DESIGNING AN EMERGENCY TRAFFIC SIGNAL SYSTEM (ETSS): A CASE STUDY OF AN INTERSECTION ALONG U.S.1, FAIRFAX COUNTY, VIRGINIA

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ABSTRACT

Access to highways from a local firehouse is a major problem for emergency services. Motorists often do not see flashing lights or hear sirens from the approaching emergency vehicles (EV) until emergency vehicles reach the highway entrance, often too late to take appropriate action. Many locations have installed special signals called emergency traffic signal systems (ETSS) or used signal preemption to notify motorists and to stop traffic to allow the emergency vehicle to enter the highway safely. This thesis will examine the effectiveness of one such installation at the intersection along U.S.1 at Beedo Street and some of the impacts it has on highway traffic. The evaluation of the said installation is carried out in terms of delay to EV; conflict potential between EV and other vehicles and response of the motorists to the ETSS. This thesis also proposes two alternative designs of ETSS to improve the existing signal system.

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CHAPTER 1. INTRODUCTION

1.1 NEED FOR SIGNAL PREEMPTION

Population growth has increased the demand for emergency vehicle response. Various transportation strategies have evolved over the years to satisfy the growing travel demand in the urban areas. These factors have led to a search for methods to improve the level of service and guide safe passage of emergency vehicles through out their path of movement. Signal preemption technology is a unique effort used by emergency vehicles such as fire engines, ambulances and police cars in satisfying growing demand of emergency response system.

An emergency call out for service has the potential for accidents while crossing intersections and while using opposite lanes. Emergency vehicles are fitted with flashing lights and continuous sirens to convey messages to vehicles traveling on the same road to give way for its passage. Another way of guiding vehicles to clear an intersection when an emergency vehicle is approaching is to preempt the traffic signal. Signal preemption overrides normal signal phasing by an emergency vehicle driver for the purpose of providing a green signal to an emergency vehicle approach on a particular intersection approach.

Signal preemption is intended to achieve the following objectives (Casturi, 2000):

Enhanced safety: Traffic signals stop all the movement especially opposing and crossing and give priority to emergency vehicle safe passage. Numbers of potential conflicts may be reduced considerably. Signal preemption may increase safety of all intersection traffic.

Reduction in travel time of emergency vehicle: Due to unimpeded passage of emergency vehicles with continuous green, considerable reduction in travel time is possible. Some studies have shown that the emergency response time is reduced by 17%. Thus, the necessary assistance can be reached within time, which in turn may enhance 911 programs.

Reduction in traffic interruptions and confusion: Fewer conflicts between emergency vehicle and traffic may result in less interference in traffic flow patterns. Signal preemption allows emergency vehicle drivers to receive an earlier indication of how drivers of the other vehicles are guided.

Reduction of stress on emergency vehicle drivers: Intersection free of conflicting movements of vehicles may reduce stress on the part of emergency vehicle drivers. Drivers can more fully focus on the emergency and less on traffic.

Positive guidance for motorists: Warns the motorists of the impending arrival of an emergency vehicle at the intersection and guides the motorists away from emergency vehicle path of movement.

1.2 PROBLEM OVERVIEW

The focus of the research here is the intersection of Beedo Street and US 1. The said intersection is the entry point for emergency vehicles entering U.S.1. Emergency vehicles enter U.S.1 from a cross street from the firehouse. An emergency traffic signal (ETS) is a special traffic control device, which gives the right of way to an authorized emergency vehicle. This signal device is typically installed on the main highway near the firehouse. An ETS is installed at the intersection to ensure safe and quick access for emergency vehicle from the firehouse, where such access might otherwise be difficult.

The ETS present at the intersection of Beedo Street and U.S.1 has a single ball. The said traffic signal normally displays flashing yellow indications for street traffic between emergency actuations. A steady green indication is an option. Upon emergency actuation, a yellow clearance interval followed by a steady red indication is provided, normally by a push-button system located at the firehouse. It has been observed during the analysis that the red time duration during emergency actuation is about 60 seconds on average and about 90 seconds at maximum. The 30 seconds red time is provided prior to arrival of emergency vehicle at the intersection and another 30 seconds of preemption is provided after the vehicle arrives at the intersection. The length of red phase is determined on the basis of emergency vehicle passage time in order to allow the emergency vehicle enter the main thoroughfare safely.

This research focuses on the auto-vehicular response to the ETS present at the intersection of Beedo Street and U.S.1 and its impact of the ETS on emergency vehicle movement through the intersection.

1.3 RESEARCH OBJECTIVES

The two main objectives of this thesis are as following:

1. To conduct a case study of ETSS at the intersection of Beedo and U.S.1, by identifying the data and other resources that will be required to conduct the evaluation.
2. To propose an efficient ETSS for entry of emergency vehicles at the intersection of Beedo and U.S.1 based on MUTCD 2000 standards.

1.4 SCOPE OF RESEARCH

A literature review will be conducted on the work carried out in field of traffic signal preemption deployment and entry strategy for emergency vehicle's access

A case study will be conducted on the ETSS at the intersection along U.S.1 at Beedo Street. A primary source of information to conduct this study includes field data collected manually and using video cameras. An alternative ETSS will be designed to meet MUTCD requirements. Conclusions and recommendations will also be presented.

1.5 SIGNIFICANCE OF WORK

This study presents an evaluation of a hard wire preemption of emergency traffic signal and its effectives in achieving the desired objective of clearing intersection for the safe movement of emergency vehicle. The results are important because of the heavy traffic levels experienced during peak periods, frequent emergency vehicle movement, disruption of vehicular traffic and the resulting effect on emergency response times. The proposed changes in emergency traffic signal system will reduce traffic disruption, and improve safety aspect for emergency vehicles and other vehicles plying through the intersection.

In the academic environment, this research provides an evaluation framework, which relies on basic elements of transportation and traffic engineering to provide insights into important elements of traffic signal design and traffic planning. This framework provides the tools required to make a full analysis of emergency traffic signal system in quantifiable terms. Finally this study provides an integrating effort between traditional tools of traffic engineering, and innovative solutions of intelligent transportations systems (ITS) for the benefit of local emergency response system.

1.6 REPORT STRUCTURE

Following the introduction (Chapter 1), Chapter 2 contains a literature review of research on existing research for ETSS. Chapter 3 includes an evaluation framework of existing ETSS, which will include Video Data Collection and Analysis. Chapter 4 consists of design of Alternative Emergency Traffic Signal System to replace existing hard-wired preemption signal at the intersection of Beedo Street and U.S.1. Chapter 5 presents the conclusions and recommendations for further research.

CHAPTER 2.
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a review of recently published literature relevant to the subject of this report. The purpose of this section is to identify appropriate references that are significant to this research and to enable the reader to establish a good foundation of relevant knowledge and raise an awareness of most of the issues surrounding ETSS implementation and operation.

2.2 Overview of Emergency Traffic Signal Fundamentals

2.2.1 Background. What is Emergency Vehicle Preemption?

Emergency Vehicle Preemption (EVP): The Manual of Uniform Control Devices (MUTCD 2000) provides a definition of preemption control as follows: "the transfer of normal operation of traffic control signals to a special control mode which may be required by rail road trains at crossings, emergency vehicles, and mass transit equipment or for other special needs". EVP provides the authorized vehicles with the right of way to travel through the signalized intersections. The emergency vehicles generally include fire trucks, ambulances and Emergency Medical services (EMS).

The EVP is accomplished by the use of vehicle installed activation equipment, signalized intersection installed detection devices and signal control equipment. Preemption request normally is done through use of light beam transmitters on the emergency vehicles, which send impulses to receivers on the signalized approach. Hard wires interconnect and push buttons at the emergency equipment stations to provide a predetermined emergency timing scheme along fixed routes may also be fixed. The receiver detects the emergency vehicle preemption request and this is communicated from the receiver to signal controller through the connecting wire. The signal controller determines the current status of the of the signal display on the emergency vehicle approach and preempts the signal to allow the easy emergency vehicle passage.

2.2.2 Emergency Traffic Signals (ETS): According to Section 4F.01 (Applications of Emergency-Vehicle Traffic Control Signals) of MUTCD 2000 "An emergency-vehicle traffic control signal is a special traffic control signal that assigns the right-of-way to an authorized emergency vehicle. An Emergency Traffic Signal (ETS) is a special traffic control signal, which gives the right-of-way for an authorized emergency vehicle/other vehicle
(Johnson, Mirman & Thomson, MSHA 2000)

In simple words" Emergency Traffic Signal is installed in order to ensure safe and quick access for emergency vehicles from their stations onto a street / major arterial / highway.

An emergency-vehicle traffic control signal may be installed at a location that does not meet other traffic signal warrants such as at an intersection or other location to permit direct access from a building housing the emergency vehicle. (MUTCD 2000)

2.2.3 Emergency Equipment Station (EES) is located at the firehouse or rescue squad station where in the equipment normally a push–button device is located to control ETS. Hardwire preemption system employs a physical connection from emergency equipment station to the ETS. The system requires a cable from the controller to an activation switch.

An emergency-vehicle traffic control signal sequence may be initiated manually from a local control point such as a fire station or police headquarters or from an emergency vehicle equipped for remote operation of the signal. (MUTCD 2000)

2.3 Operation of Emergency Traffic Signals (ETS)

An ETS normally display flashing yellow indications for street traffic between emergency actuations. A steady indication is an option. Upon emergency actuation, normally by a push-button located within EES, a yellow clearance followed by steady red indication is provided.

The signal indications, sequence, and manner of operation of an emergency-vehicle traffic control signal installed at a mid-block location shall be as follows: The signal indication, between emergency-vehicle actuations, shall be either steady green or flashing yellow. If the flashing yellow signal indication is used instead of the steady green signal indication, it shall be displayed in the normal position of the steady green signal indication, while the red and steady yellow signal indications shall be displayed in their normal positions. When an emergency vehicle actuation occurs, a steady yellow change interval followed by a steady red interval shall be displayed to traffic on them major street. A yellow change interval is not required following the green interval for the emergency-vehicle driveway. Emergency-vehicle traffic control signals located at intersections shall either be operated in the flashing mode between emergency-vehicle actuations or be semi- or fully traffic-actuated, to accommodate normal vehicular and pedestrian traffic on the streets. Warning beacons, if used with an emergency-vehicle traffic control signal, shall be flashed only: For an appropriate time in advance of and during the steady yellow change interval for the major street; and during the steady red interval for the major street. (MUTCD 2000)

The length of red phase is determined on the basis of dwell time of emergency vehicle at the intersection. According to MUTCD 2000 guidance, the duration of the red interval for traffic on the major street should be determined by on-site test-run time studies, but should not exceed 1.5 times the time required for the emergency vehicle to clear the path of conflicting vehicles.

2.4 Warrants for Emergency Traffic Signals (ETS)

The MUTCD 2000 guideline included in the Section 4F.01 – "Applications of Emergency-Vehicle Traffic Control Signals" states that "an emergency traffic control signal is justified if gaps in traffic are not adequate to permit safe entrance of emergency vehicles, or the stopping sight distance for vehicles approaching on the major street is insufficient to permit safe entrance of emergency vehicles"

Many states have developed their own emergency traffic signal warrants following the above given MUTCD 2000 guideline. Following are the warrants by different states for ETS.

Florida Department of Transportation:
The section 3.4.3 (Emergency Traffic Control Signals) of Traffic Engineering Manual of Florida DOT states "An Emergency Traffic Control Signal shall be warranted if any of the following warrants are met:

(1) Minimum Traffic Volumes: (both approaches)

	Peak Hour or	24 Hours
2 Lane Roadway	750	7500
4 Lane Roadway	900	9000
6 Lane Roadway	1200	12000

The above values shall be increased by 1/3 when arterial has traffic signal system coordination with signals located within 1000 feet in both directions from the emergency signal location.

(2) When the geometric design of the arterial and emergency vehicle facility is such that the vehicle when returning must back in, and to do so must block traffic when performing this maneuver and the traffic volume and speeds are such that the use of emergency vehicle lights and flaggers have been ineffective in controlling traffic.

(3) When the location of the emergency vehicle driveway consistently conflicts with the normal traffic queue from an adjacent signalized intersection.

(4) On all approaches when vertical or horizontal curvature or other obstructions do not provide adequate stopping sight distance for traffic approaching an emergency vehicle driveway. (Traffic Engineering Manual, FDOT, 1999)

OHIO Department of Transportation:

The warrants of Ohio Department of Transportation (ODOT) mainly talk about sight distances and volumes on the major road

Warrant 1: Volumes on the major road (ADT) exceed the values below:

Number of Lanes	Average Daily Traffic (Total of Both Directions)
Two Lanes	6000
Three lanes	9000
Four Lanes or More	16000

Warrant 2: Corner sight distances are less than minimum.

Pennsylvania Department of Transportation (The Pennsylvania Code):

Warrant 1: Volumes on the major road (ADT) exceed the values below:

Number of Lanes	Average Daily Traffic (Total of Both Directions)
Two Lanes	6000
Four lanes	9000
Six Lanes or More	10,000

Warrant 2: Intersection sight distance. This warrant is satisfied when the sight distance for an approaching driver, is less than the applicable value in the following table:

Approach Speed Limit /85thPercentile Speed	Minimum Intersection Sight Distance (feet) S= 40	S=60	S= 70	S=80
25	230	260	290	320
30	280	315	345	380
35	330	370	410	450
40	370	420	460	500
45	420	470	520	570
50	460	520	580	640
55	510	570	640	700
60	560	630	700	760

('S' indicates the slope in feet)

Texas Department of Transportation:

The warrants of Texas Department of Transportation (TDOT) mainly talk about sight distances, accident problem, high approach speed and volumes on the major road.

Warrant 1: The 75% or more of the MUTCD volume warrants for the main roadway plus a minimum of 30 emergency calls per month or 360 calls per year, plus any of the following:

- Poor sight distances
- Accident Problem
- High Approach Speed

Maryland State Highway Administration (MSHA):

An ETS may be justified at an Emergency Equipment Station (EES) an entrance onto through roadway if either of the following criteria is satisfied:

Warrant 1: On 2-Lane roadways, the corner sight distance between an approaching motorist and the flashing lights on an emerging emergency vehicle is less than the appropriate value in the table below:

Approach Speed- Miles Per Hour (85 the percentile)	Minimum Corner Sight Distance (Ft)
25	250’
30	300’
35	350’
40	400’
45	450’
50	500’
55	550’
60	600’

2.5 Critical Factors Affecting Emergency Traffic Signals

Critical factors that may affect Emergency Traffic Signals: (Johnson, Mirman & Thomson, MSHA 2000)

- Mainline traffic volumes and number of lanes. High volumes on the roadway and the roadway lane configuration the emergency vehicles to safely is certainly a measure affecting the need for ETS.
- Sight Distances: Inadequate stopping sight distances between an approaching motorist on the through street and entering emergency vehicle may indicate a need for an ETS. The sight distance determination is based on the through street, and the visibility to flashing lights on the emergency vehicle.
- Accidents: Accidents involving emergency vehicles entering the through roadway certainly may indicate a need for an ETS. It is suggested, however that the number of accidents not be criteria for providing these types of devices.

- Speeds on the through roadway: Some jurisdictions and other DOTs indicate that high speeds may warrant ETS. In that mainline speeds are part of sight distance determination, it is suggested that speeds per se not be an ETS warranting criteria.
- Number of emergency calls: Some jurisdictions also stipulate a minimum number of emergency response calls as a warranting factor. In that there is no mention of this factor in the MUTCD and it is desirable to format guidelines along MUTCD criteria.

2.6 Advantages and Disadvantages of Emergency Traffic Signals (ETS)

2.6.1 Advantages

Some of the advantages in providing Emergency Traffic Signals (ETS):

1. It provides gaps in the traffic stream to safely allow access by emergency vehicles.
2. It may reduce response time.
3. It may enhance overall 911 programs
4. It may provide the positive guidance for the emergency vehicles and other intersection traffic safely through the intersection.
5. It may reduce stress on the part of emergency drivers
6. It may increase the safety for all intersection traffic.

2.6.2 Disadvantages

Some of the disadvantages of EVP could be the following (Johnson, Mirmiran and Thompson, MHSA 2000).

1. Disruption to traffic, particular if the emergency clearance interval is set too long
2. Abuse, such as activating the ETS for non- emergency runs, or when returning from an emergency.
3. The activation of ETS may violate driver expectancy. Drivers typically observe a flashing yellow most of the time, and may not readily respond to a change to red
4. Costs: ETS's and necessary interconnect and EES equipment may typically range between $ 50,000 and $ 70,000

2.7 Emergency Vehicle Preemption Studies

Preemption study (Bullock, D., Morales, J., and Sanderson, B., 1998) on U.S. 7 consisted of three coordinated intersections over a 1.5-mile corridor. Using a simulation modeling analysis, the research findings showed that there was a statistically significant improvement in the mean travel time along the arterial for the preemption case when compared to the base case.

A macroscopic model, (Casturi, R., Lin, W., Collura, J., 2000) which combined cell transmission and traffic flow theory was developed to assess the impacts of emergency vehicle traffic signal preemption on traffic delay. The effect of preempting the traffic signals at different points in the phasing and the effect of main street preemption versus side street preemption was studied.

A micro simulation based analysis (Nelson and Bullock, 2000) of traffic signal preemption for emergency vehicles was conducted. The study analyzed a section of an arterial with four signalized intersection that included a diamond interchange.

A microscopic traffic simulation tool (McHale, 2001) was used to evaluate the travel time impacts of traffic signal priority treatments for emergency vehicles as a function of traffic characteristics, roadway geometry and the deployment configuration of the priority system. The research successfully proved that the travel time impact of emergency vehicle traffic signal priority was a function of traffic volume.

A study (Mittal, 2002) to assess the performance of emergency vehicle preemption along U.S.1 in Fairfax County, Virginia was conducted. The study successfully proved that the severity of EV-specific conflict points is significantly reduced with EVP. The delay to EV does not change significantly and the delay to the vehicles on the side street auto traffic increases.

2.8 Summary

This literature review provides a guide to the planning and design of emergency traffic signal and addresses the issues surrounding it. It provides an overview of the current practices, recommendations and guidelines stipulated in MUTCD 2000 and other states and help this research to implement some of these standards. It also enables the reader to establish a good foundation of relevant knowledge and raises awareness of most of the issues, pitfalls and the solutions surrounding the ETSS.

CHAPTER 3
EVALUATION OF EMERGENCY TRAFFIC SIGNAL SYSTEM (ETSS)

3.1 INTRODUCTION
This chapter describes the various aspects of the ETSS and vehicular response to the existing signal system. This chapter also describes evaluation framework of emergency traffic signal system, analysis and results of case study at Beedo intersection. The ETSS involves emergency traffic signal and emergency equipment station.

An ETS is a special traffic control signal, which gives the right of way for an authorized emergency vehicle. It is installed at the intersection of Beedo Street and U.S.1, which is entry point for emergency vehicles onto US.1. The ETS present at intersection consists of single ball. ETS normally displays flashing yellow indications between emergency actuations. A steady red is indicated upon emergency actuation in order to allow the emergency vehicle enter main thoroughfare.

An emergency equipment station (EES) is located at the fire station where in the equipment normally a push – button device is located to control ETS. Hardwire preemption system employs a physical connection from EES to the ETS. The system requires a cable from the controller to an activation switch. EES present at the fire station near the intersection Beedo Street and U.S.1 has a single push button device for preemption for the both ways of traffic the on U.S.1.

3.1.1 Size Based MUTCD 2000 Requirements For Emergency Traffic Signals**:**

The ETS at the intersection of Beedo Street and U.S.1 doesn't conform to the MUTCD standards. The MUTCD section for emergency traffic signal design guidelines are stipulated in 4D.13, 4D.14, and 4D.15 are as follows:

'Traffic control signals that are designed to respond under preemption or priority control to more than one type or class of vehicle should be designed to respond in the relative order of importance or difficulty in stopping the type or class of vehicle.

Standard:
There shall be two nominal diameter sizes for vehicular signal lenses: 200 mm (8 in) and 300 mm (12 in) or Three-hundred millimeter (12 in) signal lenses shall be used.
A 200 mm (8 in) signal lens for a CIRCULAR RED signal indication shall not be used in combination with 300 mm (12 in) signal lens for a CIRCULAR GREEN signal indication or 300 mm (12 in) signal lens for a CIRCULAR YELLOW signal indication.

The single ball ETS at the intersection of Beedo Street and U.S.1 does not conform to the above listed MUTCD 2000 standards.

3.2 EVALUATION FRAMEWORK

The evaluation methodology is based on a macroscopic study of a set of rules to recreate the event observed in the video footage of the intersection of Beedo Street and U.S.1. The various possible cases are rated. The least severity is assigned the lowest value while the most severe event is given the highest value.

The main objectives in analyzing video footage of the events are:

1. To identify the number of vehicles not responding to ETS
2. To measure and represent the mixed message received by an auto driver in presence of an emergency vehicle.
3. To measure the delay caused to the EV by the presence of the auto vehicles in the paths and due to the confusion displayed by the emergency vehicle.
4. To identify the conflict points between the EV and the auto vehicle and quantify the conflicts according to the severity of the conflict point which may result in reducing the safety of the emergency vehicle.

With these objectives in mind the video data analyst will score every event based on the scoring criteria, which are clearly defined. The scoring will enable the analyst to better understand the data and help to develop rules based on trends seen. It is essential that before proceeding with developing rules and determining trends, the scoring criteria and definitions are clearly defined and understood.

3.2.1 Definition of Terms (Mittal, 2002, Louisell 2002):

Event: Passage of an EV or a platoon of EV's through a signalized intersection. Each event is normally comprised of three cases. Case I is evaluation of the EV interaction with near side traffic approaching the intersection stop-line at the time of EV's entry and exit while traveling in northbound path. Case II is evaluation of the EV interaction with far side traffic approaching the intersection stop line at the time of EV's entry and exit while traveling southbound path.

EV Platoon: Range from one to five vehicles. All vehicles must be responding to the same call and must originate from the same location

Signalized Intersection: An arterial roadway intersection that is controlled by a standard traffic signal.
Entry Point: A point on the roadway marked by an emergency access signal.

Message: Traffic control device and the associated roadway markings or command to the EV movement as implied by the siren and lights.

3.2.2 Scoring Criteria

Three Scoring Categories:

Conflict Score - Assigns a score to each vehicle class involved (auto and EV). The score is based on assessment of vehicle actions as reconstructed from ground-level observation notes and/or video at Beedoo St and Southgate Dr

Mixed Message Score - Assigns a score indicating the presence and degree of conflicting message to the auto driver

Delay Score - Assigns a score to the EV delay in intersection passage due to the requirement to slow or stop to avoid collision

Conflict Score Definition

EV Unexpected Movement - the entry into the roadway of an EV without the display of a conventional traffic signal or the conventional transition from green through amber to red. Relevant proximity with autos is defined as the presence of autos within safe reaction distance (assume 2.5 sec reaction time and a speed of 45 mph - 360 feet)

EV Conflicting Movement - the movement of an EV at a signalized intersection, which requires the EV to cross the path of a protected movement from the same or another approach. Relevant proximity with autos is defined as the presence of autos within safe reaction distance (assume 2.5 sec reaction time and a speed of 45 mph - 360 feet)

Auto displayed confusion - the actions of the auto indicate that there was confusion in determining the appropriate reaction (stop, pull over or continue).

Auto Unexpected, Conflicting Movement - the execution of a movement contrary to the displayed signal or the geometric guidance.

EV Unexpected, Conflicting Movement - the unexpected execution of a movement that conflicts with the movement of autos following a displayed signal and/or geometric guidance.

Collision - the contact of emergency vehicles with autos at a signalized intersection during an evaluated event.

Delay Definitions
Delay is the time difference between the travel times over the evaluated distance under the actual conditions minus the travel time over the evaluated distance at 34 mph (34 mph is 110% of the average auto speed on the route segment during peak travel periods)

Reduced Speed - The EV reduces speed as it approaches the intersection and/or interaction.
Rolling Stop -The EV does not come to complete stop.

Momentary Stop – The EV comes to a complete stop and proceeds immediately
Delayed 2 - 5 Sec
Delayed 6 - 10 Sec
Delayed 11 - 15 Sec
Delayed 16 - 20 Sec
Delayed 21 - 25 Sec
Delayed > 26 Sec
Caught in Failed Cycle – The EV arrives in a red interval and is unable to pass the intersection during the subsequent green interval.

The delay to EV is measured by observation of video footage during the EV's passage through the intersection of Beedo Street and U.S.1.

Pathway Conflict Scores

EV Unexpected Movement	1
Above w/ Relevant Proximity	2
EV Conflicting Movement	3
Above w/ Relevant Proximity	4
Auto displayed confusion	5
Auto Unexpected, Conflicting Movement	6
EV Unexpected, Conflicting Movement	7
Collision	8

Delay Scores

Reduced Speed	1
Rolling Stop	2
Momentary Stop	3
Delayed 0-5 Sec	4
Delayed 6-10 Sec	5
Delayed 11-15 Sec	6
Delayed 16-20 Sec	7
Delayed 21-25 Sec	8
Delayed > 26 Sec	9
Caught in Failed Cycle	10

The delay scores are determined upon observation of video footage of EV's passage through the intersection of Beedo Street and U.S.1. The video footage has time caption and therefore the delay to the EV at time entrance and exit from the intersection is measured by the observing the video footage.

Mixed Message Scores

Opposing & Perpendicular, Siren, Red	0
Concurrent, Siren, Green	1
Concurrent, Siren, Red	2
Entry Point, Siren, Emergency Signal Red	3
Perpendicular, Siren, Green	4
Opposing, Siren, Green	5

Not Applicable 'NA':
Not applicable (NA) is scored when there is no case to score (No vehicle conflicts) or when it is beyond the above-defined scoring criteria.
Example: When EV is traveling in northbound direction the conflict score for the southbound exit is scored as 'NA', since the EV does not travel in southbound and there is no case for scoring at that instance to estimate conflict score between EV and other vehicles.

Methodical Approach
The methodical approach consists of clear understanding of the definitions of the terms used to quantify the results and determining the scoring criteria based on the severity of the conditions.

3.2.3 Video Data Collection and Analysis

3.2.3.1 Data Collection Form

The video data collection of events of ETS preemption and emergency vehicle access can be classified into two cases namely perpendicular northbound case and perpendicular southbound case. (Refer Appendix A4)

3.2.3.2 Evaluation of scoring sheet:

The scoring sheet allows the analyst to represent the actual EV behavior at the intersection during the preemption actuation period numerically in the form of scores.

The scoring sheet also notes date, event number, EV number in the platoon in the order of intersection appearance, level of service at time of event occurrence, real time at which emergency call received by emergency equipment station, real time at which EV reaches the intersection and direction of response of EV. The various inputs in the form are as follows:

Date – the date of the occurrence of the event.
Event – there is a unique code for every event.
Vehicle – there may be 1to 5 vehicles responding to an emergency call. This input displays the total number in the event and also its position in the platoon.
Intersection – the name of the intersection that is being evaluated is displayed. In our case study, the said intersection is Beedo Intersection.

Real Time at which call is received – the time at which the call is received at the fire station.
Real Time at which EV reaches the intersection- after receiving the emergency call, the fire fighters need some time to reach the intersection. This time is the time at which the EV reaches the said intersection.

Direction of Response – after the EV approaches the arterial it either shoots northbound or southbound. In our case study of Beedo intersection, Southgate Drive is to the north and Beacon Hill Mall is south of the of the entry point.

Type of Vehicle – there are various types of emergency vehicles present in fire station 411. Fire engine and ambulance is the most common vehicle. The other vehicle includes rescue squad, truck with ladder and medic vehicle.

Movement – the EV either goes through the intersection or it takes a right turn to go on to Southgate drive and left turn to go to Beacon Hill Road. The EV movement at the intersection greatly influences the delay and conflict and hence a need for classification of the movement.

Arterial LOS – the level of service present at a time just before the EV enters the intersection. Number of vehicles stopped and not stopped upon emergency traffic signal preemption actuation. (Mittal, 2002)

A sample-scoring sheet is shown in the Figure 1.

Date: _______
Event: _______
Vehicle: _____
Intersection: _________________
Real Time at which call is received: ____________________________

Real Time at which EV reaches the intersection: __________________

Direction of Response: Northbound ________ Southbound __________

Number Of EV's: Fire Engine __________Ambulance ______________

Arterial LOS_________________

X1 (Mixed Message) __________

At the time of EV's entry into the intersection

Case I (Perpendicular – North Bound) Case II (Perpendicular –South Bound)

X2 (Queue Length) ___________________ X2 (Queue length) _________________

X3 (Time since preemption) _____________ X3 (Time since preemption) _________

Y1 (Conflict) ________________________ Y1 (Conflict) _____________________

Y2 (Delay) _________________________ Y2 (Delay) ______________________

At the time of EV's exit from the intersection

Case I (Perpendicular –North Bound) Case II (Perpendicular – South Bound))

X2 (Queue Length) ___________________ X2 (Queue length) ________________

X3 (Time since preemption) ___________ X3 (Time since preemption) ________

Y1 (Conflict) _______________________ Y1 (Conflict) ___________________

Y2 (Delay) ________________________ Y2 (Delay) _____________________

No of Vehicles not stopping on seeing preemption signal________________________

Total no of vehicle responding to the emergency traffic signal___________________

Figure 1. Sample Scoring Sheet used in video Analysis

3.3 Emergency Vehicle Path of Movement at the Intersection of Beedo Street and U.S.1. :

There are two different paths under taken by the emergency vehicle while accessing US Route 1 through intersection of Beedo Street and U.S.1. EV travels either in north or south direction while accessing U.S.1. Siren/Lights of EV and red signal displayed by the ETS tell the auto to move to the right and clear a path for the EV.

3.3.1 EV's Northbound Movement:

The EV travels towards South Gate Drive in northbound direction while accessing the U.S.1. During the emergency signal preemption actuation, ETS shows all red phase to both directional flows. The other vehicles moving on both directions on U.S.1 completely stop during the said preemption actuation. The emergency vehicle entry and exit from the intersection is scored in terms of time required for clearing intersection, number of other vehicles responding or not responding to the ETS, associated delay, conflict, and prevalent level of service (subjective LOS) is observed from the video analysis.

Siren/Lights approaching on the arterial tell the auto on the perpendicular approach to stop or hold their positions in the queue. A Red Light at the intersection is complementary and conveys message to stop the automobiles at stop line of the intersections.

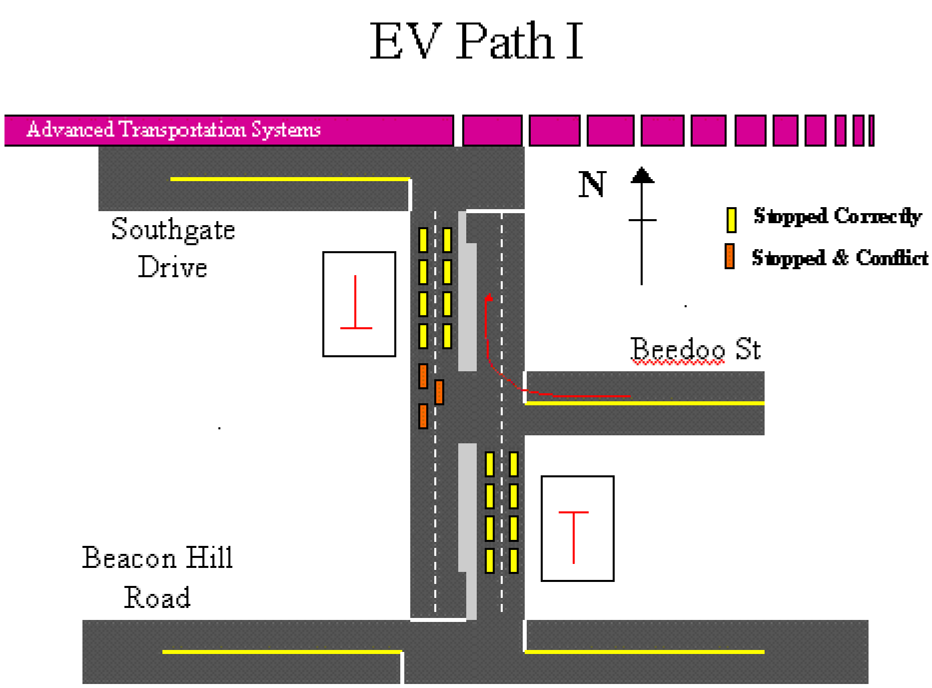


Figure 2. Graphical Representation of Northbound Movement of Emergency Vehicle at the Intersection of Beedo and U.S.1

3.3.2 EV's Southbound Movement:

The EV travels towards Beacon Hill road in southbound direction while accessing the U.S.1. During the emergency signal preemption actuation, ETS shows all red phase to both directional flows. The other vehicles moving in northbound and southbound directions on U.S.1 stop during the said preemption actuation. The emergency vehicles entry and exit from the intersection is scored in terms of time required for clearing intersection, number of vehicles responding or not responding to the signal, associated delay, conflict, mixed message and prevalent level of service (subjective LOS) is observed from the video analysis

Siren/Lights tell the auto to move to the right and clear a path for the EV. A red light at the intersection is complementary and conveys message to the automobiles to stop at the stop line of intersection.

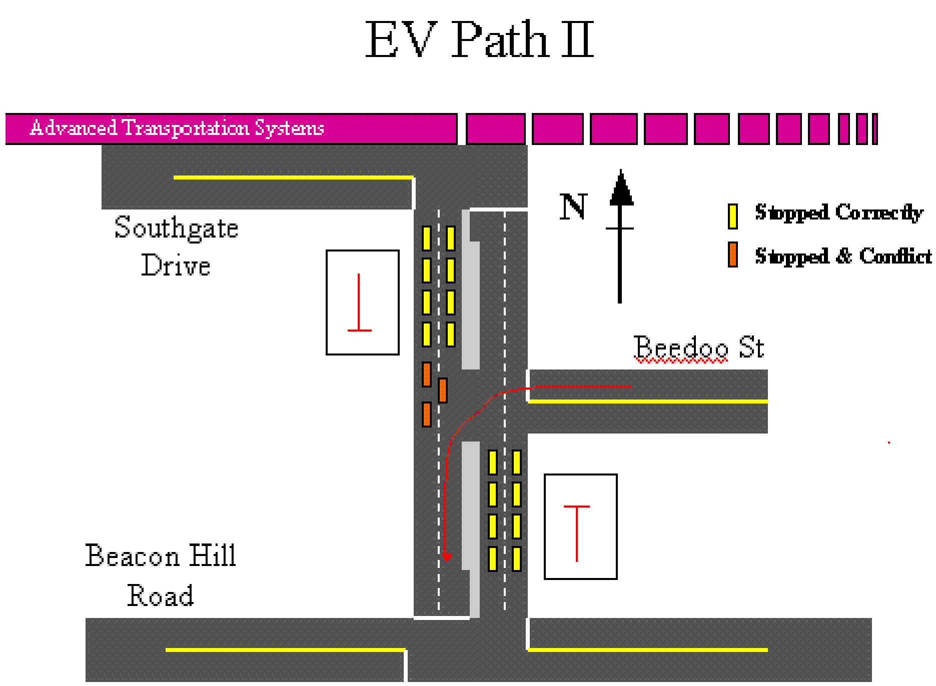


Figure 3. Graphical Representation of Southbound Movement of EV at the Intersection of Beedo and U.S.1

3.4 Results:

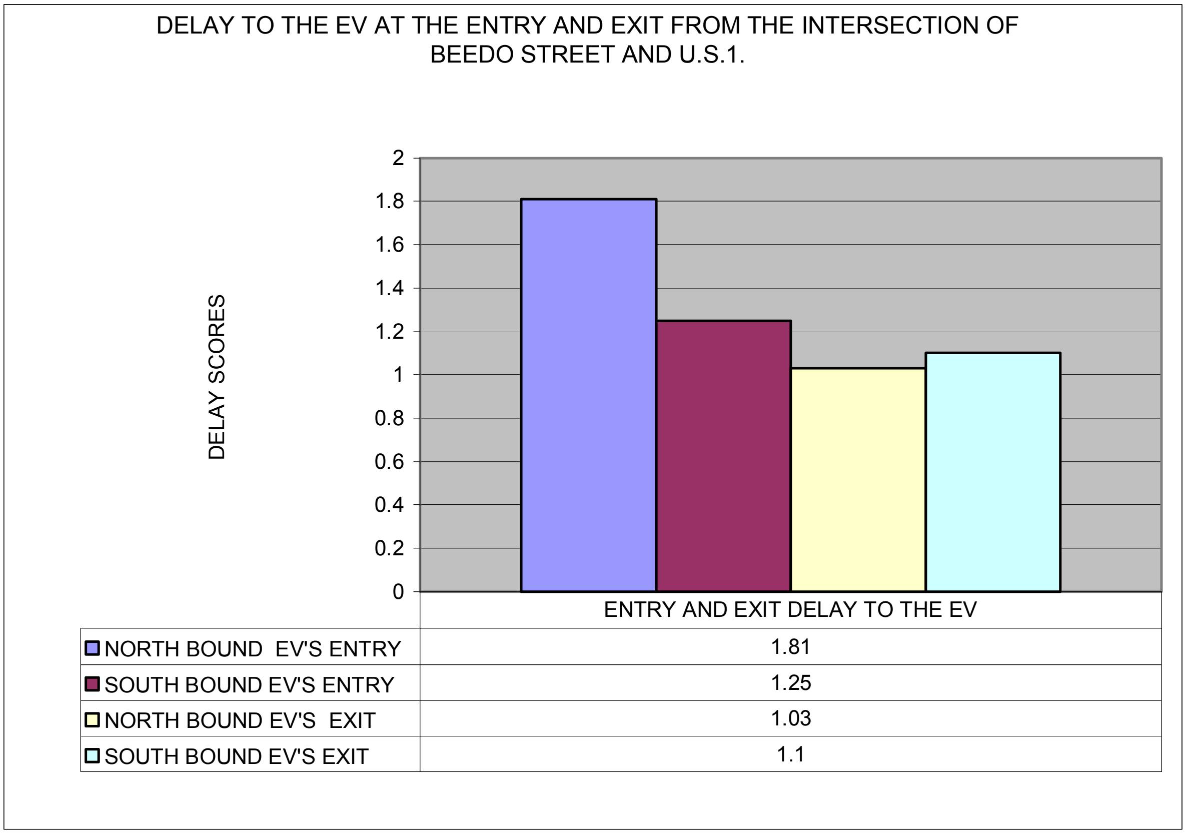


Figure 4: Delay to the Emergency Vehicle at the Time of Entry and Exit from the Intersection of Beedo and U.S.1

Observations:

1. The figure 4 shows that the delay to the EV is higher at the time EV's entry at the intersection of Beedo Street and U.S.1 than while the EV is leaving.
2. The blue portion of the Figure 4 shows that delay to the EV is high at the EV's entry while traveling towards northbound direction.
3. Delay to the EV is high at the entry to the intersection of Beedo Street and U.S.1, since other vehicles do not stop until EV is clearly visible at the intersection. This confusion of other vehicle leads to slow/delayed movement of EV in access the said intersection.
4. Delay to the EV is low at the exit from the intersection since other vehicles can clearly see EV within the intersection and stop.
5. Lack of clear message by ETSS to the other vehicles to stop before EV appears on to the intersection, is the reason for above phenomenon.

Test 1: Level of Delay Scores at Northbound and Southbound Exit of EV

	NA	1	2	3	4	5
NB ENTRY Delay Scores	0	19	5	4	3	1
NB EXIT Delay Scores	4	25	1	2	0	0

	NA	1	2	3	4	5
NB Entry Delay Scores	0	19	24	28	31	32
NB Exit Delay Scores	4	29	30	32	32	32

	NA	1	2	3	4	5
NB Entry Delay Scores	0	0.59	0.75	0.87	0.96	1
NB Exit Delay Scores	0.12	0.91	0.93	1	1	1
Differences	0.12	0.31	0.18	0.12	0.03	0

Dmax = 1.36 √(n1+ n2)/(n1)(n2) at the 0.05 significance level
= 1.36√(32+32)/(32)(32)
= 0.34

Since Dmax > Difference, there is no significant difference at 0.05 significance level between the two data sets.

The Kolmogorov-Smirnov Test: conducted on Level of delay scores of the EV at northbound and southbound exit does not show significant difference.

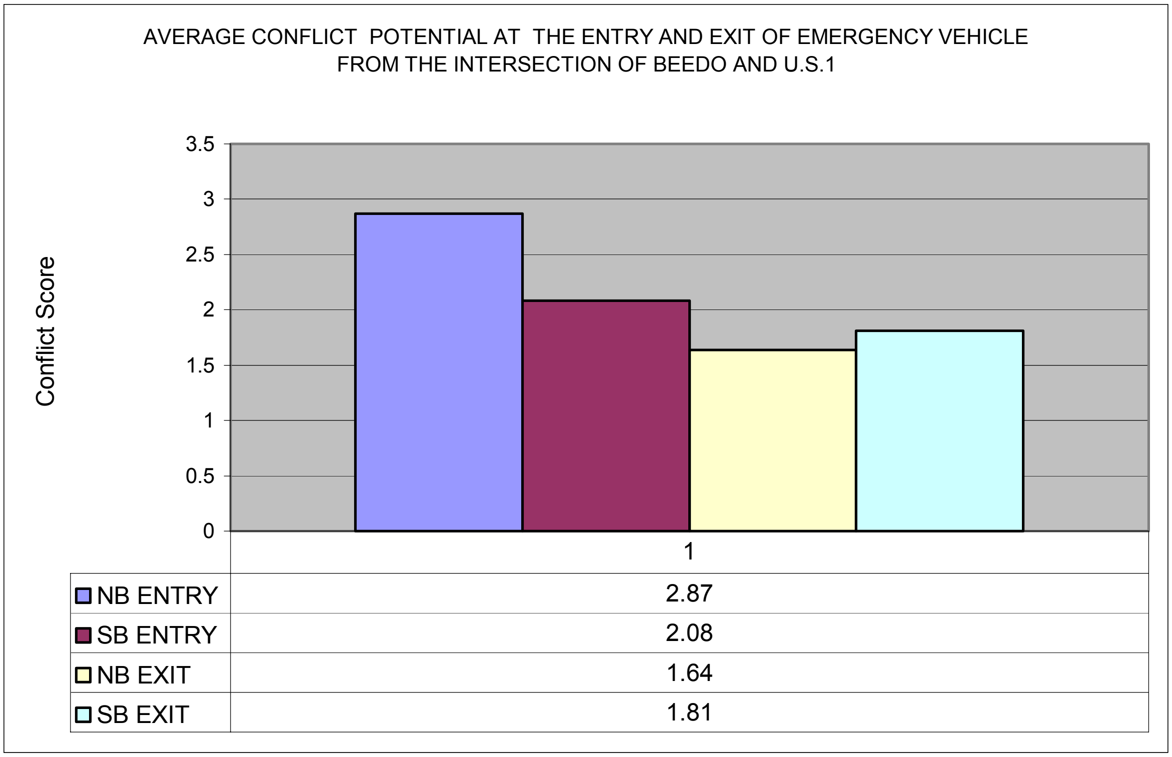


Figure 5: Average Conflict Score between E V and Other Vehicles at the Time of Entry and Exit from the Intersection of Beedo Street and U.S.1

Observations:

1. The above figure shows that conflict between EV and other vehicle's is higher at the northbound entry than at the time of EV's southbound entry of the intersection.
2. Conflict between EV and other vehicle's is higher at the northbound entry than northbound exit.
3. The other vehicles stop only on EV's arrival at the intersection at northbound entry resulting in higher conflict scores between EV and Other vehicles. Whereas at south bound entry the other vehicles stop before EV is within the intersection, since the other vehicle motorists could see the EV within the intersection and hence lower conflict is reported.
4. The conflict between EV and other vehicle's at southbound entry of EV is very low, since the EV is visible and clear message is available for other vehicles to stop.
5. As soon as EV starts to exit the intersection, some of the other vehicles follow the EV, with out responding to 30 sec after preemption of ETSS. This results in higher conflict values between EV and the other vehicle at the time of EV's southbound exit.
6. Lack of vehicular response to the ETSS displaying red leads to the above results.

Statistical Analysis:

Kolmogorov-Smirnov Test:
The Kolmogorov-Smirnov test (KS-test) tries to examine statiscal significance. The KS-test has the advantage of making no assumption about the distribution of data. It is non-parametric and distribution free. It is also referred as a goodness-of-fit test for any statistical distribution. The test relies on the fact that the value of the sample is cumulative density function is asymptotically normally distributed

Test 1: Level of conflict scores at Northbound and Southbound Exit of EV

LEVELS OF CONFLICT SCORES					
SCORES	1	2	3	4	SUM
NB Exit Conflict Score Count	19	2	5	2	32
SB Exit Conflict Score Count	6	3	0	2	32

CUMULATIVE NUMBER					
SCORES	1	2	3	4	SUM
NB Exit Conflict Score Count	19	21	26	28	28
SB Exit Conflict Score Count	6	9	9	11	11

CUMULATIVE PERCENTAGE					
NB Exit Conflict Scores Count	0.67	0.75	0.93	1	1
SB Exit Conflict Scores Count	0.54	0.82	0.82	1	1
Difference	0.08	0.07	0.11	0	0

Dmax = 1.36 $\sqrt{}$(n1+ n2)/(n1)(n2) at the 0.05 significance level
= 1.36$\sqrt{}$(28+11)(28)(11)
= 0.48
Since Dmax > Difference, there is no significant difference at 0.05 significance level between the two data sets.

The Kolmogorov-Smirnov test results on level of conflict scores between EV and other vehicles at the northbound and southbound exit of EV does not show any significant difference.

CHI –SQUARE TEST

Test 2: Conflict Score Counts at the Entry and Exit of EV Northbound and Southbound Movement at the intersection of Beedo St and U.S.1

OBSERVED	ENTRY	EXIT	*SUM*
Northbound	32	28	60
Southbound	12	11	23
SUM	44	39	83

EXPECTED	ENTRY	EXIT	*SUM*
Northbound	31.80	28.19	60
Southbound	12.19	10.80	23
SUM	44	39	83

$\chi^2 = 0.009$
$\chi^2 (0.05,1) = 3.84$

Since χ^2 (calculated) $< \chi^2(0.05,1)$, It can be concluded that, there is no significant difference between Entry and Exit conflict score counts of EV 's southbound and northbound movement.

The Chi-Square test conducted on the conflict score counts at the entry and exit of EV's Northbound and Southbound Movement at the intersection of Beedo Street and U.S.1 show no significant difference. The result supports the notion that the total observations made to calculate conflict severity do not differ significantly

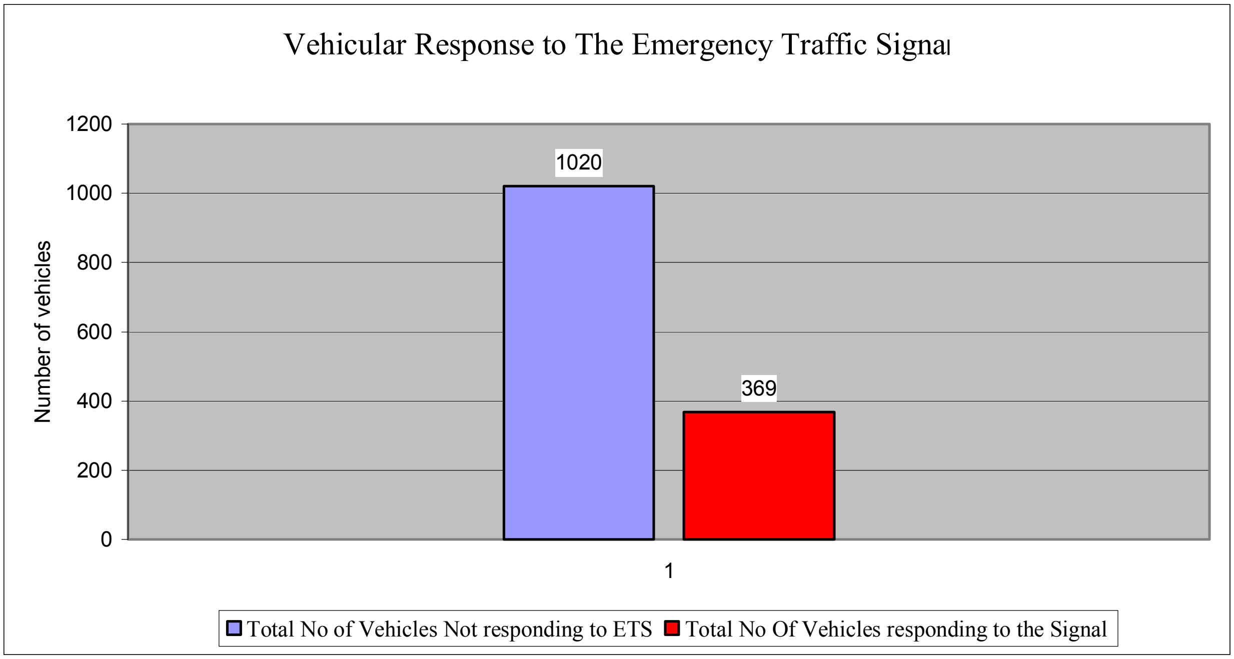


Figure 6: Graphical Representation of Vehicular Response to ETS during emergency actuations

Observation:

1. The above figure shows that only 369 (27%) other vehicles stop on seeing ETS displaying red during emergency actuations and 1020(73%) vehicle do not stop.
2. The above phenomenon shows that the emergency traffic signal does not convey clear message to stop/guide the other vehicles during the emergency actuations.

Statistical Analysis:

CHI-SQUARE TEST:
Test 3: Number of Vehicles not responding to the emergency traffic Signal.

OBSERVED	ENTRY	EXIT	SUM
Northbound	271	280	551
Southbound	281	188	469
SUM	552	468	1020

EXPECTED	ENTRY	EXIT	SUM
Northbound	298.18	252.81	551
Southbound	253.81	215.18	469
SUM	552	468	1020

$\chi^2 = 11.76$

$\chi^2\ (0.05,1) = 3.84$

Since, χ^2 (calculated) > χ^2 (0.05, 1), it can be concluded that, there is significant difference between number of vehicles not responding to emergency traffic signal in northbound and southbound directions with 60% of southbound vehicles not responding or violating the ETS displaying red.

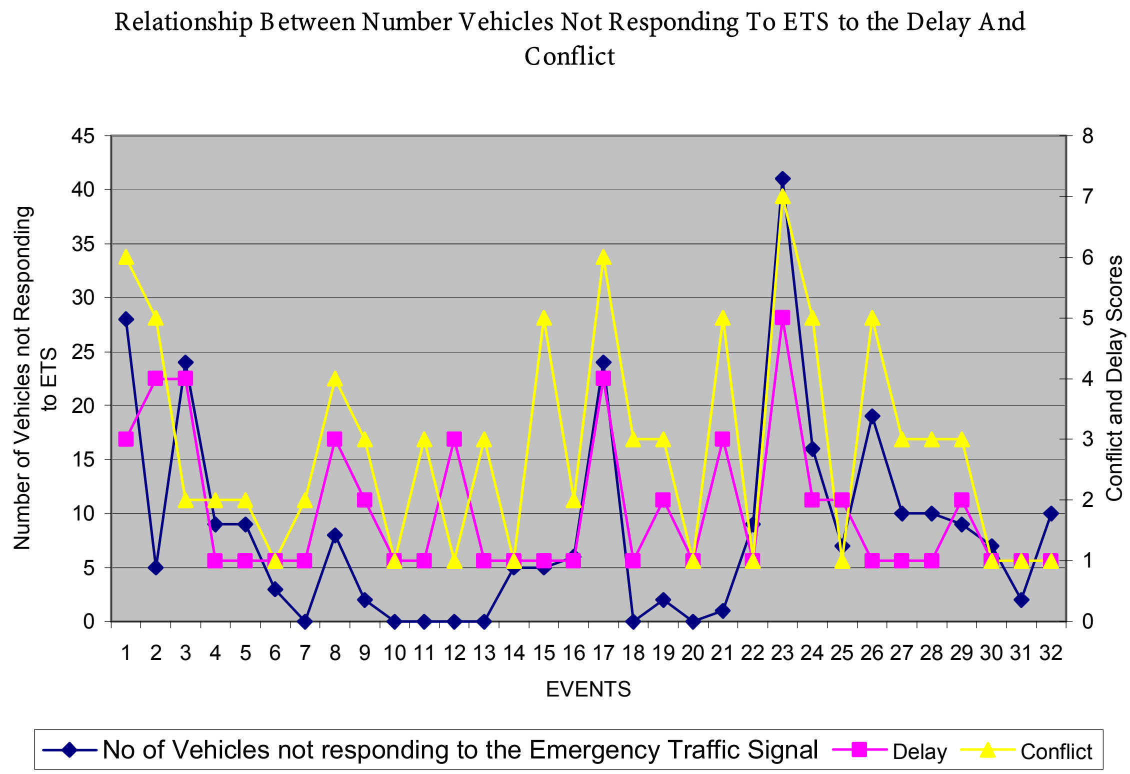


Figure 7: Relationship between the number of vehicles not responding to ETS to the delay and conflict scores.

Observation:
The above figure shows the graphical representation of relationship between number of vehicles not responding to the ETS, conflict and delay. It also shows that the increase in vehicles not responding to ETS leads to increase in conflict severity between emergency vehicles and other vehicles and also increases the delay to the emergency vehicle.

Statistical Analysis:

Test 4: Proportions of Agreement between Number of Vehicles not responding to the ETSS and Conflict Scores using Cohen's Kappa Test:

	Number of Vehicles not responding to the ETS				
Conflict Scores		**High**	**Not Correlated**	**Low**	**Sum**
	High	5	3	1	9
	Not Correlated	2	2	3	7
	Low	4	1	10	15
	Total	**11**	**6**	**14**	**31**

Proportion of Agreement				95%Confidence Index	
Category	Maximum Possible	Chance Expected	Observed	Lower Limit	Upper Limit
High	0.81	0.19	0.333	0.12	0.61
Not Correlated	0.85	0.11	0.18	0.03	0.52
Low	0.93	0.30	0.52	0.29	0.74
Composite	**0.93**	**0.36**	**0.55**	**0.363**	**0.722**

From the above analysis it can be noted that 55% (composite) of the values agree that vehicles not responding to the ETSS and conflict scores vary accordingly. Thus the Cohens Kappa statistical test suggests that the above statement is true at the 95% Confidence Index level.

Test 5: Proportions of Agreement between Number of Vehicles not responding to the ETSS and Delay Scores of EV using Cohen's Kappa Test:

	Number of Vehicles not responding to the ETS				
		High	Not Correlated	Low	Sum
Delay Scores	**High**	4	3	2	9
	Not Correlated	3	4	5	12
	Low	2	1	7	10
	Total	**9**	**8**	**14**	**31**

Proportion of Agreement				95%Confidence Index	
Category	Maximum Possible	Chance Expected	Observed	Lower Limit	Upper Limit
High	1	0.16	0.28	0.09	0.58
Not Correlated	0.66	0.18	0.25	0.08	0.52
Low	0.71	0.23	0.41	0.19	0.66
Composite	**0.87**	**0.33**	**0.48**	**0.30**	**0.66**

From the above analysis it can be noted that 48% (composite) of the values agree that vehicles not responding to the ETSS and delay scores vary accordingly. Thus the Cohens Kappa statistical test suggests that the above statement is true at the 95% Confidence Index level.

SL NO	DATE	EVENT NO	NO OF VEHICLES NOT RESPONDING TO THE ETS	DELAY SCORES	CONFLICT SCORES
1	3/5/2002	87	28	3	6
2	3/5/2002	92	5	4	5
3	3/5/2002	93	24	4	2
4	3/5/2002	94	9	1	2
5	3/5/2002	95	9	1	2
6	3/5/2002	96	3	1	1
7	3/5/2002	97	0	1	2
8	3/5/2002	98	8	3	4
9	3/5/2002	99	2	2	3
10	3/5/2002	100	0	1	1
11	3/6/2002	101	0	1	3
12	3/6/2002	104	0	3	1
13	3/6/2002	105	0	1	3
14	3/6/2002	110	5	1	1
15	3/6/2002	114	5	1	5
16	3/6/2002	115	6	1	2
17	3/6/2002	116	24	4	6
18	3/6/2002	117	0	1	3
19	3/6/2002	118	2	2	3
20	3/7/2002	136	0	1	1
21	3/7/2002	137	1	3	5
22	3/7/2002	140	9	1	1
23	3/7/2002	142	41	5	7
24	3/7/2002	145	16	2	5
25	3/8/2002	151	7	2	1
26	3/8/2002	153	19	1	5
27	3/8/2002	154	10	1	3
28	3/8/2002	155	10	1	3
29	3/8/2002	156	9	2	3
30	3/8/2002	157	7	1	1
31	3/8/2002	158	2	1	1
32	3/8/2002	161	10	1	1

Table 1. Vehicular Response, Conflict and Delay Scores during the E V's Northbound Entry at the Intersection of Beedo Street and U.S.1

SL NO	DATE	EVENT NO	NO OF VEHICLES NOT RESPONDING TO THE ETS	DELAY SCORES	CONFLICT SCORES
1	3/5/2002	87	22	2	1
2	3/5/2002	92	16	NA	NA
3	3/5/2002	93	24	NA	NA
4	3/5/2002	94	7	NA	NA
5	3/5/2002	95	7	NA	NA
6	3/5/2002	96	0	NA	NA
7	3/5/2002	97	0	NA	NA
8	3/5/2002	98	13	2	3
9	3/5/2002	99	0	NA	NA
10	3/5/2002	100	0	NA	NA
11	3/6/2002	101	0	1	1
12	3/6/2002	104	15	1	1
13	3/6/2002	105	9	1	1
14	3/6/2002	110	12	NA	NA
15	3/6/2002	114	19	NA	NA
16	3/6/2002	115	2	NA	NA
17	3/6/2002	116	10	NA	NA
18	3/6/2002	117	0	1	3
19	3/6/2002	118	3	1	3
20	3/7/2002	136	0	NA	NA
21	3/7/2002	137	22	NA	NA
22	3/7/2002	140	5	NA	NA
23	3/7/2002	142	25	2	2
24	3/7/2002	145	17	1	4
25	3/8/2002	151	8	NA	NA
26	3/8/2002	153	6	NA	NA
27	3/8/2002	154	11	1	2
28	3/8/2002	155	11	1	2
29	3/8/2002	156	5	1	2
30	3/8/2002	157	4	NA	NA
31	3/8/2002	158	1	NA	NA
32	3/8/2002	161	7	NA	NA

Table 2. Vehicular Response, Conflict and Delay Scores during EV's Southbound Entry at the Intersection of Beedo and U.S.1

SL NO	DATE	EVENT NO	NO OF VEHICLES NOT RESPONDINGTO THE ETS	DELAY SCORES	CONFLICT SCORES
1	3/5/2002	87	24	NA	NA
2	3/5/2002	92	3	1	1
3	3/5/2002	93	6	NA	NA
4	3/5/2002	94	0	2	1
5	3/5/2002	95	0	NA	NA
6	3/5/2002	96	0	1	1
7	3/5/2002	97	34	1	2
8	3/5/2002	98	5	3	4
9	3/5/2002	99	6	1	4
10	3/5/2002	100	0	1	1
11	3/6/2002	101	0	1	3
12	3/6/2002	104	0	1	3
13	3/6/2002	105	0	1	3
14	3/6/2002	110	5	1	1
15	3/6/2002	114	0	1	1
16	3/6/2002	115	3	1	1
17	3/6/2002	116	24	1	2
18	3/6/2002	117	0	1	1
19	3/6/2002	118	5	1	1
20	3/7/2002	136	1	1	1
21	3/7/2002	137	26	3	1
22	3/7/2002	140	4	1	1
23	3/7/2002	142	25	1	3
24	3/7/2002	145	16	NA	NA
25	3/8/2002	151	12	1	1
26	3/8/2002	153	20	1	1
27	3/8/2002	154	10	1	1
28	3/8/2002	155	10	1	1
29	3/8/2002	156	5	1	3
30	3/8/2002	157	7	1	1
31	3/8/2002	158	25	1	1
32	3/8/2002	161	4	1	1

Table 3. Vehicular Response, Conflict and Delay Scores during the EV's Northbound Exit from the Intersection of Beedo and U.S.1

SL NO	DATE	EVENT NO	NO OF VEHICLES NOT RESPONDING T0THE ETS	DELAY SCORES	CONFLICT SCORES
1	3/5/2002	87	11	NA	NA
2	3/5/2002	92	0	NA	NA
3	3/5/2002	93	0	NA	NA
4	3/5/2002	94	0	NA	NA
5	3/5/2002	95	0	NA	NA
6	3/5/2002	96	0	NA	NA
7	3/5/2002	97	33	NA	NA
8	3/5/2002	98	0	NA	NA
9	3/5/2002	99	0	NA	NA
10	3/5/2002	100	0	NA	NA
11	3/6/2002	101	0	1	1
12	3/6/2002	104	0	1	1
13	3/6/2002	105	0	1	1
14	3/6/2002	110	6	NA	NA
15	3/6/2002	114	0	NA	NA
16	3/6/2002	115	3	NA	NA
17	3/6/2002	116	10	NA	NA
18	3/6/2002	117	0	1	1
19	3/6/2002	118	3	1	1
20	3/7/2002	136	12	NA	NA
21	3/7/2002	137	20	NA	NA
22	3/7/2002	140	5	NA	NA
23	3/7/2002	142	18	2	4
24	3/7/2002	145	13	1	4
25	3/8/2002	151	11	NA	NA
26	3/8/2002	153	1	NA	NA
27	3/8/2002	154	6	1	2
28	3/8/2002	155	6	1	2
29	3/8/2002	156	2	1	2
30	3/8/2002	157	5	NA	NA
31	3/8/2002	158	17	NA	NA
32	3/8/2002	161	6	1	1

Table 4. Vehicular Response, Conflict and Delay Scores during the EV's Southbound Exit from the Intersection of Beedo and U.S.1.

SL NO	DATE	EVENT	TOTAL NO OF VEHICLES RESPONDING TO THE ETS	TOTAL NO OF VEHICLES NOT RESPONDINGTO THE ETS	TOTAL NO OF VEHICLES
1	3/5/2002	87	17	85	102
2	3/5/2002	92	10	24	34
3	3/5/2002	93	3	54	57
4	3/5/2002	94	25	16	41
5	3/5/2002	95	25	16	41
6	3/5/2002	96	18	3	21
7	3/5/2002	97	40	67	107
8	3/5/2002	98	4	26	30
9	3/5/2002	99	4	8	12
10	3/5/2002	100	29	0	29
11	3/6/2002	101	30	0	30
12	3/6/2002	104	26	15	41
13	3/6/2002	105	26	9	35
14	3/6/2002	110	2	28	30
15	3/6/2002	114	26	24	50
16	3/6/2002	115	2	14	16
17	3/6/2002	116	3	68	71
18	3/6/2002	117	12	0	12
19	3/6/2002	118	6	13	19
20	3/7/2002	136	2	13	15
21	3/7/2002	137	5	69	74
22	3/7/2002	140	0	23	23
23	3/7/2002	142	27	109	136
24	3/7/2002	145	0	62	62
25	3/8/2002	151	3	38	41
26	3/8/2002	153	14	46	60
27	3/8/2002	154	1	37	38
28	3/8/2002	155	1	37	38
29	3/8/2002	156	4	21	25
30	3/8/2002	157	2	23	25
31	3/8/2002	158	1	45	46
32	3/8/2002	161	1	27	28
		Total	369	1020	1389

Table 5: Vehicular Responses to the Existing Emergency Traffic Signal at the Intersection of Beedo Street and U.S.1.

3.5 Conclusion:

The following results from the evaluation of existing ETS at the intersection of Beedo Street and U.S.1 indicate that the other vehicular response to the existing ETS while displaying RED is not appropriate. (See Figures 4, 5, 6, 7).

1. Only 27% of the other vehicles stop on seeing Emergency Traffic Signal System displaying red during the emergency vehicle passage through the intersection of Beedo Street and U.S.1.
2. The above phenomenon shows that the emergency traffic signal does not convey clear message to stop the other vehicles during the emergency actuations.
3. The other vehicles not responding to the emergency traffic signal while displaying red in both Northbound and Southbound directions during preemption actuations is a main problem for existing ETS at the intersection of Beedo Street and U.S.1.
4. The delay to the EV and conflict severity between EV and the other vehicles is directly related to the failure of existing ETS while displaying RED in stopping the other vehicles during the EV's passage through the intersection.
5. The existing ETS at the intersection of Beedo Street and U.S.1 does not confirm MUTCD 2000 ETS requirements.

There fore, it can be concluded that there is warrant to replace the existing ETS at the intersection of Beedo Street and U.S.1 with an alternative efficient traffic control device or system.

CHAPTER 4:
Design of Alternative Emergency Traffic Signal Systems (ETSS)

This chapter presents a proposed alternative emergency traffic signal system needed in order to improve its performance by guiding the other vehicles and EV's passage through the intersection of Beedo Street and U.S.1 safely. It also describes the system architecture that corresponds to the proposed alternative emergency traffic signal system and plan

4.1 INTRODUCTION

The intersection of Beedo Street and U.S. 1 is of the T-intersection (see Appendix A1 for map of study corridor). The intersection of Beedo Street and U.S.1 situated between the intersection of South Drive and U.S. 1 at north direction and the Beacon Road and U.S.1. As discussed in Chapter 3 the intersection at Beedo Street and U.S.1 has hard-wired ETSS providing the entry point for the EV's coming out of the fire station 411 (see Appendix A for location of fire station in Fairfax County)

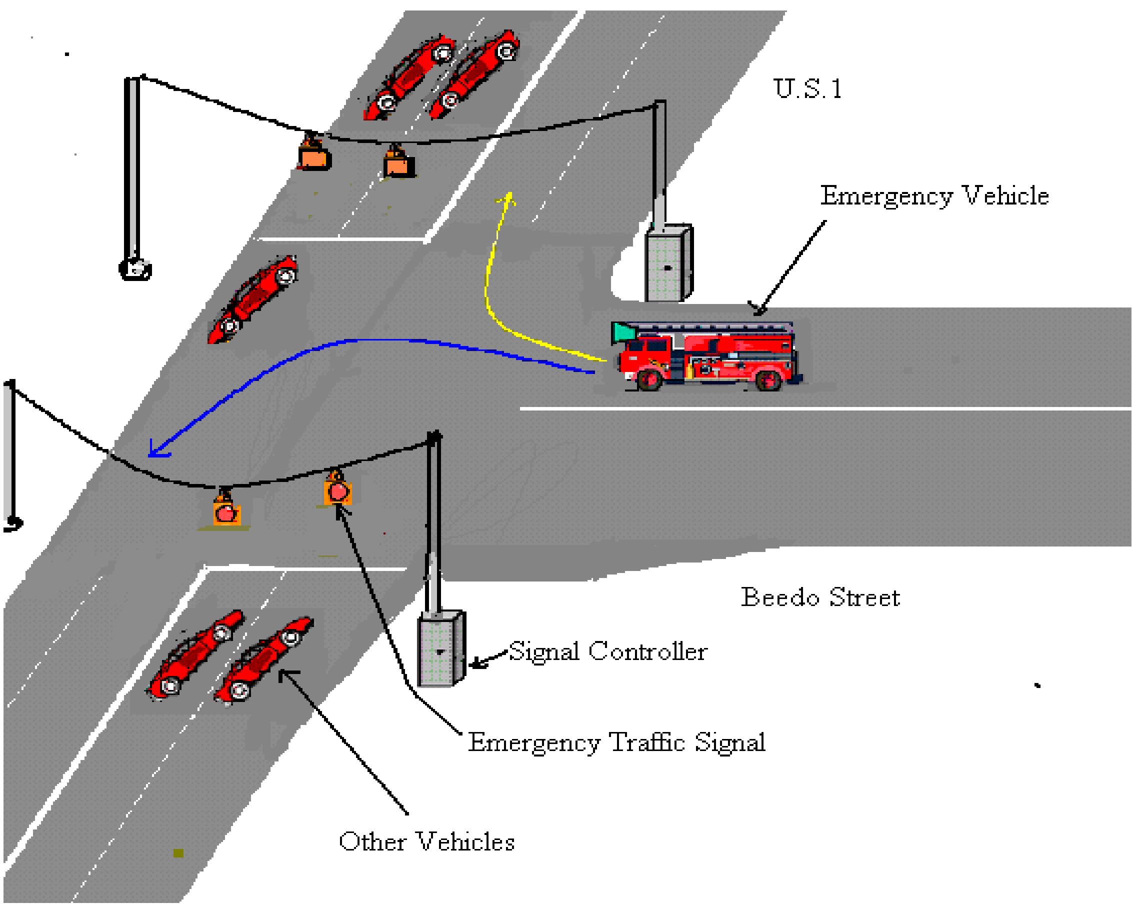


Figure 8: An overview of existing ETS at the intersection of Beedo Street and U.S.1.

4.2 Need for Alternative Emergency Traffic Signal System:

Traffic control signals, even when justified by traffic and roadway conditions, can be ill designed, ineffectively placed, improperly operated, or poorly maintained. Improper or unjustified traffic control signals can result in one or more of the following disadvantages:

1. Excessive delay;
2. Excessive disobedience of the signal indications;
3. Increased use of less adequate routes as road users attempt to avoid the traffic control signals; and
4. Significant increases in the frequency of collisions (especially rear-end collisions).
5. Engineering studies of operating traffic control signals should be made to determine whether the type of installation and the timing program meet the current requirements of traffic and MUTCD standards.

The analysis of existing ETS has provided following results:

1. Only 27% of the other vehicles stop on seeing Emergency Traffic Signal System displaying red during the emergency vehicle passage through the intersection of Beedo Street and U.S.1.(See figure 6).
2. The above phenomenon shows that the emergency traffic signal does not convey clear message to stop the other vehicles during the emergency actuations.
3. The other vehicles not responding to the emergency traffic signal while displaying red in both Northbound and Southbound directions during preemption actuations is a main problem for existing ETS at the intersection of Beedo Street and U.S.1.
4. The delay to the EV and conflict severity between EV and the other vehicles is directly related to the failure of existing ETS while displaying RED in stopping the other vehicles during the EV's passage through the intersection.
5. The conflict severity between EV and other vehicles increase with the increase in the number vehicles not responding to the ETS while displaying RED. The 55% of conflict scores vary accordingly with the number of vehicles not responding to the ETS while displaying red.
6. The existing ETS does not confirm MUTCD 2000 ETS requirements.
7. The existing ETS preempts both the Northbound and Southbound traffic.

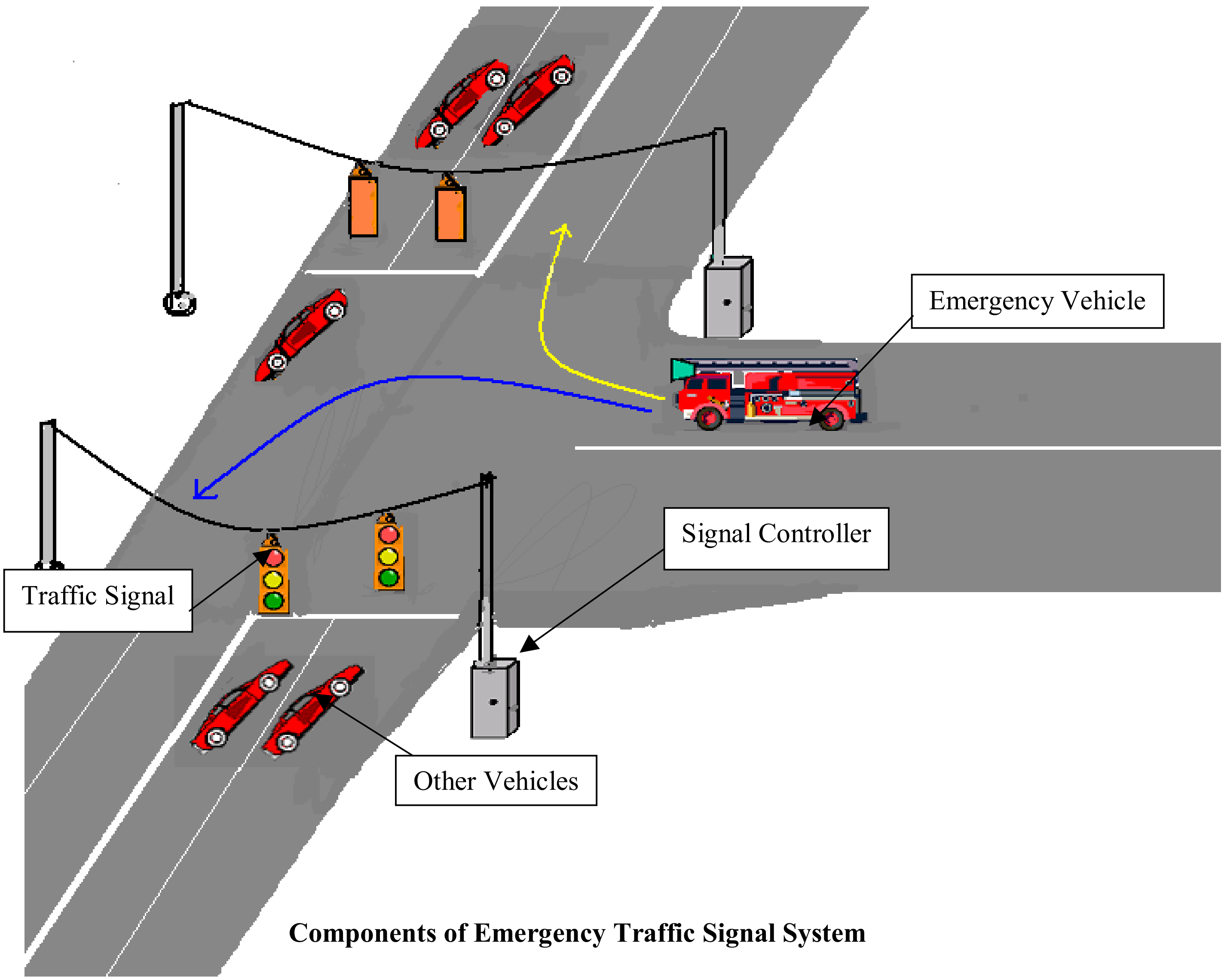
The analysis of the existing ETS dictates that new system :

1. Should guide EV safely through the intersection with minimum delay.
2. Should have ability to convey the clear message to stop when ETS is displaying RED.
3. MUTCD 2000 requirement should be met by the alternative system.
4. The new system should provide have optimum preemption time as required by the MUTCD 2000 standards.
5. Should provide ability to driver of EV to ask for preemption as it approaches the intersection.

4.3 Alternative Emergency Traffic Signal Systems I:

4.3.1 Overview of Alternative Emergency Traffic Signal System I:
The alternative emergency traffic signal will consist of three ball lights of size 300 mm. ETS here will display green on major street (i.e. is along U.S.1) before the emergency vehicle approaches and as soon as it approaches the intersection light changes from green to yellow and then transforms into red flashing. A steady red is indicated upon emergency actuation in order to allow the emergency vehicles enter main thoroughfare.

4.3.2 SYSTEM COMPONENTS:



Components of Emergency Traffic Signal System

Figure 9: An overview of the Alternative Emergency Traffic Signal System I (ATSS I)

The Emergency Traffic Signal System is broadly classified into two major system components. They are Emergency Traffic Signal, Emergency Equipment Station and Hardwire Preemption Cable

An ETS is a special traffic control signal, which gives the right of way for an authorized emergency vehicle. It is installed at the intersection of Beedo and U.S.1, which is entry point for emergency vehicles onto U.S.1. The proposed emergency vehicle traffic control signal at the intersection will consist of three ball lights of size 300 mm., namely circular red ball, circular yellow ball, circular green ball as per Sections 4D.13, 4D.14 4D.15 of MUTCD 2000

The emergency equipment station (EES) is located at the **Fire Station 411.** EES is equipped with a push – button device that is used to control the ETS at the intersection of Beedo Street and U.S.1 during emergency preemption actuations. The system components of the EES are mainly Push Button Activation Switch Device and Hard Wire Preemption Cable

Hardwire preemption cable functions as a physical connection from EES located at the **Fire Station 411** to the signal controller of ETS located at the intersection of Beedo Street and U.S.1. The system requires a cable from the controller to an activation switch. The proposed EES at the **Fire Station 411** near the intersection of Beedo Street and U.S.1 will have double-push button activation switch for preemption for the both northbound and southbound traffic at the intersection of Beedo Street and U.S.1. The existing ETSS has a single button switch to preempt both the northbound and southbound traffic.

Figure 10: Double Push Button Activation Switch Device

The other major components of the emergency vehicle traffic signal preemption system are:

The roadway
The emergency vehicle
Other vehicular traffic

The Roadway

The roadway is the surface upon which the emergency vehicle and other vehicular traffic travel. The main roadway is U.S.1 and is comprised of two lanes on each direction and the road way has the shoulders that could be used for vehicle pull-off or vehicle travel during emergency vehicle operations. The intersection of Beedo Street and U.S.1 is a T-intersection. The Beedo street is the cross street and it has single lane in each direction.

The Emergency Vehicle

An emergency vehicle would likely travel to the scene of an emergency with lights and sirens activated and travel at as high a speed as possible. An actual emergency vehicle would make an attempt to pass other vehicles, even crossing a double-yellow line to do so. An actual emergency vehicle would likely enter into a major intersection somewhat cautiously, but would not be constrained by the requirement to obey the traffic signal indications.

Other Vehicular Traffic

The other vehicular traffic includes every non-emergency vehicles traveling through the intersection irrespective of emergency traffic signal preemption. The other vehicles should react to the lights and sirens of an emergency vehicle by pulling over to the right hand side, moving to the shoulder, clearing an intersection, or using some other means to allow the emergency vehicle to pass.

Preemption Logic and Working of the System:

The Hardwire Preemption System provides right of way to emergency vehicles, as needed. It does this in three steps that occur within seconds:

1) As soon as the emergency vehicle leaves the firehouse, the Double Push Button Activation Switch Device is physically activated

2) The signal controller of ETSS at the intersection receives the preemption signal through the hardwire cable emanating from the EES.

3) A phase selector, housed in the signal controller cabinet, authorizes the emergency vehicle by preemption of ETS, i.e. displaying of red signal to other vehicles and thus giving the emergency vehicle an efficient, natural appearing right of way for the emergency vehicle.

The traffic signal preemption logic developed for this research is presented here is at very simple level and is very productive in reducing delay to the other vehicle and clearing the message to the drivers of other vehicles.

The emergency vehicle leaving the firehouse at Beedo Street will access either the northbound or southbound direction of U.S. 1.The path of the emergency vehicle is determined before leaving the firehouse by the dispatching personnel responsible for responsible for emergency calls. Therefore before the emergency vehicle leaves the firehouse the destination is decided in terms of either northbound direction towards the intersection of Southgate Drive and U.S.1 or southbound direction towards the intersection of Beacon Hill Road and U.S.1

The preemption logic is preset and controlled by the Double Push Button Activation Switch Device. The above said activation switch device will have two button signifying each north and southbound movements of EV. The upper push button is to be activated for the northbound movement of EV at the intersection of Beedo Street and U.S.1 and similarly the lower push button is to be activated for the southbound movement of EV at the intersection of Beedo Street and U.S.1

EV Northbound Movement:

The EV's movement in northbound direction (see Figure 9) is conveyed by the upper switch-indicating alphabet 'N' on the Activation Switch Board. The EV's northbound movement at the intersection is conveyed through the hard wire connecting the activation switch device present at the EES in the firehouse 411 and the signal controller located at the intersection. Upon the preemption actuation by the signal controller, the ETS transforms from steady green to yellow and followed by steady red to the other vehicular traffic going northbound. A continuous steady green is displayed by the ETS to the other vehicular traffic moving in southbound direction.

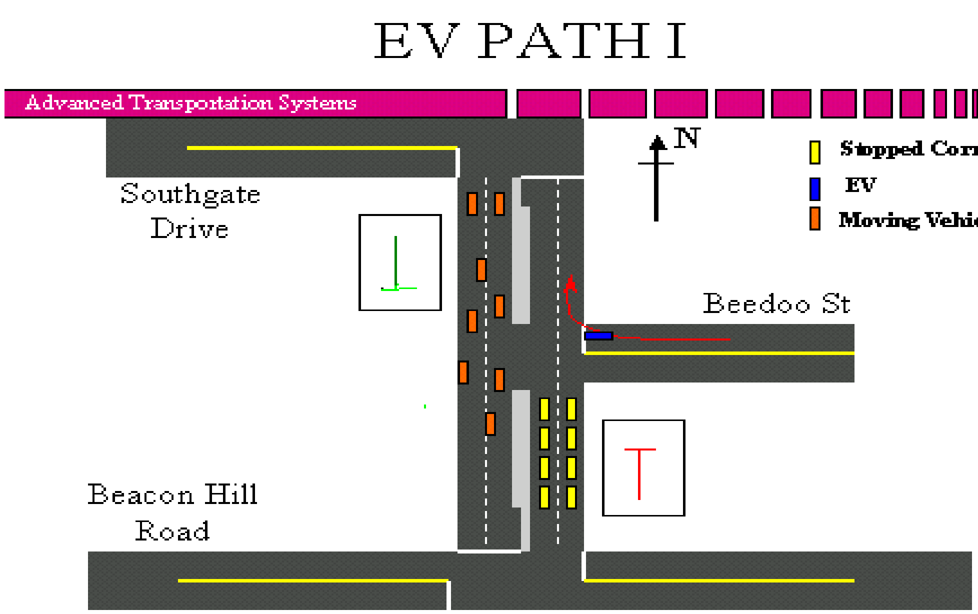


Figure 11: Graphical Representation of Northbound Movement of EV at the Intersection of Beedo Street and U.S.1

EV's Southbound Movement:

The EV's movement in southbound direction (See Figure 10) is conveyed by the lower switch-indicating alphabet 'S' on the Activation Switch Board. The EV's southbound movement at the intersection is conveyed through the hard wire connecting the activation switch device present at the EES in the Firehouse 411 and the Signal Controller located at the intersection. Upon the preemption actuation by the Signal Controller, the ETS transforms from steady green to yellow and followed by steady red to the other vehicular traffic going in both the northbound and southbound movement of the other vehicular traffic.

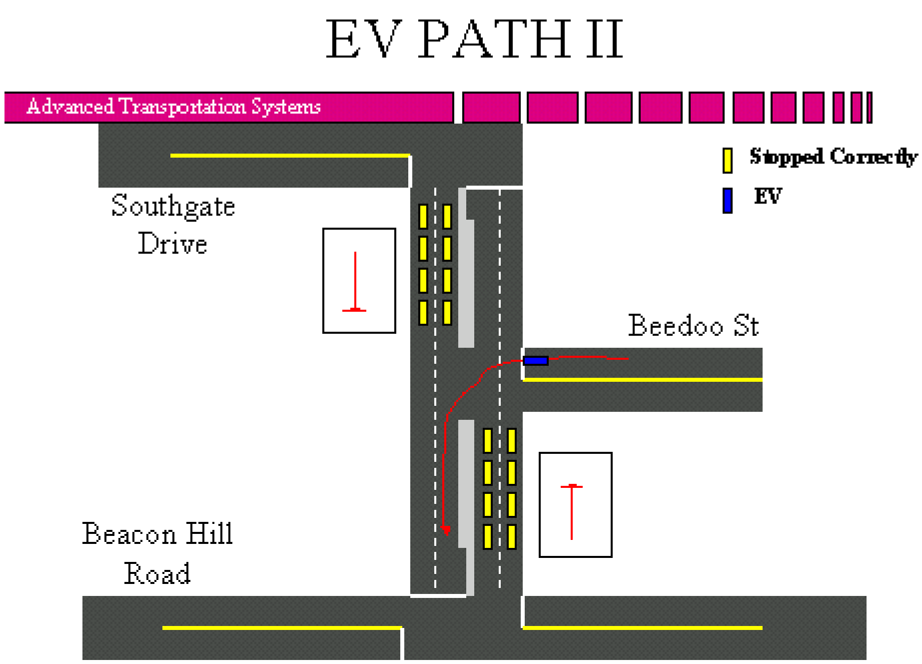


Figure 12: Graphical Representation of Southbound Movement of EV at the Intersection of Beedo Street and U.S.1

4.3.3 Signal Timing Plan for Alternative Emergency Traffic Signal I:

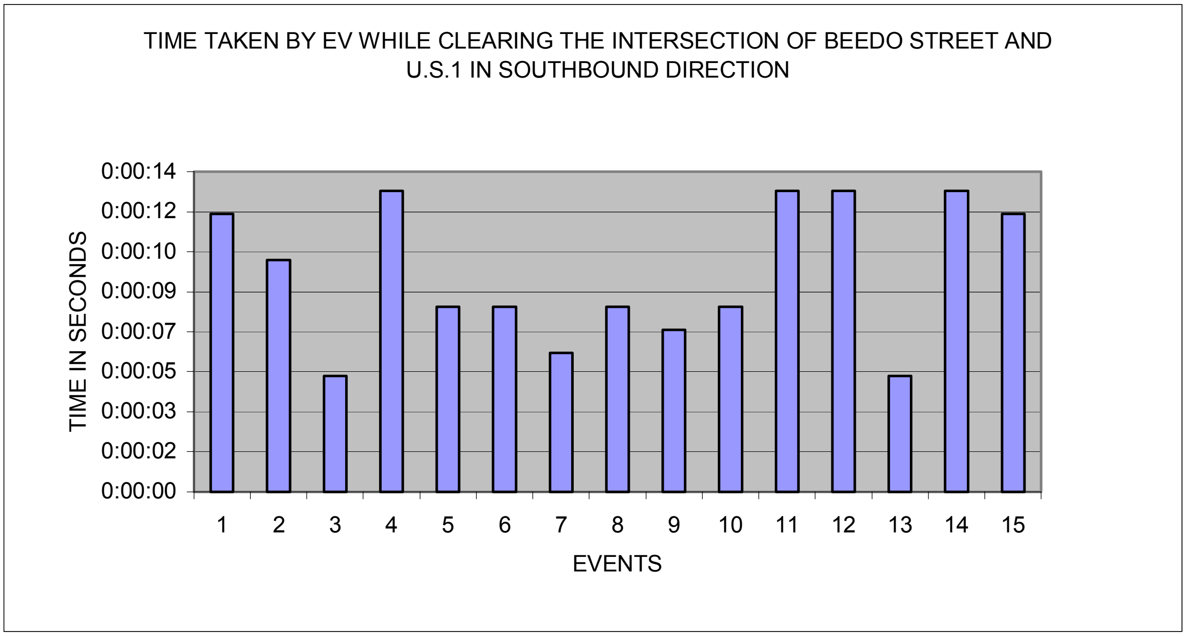


Figure 13: Time taken by the EV in Clearing the Intersection of Beedo Street and U.S.1 while Traveling in Southbound Direction

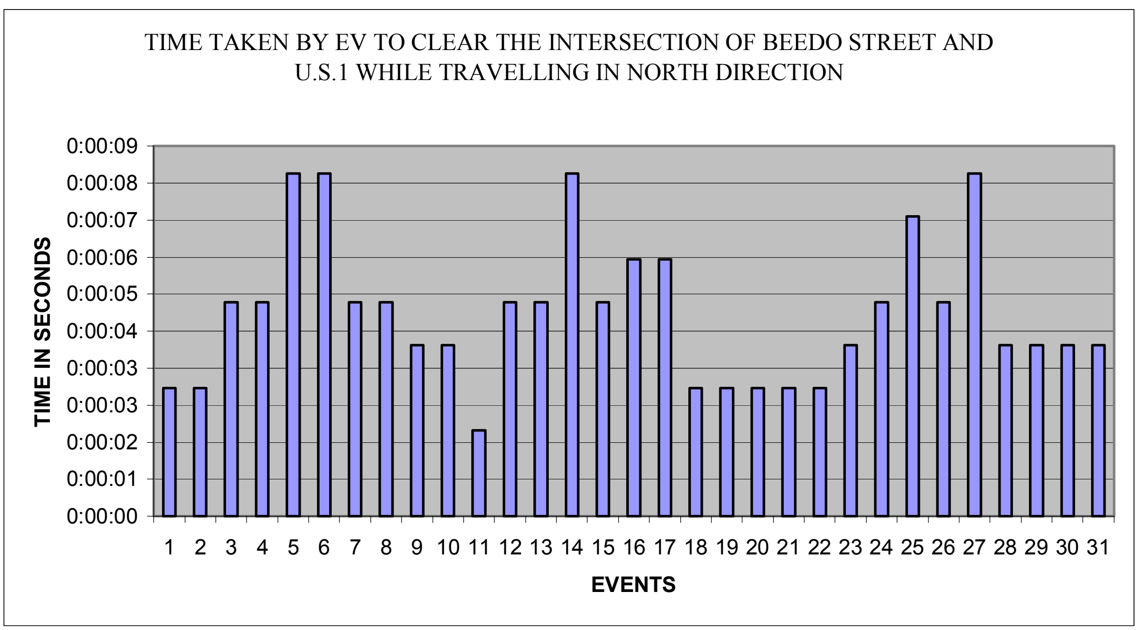


Figure 14: Time taken by the EV in Clearing the Intersection of Beedo Street and U.S.1 while Traveling in Northbound Direction

Figures 11 and 12 show the time taken by the EV from the fire station 411 in clearing the intersection of Beedo Street and U.S.1 while traveling in northbound and southbound directions respectively during the following period (5 th March to 13 th March, 2001 and 12 June to 17 June 2001)) .The vertical axis represents the time taken by the EV in clearing the intersection of Beedo Street and U.S. The horizontal axis indicates the events of EV's passage through the said intersection. The above data is obtained from fire station 411 emergency call log maintained by the Fairfax County fire and rescue community. The figures 11 and 12 also show that the maximum time required by the EV to clear the intersection of Beedo Street and U.S.1 while traveling in northbound direction is eight seconds and while traveling southbound direction EV takes thirteen seconds.

The **Section 4D.13 of MUTCD 2000** lays down the guideline for preemption and priority control of traffic control signals. It states i.e. 'The duration of the red interval for traffic on the major street should be determined by on-site test-run time studies, but should not exceed 1.5 times the time required for the emergency vehicle to clear the path of conflicting vehicles'

RED TIME: A steady RED will be displayed by the ETS along U.S.1 for other vehicular traffic. The duration of RED is calculated as follows:
RED TIME when the EV is traveling in the northbound direction (Path I): 1.5×8 Seconds = 12 Seconds
RED TIME when the EV is traveling in the southbound direction (Path II): 1.5×13 Seconds = 19.5 Seconds

GREEN TIME: The signal indication, between emergency-vehicle actuations, shall be steady green. Therefore ETS GREEN time is the duration between the successive emergency preemption actuations.
YELLOW TIME: A steady YELLOW shall be displayed during the transition in and out of preemption control. The duration of the YELLOW time can be taken as 3 seconds.

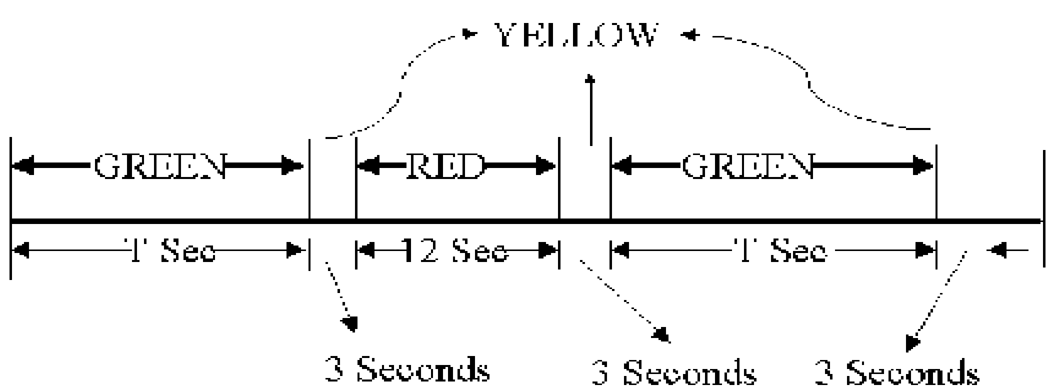


Figure 15: Signal Timing Plan for Alternative Emergency Traffic Signal I while EV travels in Northbound Direction.

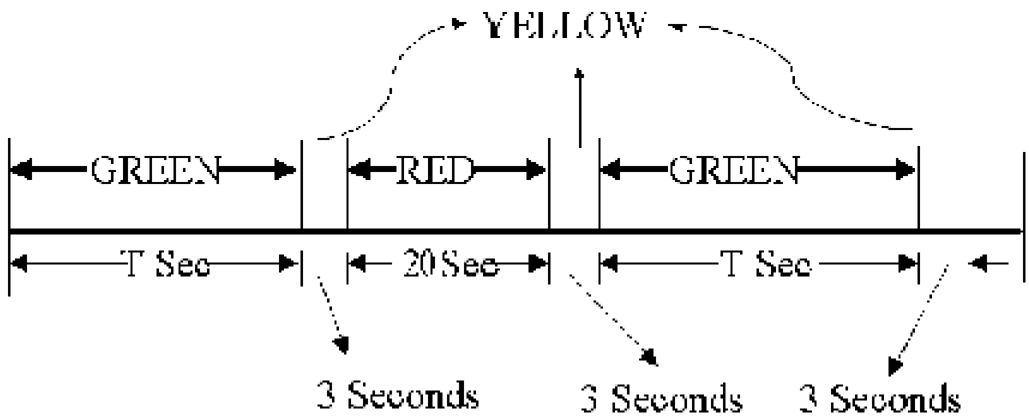


Figure 16: Signal Timing Plan for Alternative Emergency Traffic Signal I while EV travels in Southbound Direction

Figure 13 and 14 show the signal-timing plan for ETS at the intersection of Beedo Street and U.S.1. The red time to be displayed upon emergency preemption actuation is 12 seconds and 20 seconds for the EV traveling northbound and southbound respectively. The GREEN time 'T' represents the time between two successive emergency preemption actuations minus twice the 3 second Yellow times.

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The Average time taken by the EV to reach the intersection from the Fire House 411 immediately after the emergency request is about 3 minutes and one second.

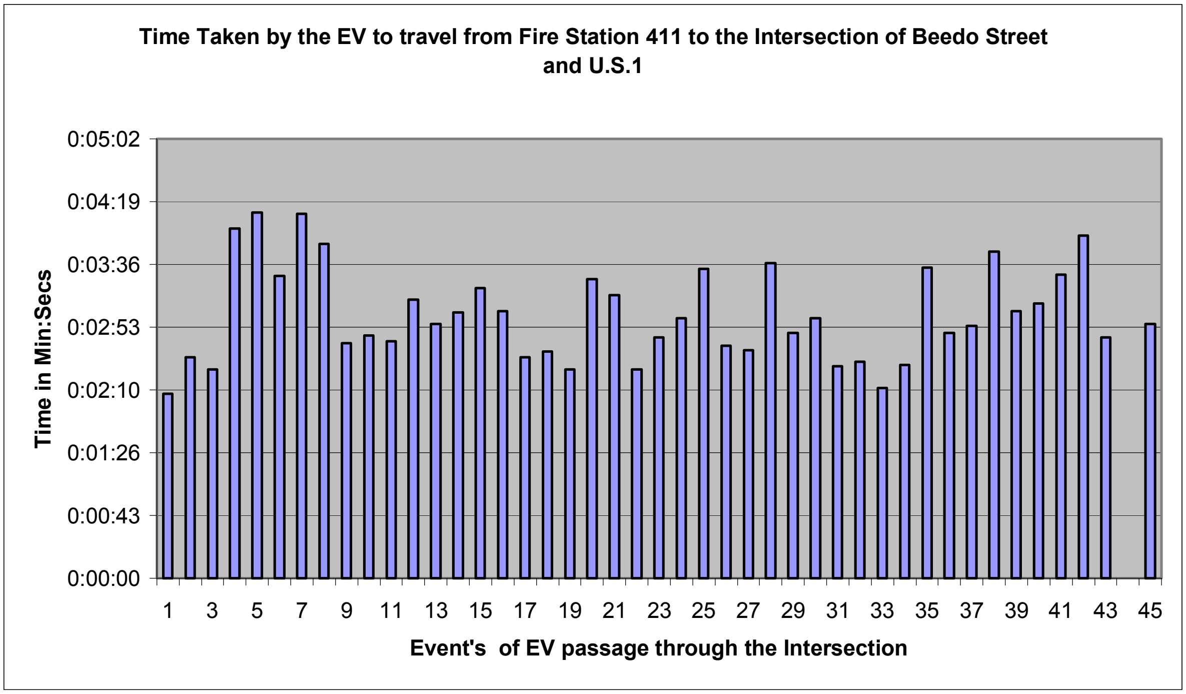

Figure 17: Time taken by the EV to Access the Intersection of Beedo and U.S.1 from Fire House 411 after the 911 Call

The figure 15 shows the travel time taken by the EV to reach the intersection of Beedo Street and U.S.1 after receiving the emergency (911) call. The time varies from minimum of two minutes to maximum of four minutes. The vertical axis shows the time in minutes and seconds. The X-axis shows the individual events of EV passage through the intersection of Beedo Street and U.S.1 between the 5th March 13th March, 2001 and 12 June to 17 June 2001 period.

4.3.4 System Architecture:

The set of components (or sub-systems) that make up the emergency vehicle preemption system is known as its physical system architecture. The logical architecture presents a functional view of the user services and data flows, while the physical architecture defines four sub-systems that perform the functions.
(Mittal, 2002)

Logical Architecture:

The logical architecture of ETSS mainly centers on managing the traffic at the intersection (See Figure 16). As the emergency vehicle leaves the firehouse, the Double Switch Activation Device located at the emergency equipment station is activated. The activation signal is communicated by the hardwire to the signal controller situated at the intersection. The signal controller preempts the ETS to allow the EV to access the intersection. The duration of preemption is pre-timed and the ETS return to normalcy after the preemption.

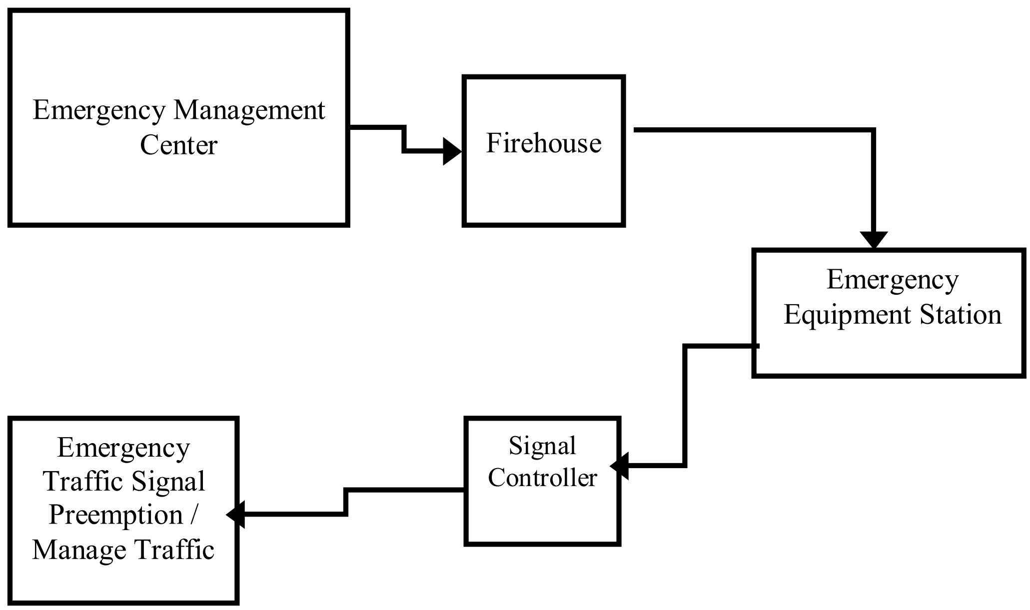

Figure 18: Logical Architecture of Alternative Traffic Signal System I

Physical Architecture:

The physical architecture of any intelligent transportation system (ITS) system is comprised of four systems, including the centers, roadside, vehicles, and travelers. These sub-systems consist of a number of one or more components that are connected by a series of wire line and wireless communication systems. The primary sub-systems involved in emergency vehicle preemption are the emergency vehicle, the roadside and emergency management center. (Mittal, 2002)

The ETSS directly relates to traffic management, emergency management sub-systems, involves wire line communication and other components of architecture sub-systems interconnect diagram. (See Figure 17)

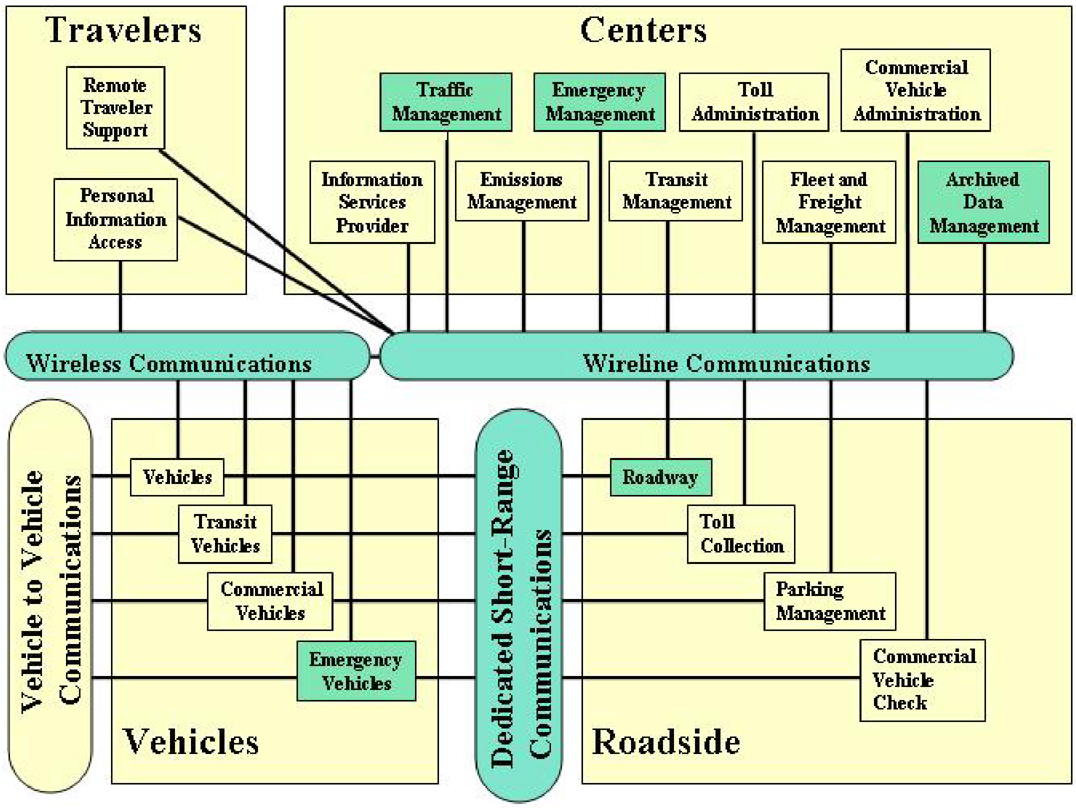

Figure 19: Architecture Sub-systems Interconnect Diagram

4.4 Alternative Emergency Traffic Signal System II:

4.4.1 Need for the Alternative Emergency Traffic Signal System II:

1. The preemption of ETS is granted by the EES, soon after the emergency vehicle leaves the Firehouse 411. A hard wire cable connects the EES situated at the firehouse 411 and the signal controller present to preempt the ETS at the intersection of Beedo Street and U.S.1. The figure 15 shows that arrival time of EV from the firehouse 411 varies significantly from 120 seconds to 420 seconds. To avoid the confusion of estimation of travel time of EV between the firehouse and the intersection of Beedo Street and U.S.1, the EV needs to be equipped with a system that allows it to request preemption as and when it reaches the said intersection.
2. The EV arrives at the Intersection of Beedo Street and U.S.1 from Firehouse 411 after 30 to 53 seconds of preemption of the ETS.
3. The time taken by the EV to clear the intersection is about 4 seconds while traveling towards the north direction and 13 seconds while traveling in the south direction along U.S.1 (See figure 11 and 12).
4. On the average EV utilizes only 17% of ETS preemption time at the intersection of Beedo Street and U.S.1 to clear/pass through the said intersection.

According to the Section 4D.13 of MUTCD 2000, the duration of the red interval for traffic on the major street should be determined by on-site test-run time studies, but should not exceed 1.5 times the time required for the emergency vehicle to clear the path of conflicting vehicles. The existing ETSS with its Hard Wire Preemption setup doesn't function as required by the MUTCD standards. There fore, an efficient ETSS is needed to satisfy above stated standards.

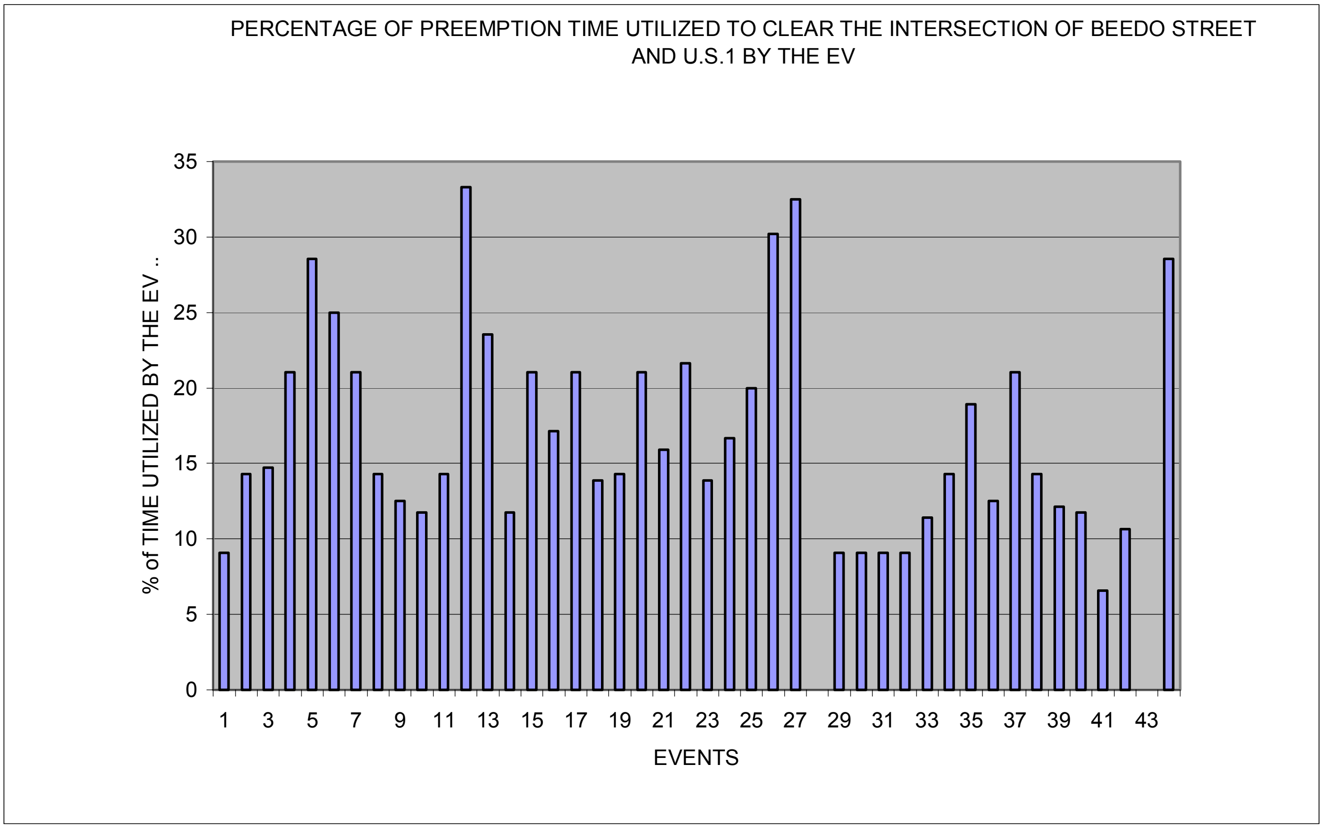

Figure 20: Percentage of Preemption Time Utilized by the EV to Clear the Intersection of Beedo Street and U.S.1

The figure 18 indicates the percentage of preemption time utilized by the EV in clearing the intersection of Beedo Street and U.S. The above figure includes 43 events of EV passage through the intersection of Beedo Street and U.S.1 during the following period (5thMarch to13th March 2001 and 12th June to 17th June 2001)).

4.4.2 Overview of Alternative Emergency Traffic Signal System II

The proposed alternative ETS consists of three ball lights of size 300 mm. The ETS here will display green before the emergency vehicle approaches. As soon as emergency vehicle approaches the intersection and request s for the preemption, the lights changes from green to yellow and then transforms into steady red. A steady red is indicated upon emergency actuation in order to allow the emergency vehicle enter main thoroughfare. The ETS has two pairs of three ball traffic lights to guide the other vehicle traffic along U.S.1.

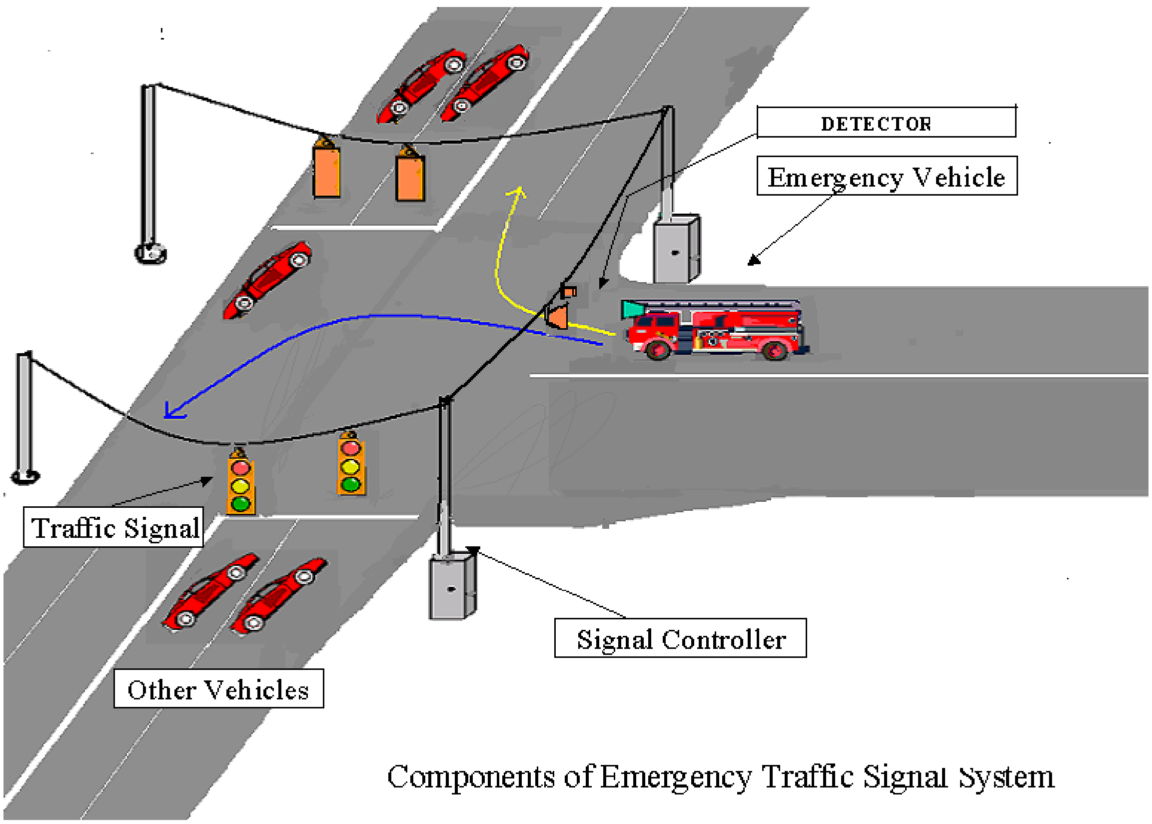

Figure 21: Graphical Representation of Alternative Emergency Traffic Signal System II

4.4.3 System Components:

The major system components of the Alternative Emergency Traffic Signal System II are:

1. Emergency Traffic Signal (ETS)
2. Signal Controller
3. 3M Opticom Equipment

The ETS is a special traffic control signal, which gives the right of way for an authorized emergency vehicle. It is installed at the intersection of Beedo and U.S.1, which is entry point for emergency vehicles onto U.S.1. The proposed emergency vehicle traffic control signal at intersection will consist of three ball lights of size 300 mm., namely circular red ball, circular yellow ball, circular green ball as per Sections 4D.13, 4D.14 4D.15 of MUTCD 2000

The signal controller manages the request for preemption and changes the ETS accordingly. The controller will interrupt the traffic signal timing plan to implement a preemption-timing plan. After servicing the preemption-timing plan, the traffic signal controller than manages the transition back the original timing plan. As soon as emergency vehicle reaches the intersection, the signal controller changes the traffic signals in such a way to facilitate the smooth, safe movement of emergency vehicle through the intersection.

A preemption system of a signal mounted type requires the installation of a receiving device within the traffic control signal cabinet that responds to a remote triggering device attached to specific authorized vehicles. These systems are used for the preemption of normal traffic control signal operation by the approach of emergency vehicles. The transmitter on board the vehicle communicates with the local controller via

Dedicated Short Range Communication (DSRC): The alternative emergency traffic signal system includes a special emitter on board of the EV, which sends a signal to a receiver at the intersection via a short-range wireless communication system. The receiver passes on the message to the signal controller equipment .On receiving the communication the signal controller will interrupt the traffic signal timing plan to implement a preemption-timing plan.

In short, there is a wireless communication between the vehicle emitter and the intersection detector and there is a wire communication between the detector and phase selector in signal controller.

The 3M Opticom Systems

The 3MOpticom System provides preferential treatment to individual vehicles, as needed. It does this in three steps that occur within seconds:

1. An emitter mounted on the EV is activated to send an encoded infrared communication.
2. The emitter mounted on the EV requests different preemption timings depending on the type of movement. (Northbound and southbound directional movement)
3. A detector located near the intersection receives the signal and converts it into electronic communication.

4. A phase selector, housed in the controller cabinet, authorizes the user, logs management information and requests the controller to preempt for particular duration, thus giving the EV an efficient, natural appearing right of way.

The system is designed for joint use by emergency services (police, fire, medical) and other vehicles such as transit. The emergency vehicles have first priority, thus eliminating the confusion and cost of maintaining a system for each. Individual authorized vehicles travel efficiently, wrapped in the security of an integrated system (3M Opticom, 1997).

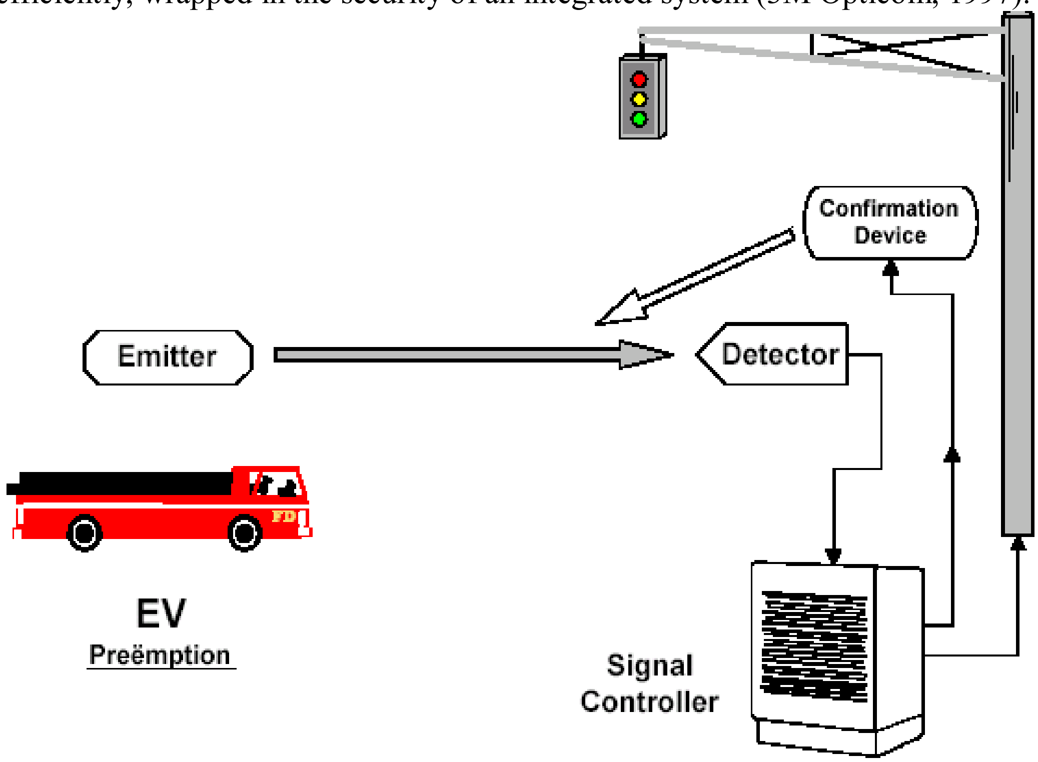

Figure 22: System Components of Alternative Emergency Traffic Signal System II

4.4.3 Signal Timing Plan

RED TIME: A steady RED will be displayed by the ETS along U.S.1 for other vehicular traffic. The duration of RED is calculated as follows:
RED TIME when the EV is traveling in northbound direction: 1.5×8 Seconds = 12 Seconds
RED TIME when the EV is traveling in southbound direction: 1.5×13 Seconds = 19.5 Seconds

GREEN TIME: The signal indication, between emergency-vehicle actuations, shall be steady green. There fore ETS GREEN time is the duration between the successive preemption actuations.

YELLOW TIME: A steady YELLOW shall be displayed during the transition in and out of preemption control. The duration of the YELLOW time can be taken as 3 seconds.

4.4.4 System Architecture

The set of components (or sub-systems) that make up the emergency vehicle preemption system is known as its physical system architecture. The logical architecture presents a functional view of the user services and data flows, while the physical architecture defines four sub-systems that perform the functions. (Mittal, 2002)

4.4.5 Logical Architecture

The logical architecture of ETSS mainly centers on managing the traffic at the intersection (See Figure 21). The EV makes request for the preemption as soon as it approaches the intersection. That signal then must be relayed to the traffic signal controller, and the controller must analyze the information and determine the appropriate action to enable the emergency vehicle to proceed with minimal delay. The Emergency Traffic signal is preempted for a fixed time depending on the travel direction of, which is conveyed to the signal controller.

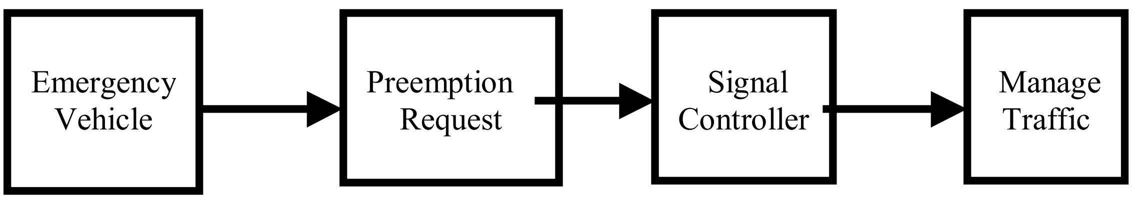

Figure 23: Logical Architecture of Alternative Signal System II

4.4.6 Physical Architecture:

The physical architecture of Alternative Emergency Traffic Signal System II directly relates to traffic Management, emergency management sub-systems, involves wire line communication, DSRC and other components of architecture sub-systems interconnect diagram (See Figure 16)

CHAPTER 5.
CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY of RESULTS:

The evaluation of responses of vehicles to ETSS near the firehouses during emergency actuations generated interesting results. The 73% of the vehicles do not respond to ETS during emergency preemption actuations. The 55% of the observed conflict scores vary according with the number of vehicles not responding to the existing ETS while displaying red at the intersection of Beedo Street and U.S.1. In summary the results indicate that the relatively high percentage of vehicles not responding to ETS contribute to conflict severity between emergency vehicles and other vehicles and the delay to EV

5.2 CONCLUSIONS

Reduction in response time of emergency service is a bona-fide objective of ETSS deployments. Furthermore, the lack of efficient traffic signal systems to guide the emergency vehicle from the firehouse to major highways causes most of the major delays to emergency vehicles and offer opportunities for collisions with other vehicles that did not see or hear the emergency vehicle approaching. This thesis evaluates the existing ETSS present at the intersection of Beedo Street and U.S.1 in terms of delay to emergency vehicle and crash potential between emergency vehicles and other vehicles. The video coverage of events of EV passage through the said intersection during emergency preemption actuations provided data for the above evaluation.

The thesis also examines the non-emergency vehicular or other vehicular responses to the existing ETSS at the said intersection and its impact on delay to EV and crashes potential. The other vehicles or non emergency vehicles not responding to the emergency traffic signal while displaying red in both northbound and south bound directions during preemption actuations is a main problem for existing ETS at the intersection of Beedo Street and U.S.1. The analysis of the crash potential between EV and other vehicles indicates that the increase in number of other vehicles not responding to existing emergency traffic signal, leads to increase in crash potential between EV and all other vehicles. The 55% of the observed conflict scores increase with the increase in number of other vehicles or non-emergency vehicles not responding to the existing ETS at the intersection of Beedo Street and U.S.1. The delay to the EV and conflict severity between EV and the other vehicles is directly related to the failure of existing ETS while displaying RED in stopping the other vehicles during the EV's passage through the intersection. It was concluded that the other vehicular response to the existing ETSS is very low due to lack of clear message and furthermore the existing ETSS doesn't not conform to the Manual on Uniform Traffic Control Devices 2000 (MUTCD 2000) standards.

The thesis also offers two alternative ETSS designs at the intersection of Beedo Street and U.S.1, based on MUTCD 2000 recommendations. The Alternative ETSS Design I is based on hard-wired preemption technology with improved signal timings and is designed to convey a clear message to guide the other vehicles during emergency preemption actuations. The Alternative ETSS Design II is based on Dedicated Short Range Communication (DSRC) using the 3M Opticom System.

The proposed Alternative ETSS II uses optimum preemption signal timing and displays green as soon as the emergency vehicle leaves the intersection. It also displays steady green for southbound traffic when emergency vehicle is traveling in northbound direction, thus eliminating the need to stop for the vehicle moving in the southbound through the intersection. This alternative also reduces the delay to emergency vehicles by clearing the mixed message and eliminates confusion to the motorists.

5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is needed to formulate guidelines and warrants for emergency traffic signals and emergency vehicle preemption. The MUTCD 2000 has a very limited discussion on warrants for emergency traffic control signals. As pointed out in the literature review of this thesis, many state DOTs have tried to develop their own warrants. There should be nationwide effort to develop uniform standards in form of warrants and design guidelines for emergency traffic signals.

Emergency traffic signals should be evaluated. The evaluation should focus on safety and response time. Emergency personnel and traffic engineers should be involved in the evaluation.

Research should be carried out with the intention to centralize and co-ordinate different emergency traffic signals with central command center. Intelligent transportation systems such as automated vehicle location and signal priority system combined with preemption should be included as part of the design of emergency traffic signal system.

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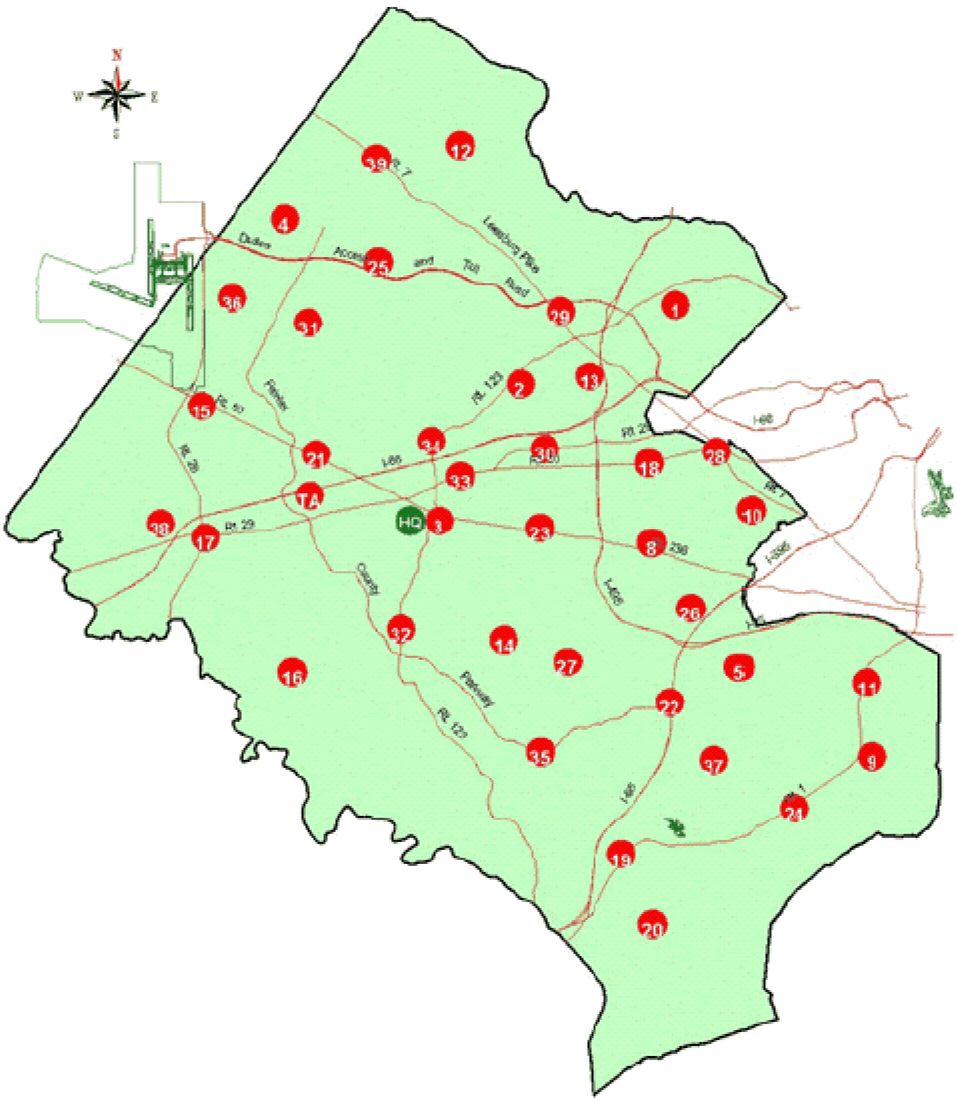
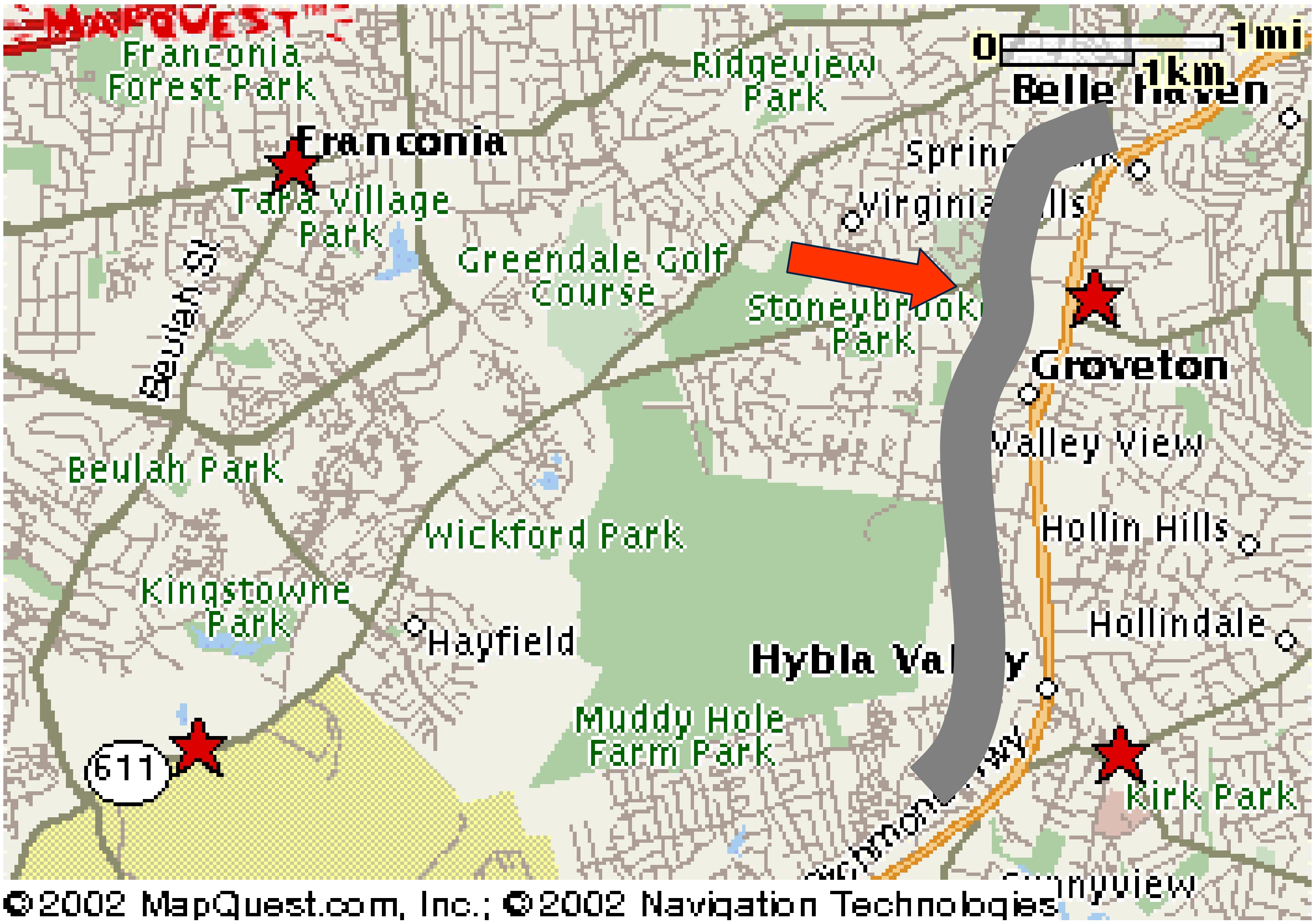
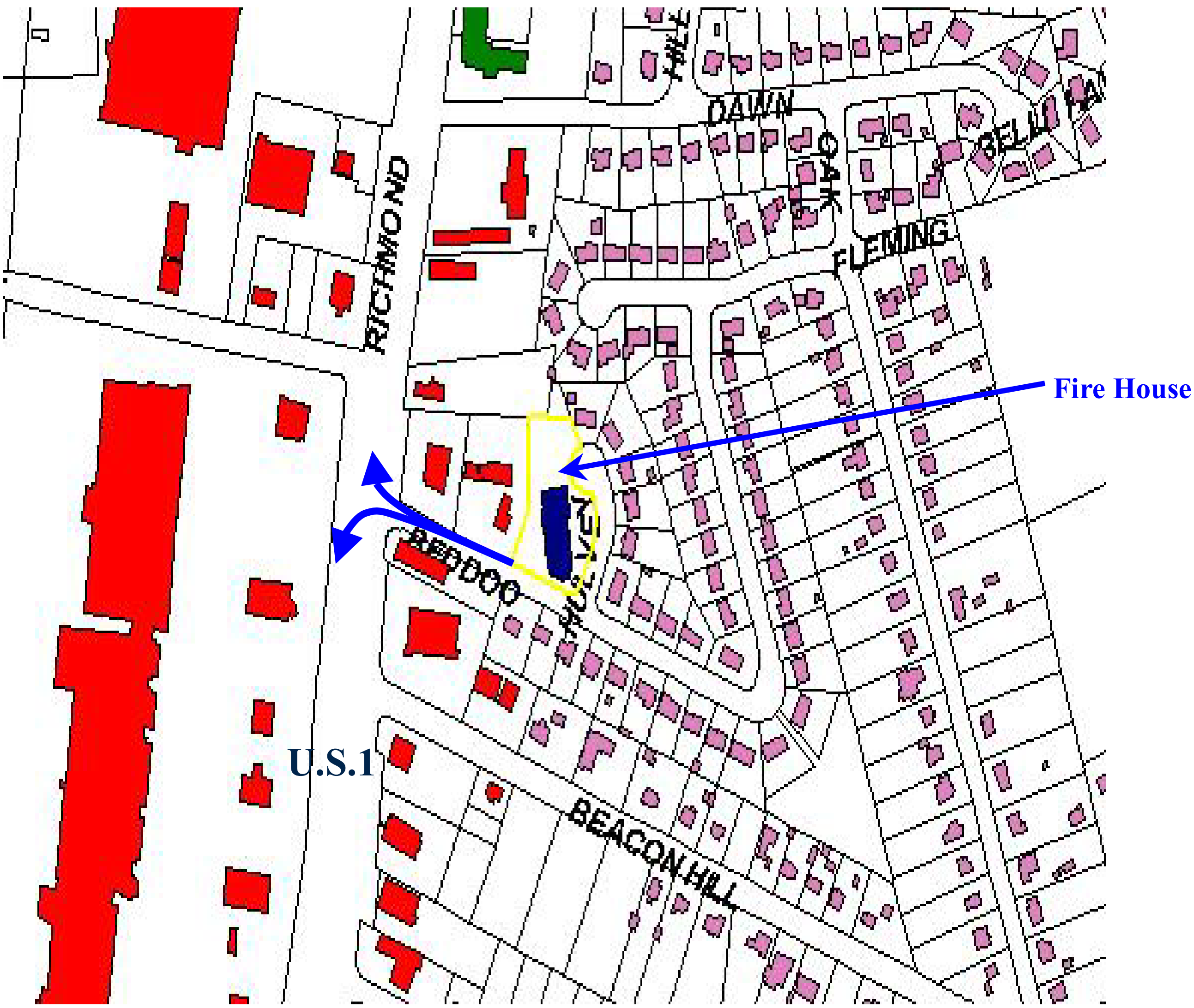
Appendix A1: Location of Fire Stations in Fairfax County



Appendix A2: A closer view of the U.S 1 corridor. The stars represent actual locations of fire stations.

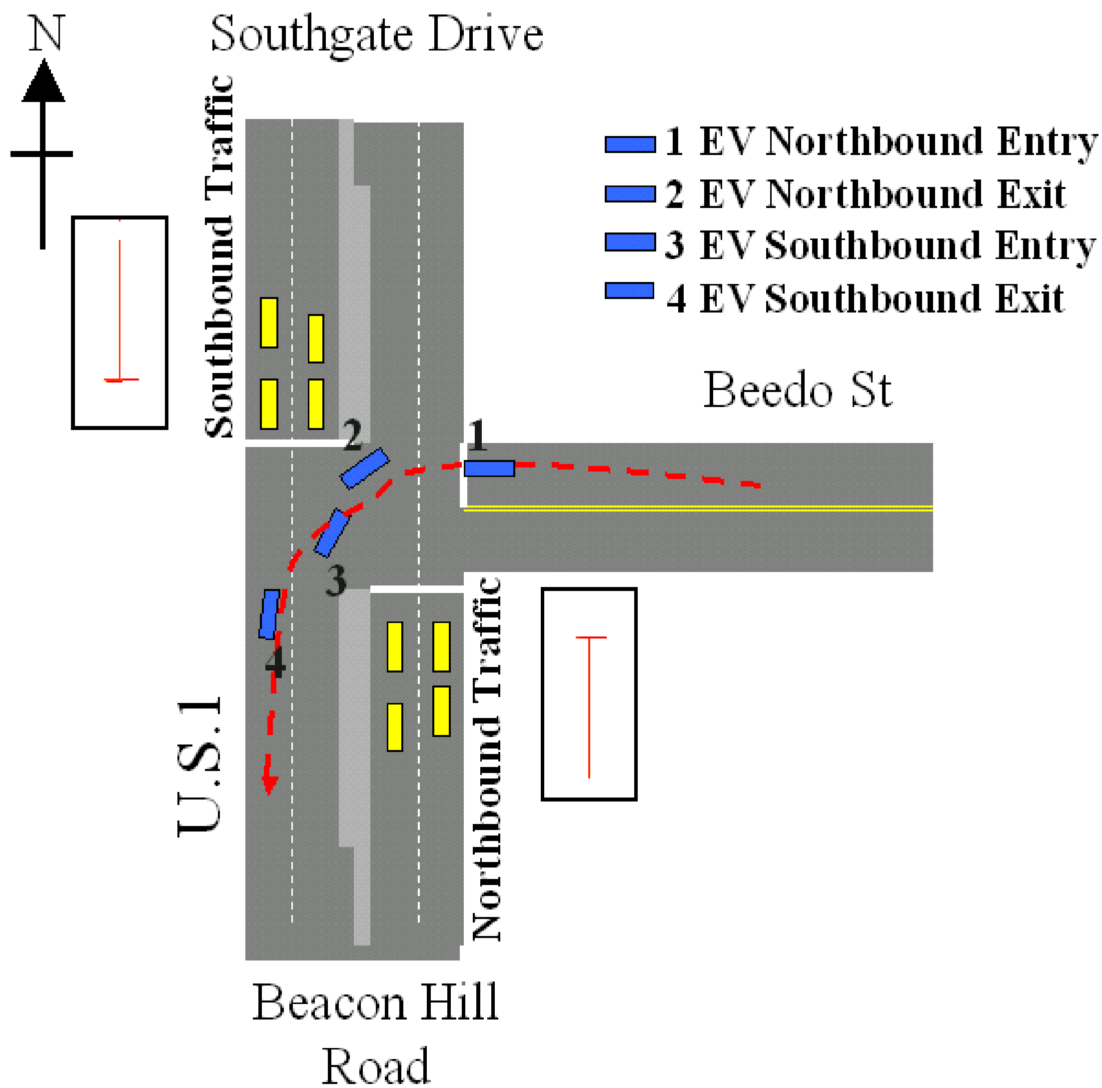


APPENDIX A3: AERIAL VIEW OF THE INTERSECTION OF BEEDO STREET AND U.S.1



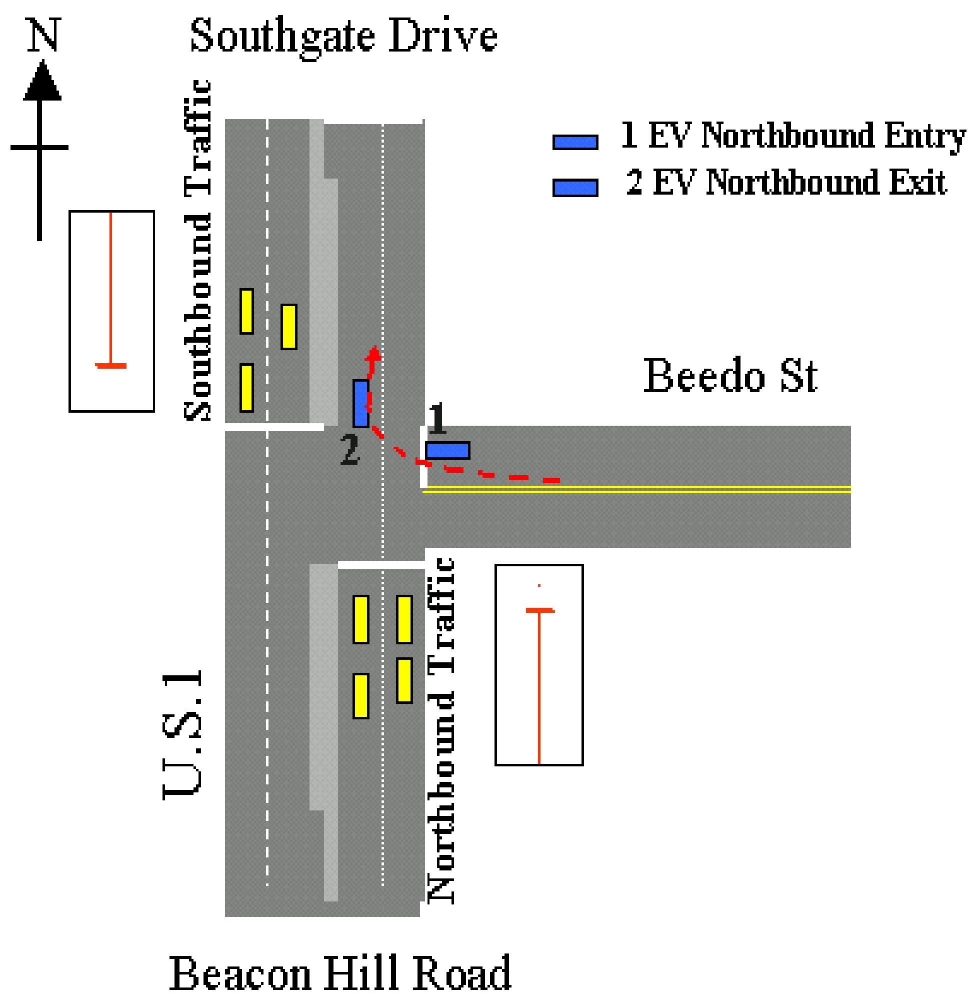
Appendix A4: EV TRAVELLING IN THE SOUTHBOUND DIRECTION AT THE INTERSECTION OF BEEDO ST AND U.S.1

EV Traveling in the Southbound Direction at Intersection of Beedo St and U.S.1



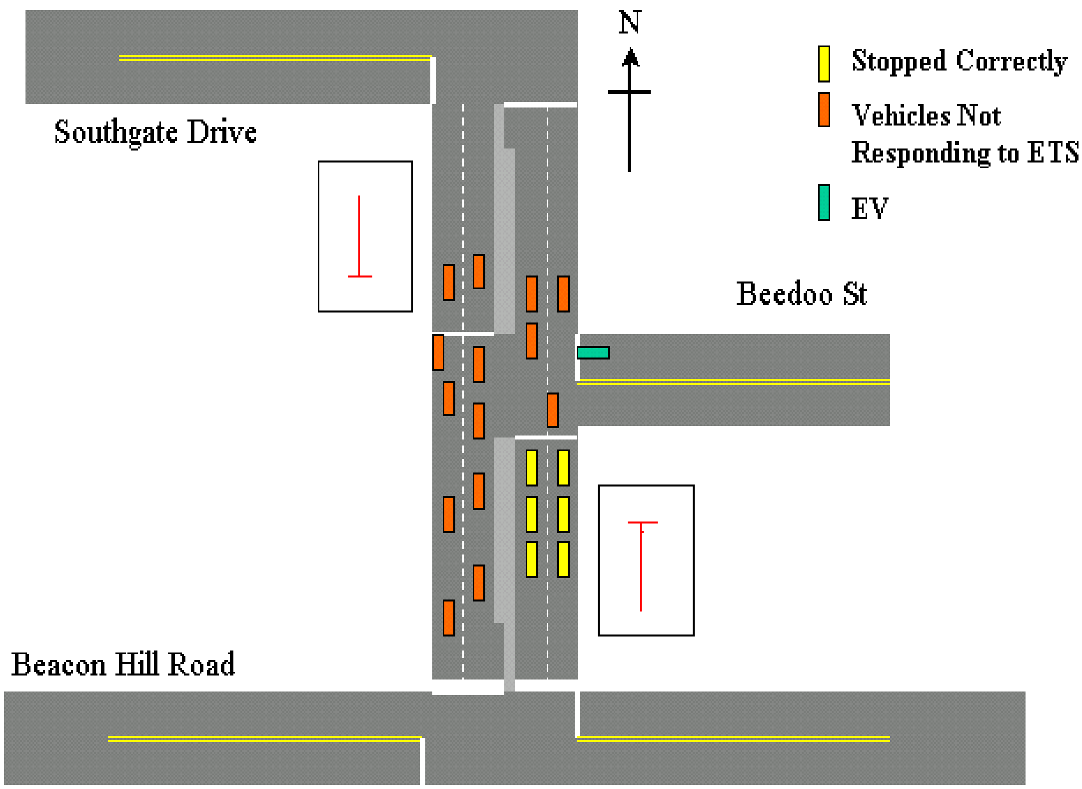
APPENDIX A5: EV TRAVELLING IN THE SOUTHBOUND DIRECTION AT THE INTERSECTION OF BEEDO ST AND U.S.1

EV Traveling in the Nouthbound Direction at Intersection of Beedo St and U.S.1



APPENDIX A6: GRAPHICAL DEPICTION EVENT NO: 87 AT THE TIME OF EV'S ENTRY AT THE INTERSECTION OF BEEDO STREET AND U.S.1

EVENT NO : 87
TIME :27 Feb -- 12:07:12 AM
STATUS OF EV: Northbound Entry



Event Number: 87
Time since preemption: 30 seconds
Mixed Message Score : 3
Real time at which EV reaches the intersection: 12:03: 12

Northbound direction:

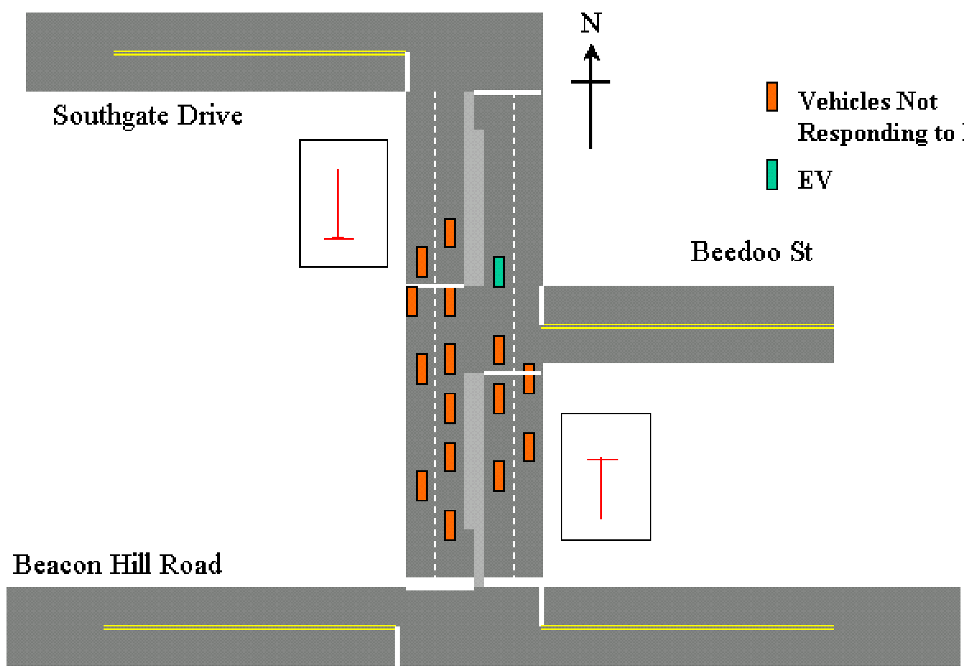
Number of vehicles not responding to ETS displaying RED and traveling in northbound direction : 28
Queue length or number of vehicles correctly stopped : 6
Conflict Potential Score : 6
Delay Score : 3

Southbound direction:

Number of vehicles not responding to ETS displaying RED and traveling in southbound direction : 28
Queue length or number of vehicles correctly stopped : 0
Conflict Potential Score : NA
Delay Score : 3

APPENDIX A7: GRAPHICAL DEPICTION EVENT NO: 87 AT THE TIME OF EV'S ENTRY AT THE INTERSECTION OF BEEDO STREET AND U.S.1

EVENT NO : 87
TIME :27 Feb -- 12:07:32 AM
STATUS OF EV: Northbound Exit



Event Number: 87
Time since preemption: 38 seconds
Mixed Message Score : 3
Real time at which EV reaches the intersection: 12:03: 12

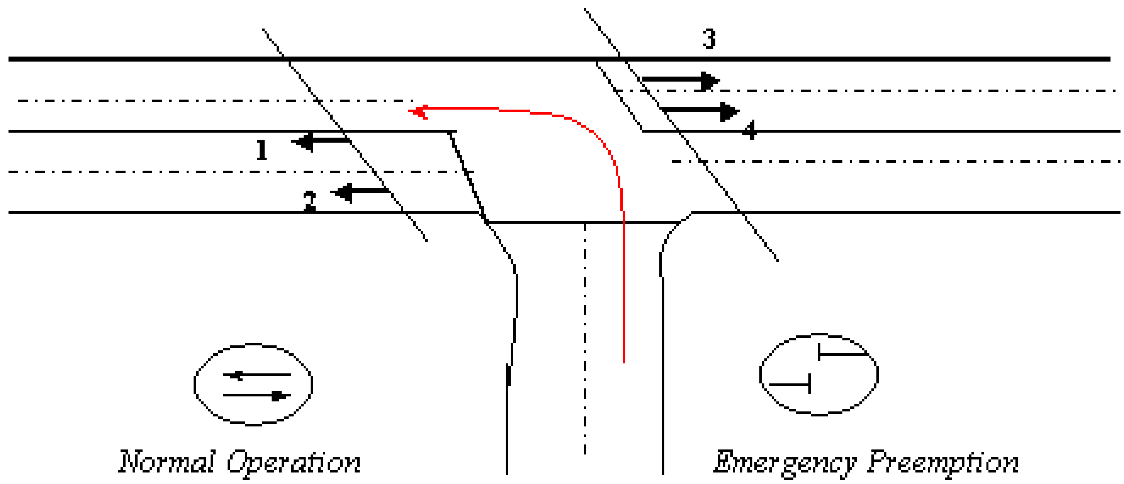
Northbound direction:

Number of vehicles not responding to ETS displaying RED and traveling in northbound direction : 24
Queue length or number of vehicles correctly stopped : 0
Conflict Potential Score : 2
Delay Score : 1

Southbound direction:

Number of vehicles not responding to ETS displaying RED and traveling in southbound direction : 11
Queue length or number of vehicles correctly stopped : 0
Conflict Potential Score : NA
Delay Score : NA

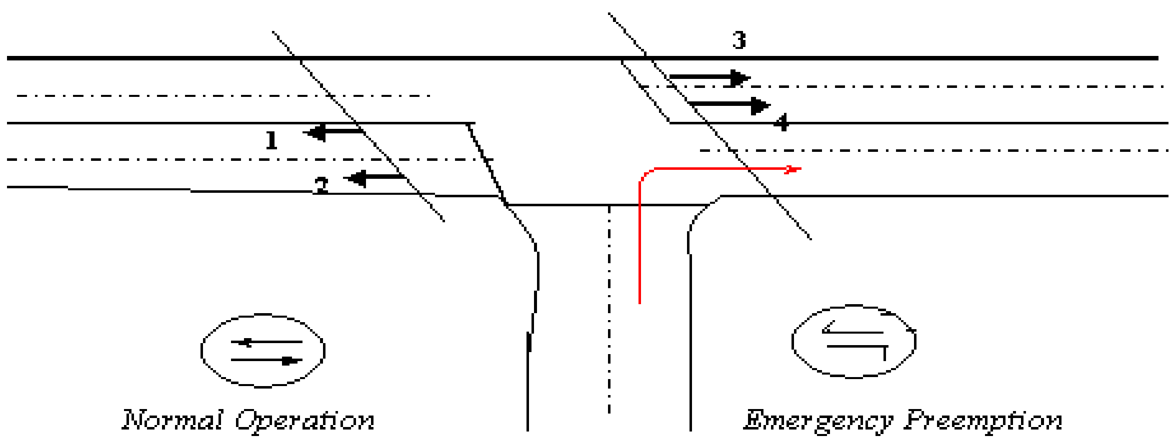
APPENDIX A8: ALTERNATIVE EMERGENCY TRAFFIC SIGNALS II OPERATIONS &I DURING EMERGENCY PREEMPTION



R 300 mm Steady
Y 300 mm Steady
G 300 mm Steady

Signal	Normal Operation	Change to Preemption	Emergency Preemption	Change from preemption	Release
1-2,3-4	Green	Yellow	Red Steady	Yellow	Green

Alternative Emergency Traffic Signal I&II Operation during Emergency Preemption While EV is traveling in Southbound Direction



R 300 mm Steady
Y 300 mm Steady
G 300 mm Steady

Signal	Normal Operation	Change to Preemption	Emergency Preemption	Change from preemption	Release
3-4	Green	Green	Green	Green	Green
1-2	Green	Yellow	Red Steady	Yellow	Green

Alternative Emergency Traffic Signal I&II Operation during Emergency Preemption While EV is traveling in Northbound Direction