modulation.

### 3.2.1.1 Analog and Digital

Analog signals, also referred to as continuous time signals, consist of an infinite number of values that are always fluctuating with time. An example of analog signal is speaking directly to another person. Sound waves that continuously disturb air particles are generated at every instance of time. The difference with digital signals, also referred to as discrete time signals, is that the data is sampled periodically. An example of a digital signal is talking to person over a cellular phone. When speaking through a phone, the device takes samples of the data about 8,000 times per second (8 kHz). In other words, the listener on the other end only receives data every 1/8000$^{th}$ of a second, not every instance in time. This is why speaking through a phone does not sound as clear as speaking directly face-to-face.

All wireless communications use digital signals. Car radios, cell phones, and wireless routers at WiFi hot spots all use digital signals. One major difference is their sampling rate; higher sampling rates mean more data must be transferred but at the tradeoff for higher quality. This is why speaking through a Voice over Internet Protocol (VoIP) program such as Skype has higher quality than speaking through a cell phone; VoIP supports sampling rates up to 32 kHz, 4 times that of a cell phone.

### 3.2.1.2 Sampling Rates

All digital signals must be sampled but what determines the sampling rate? According to the Nyquist-Shannon Sampling Theorem, a signal must be sampled at twice the highest frequency of the signal; this frequency is commonly referred to as the Nyquist Frequency. When a signal is sampled, copies occur at multiples of the sampling frequency. Figure 33 shows the frequency spectrum of a signal.

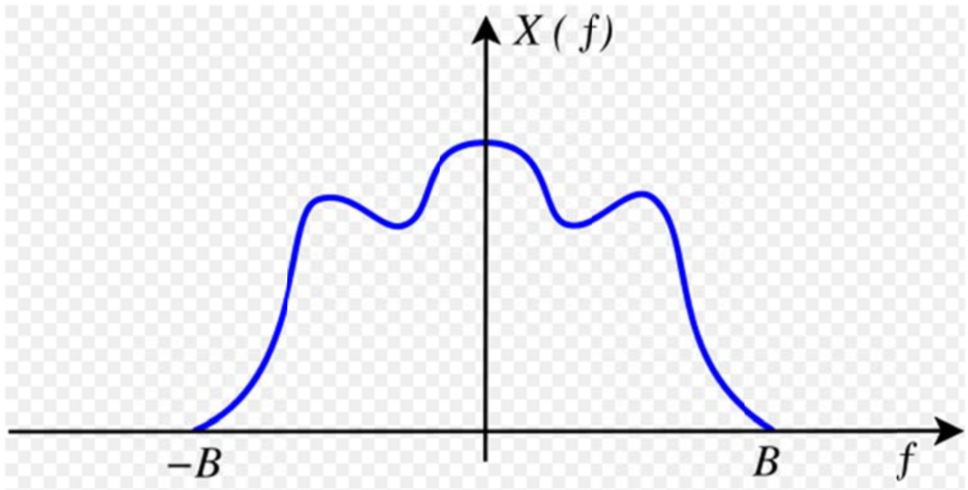


*Figure 33: Frequency spectrum*

If it is sampled at a frequency less than *2B*, the copied samples will overlap causing an effect called aliasing, as shown below in Figure 34. The signal is sampled at $f_s$ as shown by the samples. When the original signal (blue) and the sampled signal (green) overlap, aliasing occurs and that data is lost. Thus, sampling at the Nyquist frequency preserves the quality of the original signal.

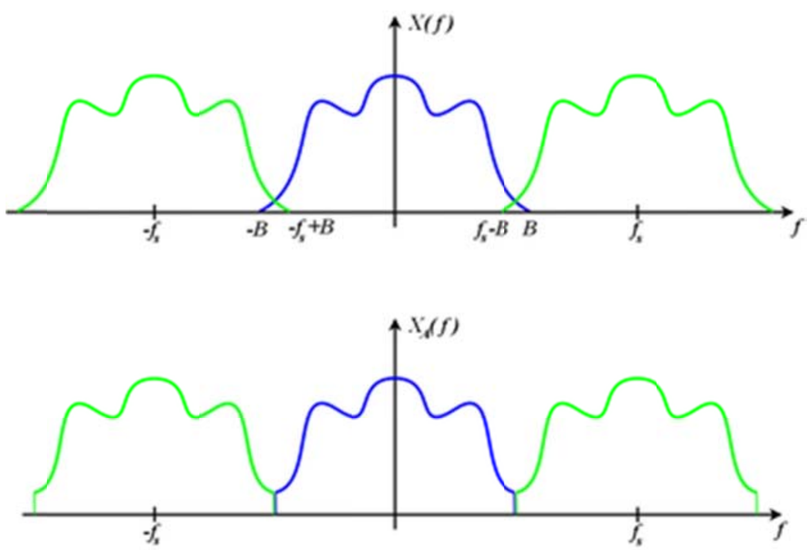


*Figure 34: Signal sampled at less than 2B which results in aliasing*

Sampling at the Nyquist frequency is important for any wireless communication system that is transmitting data that cannot be corrupted. For this proof of concept, the radios we are using sample at 100 MHz, or 100 million times per second. This rate cannot be increased but it can be decreased by using a decimation factor. For most applications, such a high sampling rate is not necessary and requires a powerful processor for the computations; this is particularly non-ideal for a mobile device. To help improve the speed, we are using a decimation factor of 512 (note that it must be a factor of 2). This reduces the sampling rate to about 195,000 samples per second.

### 3.2.1.3 Time and Frequency Domains

Time and frequency are inversely proportional such that $t = 1/f$. If the frequency of a signal increases, then the period (time) decreases. Signals can be expressed in either the time or frequency domain. For example, let's analyze a sinusoid, $x = sin(2\pi f*t)$. This waveform is periodic with a frequency *f* which means that at every time *t*, the signal will repeat as shown in Figure 35.

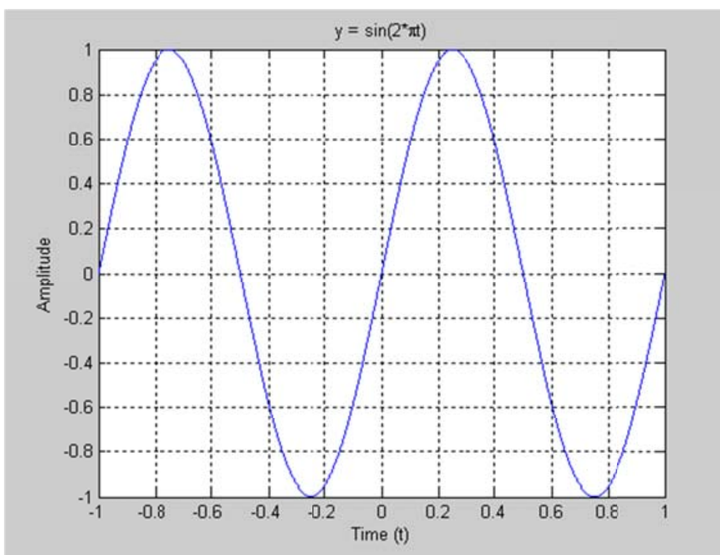


*Figure 35: Sinusoid with period of 1*

Note that this sinusoid only has one frequency (1 Hz) and no harmonics. Thus, the plot of this sinusoid in the frequency domain will appear as a single spike at 1 Hz, as shown in Figure 36. This spike is often referred to as Dirac delta function, or $\delta(x)$ for short. The delta function is zero at all points except *x* in which case the value approaches infinity. A mathematical operation called a Fourier transform is a simple way to convert a signal in the time domain to the frequency domain. Similarly, an inverse Fourier transform can convert a signal from the frequency to time domain. How this operator works is beyond the scope of this paper but it will be used in simulation as described in Section 2.B.

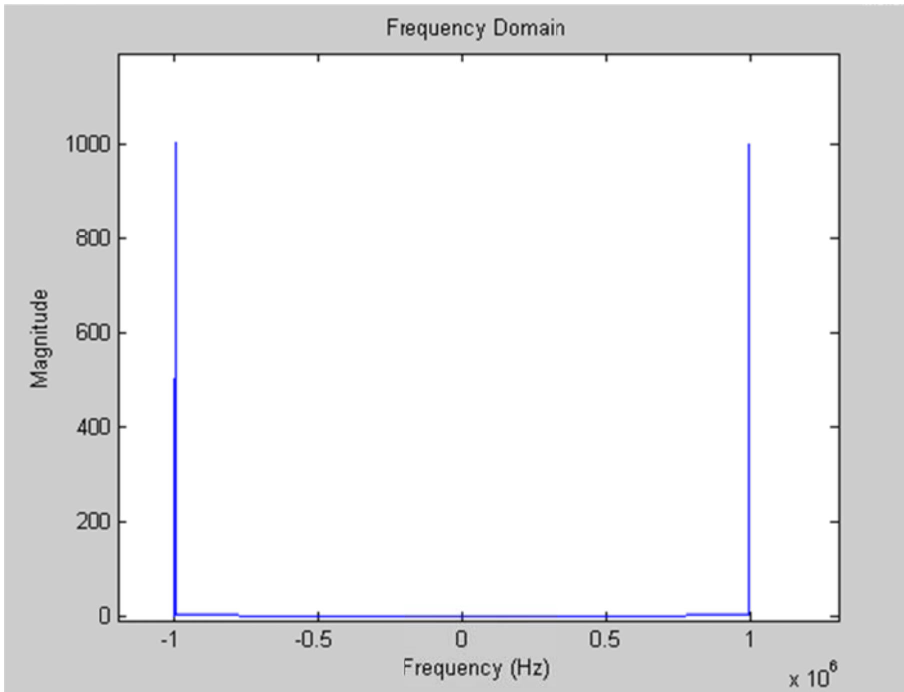


*Figure 36: Frequency Domain*

Transmitting sinusoids is ideal for this wireless transmission application because of its narrow frequency properties. The Federal Communications Commission (FCC) regulates virtually all frequencies in the range of 3 kHz to 300 GHz. Since most of these frequencies have already been allocated different types of wireless communication such as AM radios, cell phones, televisions, and satellite navigation, it would be difficult to receive a wide range of frequencies. A sinusoid, however, occupies very little bandwidth.

Although in theory a sinusoid only occupies one frequency, this is not the case in practice. An ideal transmitter will approach this limit; however factors such as internal resistance and resonant frequencies of the electronics inside of the radio prevent this. Nonetheless, the occupied frequencies are still significantly less than many other signals.

#### 3.2.1.4 Modulation

When listening the radio in a car, there are typically several stations to choose from, each with a different type of music or talk show. The ability to listen to any of these stations is a possible because of modulation.

Modulation changes the frequency which a signal is transmitted and allows data to be transmitted from 3 kHz to 300 GHz. For example, let us analyze the transmission process of an AM radio talk show. The listener may tune their radio to 700 kHz. Does this mean the people at the radio station are speaking at 700 kHz? Of course not. They are speaking at the same frequency as any normal human being, about 1 – 11 kHz. Their speech is currently at baseband. In other words, the frequency of the data (their voices) and the frequency at which it is transmitted is the same. To transmit at 700 kHz, the data must be modulated, or boosted, to a higher frequency. This is achieved by multiplying the signal with another sinusoid. As mentioned previously, the frequency spectrum of a sinusoid is a delta function which is zero at all values except for one frequency. If this frequency is specified to be 700 kHz, then the baseband signal will shift to 700 kHz.

### 3.2.2 Simulation using MATLAB and Simulink

In this section, we will discuss how a wireless transceiver system can be modeled using MATLAB and Simulink.

#### 3.2.2.1 Transmitter

For simplicity, a simple sinusoid tone is used as the “message” transmitted from the emergency vehicle. This is very easy to create using Simulink since there is programming block that generates a discrete sinusoid at a specified frequency and amplitude. The sinusoid is then sent to the transmitter block which links to the software defined radio, the USRP2. This will be explained further in section 2.C.

#### 3.2.2.2 Receiver

Unlike most radios such as a car radio that must correctly decode a transmission and play it back through an audio port, this receiver just has to identify whether or not a signal is present. In other words, the receiver is nothing more than a threshold detector. When the magnitude of the received signal is greater than some predetermined threshold, the program concludes that an emergency vehicle is in the vicinity; otherwise, it continues scanning as normal.

Like other wireless transmissions, this sinusoid will be sent and received in the time domain. However, threshold detectors operate in the frequency domain. In order to make use of the received signal, it must be converted using a Fourier Transform. Taking its absolute value (all positive values) will yield the magnitude which can then be compared to the threshold value. Recall that since this sinusoid has no harmonics, there will be a single delta function located at its specific frequency. This is important to note since the magnitude of that one delta function will be much greater than the average magnitude of the rest of the signal and thus relatively easy to detect. The average value and the standard deviations of the magnitude of a sinusoid are shown in Figure 37.

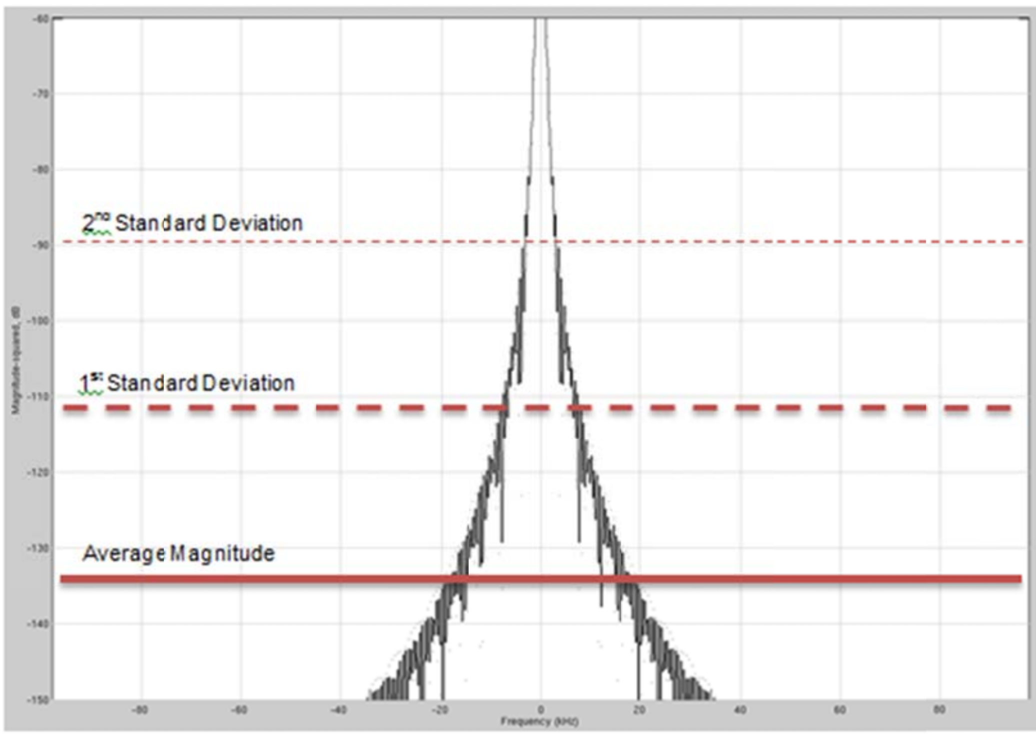


*Figure 37: Average magnitude and standard deviations for a transmitted sinusoid*

Since sinusoids are consistent and very well defined, a convenient choice for the threshold is the second standard deviation of the magnitude of the received signal. This level can be set one of two ways. First, a known or expected threshold level can be hard coded into the receiver such. This method works well if there is not a lot of fluctuation in the transmission properties. For example, since the signal is always going to be a sinusoid, the relative shape and magnitude are consistent. However, other characteristics could change this property. For instance, building or trees along the road can create obstructions to the line-of-sight transmission and rain could introduce a channel that reduces the signal transmission strength.

The second method is for the receiver to create a new threshold every time it turns on by scanning the spectrum and calculating its average value. This system is more robust since it can adapt; however, one major flaw is that if the spectrum is scanned when there actually is a transmission, not just ambient noise, the threshold value may be skewed and not work accurately. For testing purposes however, we can control when the emergency vehicle radio is transmitting and thus we will be demonstrating this method. The Simulink model is shown below in Figure 38.

#### *3.2.2.2.1 Simulink Model*

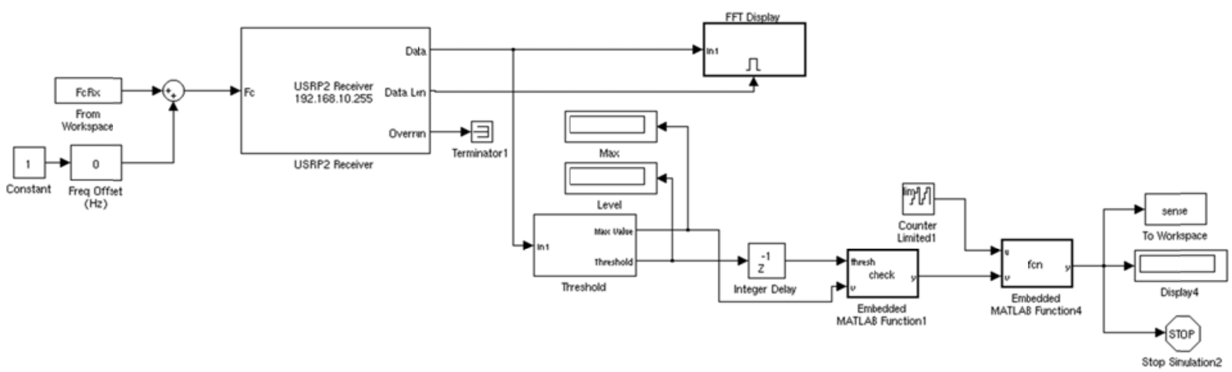


*Figure 38: Simulink receiver model*

Beginning on the left, the USRP2 receiver block is controlled by a specific carrier frequency, FcRx, which is defined in the MATLAB script and will be described in detail in the following section. Basically, this frequency must be the same as the transmit frequency so both the transmitter (the emergency vehicle) and the receiver (the civilian vehicle) are on the same channel. If they are off by even a few kilohertz, the receiver will not be able to identify the emergency transmission. However, calibration is simple to achieve either manually or using a carrier detection algorithm. For this demonstration, the frequency will be calibrated manually by centering the spectrum produced by the “FFT Display” block at baseband.

The receiver block is connected to the USRP2 software defined radio via a gigabit Ethernet connection. Ethernet is used instead of USB because it has a much faster data transfer rate which is necessary to support the radio’s 100 MHz data transfer rate. Configuring a radio requires root privileges in Terminal; the internet protocol (IP) address for the radio, typically 192.168.10.255, must be configured at the gigabit Ethernet port. Furthermore, the firewall controlling that port must also be turned off. The code is shown below in Listing 1.

*Listing 1: USRP2 Configuration*

```
sudo –i

nano /root/scripts/iptables.sh                  // turn off firewall

$IPTABLES_COM –P INPUT ACCEPT                   // type these lines
$IPTABLES_COM –P OUTPUT ACCEPT
$IPTABLES_COM –P FORWARD ACCEPT

/root/scripts/iptables.sh                       // run script

nano /etc/network/interfaces                    // edit ifconfig file

auto lo                                         // type these lines
iface lo inet loopback

auto eth0
iface eth0 inet static
address 192.168.10.1
netmask 255.255.255.0

auto eth1
iface eth1 inet dhcp

/etc/init.d/networking restart                  // update file contents

exit                                            // exit root
```

The receiver block emits a continuous stream of raw data which must be processed by the Threshold block, as shown in Figure 39. The magnitude is calculated by passing the signal through a Fast Fourier Transform (FFT), an algorithm for the Fourier Transform that uses a recursive algorithm and is optimized for computers.

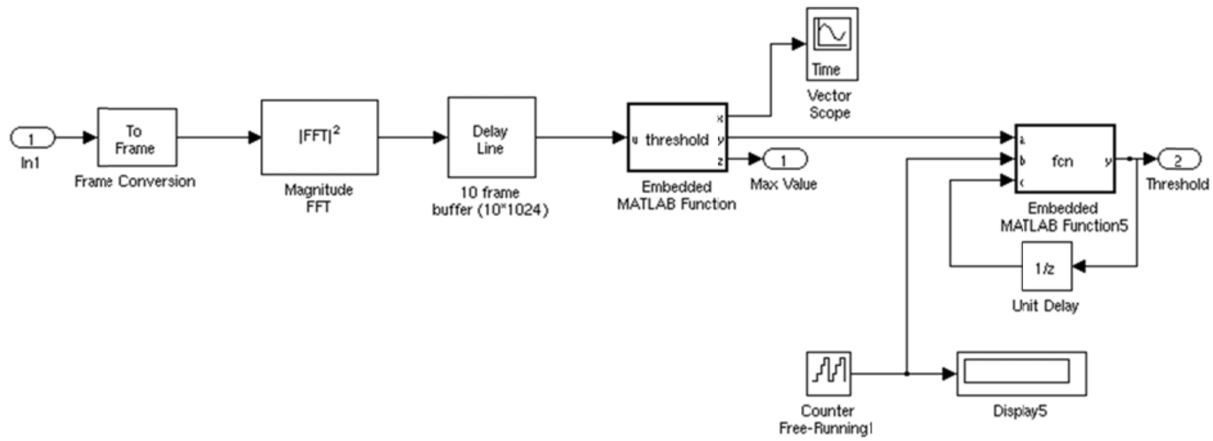


*Figure 39: Threshold Block*

The first Embedded MATLAB Function, shown in Listing 2, calculated the peak value, the mean value, and a 2-sigma threshold located two standard deviations above the mean.

*Listing 2: Embedded MATLAB Function: Threshold Calculation*

```
function [x,y,z] = threshold(u)

dbpskrx = reshape(u,1024,[]);

dmean = mean(dbpskrx,2); % mean over 10 frames
maximum = max(dmean);
dtmean = mean(dmean); % mean total value
dstd = std(dmean);

dthresh = dtmean + 2*dstd; % 2 sigma threshold

x = dtmean;
y = dthresh;
z = maximum;
```

The second function uses a timer (“Counter, Free Running” block) to set and lock the threshold after running for about half of a second. This is the initial “scanning period” in which the receiver adjusts the threshold as necessary based on the channel environment. After this second has elapsed, the threshold remains constant until the receiver restarts about 3 seconds later. Back in the main model, the maximum value of each frame of received data is compared to the threshold. If it exceeds the threshold, it outputs a ‘1’ or logic high; otherwise, it defaults a ‘0’ or logic low.

#### *3.2.2.2.2 MATLAB Script*

All of the signal processing is conducted in Simulink however the architecture of the entire program is conducted in MATLAB. Due to the properties of the USRP2, the carrier frequency tends to slowly drift due to a small phase shift. If left unattended for extended periods of time (more than 30 seconds), the received data could be badly corrupted. A simple fix to this problem is to periodically restart the radio at regular intervals. When the radio is turned off momentarily, MATLAB updates a text field with one of two appropriate messages based on the current output of the Simulink model. If the value is 1, “Emergency vehicle within the vicinity” is printed; otherwise, “All clear” is printed. This process continues indefinitely until the system is manually turned off. The script is shown below.

*Listing 3: MATLAB Script*

```
FcRx = [1, 2.47e09];    % set center frequency to 2.47 GHz
n = 10;                 % number of iterations (replace with inf. loop)

for i=1:n
    sim('Detector02');
    if sense > 0
    %if sense < 1
        timestamp('Emergency vehicle within the vicinity');
    else
        timestamp('All clear');
    end
    spin(1);
end
```

### 3.2.3 USRP2 Implementation and Testing

The final step is to connect the USRP2s to two separate computers, upload the program, and test the functionality. For this proof of concept, we are limited to the frequency range of the radios which is from about 2.45 – 2.49 GHz. For an actual system, a more ideal frequency would be in the kHz or MHz range because they can transmit several hundred even on low power. The USRP2 has a maximum range of about 20 feet but the concept can still be demonstrated. The first situation to test is when the two radios are far apart (10 – 15 feet), simulating an “All clear” scenario. As shown in Figure 40, the two radios are about 12 feet apart. The radio on the right is simulating the emergency vehicle and transmitting a sinusoid. The one on the left is checking for a signal but since it is out of range, the message “All clear” is printed.

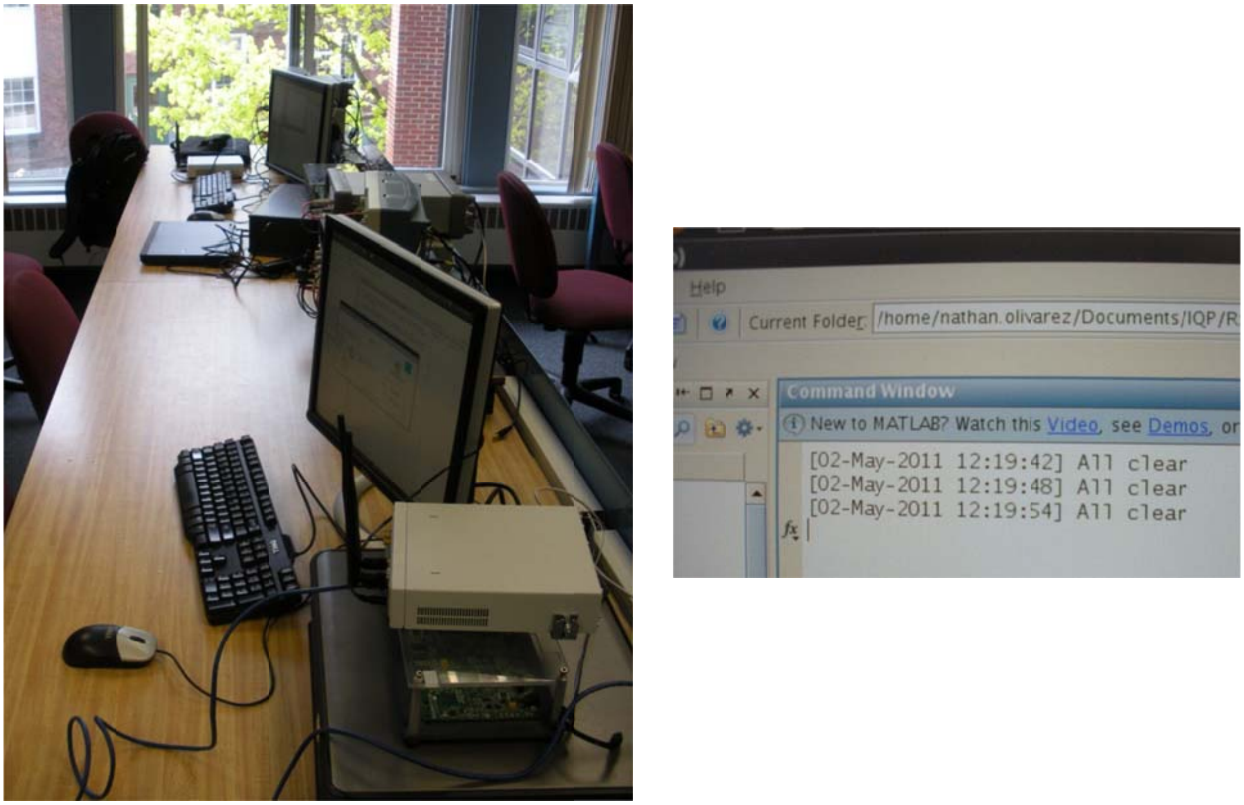


*Figure 40: Scenario 1- Emergency vehicle not in the vicinity*

The second situation is when the two radios are near each other (0 – 5 feet) simulating an approaching emergency vehicle. As shown in Figure 41, the two radios are about 2 feet apart. The maximum value of the sinusoid exceeds the threshold because the receiver is within range of the transmitter. As a result, the message “Emergency vehicle within the vicinity” is printed.

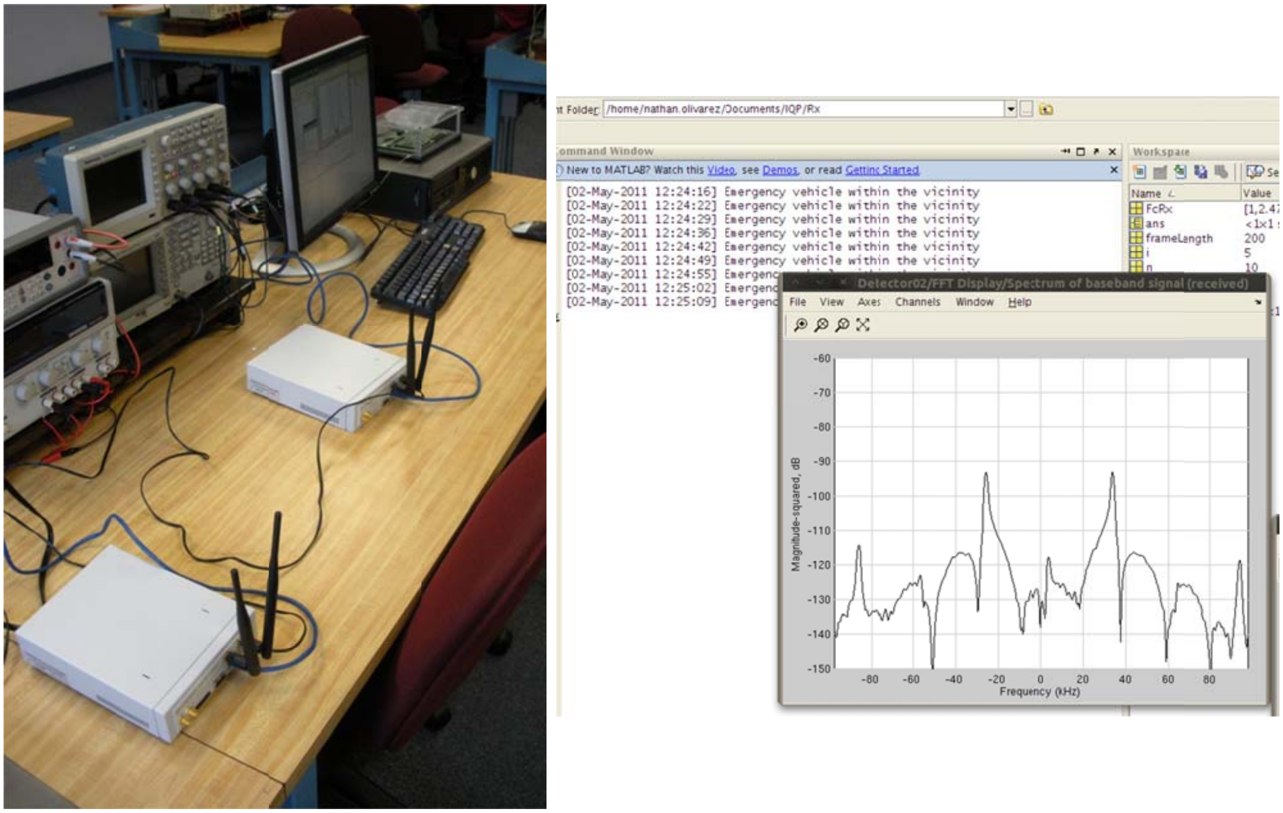


*Figure 41: Scenario 2- Emergency vehicle in the vicinity*

### 3.2.4 Conclusions

This proof of concept demonstrates that a wireless transceiver system can be used to alert a driver when an emergency vehicle is in the vicinity. The radios used for this experiment, the USRP2, include two field programmable gate array (FPGA) daughter cards configured for 2.47 GHz and 5.2 GHz. These FPGAs take care of the modulation when transmitting, and demodulation, digital signal processing, and equalization at the receiving end. If a similar system is implemented with different radios, each of the components described in the in the overview, Section 3.2.1, will have to be accounted for. In addition, it would be best to use a more powerful transmitter at a lower frequency in the high kHz or low MHz range in order to maximize the effectiveness.

## 3.3 Active Communications: Sirens

Part of our initial testing plan involved testing electronic versus mechanical sirens with various ambulance colors and patterns. While at UMASS, we were told that they had no ambulances that utilized mechanical sirens and they were not aware of any that did in the area. In order to test the effectiveness of electronic versus mechanical sirens, we needed to speak with the local fire department. Our testing procedure for fire truck sirens was similar to our ambulance testing procedure. We would ride along on several calls and ask the drivers to use either an electronic or a mechanical siren. During the call, we would record the time between each turn, the name of the streets we were on, and whether or not there was traffic. Once we had this data, we would then re-create the route using Google Maps to find out the distance between each turn and what type of road we were on. With this data, we could determine approximately how long it took the truck to travel down certain types of roads using electronic or mechanical sirens. This meant we could see which siren was more effective on what type of road.

### 3.3.1 Background

During our testing we spoke with many Worcester firemen about their opinions of siren effectiveness. The general consensus seemed to be that the mechanical "Federal" siren was the most effective. The firemen believed the effectiveness wasn't due to the propagation of the sound waves but the familiarity the public has for the "Federal" siren. This meant that the public assumes a large fire truck is coming when they hear the distinct siren. Only one captain of a station believed there was a siren more effective than the Federal. He claimed to use the "High-Low" siren. The "High-Low" siren is a siren commonly heard in Europe and gets its name from its distinct alternating high and low pitches. Some firemen believed this was found to be effective because the public is unfamiliar with the sound and would be more inclined to find out what it was.

*Figure 42: Federal Siren*

The firemen were also able to give us more variables to consider. They informed us that every driver used a combination of horns and sirens in their own way. The Federal siren is the most popular siren but its use varies from passenger to passenger. The Federal siren is operated via a foot pedal on the passenger side of the fire truck. When the pedal is depressed, the Federal siren begins to spin. The longer the pedal is depressed, the faster the siren spins. This means the siren is always different. Some passengers will alternate the Federal at fast and slow speeds while others will just hold it down for the louder and faster sounding siren.


*Figure 43: Worcester Ladder 1 with electronic siren, Horns, and mechanical Federal siren*

Fire trucks with both types of sirens occasionally use both at the same time when an especially loud siren is required. The air horns mounted in the bumper, as seen in Figure 43, are typically used for instances where a vehicle is not moving. We were informed that while the Federal siren is the most popular siren, not all trucks are equipped with the Federal Siren. In fact, the trucks used most often at the Franklin Street fire station did not have Federal sirens. Each truck is equipped differently and thus will have different equipment depending on the manufacturer, year of construction, and purpose.


*Figure 44: Engine 12 from Worcester Franklin Street fire station*

Each truck in a fire station serves a different purpose and has its own jurisdiction. “Engines” are typically the first responders of fire stations. As seen in Figure 44, they are the smallest trucks and have all of the tools to carry out basic and vital emergency rescue services. The “Ladder” trucks, as seen in Figure 45, are the largest trucks and have a massive ladder to access people in tall buildings without risking going into the building. These ladder trucks are also equipped with extendable support buttresses that retract into the truck when not in use. In essence, the ladder truck is an engine with more tools and is more effective at fighting larger fires.


*Figure 45: Ladder 1 from Worcester Franklin Street fire station*

The final truck is the rescue truck. The rescue truck has no firefighting abilities and its sole purpose is to aid in the removal of victims from scenes of automobile accidents and structure collapses. These trucks are never sent out alone and will typically respond with an engine truck. The Worcester Franklin Street Fire Station had two engines, one ladder, and two rescue trucks. The Worcester Park Avenue Fire Station had one engine, one ladder, and one reserve engine.

*Figure 46: Rescue 1 from Worcester Franklin Street fire station*

### 3.3.2 Empirical Testing

By conducting ride alongs with the fire department going to calls, alternating between using the electronic and mechanical sirens, we were able to gather data to help show the effectiveness of electronic sirens versus mechanical Q2 sirens. Between two separate fire stations in the city of Worcester on two different Fridays in April of 2011, we were able to gather data from 6 separate runs. One run had two sets of data since one ladder and one engine were dispatched to the same location, each using a different type of siren. This gave us a total of 7 runs, which in the end, turned out to be just barely enough to get some data analysis results. However, had we had time to do more runs on some additional days, we may have been able to acquire more data to give more concrete results.

Between the 7 runs, 3 of these were done using the mechanical siren while the other 4 were accomplished using the electronic siren. The runs we acquired data for ranged in length from 0.44 miles in length to 2.26 miles in length. All data that was acquired for each run is shown and explained in Appendix B along with a screenshot, courtesy of Google Maps, of the route taken from the firehouse to the call location for each run.

For initial simple analysis of the data acquired, we first used the length and time spent on each road stretch for each run to get the average speed of the vehicle on said road. Next, the speeds acquired were averaged together for each individual run to give a total average speed for the run. These average values were placed into the table shown below, separated into categories as to whether the run was done using the electronic or mechanical siren and were then averaged for a final overall value for runs done using the mechanical and runs done using the electronic siren:

**Overall Averages Per Run**

| Siren | Distance | Average Speed | Electronic | Mechanical |
|---|---|---|---|---|
| Electronic | 0.90 | 22.04 | 22.040816327 | |
| Mechanical | 0.44 | 22.49 | | 22.490396927 |
| Mechanical | 2.26 | 33.67 | | 33.671111946 |
| Mechanical | 1.84 | 39.04 | | 39.040106952 |
| Electronic | 0.54 | 21.99 | 21.986721144 | |
| Electronic | 1.80 | 39.27 | 39.272727273 | |
| Electronic | 0.74 | 22.88 | 22.878787879 | |
| | | | **Average** | |
| | | | **26.544763155518** | **31.733871941598** |

*Figure 47: Siren Type Average Speed*

From this simple initial analysis, it is clear that this data concludes that using the mechanical siren yielded a slightly higher overall speed than the electronic siren did. However, for the amount of data collected with attention paid to the kind of road and other factors, analysis could not stop here. To continue analyzing the data, details about every stretch of road from all 7 runs were entered into a database to be organized based on factors such as the length of the road and the type of road. Analysis continued with 5 separate categories in mind: stretches of road less than 0.2 miles in length, stretches of road greater than 0.2 miles in length, residential roads, 2-lane roads, and 4-lane roadways.

For each of these 5 categories, they were split up individually for where the electronic siren was used versus the mechanical siren. Then, for each category and siren type within each category, two separate average speed values were acquired: one weighted based on the length of the road, and one that was not weighted at all (just an average of the average speeds on each stretch of road). The weighted average was calculated by multiplying the average speed for each stretch of road by the length of the road, adding all these values together, and dividing the result by the sum of the lengths of each of these roads. The tables used to calculate these final values are shown below. At the bottom of each column in the tables below are the average values of the values in each column (with the exception of the "Weighted" columns in each table, which was calculated as described above):

**Less than 0.2 miles**

| Electronic | | | Mechanical | | |
|---|---|---|---|---|---|
| Distance | Speed | Weighted | Distance | Speed | Weighted |
| 0.1 | 21.176470588 | 2.1176470588 | 0.1 | 27.692307692 | 2.7692307692 |
| 0.1 | 27.692307692 | 2.7692307692 | 0.0435606061 | 9.2245989305 | 0.4018291201 |
| 0.0435606061 | 9.2245989305 | 0.4018291201 | 0.1 | 12.857142857 | 1.2857142857 |
| 0.1 | 11.25 | 1.125 | 0.0634469697 | 19.034090909 | 1.2076553891 |
| 0.1 | 21.176470588 | 2.1176470588 | 0.0801136364 | 16.965240642 | 1.3591471196 |
| 0.1 | 27.692307692 | 2.7692307692 | 0.0634469697 | 9.1363636364 | 0.5796745868 |
| 0.0435606061 | 6.8181818182 | 0.2970041322 | | | |
| 0.1 | 9.2307692308 | 0.9230769231 | | | |
| **0.6871212121** | **16.782638318** | **18.221917197** | **0.4505681818** | **15.818290778** | **16.87480736** |

*Figure 48: Data Analysis for <0.2 Miles*

**Greater than 0.2 miles**

| Electronic | | | Mechanical | | |
|---|---|---|---|---|---|
| Distance | Speed | Weighted | Distance | Speed | Weighted |
| 0.3 | 20.769230769 | 6.2307692308 | 0.3 | 37.24137931 | 11.172413793 |
| 0.3 | 27.692307692 | 8.3076923077 | 1.2 | 36.610169492 | 43.93220339 |
| 0.3 | 30 | 9 | 0.9 | 38.571428571 | 34.714285714 |
| 1.7 | 46.015037594 | 78.22556391 | 1.7 | 43.714285714 | 74.314285714 |
| 0.5 | 25.714285714 | 12.857142857 | | | |
| **3.1** | **30.038172354** | **36.974570421** | **4.1** | **39.034315772** | **40.032485027** |

*Figure 49: Data Analysis for >0.2 Miles*

**Residential**

| Electronic | | | Mechanical | | |
|---|---|---|---|---|---|
| Distance | Speed | Weighted | Distance | Speed | Weighted |
| 0.3 | 27.692307692 | 8.3076923077 | 0.0801136364 | 16.965240642 | 1.3591471196 |
| 0.2 | 42.352941176 | 8.4705882353 | 0.1 | 12.857142857 | 1.2857142857 |
| 0.1 | 9.2307692308 | 0.9230769231 | | | |
| 0.1 | 21.176470588 | 2.1176470588 | | | |
| **0.7** | **25.113122172** | **28.312863607** | **0.1801136364** | **14.911191749** | **14.684404017** |

*Figure 50: Data Analysis for Residential Roads*

**2 Lane**

| Electronic | | | Mechanical | | |
|---|---|---|---|---|---|
| Distance | Speed | Weighted | Distance | Speed | Weighted |
| 0.0435606061 | 6.8181818182 | 0.2970041322 | 0.3 | 37.24137931 | 11.172413793 |
| 0.3 | 30 | 9 | 1.2 | 36.610169492 | 43.93220339 |
| 1.7 | 46.015037594 | 78.22556391 | 0.9 | 38.571428571 | 34.714285714 |
| 0.0435606061 | 9.2245989305 | 0.4018291201 | 0.0435606061 | 9.2245989305 | 0.4018291201 |
| | | | 1.7 | 43.714285714 | 74.314285714 |
| **2.0871212121** | **23.014454586** | **42.127115882** | **4.1435606061** | **33.072372404** | **39.708606528** |

*Figure 51: Data Analysis for 2 Lane Roads*

**4 Lane**

| Electronic | | | Mechanical | | |
|---|---|---|---|---|---|
| Distance | Speed | Weighted | Distance | Speed | Weighted |
| 0.1 | 21.176470588 | 2.1176470588 | 1.7 | 43.714285714 | 74.314285714 |
| 0.5 | 25.714285714 | 12.857142857 | 0.1 | 27.692307692 | 2.7692307692 |
| 0.1 | 27.692307692 | 2.7692307692 | 0.0634469697 | 19.034090909 | 1.2076553891 |
| 1.7 | 46.015037594 | 78.22556391 | 0.0634469697 | 9.1363636364 | 0.5796745868 |
| 0.1 | 11.25 | 1.125 | | | |
| 0.1 | 27.692307692 | 2.7692307692 | | | |
| 0.3 | 20.769230769 | 6.2307692308 | | | |
| **2.9** | **25.758520007** | **36.584339516** | **1.9268939394** | **24.894261988** | **40.93159714** |

*Figure 52: Data Analysis for 4 Lane Roads*

From the tables shown above, the average values of the speed and weighted speed average values were copied into a second table (for both weighted and unweighted values) in order to be plotted on a graph. Below are the two tables showing the final values that resulted from the analysis conducted for each of the five categories:

**Unweighted Data**

| | Less than 0.2 | Greater than 0.2 | Residential | 2 Lane | 4 Lane |
|---|---|---|---|---|---|
| Electronic | 16.782638318 | 30.038172354 | 25.113122172 | 23.014454586 | 25.758520007 |
| Mechanical | 15.818290778 | 39.034315772 | 14.911191749 | 33.072372404 | 24.894261988 |

*Figure 53: Non-weighted Averages*

**Weighted Data**

| | Less than 0.2 | Greater than 0.2 | Residential | 2 Lane | 4 Lane |
|---|---|---|---|---|---|
| Electronic | 18.221917197 | 36.974570421 | 28.312863607 | 42.127115882 | 36.584339516 |
| Mechanical | 16.87480736 | 40.032485027 | 14.684404017 | 39.708606528 | 40.93159714 |

*Figure 54: Weighted Averages*

From the above two tables, the following two bar graphs were created to visually show how the data compares. Discrepancies and differences in the data shown between the two tables are explained below.

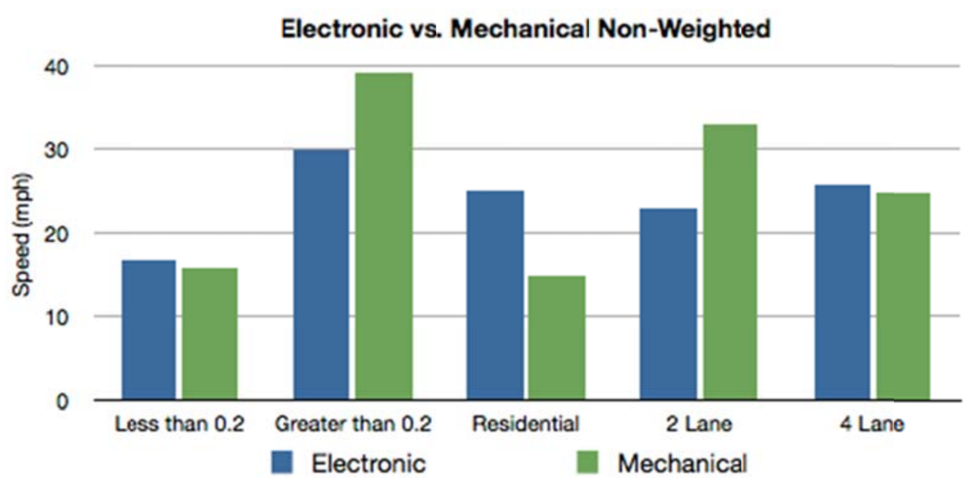


*Figure 55: Non-weighted Data Comparison*

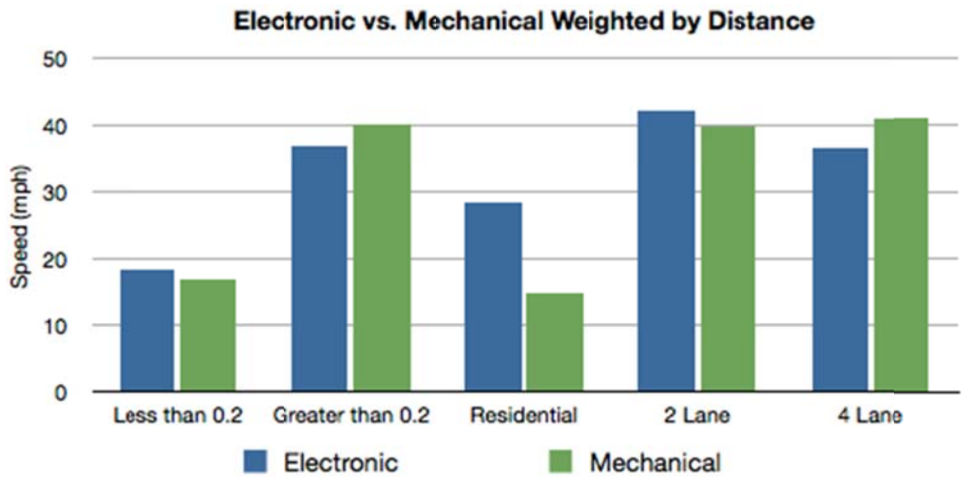


*Figure 56: Weighted Data Comparison*

From both graphs above, it is apparent that in only two out of the five separate categories chosen to be analyzed the mechanical siren was found to allow the fire truck to drive quicker. It is interesting to see, however, that from the non-weighted to weighted analysis, the 2 Lane road and 4 Lane road categories switched places with each other in terms of which siren allowed for quicker travel through traffic. However, despite that difference, in both categories, the values for each siren type are relatively close to each other. Another important thing to note between both graphs is that the residential roads category shows that the electronic siren performed much better than the mechanical. However, by examining the data table containing the data for all residential roads, one can see that there are 4 roads between all 7 runs that used the electronic siren and only two roads between the 7 runs that manipulated the mechanical siren. Also, the distance traveled on both roads that used the mechanical siren in the residential roads category was very short (less than or equal to 0.1 miles). Because these stretches were so short, the fire truck spent a lot of time accelerating and decelerating on these stretches, resulting in a very low average speed value. The trend showing how stretches less than 0.2 miles resulted in low average speed values can be shown in either graph where the average speed values for both siren types in the less than 0.2 miles category (both weighted and unweighted) are significantly lower than the average speed values for both siren types in the greater than 0.2 miles category.

Also, in the 2 Lane category, from the non-weighted to weighted graph, the electronic siren average speed value increased to a point where it was greater than that of the mechanical siren. This is mainly due to one long stretch of road in the electronic siren data (1.7 miles) where the average speed was 46 mph. In the mechanical data for this category, there was a similar entry that was shorter and had a lower speed value, but was still not enough to hold the average value above the electronic weighted average final value.

# Chapter 4: Concluding Remarks

The original objective at the beginning of this project was to analyze all aspects of emergency digital communications, particularly those that pertain to Emergency Medical Services. This includes the initial 911 call from the patient, routing the call, dispatching an ambulance, and communicating with the appropriate hospital. A thorough analysis of the protocols for the state of Massachusetts helped our group to identify several items that could be improved. After interviewing some EMTs at UMass Memorial Hospital, we realized that communicating with the drivers on the road is one of the most serious problems and needs the most improvement.

One idea our advisor suggested was a wireless transceiver system that would allow emergency vehicles to broadcast to other drivers on the road their location and direction of travel. Ambulances would be equipped with a transmitter and other vehicles would have dashboard receiver modules that display the information to the driver. Our patent search revealed that there are actually several ideas for similar concepts but none have actually been produced. One of the biggest flaws in this idea is that it is very difficult to implement in society since it requires virtually every vehicle to have a receiver. The only way to make this possible is if either the state or federal Department of Transportation requires the device. If this were to happen, it would have to be subsidized by the government or insurance companies would have to offer incentives so their customers would purchase one. Although it was clear that we needed to find an alternative, more practical solution, we still decided to devise a proof of concept to show that such a system could actually work if it could ever be implemented.

The problem with our first idea was that it required a device to be installed on every vehicle on the road. A simpler solution should only need to be added to the emergency vehicle because it is much cheaper and easier to implement. Thus, our research shifted to methods of communication that are located only on the emergency vehicle. We were able to divide this into two categories, active and passive communication. Active communication methods are dynamic and include items such as lights and sirens. Passive communication methods are static, fixed, and do not change; they include the color and shape of the vehicle as well as any distinctive markings, patterns, or reflective surfaces.

One of the most distinctive colors is chartreuse, a bright yellow that stimulates the most rods and cones in the human eye. It is even more conspicuous when paired with a dark color (such as blue or black) in a checker or chevron pattern. This color is often used on airport fire engines and some ambulances, especially in Europe. We also discovered that there are two different types of sirens used, electronic and mechanical. Electronic sirens are newer and generate sinusoid waves from a digital file or analog circuitry. Mechanical sirens, however, use moving parts to generate their sound. They are generally louder, require more power and produce square waves which can more effectively penetrate sound resistant cars than sinusoid waves. In cities, sine waves are easily reflected off building which can make it difficult for drivers to correctly identify where the emergency vehicle is coming from. Because of these properties, we hypothesized that a chartreuse colored ambulance with a mechanical siren would have the fastest response time.

To test this hypothesis, we planned to ride in ambulances with different combinations of colors and sirens and record the times to respond to their respective calls. Unfortunately, this was not possible because only fire engines use mechanical sirens, not ambulances, and because of patient privacy laws, we were not permitted to ride in ambulances. However, we were able to ride in fire engines equipped with both electronic and mechanical sirens thanks to the Worcester Fire Department. On each call the fire station responded to, we alternated between using electronic and mechanical sirens. The time en route was recorded and the speeds on similar roads were compared upon completing seven runs.

We analyzed the speeds on residential, 2 lane, and 4 lane roads. Based on our analysis, we determined that using mechanical sirens can provide a slight advantage on busier streets (4 lane roads). While the difference is relatively small on 2 lane roads, electronic sirens appear to provide an increase in speed on residential roads. Although not enough trials were conducted to provide concrete data, these results are not too far-fetched. 4 lane roads generally run through busier parts of cities, especially where there are building and other obstructions. The square wave maintains a straighter path and can penetrate vehicles far away thus alerting drivers well in advance of the oncoming emergency vehicle. When travelling on smaller, 2 lane or residential roads, the electronic siren shows greater effectiveness over a short range.

In order to get more accurate results, many more tests need to be conducted that take into account the dozens of variables that can affect response time. For example, the temperature determines whether drivers have their windows rolled down or a noisy air conditioner running and time of day determines the amount of traffic on the road. Some routes cross intersections equipped with traffic preemption devices and some may cross few or no intersections at all. Even the type of vehicle matters because engines are a lot smaller and more maneuverable than ladders, especially around tight corners. But even if all of these factors could be accounted for, the siren of choice is usually left to personal preference. According to the fire fighters we interviewed, drivers become comfortable using one siren over another and tend to stick with it. Of these fire fighters, over 80% prefer using the Federal Q2 siren. Although it might be difficult to find conclusive evidence that proves mechanical sirens are most effective, experience in the field tends to show that it does. As a result, we recommend using mechanical over electronic sirens whenever possible.

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[17] *General Laws CHAPTER 89, Section 7B.* The General Court. 2010. The 187th General Court of the Commonwealth of Massachusetts. 11 Dec, 2010. <http://www.malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter89/Section7B>.

[18] *General Laws CHAPTER 89, Section 7C.* The General Court. 2010. The 187th General Court of the Commonwealth of Massachusetts. 11 Dec, 2010. <http://www.malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter89/Section7C>.

[19] *The National Safety Commission Alerts: Emergency Vehicle Right of Way and Laws.* The National Safety Commission. 6 July 2010. The National Safety Commission. 5 March 2011. <http://alerts.nationalsafetycommission.com/2010/07/emergency-vehicles-right-of-way-and.html>.

# Appendix

In this section of the Appendix, the data tables containing all data collected for each individual route are shown. For each table, the Total time column refers to the number of seconds that have passed since the trip started at the fire station. Additionally, the lap column refers to the number of seconds that have passed since the fire engine turned onto the previous road (one row higher). The average speed per leg was calculated by taking the distance of each leg and dividing it by the lap time in the subsequent row.

**Electronic - Run 1 (1100 Hours)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Right on Park Ave. | 0 | 0 | 0 | 0 | 0.30 | 20.77 | 4 lane |
| Right on Maywood | 0 | 52 | 52 | 52 | 0.30 | 27.69 | Residential |
| Left, Ferdinand | 1 | 31 | 91 | 39 | 0.20 | 42.35 | Residential |
| Left, Circuit Ave. | 1 | 48 | 108 | 17 | 0.10 | 9.23 | Residential |
| 54 S. Circuit Ave | 2 | 27 | 147 | 39 | 0.00 | | Residential |
| | | | | | **Total Distance** | **Avg. Speed** | |
| **Electronic** | | | | | **0.90** | **22.04** | |

*Figure A.1: Electronic Run 1 Original Data*

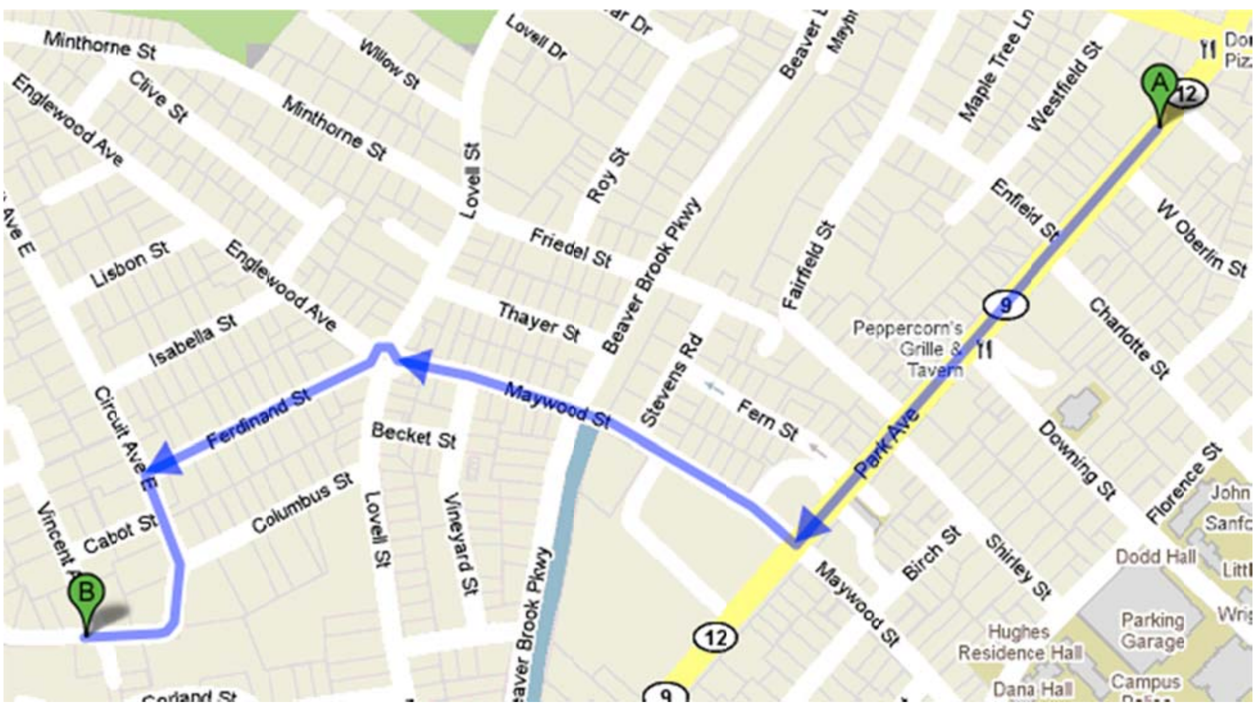


*Figure A.2: Electronic Run 1 Route Map*

**Electronic - Run 2 (1145 Hours) (Engine 12)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left | 0 | 0 | 0 | 0 | 0.043560606 | 6.8181818181818 | 2 lane |
| Left, Grafton | 0 | 23 | 23 | 23 | 0.1 | 27.692307692308 | 4 Lane |
| Left, Grafton | 0 | 36 | 36 | 13 | 0.3 | 30 | 2 Lane |
| Right, Mendon | 1 | 12 | 72 | 36 | 0.1 | 21.176470588235 | Residential |
| 19 Mendon St. | 1 | 29 | 89 | 17 | 0 | | |
| | | | | | **Total Distance** | **Avg. Speed** | |
| **Electronic** | | | | | **0.54** | **21.99** | |

*Figure A.3: Electronic Run 2 Original Data*

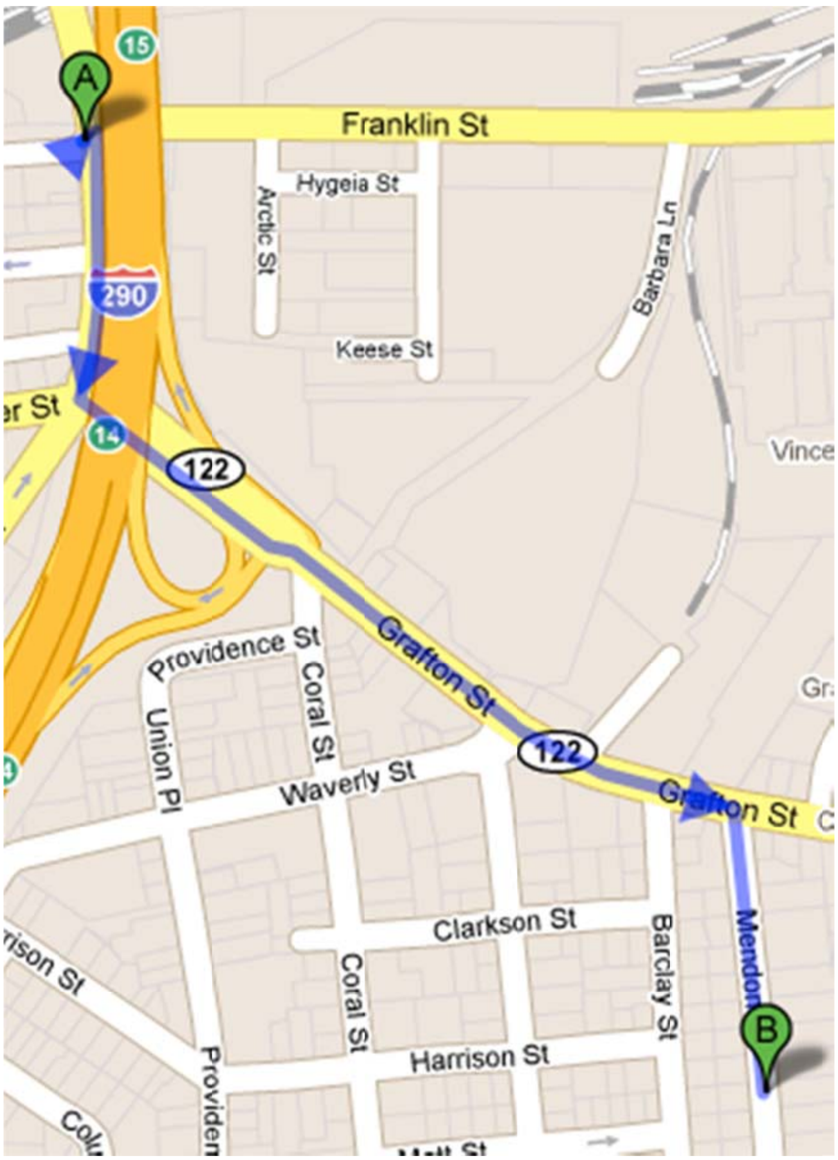


*Figure A.4: Electronic Run 2 Route Map*

**Electronic - Run 3 (1310 Hours) (Engine 12)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left | 0 | 0 | 0 | 0 | 0.1 | 11.25 | 4 Lane |
| Left, Grafton | 0 | 32 | 32 | 32 | 1.7 | 46.015037593985 | 2/4 Lane |
| Code Yellow: Count | 2 | 45 | 165 | 133 | 0 | | |
| | | | | | Total Distance | Avg. Speed | |
| Electronic | | | | | 1.80 | 39.27 | |

*Figure A.5: Electronic Run 3 Original Data*

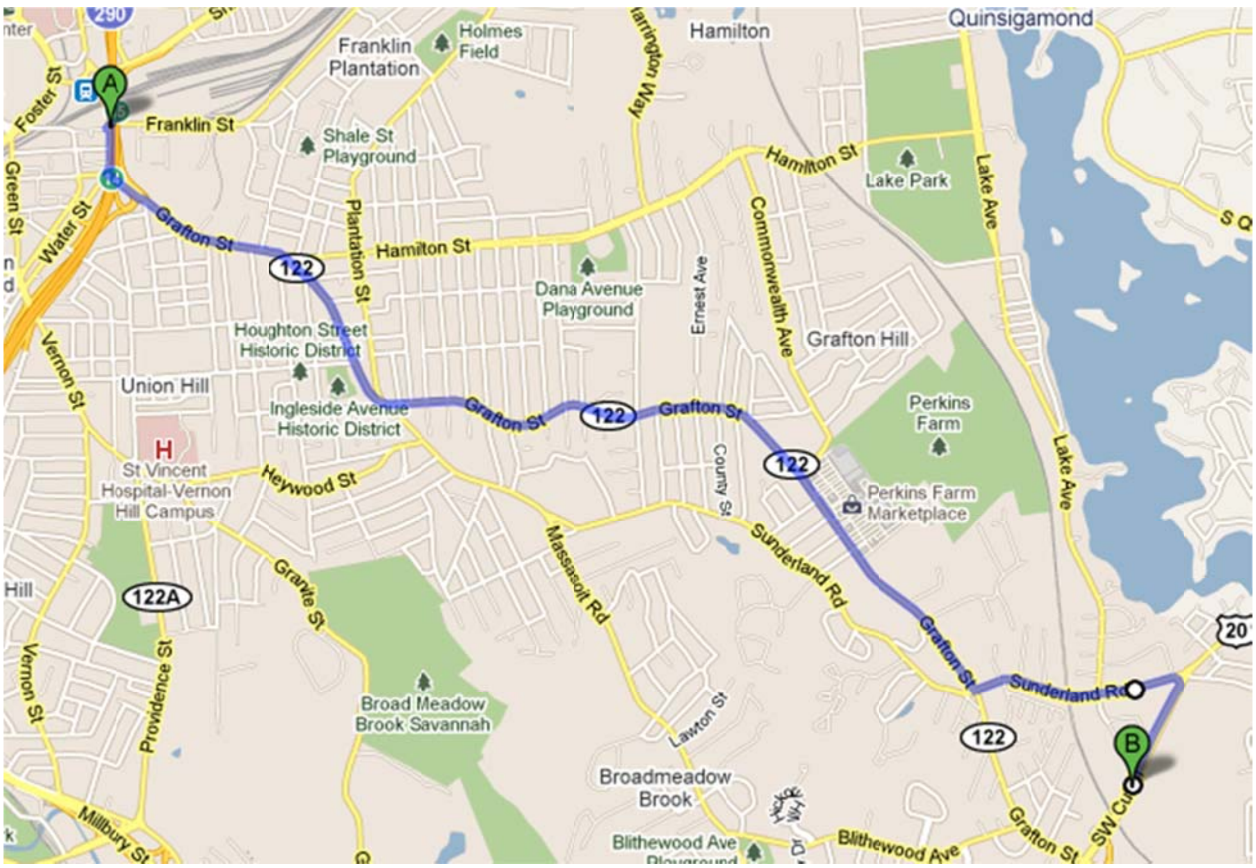


*Figure A.6: Electronic Run 3 Route Map*

Electronic - Run 4 (1420 Hours) (Engine 6)

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left | 0 | 0 | 0 | 0 | 0.043560606 | 9.2245989304813 | 2 Lane |
| Right, Grafton | 0 | 17 | 17 | 17 | 0.1 | 27.692307692308 | 4 Lane |
| Right, Shrewsbury | 0 | 30 | 30 | 13 | 0.5 | 25.714285714286 | 4 Lane |
| Traffic at light | 1 | 40 | 100 | 70 | 0.1 | 21.176470588235 | 4 Lane |
| Arrive: inHouse Cof | 1 | 57 | 117 | 17 | 0 | | |
| | | | | | Total Distance | Avg. Speed | |
| Electronic | | | | | 0.74 | 22.88 | |

*Figure A.7: Electronic Run 4 Original Data*

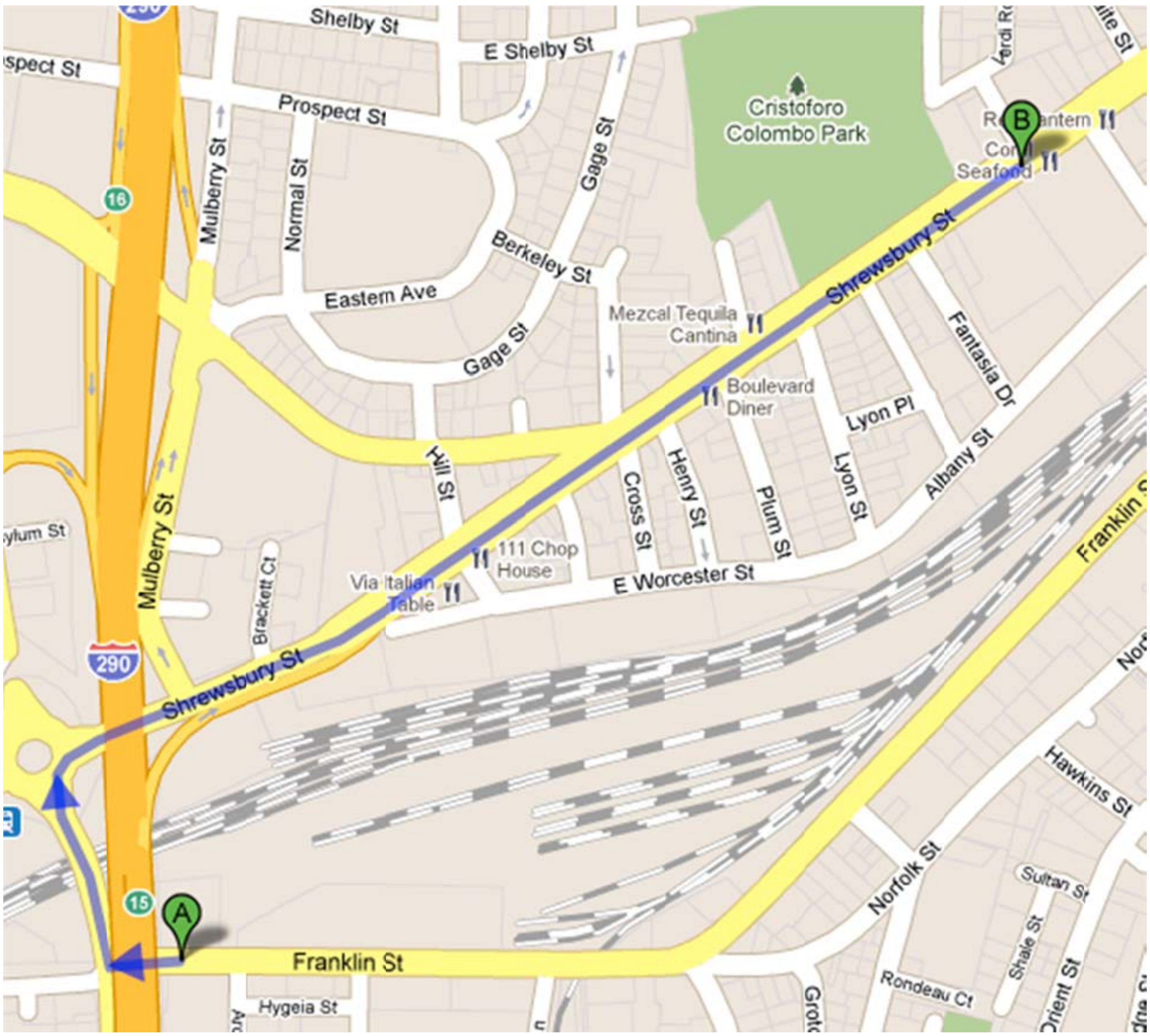


*Figure A.8: Electronic Run 4 Route Map*

**Mechanical - Run 1 (1150 Hours)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left on Park Ave. | 0 | 0 | 0 | 0 | 0.06344697 | 9.1363636363636 | 4 Lane |
| Right on May St. | 0 | 25 | 25 | 25 | 0.3 | 37.241379310345 | 2 Lane |
| Right on Woodland | 0 | 54 | 54 | 29 | 0.080113636 | 16.965240641711 | Residential |
| 84 Woodland | 1 | 11 | 71 | 17 | 0 | | |
| | | | | | Total Distance | Avg. Speed | |
| Mechanical | | | | | 0.44 | 22.49 | |

*Figure A.9: Mechanical Run 1 Original Data*


*Figure A.10: Mechanical Run 1 Route Map*

**Mechanical - Run 2 (1330 Hours)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left on Park Ave. | 0 | 0 | 0 | 0 | 0.06344697 | 19.034090909091 | 4 Lane |
| Left on May | 0 | 12 | 12 | 12 | 1.2 | 36.610169491525 | 2 Lane |
| Right on Chandler | 2 | 10 | 130 | 118 | 0.9 | 38.571428571429 | 2 Lane |
| Right on Mill | 3 | 34 | 214 | 84 | 0.1 | 12.857142857143 | Residential |
| 1094 Pleasant | 4 | 2 | 242 | 28 | 0 | | |
| | | | | | Total Distance | Avg. Speed | |
| Mechanical | | | | | 2.26 | 33.67 | |

*Figure A.11: Mechanical Run 2 Original Data*

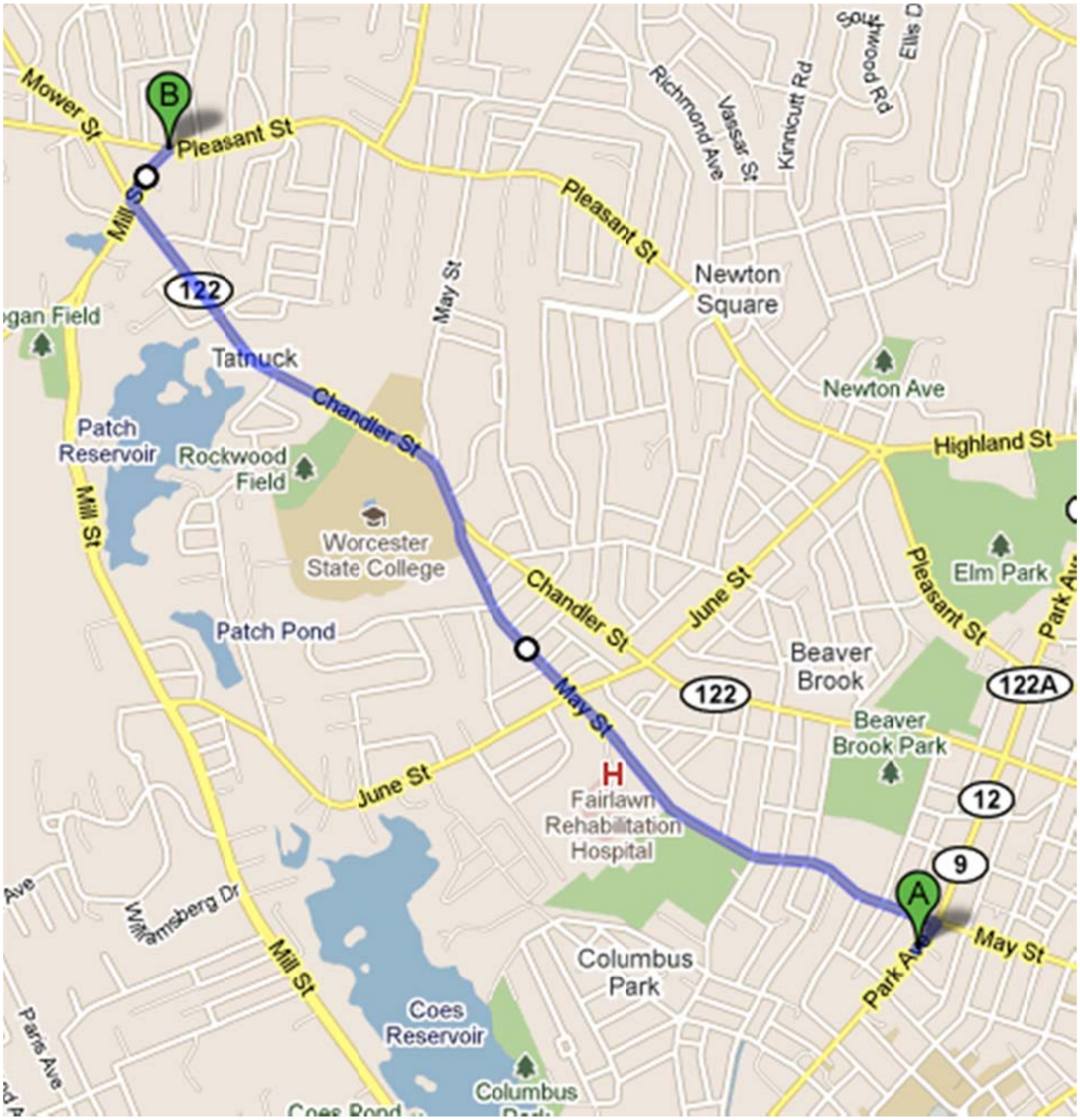


*Figure A.12: Mechanical Run 2 Route Map*

**Mechanical - Run 3 (1315 Hours) (Ladder 1)**

| Street | Minutes | Seconds | Total time | Lap | Distance (miles) | Avg. Speed (per leg) | Street Type |
|---|---|---|---|---|---|---|---|
| Left | 0 | 0 | 0 | 0 | 0.043560606 | 9.2245989304813 | 2 Lane |
| Left, Grafton | 0 | 17 | 17 | 17 | 0.1 | 27.692307692308 | 4 Lane |
| Left, Grafton | 0 | 30 | 30 | 13 | 1.7 | 43.714285714286 | 2/4 Lane |
| Code Yellow | 2 | 50 | 170 | 140 | 0 | | |
| | | | | | **Total Distance** | **Avg. Speed** | |
| **Mechanical** | | | | | **1.84** | **39.04** | |

*Figure A.13: Mechanical Run 3 Original Data*

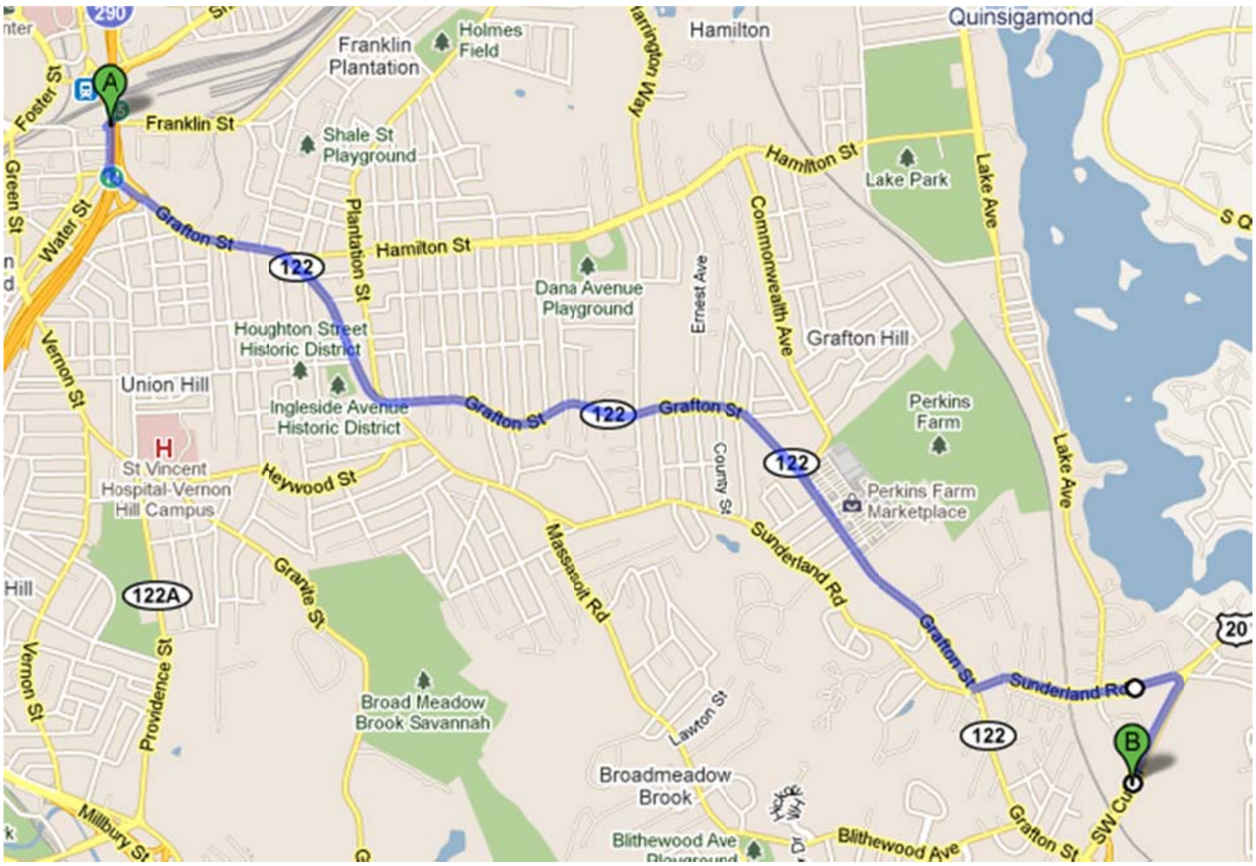


*Figure A.14: Mechanical Run 3 Route Map*

For this last set of data (Mechanical Run 3), it is important to note that in the data table, the data stops when a code yellow is announced (signaling the driver of the firetruck to shut off his lights and sirens and proceed to the scene with the flow of traffic). Due to this, the route shown in the route map is different from the original data. The code yellow was received almost exactly in the middle of the route where Grafton street starts to slope down to the Southeast.