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Vehicle Safety Communications Project Task 3 Final Report

Identify Intelligent Vehicle Safety Applications Enabled by DSRC

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16. Abstract

The Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications Consortium (VSCC) comprised of BMW, DaimlerChrysler, Ford, GM, Nissan, Toyota, and Volkswagen, in partnership with USDOT, established the Vehicle Safety Communications (VSC) project to: estimate the potential benefits of communication-based vehicle safety applications and define their communications requirements; ensure that proposed DSRC communications protocols meet the needs of vehicle safety applications; investigate specific technical issues that may affect the ability of DSRC to support deployment of vehicle safety applications; and, estimate the deployment feasibility of communications-based vehicle safety applications.

A comprehensive list of communications-based vehicle safety and non-safety application scenarios was compiled. More than 75 application scenarios were identified and analyzed resulting in 34 safety and 11 non-safety application scenario descriptions. Preliminary communications requirements were developed and an analysis of alternative wireless technologies was completed. Potential advantages of DSRC technology are the capability for 1) very low latency communications, and 2) transmission of broadcast messages.

Each safety application scenario was further defined to include an initial estimate of potential safety benefits. Eight high potential benefit safety application scenarios were selected for further study: Traffic Signal Violation Warning, Curve Speed Warning, and Emergency Electronic Brake Lights, Pre-Crash Warning, Cooperative Forward Collision Warning, Left Turn Assistant, Lane Change Warning and Stop Sign Movement Assistance. These are representative of the range of communications requirements for vehicle safety applications. These scenarios were further analyzed and more detailed
communications requirements were developed.

Task 3 analysis suggests that DSRC is a potential enabler for a number of vehicle safety applications.

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EXECUTIVE SUMMARY

Wireless technologies are rapidly evolving, and this evolution provides opportunities to utilize these technologies in support of advanced vehicle safety applications. In particular, the new Dedicated Short Range Communications (DSRC) at 5.9 GHz offers the potential to effectively support wireless data communications between vehicles, and between vehicles and infrastructure.

The Crash Avoidance Metrics Partnership – Vehicle Safety Communications Consortium (VSCC) comprised of BMW of North America, LLC, DaimlerChrysler Research and Technology North America, Inc., Ford Motor Company, General Motors Corporation, Nissan Technical Center North America, Inc., Toyota Technical Center USA, Inc., and Volkswagen of America, Inc., in partnership with USDOT, established the Vehicle Safety Communications (VSC) project to: estimate the potential benefits of communication-based vehicle safety applications and define their communications requirements; ensure that proposed DSRC communications protocols meet the needs of vehicle safety applications; investigate specific technical issues that may affect the ability of DSRC to support deployment of vehicle safety applications; and, estimate the deployment feasibility of communications-based vehicle safety applications.

In Task 3 of the VSC project, a comprehensive list of communications-based vehicle safety and non-safety application scenarios was compiled. More than 75 application scenarios were identified and analyzed resulting in 34 safety and 11 non-safety application scenario descriptions. Preliminary communications requirements were developed for these application scenarios.

Based upon these preliminary requirements, an analysis of alternative wireless technologies was completed. One of the most significant potential advantages of DSRC technology is the capability for very low latency communications. Latencies of less than 100 milliseconds seem to be possible with DSRC, and many of the vehicle safety application scenarios appear to have latency requirements in this range. Latencies in this range do not appear to be achievable with alternative wireless communications technologies. DSRC also offers the capability of transmitting broadcast messages. This is a significant advantage over point-to-point wireless communications, such as cellular, for vehicle safety applications since cellular communications does not support broadcast messages.

Each safety application scenario was further defined to include an initial estimate of potential safety benefits. The basis for this estimate was the report "44 Crashes" [1]. The resulting summary of relevant crash types and causal factors was used to estimate the opportunity for each application to reduce vehicle crashes and the associated harm in terms of functional years lost. Estimates for market penetration were used to determine the estimated number of vehicles in the U.S market that might be equipped with an application in each year after initial deployment. Near-term application systems were considered to be deployable in the U.S market between the years 2007 to 2011, mid-term application systems between the years 2012 to 2016, and long-term beyond the year 2016. The fifth year after deployment was chosen for computation of benefit opportunity. The VSCC and the USDOT jointly selected a subset of safety applications of mutual interest from the comprehensive list. Safety applications were selected based on potential safety benefit, and were representative of the range of applications identified.

Based on the analysis eight high potential benefit safety application scenarios were selected for further study: Traffic Signal Violation Warning, Curve Speed Warning, and Emergency Electronic Brake Lights were selected as the highest rated near-term application scenarios; Pre-Crash Warning, Cooperative Forward Collision Warning, Left Turn Assistant, Lane Change Warning and Stop Sign Movement Assistance were selected as the highest rated mid-term application scenarios.

The eight application scenarios selected are viewed as representative of range of communications requirements for vehicle safety applications. These scenarios were further analyzed and more detailed communications requirements were developed. This analysis reinforced the general 100 millisecond latency requirement, and the broadcast nature of the communications required. In addition, the data packets to support most vehicle-to-vehicle communications were determined to be less than 100 bytes. Infrastructure-to-vehicle packets were generally a bit larger, with a maximum size of around 430 bytes required for the left turn assistant application scenario. The communications requirements identified for each high-priority vehicle safety application scenario will be further evaluated against the expected DSRC capabilities through field testing and test simulation during Task 4 research.

Task 3 analysis suggests that DSRC is a potential enabler for a number of vehicle safety applications. However, the importance of communications security remains to be assessed If a significant level of security is determined to be required for the vehicle safety applications, then the necessary security overhead may seriously degrade the system capabilities in terms of latency and/or channel capacity.

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1 Introduction

1.1 Driver Assistance Systems and Wireless Communication

Driver assistance systems are currently being developed and deployed as the result of improvements in critical sensing areas such as computer vision and radar. The VSC project introduces the added technical dimension of wireless technology to the potential development of driver assistance systems. The addition of wireless communications from vehicle-to/from-infrastructure, and from vehicle-to-vehicle, potentially enables a number of vehicle safety applications.

Wireless technologies are rapidly evolving, and this evolution provides opportunities to utilize these technologies in support of advanced vehicle safety applications. Whereas cellular technologies have contributed the ability to rapidly report accidents after they occur, new wireless data communications technologies have the potential to support crash avoidance countermeasures. In particular, the new Dedicated Short Range Communications (DSRC) at 5.9 GHz offers the potential to support low latency wireless data communications between vehicles, and between vehicles and infrastructure. These low latency data communications within the immediate vicinity of a vehicle potentially enable a large number of vehicle safety applications. Many of these potential applications fall within the category of crash avoidance countermeasures.

1.2 VSC Project Goals

The goals of the VSC project are to:

- Estimate the potential safety benefits of communication-based vehicle safety applications in terms of reductions in vehicle crashes and functional years saved.
- Clearly define the communications requirements of selected vehicle safety applications.
- Work with standards development organizations to ensure that proposed DSRC communications protocols meet the needs of vehicle safety applications.
- Investigate specific technical issues that may affect the ability of DSRC (as defined by the standards) to support deployment of vehicle safety applications.
- Estimate the deployment feasibility of communications-based vehicle safety applications.
- Assess the ability of proposed DSRC communications protocols to meet the needs of safety applications.

1.3 Task 3 Methodology

Using the vehicle safety applications compiled by reviewing existing literature under Task 1 as a starting point, a more comprehensive list of vehicle safety applications was formed. Each of the participants identified safety applications that they believe may benefit or be enabled by wireless communications (either vehicle-vehicle or vehicle-infrastructure). In addition, brainstorming sessions between all members of the VSCC were organized to expand the list of potential safety applications, and group the safety applications with respect to complexity and when they may become commercially feasible for light vehicles. This list represents the best efforts of the participants at the time of publication. It may not contain all vehicle safety applications (due to similarity) but does contain, at a minimum, examples and brief descriptions of representative safety applications.

Each safety application was defined and an initial estimate of potential safety benefits was derived. A summary of crash types and causal factors was used to estimate the ability of the selected application to reduce vehicle crashes and functional years lost.

The VSCC ranked the safety applications based on their anticipated maximum potential safety benefits and when they may become commercially feasible for light vehicles. The commercial feasibility estimates depended on the complexity of the safety application derived based on factors such as technical feasibility, stringency of system/communications requirements, economic viability, estimated market penetration, estimated effectiveness, etc.

The VSCC and the USDOT jointly selected a subset of safety applications of mutual interest from the comprehensive list. Safety applications were selected based on potential safety benefit and were representative of the range of identified safety applications.

The safety applications were further evaluated to more fully develop rough communication attributes and their requirements. The approach involved the development of safety system concepts and system analysis. The system analysis was based on the physics, geometry, modeling and simulation as appropriate. This task also identified other available communication paths that may enable each selected safety application.

1.4 Report Layout

In Chapter 2, the comprehensive list of identified application scenarios is presented. The relevant vehicle safety applications include brief application descriptions, and initially estimated rough communications requirements. These applications are also grouped into safety and non-safety categories, based upon the VSCC understanding of safety. This chapter also provides a discussion of potential alternative wireless technologies to DSRC, and their applicability to supporting the rough communications requirements of the identified application scenarios.

Chapter 3 describes the analysis of the applications based upon estimated potential safety benefits. The chapter describes the process used to estimate relative potential safety benefits, as well as the ranking process. Finally, the results of the application rankings are described, and the selection of the high-priority vehicle safety applications is presented.

The high-priority vehicle safety applications are further described and analyzed in Chapter 4, and more detailed communications requirements are developed and presented.

Chapter 5 provides conclusions based upon the research results of Task 3.

2 Application Descriptions and Communications Requirements

2.1 Introduction and Assumptions

The description and the preliminary communication requirements needed for each of the DSRC-based application systems to function properly in its mode of operation are provided in the following sections. Each of the application systems requires a 5.9 GHz on-board unit (OBU) and antenna for proper functioning. In addition, standard in-vehicle sensors provide inputs that may be used by the applications. Additional sensors may be required by the application systems depending on functionality.

Two sections are provided to introduce potential in-vehicle applications that can be enabled or enhanced through the use of DSRC communications. Section 2.3 identifies applications that are likely to be considered safety applications based on their ability to reduce traffic accidents and to improve general public safety. This section is divided into the following application categories:

Intersection Collision Avoidance
Public Safety
Sign Extension
Vehicle Diagnostics and Maintenance
Information from Other Vehicles

Section 2.4 identifies applications that are likely to be considered non-safety applications, following these application categories:

Traffic Management
Tolling
Information from Other Vehicles
Other Potential Applications

Assumptions

In defining the operational characteristics and communication requirements of the DSRC-based applications listed in Sections 2.3 and 2.4, several assumptions have been made:

- A standardized DSRC message set and data dictionary would need to be established for safety applications that utilize vehicle-to-vehicle and/or vehicle-to-infrastructure communications. The message set would need to be agreed upon by all public and private sector organizations involved in this aspect of DSRC.
- Some applications would require vehicles to make periodic broadcasts (e.g. every 100 msec.) in order to identify their position on the roadway. The transmitted data would

need to be based on a location referencing standard that is accepted by DSRC stakeholders.

- Many of the preliminary communication requirements call for an on-board unit with a communication range between 100 – 1000 meters. The practicality of these requirements in light of transmission characteristics such as multipath and interference with other DSRC applications should be studied before such requirements are finalized.
- Many of the applications require communications in multiple directions from the vehicle. This could conceptually be achieved through an on-board unit using an omni-directional antenna, though transmission characteristics should be considered when evaluating the performance of such a system. The use of a directional antenna (especially for roadside units) should be considered for those applications in which data need only be transmitted or received in a specific direction.
- Security is an open issue for all of the listed applications. Potential security measures could include a method of assuring that the packet/data was generated by a trusted source, as well as a method of assuring that the packet/data was not tampered with or altered after it was generated. Any application that involves a financial transaction (such as tolling) requires the capability to perform a secure transaction.

2.2 Definitions of Communication Parameters

A summary of communication characteristics and preliminary requirements follows each application description. These characteristics and preliminary requirements consist of:

- The **Types of Communications,** which describe:
  - the source and destination of the transmission (i.e. infrastructure-to-vehicle, vehicle-to-infrastructure, or vehicle-to-vehicle communications)
  - if a DSRC unit broadcasts a transmission (i.e. one-way communication)
  - if a DSRC unit establishes a dialog with another unit or with multiple units (i.e. two-way communication)
  - if the transmission is intended for a particular DSRC unit (i.e. point-to-point communications)
  - if the transmission is intended for multiple DSRC units (i.e. point-to-multipoint communications)

  Either one-way or two-way communications may be point-to-point or point-to-multipoint.

  This description does not include the forwarding of information through multiple paths of communication (e.g. vehicle-to-vehicle-to-vehicle). It is recommended that this multi-step approach be considered when designing an application that may benefit from the forwarding of data when distance or line-of-sight is an issue.

- The **Transmission Mode** describes whether the transmission is triggered by an event (i.e. event-driven), or whether it is sent automatically at regular intervals (i.e. periodic).
- The **Minimum Frequency** is the rate at which a transmission should be repeated (e.g. 1 Hz).
- The **Allowable Latency** is the maximum duration of time allowable between when information is available to be transmitted and when it is received (e.g. 100 msec).
- The **Data to be Transmitted and/or Received** describes the contents of the communication (e.g. vehicle location, speed and heading). Design considerations include whether or not vehicles make periodic broadcasts to identify their position on the roadway, and how privacy is best maintained.
- The **Maximum Required Range of Communication** is the communication distance between two units that is needed to effectively support a particular application (e.g. 100 m).

2.3 Safety Applications

Intersection Collision Avoidance

2.3.1 Traffic Signal Violation Warning

2.3.1.1 Application Definition

Traffic signal violation warning uses infrastructure-to-vehicle communication to warn the driver to stop at the legally prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation.

2.3.1.2 Application Description

The in-vehicle system will use information communicated from infrastructure located at traffic signals to determine if a warning should be given to the driver. The communicated information would include traffic signal status and timing, traffic signal stopping location or distance information, and directionality. The type of road surface and weather conditions near the traffic signal may also be communicated as this could be used to estimate braking distance.

2.3.1.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency ~ 100 msec
- Data to be transmitted and/or received: traffic signal status, timing, directionality, position of the traffic signal stopping location, weather condition (if data is available), road surface type near traffic signal
- Maximum required range of communication: ~ 250 m

2.3.2 Stop Sign Violation Warning

2.3.2.1 Application Definition

Stop sign violation warning uses infrastructure-to-vehicle communication to warn the driver if the distance to the legally prescribed stopping location and the speed of the vehicle indicate that a relatively high level of braking is required for a complete stop.

2.3.2.2 Application Description

The in-vehicle application will use information communicated from the infrastructure to provide the warning. The communicated information would include stopping location or distance information, and directionality. The type of road surface and weather conditions near the stopping location may also be communicated as this could be used to better estimate braking distance. As an alternative to DSRC, digital maps and GPS could be used.

2.3.2.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency ~ 100 msec
- Data to be transmitted and/or received: directionality, position of the stopping location, weather condition, road surface type near the stop sign
- Maximum required range of communication: ~ 250 m

2.3.3 Left Turn Assistant

2.3.3.1 Application Definition

The Left Turn Assistant application provides information to drivers about oncoming traffic to help them make a left turn at a signalized intersection without a phasing left turn arrow.

2.3.3.2 Application Description

Information is obtained by the infrastructure system, which uses sensors and/or DSRC communications to detect vehicles approaching from the opposite direction. After the infrastructure system collects the status of oncoming traffic, the information is transmitted to the in-vehicle system via DSRC, or provided to the driver through infrastructure equipment such as a traffic signal. The key options for implementing the LTA application can be differentiated based on the following criteria:

- whether or not DSRC technology is used to locate approaching vehicles,
- whether or not there is application intelligence (judgment of collision potential) in the infrastructure or in the vehicle,
- whether or not the information is provided through infrastructure equipment (e.g. a left turn arrow that changes between yellow and red depending on the situation),
- whether or not the information is provided through an in-vehicle application,
- Whether or not an in-vehicle system needs to request information that is particular to the left turn maneuver (in cases where the infrastructure can download many different types of information)

One potential application is an in-vehicle system which determines that there is a need for information about approaching traffic near an intersection based upon the driver's activation of the left turn signal. The traffic data is gathered automatically by the infrastructure system, which detects the location and movement patterns of oncoming vehicles using vehicle detection sensors. The infrastructure system transmits the data to vehicles at regular intervals via DSRC, and the in-vehicle system provides the relevant information to the driver.

2.3.3.3 Communication Requirements

- Communication from vehicle-to-infrastructure, and infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz

- Allowable latency: ~100 msec
- Data to be transmitted and/or received: traffic signal status, timing, and directionality; road shape and intersection information; vehicle position, velocity, and heading
- Maximum required range of communication: ~300 m

2.3.4 Stop Sign Movement Assistance

2.3.4.1 Application Definition

This application provides a warning to a vehicle that is about to cross through an intersection after having stopped at a stop sign.

2.3.4.2 Application Description

The warning is provided in order to avoid a collision with traffic approaching the intersection. Information is obtained from the infrastructure system, which uses sensors or DSRC communications to detect vehicles moving through an intersection. When the in-vehicle application determines that proceeding through the intersection is unsafe, it provides a warning to the driver.

2.3.4.3 Communication Requirements

- Communication from vehicle-to-infrastructure and infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 msec
- Data to be transmitted and/or received: vehicle position, velocity, and heading; warning
- Maximum required range of communication: ~300 m

2.3.5 Intersection Collision Warning

2.3.5.1 Application Definition

This application warns drivers when a collision at an intersection is probable.

2.3.5.2 *Application Description*

Infrastructure sensors and/or DSRC communications can be used to detect all vehicles, their position, velocity, acceleration, and turning status while approaching an intersection. Weather status and the road shape/surface type can be variables for calculating the likelihood of a collision. The infrastructure unit or the in-vehicle unit determines when a collision is imminent and issues a warning to either a specific vehicle or all drivers in the vicinity, depending on the warning strategy.

The options for implementing this application can be differentiated based on the following criteria:

- whether or not DSRC technology is used to sense vehicles approaching the intersection,
- whether the application intelligence (judgment of collision potential) is in the infrastructure or in the vehicle, and
- whether the warning is given via DSRC or via some other means (e.g. warning lights, variable message signs, etc.)

One potential combination of these elements is an application in which the infrastructure determines the location of vehicles through infrastructure sensors (radar, cameras, etc.) and transmits this information to vehicles in the vicinity. If the in-vehicle application determines that a collision is imminent, it provides a warning to the driver.

2.3.5.3 *Communication Requirements*

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency ~ 100 msec
- Data to be transmitted and/or received - traffic signal status, timing, and directionality; road shape and intersection information; vehicle position, velocity, and heading
- Maximum required range of communication: ~ 300 m

2.3.6 Blind Merge Warning

2.3.6.1 Application Definition

This application warns a vehicle if it is attempting to merge from a location with limited visibility (either for itself or for the oncoming traffic) and another vehicle is approaching and predicted to occupy merging space.

2.3.6.2 Application Description

The roadside unit is in view of the primary road and the merging vehicle. It warns both the merging traffic and the right-of-way traffic of potential collisions. Vehicles notify the infrastructure unit of their velocity, acceleration, heading, and location. The roadside unit calculates whether a collision is imminent, based on the information sent from the vehicles and knowledge of the road. The roadside unit will notify all surrounding vehicles if a collision is likely. It will also provide an all-clear signal when there is no approaching traffic.

2.3.6.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 ms
- Data to be transmitted and/or received: velocity, position, heading, and acceleration
- Maximum required range of communication: ~200 m

2.3.7 Pedestrian Crossing Information at Designated Intersections

2.3.7.1 Application Definition

This application provides an alert to vehicles if there is danger of a collision with a pedestrian or a child that is on a designated crossing.

2.3.7.2 Application Description

The presence of a pedestrian is detected through infrastructure sensing equipment, including the "walk" button that pedestrians press before crossing an intersection. A broadcast message with information regarding the pedestrian is transmitted from roadside units to vehicles approaching the crossing area.

2.3.7.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 msec
- Data to be transmitted and/or received: presence of a pedestrian
- Maximum required range of communication: ~200 m

Public Safety

2.3.8 Approaching Emergency Vehicle Warning

2.3.8.1 Application Definition

This application provides the driver a warning to yield the right of way to an approaching emergency vehicle.

2.3.8.2 Application Description

The emergency vehicle broadcast message would include information regarding its position, lane information, speed and intended path. The in-vehicle application will use this information to alert the driver.

2.3.8.3 Communication Requirements

- Communication from vehicle-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven

- Minimum frequency (update rate): ~ 1 Hz
- Allowable latency ~ 1 sec
- Data to be transmitted and/or received: emergency vehicle position, lane information, speed and intended path/route
- Maximum required range of communication: ~ 1000 m

2.3.9 Emergency Vehicle Signal Preemption

2.3.9.1 Application Definition

This application allows an emergency vehicle to request right of way from traffic signals in its direction of travel.

2.3.9.2 Application Description

Emergency vehicle signal preemption allows the emergency vehicle to override intersection signal controls. The intersection mounted roadside unit verifies that the request has been made by an authorized source and alters the traffic signal and timing to provide right of way to the emergency vehicle. This application may need to be integrated with the Approaching Emergency Vehicle Warning application.

2.3.9.3 Communication Requirements

- Communication from vehicle-to-infrastructure
- Two-way communication
- Point-to-point communication
- Transmission mode: Event-driven
- Minimum frequency (update rate): ~ N/A
- Allowable latency ~ 1 sec
- Data to be transmitted and/or received: emergency vehicle position, speed, direction of travel and intended path/route
- Maximum required range of communication: ~ 1000 m

2.3.10 SOS Services

2.3.10.1 Application Definition

This in-vehicle application will send SOS messages after airbags are deployed, a rollover is sensed, or the vehicle otherwise senses a life-threatening emergency.

2.3.10.2 Application Description

An occupant could also initiate the message for a non-crash related medical or other emergency.

Vehicle to infrastructure: The emergency message will be sent from the vehicle to a roadside unit and then forwarded to the nearest local authority for immediate assistance.

Vehicle to vehicle: The emergency message will be sent from the vehicle to a passing vehicle, which stores and then relays the message when in range of a roadside unit. It will then be forwarded to the nearest local authority for immediate assistance.

2.3.10.3 Communication Requirements

- Communication from vehicle to infrastructure or from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: position, vehicle status, vehicle description, time
- Maximum required range of communication: ~400 m

2.3.11 Post-Crash Warning

2.3.11.1 Application Definition

This in-vehicle application warns approaching traffic of a disabled vehicle (disabled due to an accident or mechanical breakdown) that is stuck in or near traffic lanes, as determined using map information and GPS.

2.3.11.2 Application Description

The application assumes communication, digital map, and GPS are still operable and may require a bottom-mounted antenna for rollover situations. This should have the greatest benefit in poor visibility and inclement weather situations and may reduce the potential for a secondary crash.

Vehicle to infrastructure: The disabled vehicle transmits its position, heading, and status to a nearby Road Side Unit (RSU). The RSU will broadcast a warning message to vehicles approaching the accident scene and will discontinue broadcast when the accident is cleared.

Vehicle to vehicle: A disabled vehicle will warn approaching vehicles of its position.

2.3.11.3 Communication Requirements

- Communication from vehicle to infrastructure or from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~0.5 s
- Data to be transmitted and/or received: position, heading, vehicle status
- Maximum required range of communication: ~300 m

Sign Extension

2.3.12 In-Vehicle Signage

2.3.12.1 Application Definition

The in-vehicle signage application provides the driver with information that is typically conveyed by traffic signs.

2.3.12.2 Application Description

Roadside units mounted at key points along the roadway send messages to approaching vehicles, increasing the likelihood of drivers being aware of potentially dangerous conditions if a traffic sign is not noticed. In-vehicle signage features safety-critical information such as:

School zone warning: Alerts drivers that they are near a school.

Animal crossing zone information: Alerts drivers that animals tend to cross the road in the near vicinity.

Sign information: Provides information concerning dips, rough road, sudden turns, and other roadway and infrastructure characteristics.

‘Keep clear’ warning: Warns drivers that their vehicle is parked or standing in an area that should be kept clear.

2.3.12.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: condition, position, direction of travel
- Maximum required range of communication: ~200 m

2.3.13 Curve Speed Warning

2.3.13.1 Application Definition

Curve speed warning aids the driver in negotiating curves at appropriate speeds.

2.3.13.2 Application Description

This application will use information communicated from roadside beacons located ahead of approaching curves. The communicated information from roadside beacons would include curve location, curve speed limits, curvature, bank and road surface condition. The in-vehicle system would determine, using other on-board vehicle information, such as speed and acceleration whether the driver needs to be alerted.

2.3.13.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: curve location, curve speed limits, curvature, bank, road surface condition
- Maximum required range of communication: ~200 m

2.3.14 Low Parking Structure Warning

2.3.14.1 Application Definition

This application provides drivers with information concerning the clearance height of a parking structure.

2.3.14.2 Application Description

A beacon mounted on or near the parking facility provides clearance height information and location to vehicles in the area. The in-vehicle system will use this information to decide whether to provide the driver with a warning before entering the parking structure.

2.3.14.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: clearance height and location of parking structure
- Maximum required range of communication: ~100 m

2.3.15 Wrong Way Driver Warning

2.3.15.1 Application Definition

This application warns drivers that a vehicle is driving or about to drive against the flow of traffic.

2.3.15.2 Application Description

A vehicle can sense its own right-of-way violation through precise positioning technology and map database data. If a right-of-way violation is sensed, a warning is provided to the driver of the errant vehicle, and the vehicle can broadcast its situation to other vehicles. A broadcast message with information regarding location, direction, speed, etc., is transmitted to vehicles near the at-risk area.

2.3.15.3 Communication Requirements

- Communication from vehicle-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: 100 msec
- Data to be transmitted and/or received: position, direction, warning
- Maximum required range of communication: ~500 m

2.3.16 Low Bridge Warning

2.3.16.1 Application Definition

Low bridge warning is used to provide warning messages especially to commercial vehicles when they are approaching a bridge of low height.

2.3.16.2 Application Description

It is implemented with roadside beacons close to the bridge. Warning messages are sent to all vehicles approaching the bridge from both directions, and each vehicle determines whether a warning is issued to its driver.

2.3.16.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communications
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 1 Hz
- Allowable latency ~ 1 sec
- Data to be transmitted and/or received- height of bridge, distance to bridge
- Maximum required range of communication: ~ 300 m

2.3.17 Work Zone Warning

2.3.17.1 Application Definition

Work zone safety warning refers to the detection of a vehicle in an active work zone area and the indication of a warning to its driver.

2.3.17.2 Application Description

Roadside beacons would broadcast the warning data to vehicles as they approach a work zone or construction zone.

2.3.17.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communications
- Point-to-multipoint communications
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 1 Hz
- Allowable latency ~ 1 sec
- Data to be transmitted and/or received- distance to work zone, reduced speed limits
- Maximum required range of communication: ~ 300 m

2.3.18 In-Vehicle Amber Alert

2.3.18.1 Application Definition

This application sends Amber Alert information to the in-vehicle unit.

2.3.18.2 Application Description

The Amber Alert response program utilizes the resources of the law enforcement and the media to notify the public when children are suspected to be kidnapped. The vehicle being sought after could be excluded from receiving the message. Information is provided to the driver through the in-vehicle application.

2.3.18.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Data to be transmitted and/or received: Amber Alert information
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Maximum required range of communication: ~250 m

Vehicle Diagnostics and Maintenance

2.3.19 Safety Recall Notice

2.3.19.1 Application Definition

This application allows the distribution of safety recalls through DSRC communications sent directly to vehicles via roadside units, and/or in-home PCs.

2.3.19.2 Application Description

A reminder of a safety recall that requires immediate attention can be provided through a warning lamp or other methods

2.3.19.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): N/A
- Allowable latency: ~5 sec
- Data to be transmitted and/or received: safety recall message
- Maximum required range of communication: ~400 m

2.3.20 Just-In-Time Repair Notification

2.3.20.1 Application Definition

This application communicates in-vehicle diagnostics to the infrastructure and advises the driver of nearby available services.

2.3.20.2 Application Description

The roadside unit can pass information to an OEM technical support center for assessment. This information could be used to advise the driver of potential maintenance required.

2.3.20.3 Communication Requirements

- Communication from vehicle to infrastructure and from infrastructure to vehicle
- Two-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~ N/A
- Allowable latency: ~ N/A
- Data to be transmitted and/or received: position, heading, fault code information; location of nearest services
- Maximum required range of communication: ~400 m

Information from Other Vehicles

2.3.21 Cooperative Forward Collision Warning

2.3.21.1 Application Definition

Cooperative forward collision warning system is designed to aid the driver in avoiding or mitigating collisions with the rear-end of vehicles in the forward path of travel through driver notification or warning of the impending collision. The system does not attempt to control the host vehicle in order to avoid an impending collision.

2.3.21.2 Application Description

A cooperative forward collision warning system is an enhancement of the radar-based forward collision warning system and would use information communicated from neighboring vehicles via vehicle-to-vehicle communication. The performance of the forward collision warning system can be enhanced by vehicle-to-vehicle communication received from neighboring vehicles. The vehicle receives data regarding the position, velocity, heading, yaw rate, and acceleration of other vehicles in the vicinity. Using this information along with its own position, dynamics, and roadway information (map data), the vehicle will determine whether a rear-end collision with the lead vehicle is likely. In addition, the host vehicle will transmit position, velocity, acceleration, heading, and yaw rate to other vehicles.

2.3.21.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency: ~ 100 ms
- Data to be transmitted and/or received: position, velocity, acceleration, heading, yaw-rate
- Maximum required range of communication: ~ 150 m

2.3.22 Vehicle-Based Road Condition Warning

2.3.22.1 Application Definition

This in-vehicle application will detect marginal road conditions using on-board systems and sensors (e.g. stability control, ABS), and transmit a road condition warning, if required, to other vehicles via broadcast.

2.3.22.2 Application Description

Road condition information can be used by vehicle safety applications in the receiving vehicle. For example, an application can be designed to work in the vehicle to calculate maximum speed recommendations based on road conditions and upcoming road features (e.g. curve, bank, intersection, or stop sign) and notify the driver appropriately.

2.3.22.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~2 Hz
- Allowable latency: ~0.5 s
- Data to be transmitted and/or received: position, heading, road condition parameters
- Maximum required range of communication: ~400 m

2.3.23 Emergency Electronic Brake Lights

2.3.23.1 Application Definition

When a vehicle brakes hard, the Emergency Electronic Brake light application sends a message to other vehicles following behind.

2.3.23.2 Application Description

This application will help the driver of following vehicles by giving an early notification of lead vehicle braking hard even when the driver's visibility is limited (e.g. a large truck blocks the driver's view, heavy fog, rain). This information could be integrated into an adaptive cruise control system.

2.3.23.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 ms
- Data to be transmitted and/or received: position, heading, velocity, deceleration
- Maximum required range of communication: ~300 m

2.3.24 Lane Change Warning

2.3.24.1 Application Definition

This application provides a warning to the driver if an intended lane change may cause a crash with a nearby vehicle.

2.3.24.2 Application Description

The application receives periodic updates of the position, heading and speed of surrounding vehicles via vehicle-to-vehicle communication. When the driver signals a lane change intention, the application determines and predicts the presence or absence of adequate gap between vehicles in the adjacent lane that will permit a safe lane change. If the gap between vehicles in the adjacent lane will not be sufficient, the application will determine that a safe lane change is not possible and, therefore, would provide a warning to the driver.

2.3.24.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 ms
- Data to be transmitted and/or received: position, heading, velocity, acceleration, turn signal status
- Maximum required range of communication: ~150 m

2.3.25 Blind Spot Warning

2.3.25.1 Application Definition

This application warns the driver when he intends to make a lane change and his blind spot is occupied by another vehicle.

2.3.25.2 Application Description

The application receives periodic updates of the position, heading and speed of surrounding vehicles via vehicle-to-vehicle communication. When the driver signals a lane change intention, the application determines the presence or absence of other vehicles in his blind spot. If the presence of another vehicle in his blind spot is determined by the application, a warning is provided to the driver.

2.3.25.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 m
- Data to be transmitted and/or received: velocity, position, heading, acceleration, turn signal status
- Maximum required range of communication: ~150 m

2.3.26 Highway Merge Assistant

2.3.26.1 Application Definition

This application warns a vehicle on a highway on-ramp if another vehicle is in its merge path (and possibly in its blind spot).

2.3.26.2 Application Description

The merging vehicle uses its navigation information to recognize that it is on an on-ramp. The in-vehicle system monitors information received from other vehicles in the area regarding their position, speed and heading. The system warns the driver if one of the vehicles is in the merge path and is considered a potential collision threat.

2.3.26.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~10 Hz
- Allowable latency: ~100 ms
- Data to be transmitted and/or received: position, speed and heading
- Maximum required range of communication: ~250m

2.3.27 Visibility Enhancer

2.3.27.1 Application Definition

This application senses poor visibility situations (fog, glare, heavy rain, white-out, night, quick light-to-dark transitions) either automatically or via user command.

2.3.27.2 Application Description

Vehicle-to-vehicle communication is used to obtain position, velocity and heading of nearby vehicles. The application uses this information with its own GPS and map database for visibility enhancement that may range from simple (veer left or right indications) to complex (superimposed road and vehicles on inside of windshield) implementations.

2.3.27.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~2 Hz
- Allowable latency: ~100 ms
- Data to be transmitted and/or received: velocity, position, heading
- Maximum required range of communication: ~300 m

2.3.28 Cooperative Collision Warning

2.3.28.1 Application Definition

Cooperative collision warning collects surrounding vehicle locations and dynamics and warns the driver when a collision is likely.

2.3.28.2 Application Description

The vehicle receives data regarding the position, velocity, heading, yaw rate, and acceleration of other vehicles in the vicinity. Using this information along with its own position, dynamics, and roadway information (map data), the vehicle will determine whether a collision with any vehicle is likely. In addition, the vehicle will transmit position, velocity, acceleration, heading, and yaw rate to other vehicles.

2.3.28.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency: ~ 100 ms
- Data to be transmitted and/or received: position, velocity, acceleration, heading, yaw-rate
- Maximum required range of communication: ~ 150 m

2.3.29 Cooperative Vehicle-Highway Automation System (Platoon)

2.3.29.1 Application Definition

This application provides both positional and velocity control of vehicles in order to operate safely as a platoon on a highway.

2.3.29.2 Application Description

Platooning requires vehicle-to-vehicle communication and may include vehicle-to/from-infrastructure communication. This application functions only in the control role and improves highway traffic flow and capacity by allowing short-range headway distance following in platoon architecture. The application combines vehicle data with position and map data. The application reduces the amount of time a human controls the vehicle thereby reducing opportunities for driver error. For proper function, vehicles with this application may be required to use dedicated highway lanes. Longitudinal control of the vehicle is provided in order to maintain the short-range headway following within a platoon (similar to adaptive cruise control). Lateral control via automated steering provides lane-keeping and lane change maneuvers of platoon vehicles in a coordinated manner.

2.3.29.3 Communication Requirements

- Communication from vehicle to vehicle and with infrastructure
- One-way and two-way communication
- Point-to-point and point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 50 Hz

- Allowable latency: ~ 20 ms
- Data to be transmitted and/or received: position, velocity, acceleration, heading, yaw-rate.
- Maximum required range of communication: ~ 100 m

2.3.30 Cooperative Adaptive Cruise Control

2.3.30.1 Application Definition

Cooperative adaptive cruise control will use vehicle-to-vehicle communication to obtain lead vehicle dynamics and enhance the performance of current adaptive cruise control (ACC).

2.3.30.2 Application Description

Enhancements that could be made to ACC include stopped vehicle detection, cut-in vehicle detection, shorter headway distance following, improved safety, etc. The application can be enhanced by communication from the infrastructure, which could include intelligent speed adaptation through school zones, work zones, off-ramps, etc.

2.3.30.3 Communication Requirements

- Communication from vehicle to vehicle and infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~ 10 Hz
- Allowable latency: ~ 100 ms
- Data to be transmitted and/or received: position, velocity, acceleration, heading, yaw-rate
- Maximum required range of communication: ~ 150 m

2.3.31 Road Condition Warning

2.3.31.1 Application Definition

Road condition warning is used to provide warning messages to nearby vehicles when the road surface is icy, or when traction is otherwise reduced.

2.3.31.2 Application Description

Road condition warning may be implemented with roadside beacons mounted along the road at points where the road condition could change rapidly (i.e., bridges, low points, weather related high frequency accident areas). The road surface condition would have to be determined through the use of infrastructure sensors (moisture, temperature, etc.) When the road surface traction is considered low enough to constitute a driving hazard, a warning message is sent to nearby vehicles.

2.3.31.3 Communication Requirements

- Communication from infrastructure-to-vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: road condition warning message
- Maximum required range of communication: ~200 m

2.3.32 Pre-Crash Sensing

2.3.32.1 Application Definition

Pre-crash sensing can be used to prepare for imminent, unavoidable collisions.

2.3.32.2 Application Description

This application could use DSRC communication in combination with other sensors to mitigate the severity of a crash. Countermeasures may include pre-tightening of seatbelts, airbag pre-arming, front bumper extension, etc.

2.3.32.3 Communication Requirements

- Communication from vehicle to vehicle
- Two-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~50 Hz
- Allowable latency: ~20 ms

– Data to be transmitted and/or received: vehicle type, position, velocity, acceleration, heading, yaw-rate
– Maximum required range of communication: ~50 m

2.3.33 Highway/Rail Collision Warning

2.3.33.1 Application Definition

Railroad collision avoidance aids in preventing collisions between vehicles and trains on intersecting paths.

2.3.33.2 Application Description

Infrastructure to vehicle: This application will use information communicated from roadside beacons located near railroad crossings. The communicated information from roadside beacons would include data about approaching trains such as position, heading, and velocity.

Vehicle to vehicle: This application will use information communicated from a train. The communicated information would include data about the approaching train such as position, heading, and velocity.

2.3.33.3 Communication Requirements

– Communication from infrastructure to vehicle or vehicle to vehicle
– One-way communication
– Point-to-multipoint communication
– Transmission mode: event-driven or periodic
– Minimum frequency (update rate): ~1 Hz
– Allowable latency: ~1 s
– Data to be transmitted and/or received: position, heading, velocity
– Maximum required range of communication: ~300 m

2.3.34 Vehicle-To-Vehicle Road Feature Notification

2.3.34.1 Application Definition

This in-vehicle application senses the road features such as grade, curve, etc. that exceed pre-set limits and transmits the information to other vehicles via broadcast.

2.3.34.2 Application Description

All vehicles within a certain area of the same road feature will be notified. The road feature information can be used by vehicle safety applications in the receiving vehicle. For example, an application can be designed to work in the vehicle to calculate maximum speed recommendations based on road features such as curvature of road ahead and notify the driver appropriately.

2.3.34.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~2 Hz
- Allowable latency: ~0.5 s
- Data to be transmitted and/or received: position, heading, road feature parameters
- Maximum required range of communication: ~400 m

2.4 Non-Safety Applications

Traffic Management

2.4.1 Intelligent On-Ramp Metering

2.4.1.1 Application Definition

This infrastructure application uses vehicle-to-infrastructure communication to measure real-time traffic density on the highway and dynamically alters on-ramp metering signal phasing.

2.4.1.2 Application Description

It is assumed that the infrastructure will make periodic point-to-multipoint broadcasts requesting the information from nearby vehicles. Vehicle-to-infrastructure communication from nearby highway traffic permits the ramp meter controller to adjust the signal timing based on real-time traffic flow and thereby improves traffic flow.

2.4.1.3 Communication Requirements

- Communication from vehicle to infrastructure
- One-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): 1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: vehicle position, speed and direction of travel
- Maximum required range of communication: ~100 m

2.4.2 Intelligent Traffic Flow Control

2.4.2.1 Application Definition

This infrastructure application uses vehicle-to-infrastructure communication and thereby facilitates traffic light signal phasing based on real-time traffic flow.

2.4.2.2 Application Description

It is assumed that the infrastructure will make periodic broadcasts requesting the information from nearby vehicles. Vehicles send a message regarding their position, heading, and speed to the traffic signal infrastructure, which processes the information from each direction and determines the optimal signal phasing based on the real-time information. This application would improve traffic flow.

2.4.2.3 Communication Requirements

- Communication from vehicle to infrastructure
- One-way communication
- Point-to-point communication
- Transmission mode: event driven
- Minimum frequency (update rate): 1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: vehicle position, speed, and direction of travel
- Maximum required range of communication: ~250 m

Tolling

2.4.3 Free-Flow Tolling

2.4.3.1 Application Definition

This infrastructure application works on toll roads and uses communications for toll collection without the need for toll plazas along the roadway.

2.4.3.2 Application Description

The application can be designed to eliminate the need for vehicles to stop at toll plazas, thereby reducing stop-and-go traffic near toll collection areas. This application would reduce congestion and improve traffic flow on toll roads.

2.4.3.3 Communication Requirements

- Communication from infrastructure to vehicle and vehicle to infrastructure
- Two-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): N/A
- Allowable latency: ~50 msec
- Data to be transmitted and/or received: toll transaction
- Maximum required range of communication: ~50 m

Information from Other Vehicles

2.4.4 Cooperative Glare Reduction

2.4.4.1 Application Definition

This application uses DSRC to allow a vehicle to automatically switch from high-beams to low-beams when trailing another vehicle.

2.4.4.2 Application Description

Each vehicle broadcasts its position and heading in low-light situations. If one vehicle calculates that another vehicle in front of it is within a specified range, it will switch from high-beams to low-beams.

2.4.4.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: position, heading, velocity
- Maximum required range of communication: ~400 m

2.4.5 Instant Messaging

2.4.5.1 Application Definition

This application enables a vehicle to send an instant message to another vehicle.

2.4.5.2 Application Description

If an occupant notices any problem (e.g. flat tire, missing gas cap, open trunk, etc.), it can send a message to the corresponding vehicle. The message could be chosen from a list of pre-defined or customized messages. The interface for the sender of the message (i.e. how to identify the target vehicle) is not defined.

2.4.5.3 Communication Requirements

- Communication from vehicle to vehicle
- One-way or two-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): N/A
- Allowable latency: ~1 s
- Data to be transmitted and/or received: text message

- Maximum required range of communication: ~ 50 m

2.4.6 Adaptive Headlamp Aiming

2.4.6.1 Application Definition

This application allows vehicles to aim their headlights in the direction of travel and more effectively illuminate the road ahead.

2.4.6.2 Application Description

Roadside units communicate road features (e.g. curves, grades) that enable the vehicles to appropriately aim their headlights. As an alternative to DSRC, digital maps could be used.

2.4.6.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: road features (curve, bank, grade, etc.) and their locations
- Maximum required range of communication: ~200 m

2.4.7 Adaptive Drivetrain Management

2.4.7.1 Application Definition

Adaptive Drivetrain Management uses information provided by the infrastructure regarding road features ahead, such as grades, to assist the engine management system of a vehicle in stabilizing its transmission.

2.4.7.2 Application Description

Roadside units communicate road features (e.g. curves, grades) that enable the vehicles to anticipate appropriate shift patterns. The goal of the application is to improve fuel economy, emissions and transmission shifting performance. As an alternative to DSRC, digital maps and GPS could be used.

2.4.7.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 s
- Data to be transmitted and/or received: road features (curve, bank, grade, etc.) and their locations
- Maximum required range of communication: ~200 m

2.4.8 Enhanced Route Guidance and Navigation

2.4.8.1 Application Definition

Up-to-date and localized navigation information is sent to vehicles via roadside units.

2.4.8.2 Application Description

Information that could be sent includes construction advisories, detours, right and left turn restrictions, and parking restrictions. This information may be temporary or too recent to appear in published navigation maps. Roadside units send enhanced route guidance and navigation information to the vehicle, which processes it and possibly merges it with its navigation system.

2.4.8.3 Communication Requirements

- Communication from infrastructure to vehicle
- Two-way communication
- Point-to-point communication
- Transmission mode: event-driven
- Minimum frequency (update rate): ~ N/A
- Allowable latency: ~1 s
- Data to be transmitted and/or received: navigation information (construction advisories, detours, right and left turn restrictions)
- Maximum required range of communication: ~200 m

2.4.9 Point of Interest Notification

2.4.9.1 Application Definition

A roadside unit will provide information to passing vehicles periodically via broadcast.

2.4.9.2 Application Description

The information can describe features about the local area or services that are provided in the near vicinity. In the case of nearby gas stations, for example, the gas station names, gas prices, and turn-by-turn directions could be transmitted. This relieves the driver from searching for a specific type of service.

2.4.9.3 Communication Requirements

- Communication from infrastructure to vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: information about points of interests.
- Maximum required range of communication: ~400 m

2.4.10 Map Downloads and Updates

2.4.10.1 Application Definition

Maps can be downloaded to a vehicle and a vehicle's existing maps can be updated by a roadside unit.

2.4.10.2 Application Description

The kind of information which can be provided varies with the type of roadside unit. For example, a city portal can provide points of interests or traffic information. This information can be used to update the vehicle's map database. Other units could allow entirely new maps to be bought and downloaded. If specific queries can be made from the vehicle or if a transaction is performed, two-way communication is required.

2.4.10.3 Communication Requirements

- Communication from infrastructure to vehicle and from vehicle to infrastructure
- One-way or two-way (if queries or purchases are made) communication
- Point-to-point communication or point-to-multipoint communication
- Transmission mode: periodic or event-driven
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: position, traffic information, map downloads or updates
- Maximum required range of communication: ~400 m

2.4.11 GPS Correction

2.4.11.1 Application Definition

The roadside unit is pre-programmed with its precise location, and it gives this information to passing vehicles.

2.4.11.2 Application Description

Based on its GPS coordinates and the time stamp of the message from the unit to the vehicle, the vehicle can calculate its position more accurately (using DGPS techniques). This application is particularly useful when the vehicle is far from a commercial DGPS station or when the differential signal is difficult to receive.

2.4.11.3 Communication Requirements

- Communication from infrastructure to the vehicle
- One-way communication
- Point-to-multipoint communication
- Transmission mode: periodic
- Minimum frequency (update rate): ~1 Hz
- Allowable latency: ~1 sec
- Data to be transmitted and/or received: position corrections
- Maximum required range of communication: ~400 m

Other potential applications:

- Green light optimal speed advisory
- Infrastructure-based traffic management – probes
- Traffic information
- Transit vehicle data transfer
- Emergency vehicle video relay
- Border clearance
- On-board safety data transfer
- Vehicle safety inspection
- Driver’s daily log
- Access control
- Drive-thru payment
- Parking lot payment
- Data transfer / Info-fueling
- Vehicle computer program updates
- Video downloads
- Vehicle sensing alternative for inductive loop
- Transmitter for bicycle/pedestrian/blind person/etc. (in-vicinity advisory)
- On-call mechanic
- SOS environmental assessment (picture/video)
- Overhead storage reminder (height clearance)
- Drowsy driver advisory
- Distracted driver advisory
- Beacon for child left in vehicle
- Peer voting of driving patterns (commercial vehicle)
- Dynamic emissions tests
- Speed limit assistant
- Parking spot locator
- Electronic license plate*
- Electronic driver’s license* (hazardous waste delivery, etc.)
- Vehicle lock-down* (disable a vehicle remotely)
- All-points bulletin* (request vehicle with particular identity to respond)

*Implementation is not recommended unless privacy issues are resolved.

2.5 Wireless Communication Technologies

This section discusses the wireless communications technologies that are available or planned. The capabilities for each technology are briefly described in relation to the basic communications requirements of the vehicle safety applications identified earlier in this chapter. In the final portion of this section, the capabilities of the wireless technologies are compared in a summary table.

2.5.1 5.9 GHz DSRC

The short-range communications capabilities of 5.9 GHz DSRC are uniquely targeted toward supporting location-based mobile services. This type of system has the bandwidth and, potentially, other beneficial performance characteristics, to be the most reliable, effective and efficient way to support the communication of localized information from the roadside to vehicles, as well as between vehicles in close proximity. As well, DSRC has the potential to provide low latency communications, which have been identified as a necessary capability to support the vehicle safety applications identified earlier in this chapter. In order to realize this potential, however, the correct technological choices must be made for the FCC rules for this spectrum, and for the standards to be used in this band.

The band plan being proposed in the United States for the 75 MHz of spectrum in the 5.9 GHz range has been under development for some time. The DSRC Standards Writing Group has included a number of safety-related applications in their deliberations from the start. The VSCC has been participating actively in the DSRC standards development meetings throughout 2002, and has been successful in gaining consideration of the communications requirements of vehicle safety applications. These DSRC standards have the potential to provide support for many automotive safety-related applications, but diligence continues to be required to ensure that the DSRC standards development process enables cost-effective systems that fully support the desired vehicle safety applications.

2.5.2 Digital Cellular and 2.5-3G PCS

The “always on” packet data capabilities of the 2.5-3G cellular technologies will virtually eliminate the call set-up delays of data connections over current cellular systems. However, end-to-end latency is likely to remain in the range of at least several seconds, due to the server processing required in the mobile location registers, and the multiple packet forwarding necessary to deliver data to/from dynamically changing cellular sites. As well, data communications over these networks tend to be lower priority than voice communications, so data packets can be expected to encounter buffer-based latency if the networks are busy with voice traffic. These latency limitations will likely preclude the use of cellular communications for the majority of the vehicle safety applications being studied by the VSCC. Besides the latency issue, cellular technology inherently requires knowledge of the number to be called. It is virtually impossible to know in advance the "phone" numbers for all vehicles to be encountered, or for all intelligent infrastructure to be encountered in the real-world driving environment. The majority of the vehicle safety applications under study therefore require broadcast-based communications capabilities.

2.5.3 Bluetooth

Bluetooth may serve as a vehicle-to/from-infrastructure communications channel for stationary vehicles in close proximity to the desired communications point. Although the operational parameters of Bluetooth in terms of range and latency, preclude its ability to support most of the identified vehicle safety applications, it could be used for safety-related tasks, like updating navigational databases while the vehicle is parked in the garage, for example. The range limitations that prevent the use of Bluetooth to support vehicle safety applications, however, would not prevent it from supporting commercial applications like electronic payments at fast food drive-thrus, for example, or entertainment-related communications between a vehicle and its garage.

2.5.4 Digital Television (DTV)

The DTV standard adopted for the United States utilizes the 8-Level Vestigial Side-band (8-VSB) modulation method as the basis for digital transmissions. However, the vestigial sideband approach is not readily applicable for mobile applications. Without major technological breakthroughs in antennas and receivers, the vestigial sideband DTV system will not be at all relevant to the vehicle communications environment.

2.5.5 High Altitude Platforms

The potential for data broadcasting (point-to-multipoint) from stratospheric platforms has particular relevance for continuous updating of in-vehicle map databases. Local/regional information such as traffic, weather, road work zones, as well as commercially-significant location-based information, could potentially be very well-supported by wireless datacasting from stratospheric platforms. Vehicle safety applications that require high accuracy database support with more dynamic information elements at the local/regional level could potentially have this aspect of their wireless informational needs supported by high altitude platforms. The stratospheric platform approach employs several very new technologies, therefore there is a real risk that the entire concept may not be feasible.

2.5.6 IEEE 802.11 Wireless LAN

The 802.11 series of standards were developed by the IEEE specifically to support wireless LANs. Both 802.11a and 802.11b (depending upon data rates required) could potentially support the inclusion of vehicles in wireless home LANs. Such home systems could provide extensive data downloads to garaged vehicles, as well as allowing the vehicles to download non-time-critical information to wider area networks. At the present time, 802.11b systems are rapidly being deployed for home, office and public area LANs. These developments offer the opportunity for 802.11b-equipped vehicles to upload and download data through these wireless LANs while the vehicles are within range of the “hot spots”.

Although most of the vehicle safety applications under study by the VSCC do not require two-way communications, as is generally the case in LAN environments, many aspects of the 802.11a standard are quite desirable for the mobile environment. That is why the 802.11a standard was chosen as the basis for the 5.9 GHz DSRC lower layer standard. The modifications necessary include reducing the data rate for more reliable communications at highway speeds, and reducing/eliminating the LAN-based “handshaking” required in order to reduce the system latency from seconds to milliseconds. The modified 802.11a capabilities are therefore included in the DSRC discussion section.

2.5.7 Nationwide Differential Global Positioning System (NDGPS)

When fully deployed, the NDGPS system will use differential GPS reference station transmitter systems located throughout the country to broadcast additional information that can be used by GPS receivers to generate more accurate location estimates. These DGPS transmitters broadcast in the 300 KHz frequency range. Using NDGPS to augment the GPS system currently provides accuracy in the one-meter range for “good quality” receivers that are moving (such as those located in vehicles).

Once this system is fully deployed, 1-meter positioning accuracy can be expected to be widely available from the combination of GPS / NDGPS signal reception and more processing power in receivers. This should allow the geopositioning requirements of many of the vehicle safety applications envisioned by the VSCC to be realized, assuming that navigational databases of sufficient detail and accuracy are also available.

2.5.8 Radar

The expense of transmitters operating in these frequency ranges is the most likely limiting factor regarding 2-way wireless communications capabilities. However, even receive-only capabilities could enable useful messaging applications over radar frequencies. With a high likelihood of at least forward-looking radar capabilities on future vehicles (in conjunction with ACC), a standards-based method of providing messaging capabilities for these systems could extend the vehicle’s capabilities for deriving useful information from the roadside. Any systems that support a realistic data payload, however, are not yet on the development horizon. The potential capabilities of such systems, if they are developed, may be very complementary to DSRC capabilities, although some overlap is likely.

2.5.9 Remote Keyless Entry (RKE)

The vehicle safety applications being considered by the VSCC require reliable radio links, as well as interoperability between the vehicles of different manufacturers (and between vehicles and the road infrastructure). RKE systems, as they are currently designed, could not effectively support either of these requirements. The new wireless systems that may be developed to integrate RKE functionality are most likely to be standardized wireless systems, such as 3G, Bluetooth and DSRC.

2.5.10 Satellite Digital Audio Radio Systems (SDARS)

Both Sirius and XM satellite radio systems contain digital bit streams sent to their respective receivers. These digital bit streams have the ability to support many forms of digital data – voice, graphics, control messages or file downloads, for example. Each of the approximately 100 digital “channels” available on these systems supports data transmissions in the range of 64 Kbps. This technology is inherently point-to-multipoint, so the 64 Kbps data channel would be available simultaneously on a nationwide basis. Therefore, any digital data that would fit within the available SDARS bit stream could be sent nationwide using these systems. Conceivably, a single data message sent through one of these systems could simultaneously reach every satellite-radio-equipped automobile in the United States. For vehicle communications that could effectively use a relatively inexpensive, one-way nationwide data channel, SDARS systems may prove to be the most economical wireless communications method. Although this potentially could include map database updates that relate to the vehicle safety applications, the density of information expected as map database levels of detail increase, in conjunction with the narrow channel bandwidth and nationwide coverage of SDARS, seem to limit the feasibility of this approach. Certainly, the nationwide coverage aspect and other system characteristics, preclude SDARS from supporting the direct wireless communications requirements of the envisioned vehicle safety applications.

2.5.11 Terrestrial Digital Radio

The FM portion of In-Band, On-Channel (IBOC) technology is being recommended by the National Radio Systems Committee (NRSC) for adoption by the United States broadcasting industry. The FM portion of this technology has been approved by the FCC. In the FM IBOC system, if the audio signal occupies the full 96 Kbps available for high quality audio, then only 1 Kbps will be available for data broadcasting. If, however, a station chooses to use only 64 Kbps for its audio signal, then 33 Kbps would be available for datacasting.

There are a significant number of telematics-type applications that could potentially use terrestrial digital radio datacasting to communicate with vehicles. These types of applications are generally point-to-multipoint in nature, where the same information is sent to all the vehicles at the same time. One potentially effective use of datacasting over terrestrial radio systems is near real time, continuous updates of on-board geographical databases. Low-bandwidth, variable information, like work zone locations, lane closures, detours, malfunctioning traffic signals and time-of-day restrictions, for example, might best be conveyed to the vehicle databases through such point-to-multipoint systems. However, the regional coverage aspect and one-way (radio station-to-vehicle) nature of IBOC, prevent this technology from meeting the direct wireless communications requirements of the vehicle safety applications being considered by the VSCC.

2.5.12 Two-way Satellite

Ubiquitous coverage over the continental US (as well as extended global coverage), provides a strong argument to consider two-way satellite services for wireless connectivity on vehicles. So far, however, the data services that are available and affordable have rather limited data capacity. Even with these data capacity limitations, there are a fairly wide range of telematics-type applications that could be supported using a short message data structure. For example, low bandwidth packet data services over satellite could be used to support vehicle telemetry applications, such as probe vehicle monitoring. Since the two-way satellite services are designed to operate as point-to-point communications channels, their mode of operation is not compatible with the vehicle safety applications under study by the VSCC. Another serious deficiency of these systems in relation to the vehicle safety applications communications requirements is the large inherent system latency. The expected airtime costs are yet another serious issue.

2.5.13 Ultrawideband (UWB)

In 2002, the FCC granted limited approval for the use of UWB at very low power outputs, and within a limited range of spectrum. Consequently, the commercial development of this technology has been focused upon very low-power applications for sensing and communications. The largest limitation of UWB for vehicle communications is the limited range expected with the initial systems that are likely to become available. One of the positive aspects of UWB for vehicles is the all-digital implementation, which potentially allows low cost, light weight and small size to be realized. As well, UWB appears to be fairly immune to multipath interference, a significant benefit for moving vehicles. The low-cost, small size characteristic of UWB devices, coupled with their potential use as an integrated communications, positioning and radar solution, makes UWB a reasonable candidate to monitor for further developments that may allow its use for vehicle safety applications. Since this technology is so new on the commercial scene, however, it may be several years before real relevance for vehicle safety applications can be confirmed.

2.5.14 Comparison of Wireless Technologies

In a comparison of available and planned wireless technologies, as shown in Table 2.1, DSRC appears to uniquely meet the basic communications requirements for most of the vehicle safety applications identified earlier in this chapter. These requirements, which are potentially supported by DSRC, include:

- range of less than 1000 meters, which is supported by DSRC;
- one-way and two-way directionality, both to and from the vehicle;
- both point-to-point and point-to-multipoint communications; and
- most compellingly, latency less than 100 milliseconds (the potential DSRC latency is three orders of magnitude lower than other existing wireless technologies).

Table 2.1 Comparison of Wireless Technologies

		Wireless Technologies												
		5.9 GHz DSRC	2.5-3G PCS and Digital Cellular	Bluetooth	Digital Television (DTV)	High Altitude Platforms	IEEE 802.11 Wireless LAN	Nationwide Differential Global Positioning System (NDGPS)	Radar	Remote Keyless Entry (RKE)	Satellite Digital Audio Radio Systems (SDARS)	Terrestrial Digital Radio	Two-way Satellite	Ultrawideband (UWB)
Capabilities	Range	1000 m	~4-6 km	10 m	~40 km	120 km	1000 m	300-400 km	2 km	30 m	US 48 states	30-50 km	NA	15-30 m ?
	One-way to vehicle	X			X	?		X	X	X	X	X		
	One-way from vehicle	X				?			X					?
	Two-way	X	X	X		?	X						X	
	Point-to-point	X	X	X		?	X			X			X	
	Point-to-multipoint	X			X	?		X	X		X	X		?
	Latency	200 micro sec	1.5-3.5 sec	3-4 sec	10-30 sec	?	3-5 sec	NA	NA	NA	10-20 sec	10-20 sec	60+ sec	?

3 Application Analysis and Ranking

3.1 Introduction

In Chapter 2, descriptions and communication requirements of application scenarios that are enabled or enhanced by vehicle-to/from-infrastructure communications, or vehicle-to-vehicle communications are presented. Part of the goal of Task 3 is to identify potential safety benefits of the applications, and to use this as criteria for selecting some of the high-priority safety applications for further detailed analysis. A methodology for analysis and ranking of application scenarios was developed to estimate the relative ranking of the application scenarios. Application safety benefits were estimated by considering a crash statistic loss metric called Functional Years Lost from the General Motors 44 Crashes report [1]. Years of functioning and life lost was defined as "the number of years lost to fatal injury plus the number of years of functional capacity lost to nonfatal injury [4]. In this chapter, results of the application safety benefits analysis and application ranking are discussed.

The VSC project team defined a set of analysis categories by which the potential safety benefits of each application scenario could be compared. Each application scenario was rated with respect to the analysis categories. The four main category areas are:

- Estimated deployment timeframe
- Estimated effectiveness with respect to crash scenarios
- Estimated market penetration
- Estimated cooperation from infrastructure and/or other vehicles

The application scenarios were first classified as near-term, mid-term or long-term applications based on expected deployment timeframe. Application safety benefits were estimated by considering a crash statistic loss metric called Functional Years Lost. This metric may not be correct in the absolute sense, but is correct in a directional sense. The effect of frequency by which applications would potentially be introduced into the market was handled by market penetration estimates. All the application scenarios described in Chapter 2 require cooperation from the infrastructure, other vehicles, or both, in the form of relevant safety-related data exchange using infrastructure-to/from-vehicle communication, and/or vehicle-to-vehicle communication. Estimates were used for the probability that a vehicle equipped with the application will get cooperative communication from other vehicles and/or the infrastructure.

All of the applications, evaluation category ratings, and crash statistics were then put into spreadsheets for analysis. The estimated data was used to obtain the potential safety benefits for the VSC application scenarios and to provide a relative ranking of high-priority safety applications that are enabled or enhanced by communications.

It is important to stress that the VSC application safety benefits analysis was for the purpose of relative ranking of communications-enabled application scenarios. The high-priority safety focused applications identified here are further developed in Chapter 4 in order to derive the concept and detailed communication requirements.

3.2 Application Evaluation Attributes

Descriptions of application analysis categories that were used for application safety benefits estimation are presented. In order to evaluate the potential safety benefits and prioritize development of the application scenarios, the following questions were asked:

1. What is the expected deployment timeframe of the application scenario?
2. What is the expected effectiveness of the application scenario in preventing the crash types?
3. What is the expected market penetration of the application for each year starting with deployment?
4. Does the application scenario require vehicle-to-vehicle or infrastructure-to-vehicle communication? What is the expected cooperation that the application scenario can get from other vehicles or infrastructure?

Several evaluation criteria categories that were used to evaluate the application scenarios are described in the following sections. The goal in the selection of application analysis categories has been to develop a methodology for estimating the relative ranking of the application scenarios.

3.2.1 Deployment Timeframe

This category defines the estimated timeframe before the application may be available on light duty vehicles in the U.S. Estimated deployment time frame of an application depends on technical factors such as additional sensor requirements, vehicle position plus map accuracy required, communication requirements, and cost. Our estimate of deployment time frame for the application systems considers these factors. It is expected that the main DSRC standards will be completed by the second quarter of 2004.

Possible values examined are near-term, mid-term, or long-term.

Near-term application systems are considered to be deployable in the U.S market between the years 2007 to 2011.

Mid-term application systems are considered to be deployable in the U.S market between the years 2012 to 2016.

Long-term application systems are considered to be deployable in the U.S market beyond the year 2016.

3.2.2 GM 44 Crashes Percent Effectiveness (E_i)

This category defines the estimated effectiveness of the application scenario to each crash scenario. Each crash scenario considered contained a cause, a crash configuration, a representative narrative, and the estimated frequency and losses. This method was used to estimate three types of benefit distributions that are potentially obtained with each of the application systems – Direct Costs Saved, Functional Years Saved and Vehicles Saved. Direct Costs Saved is defined as the value of crash incurred direct costs that are saved, potentially, by the deployment of a specific application system. Functional Years Saved is defined as the Years of Functioning and Life that is potentially saved by the deployment of a specific application system. Vehicles Saved is defined as the vehicles that are potentially saved from crashes by the deployment of a specific application system.

The effectiveness estimate, E_i, is chosen from a set of possible values given below.

Possible values examined are 0%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100%.

In order to limit application effectiveness to certain crash types, factors were considered in scoring estimated effectiveness of application systems to each of the crash scenarios. For example, systems are not expected to be 100% effective when the driver is impaired. As a result, effectiveness for crashes involving an impaired driver is limited. The factors include:

- Aggressive Driver
- Distracted / Inattentive Driver
- Poor Driver Decision
- Impaired / Drowsy Driver
- Rough / Slick Road

3.2.3 Market Penetration Model

The market penetration model takes into account each potential vehicle safety application individually, and is not meant to estimate the deployment of DSRC systems in general. For the purposes of the Task 3 research, a two degree-of-freedom model is used to estimate the market penetration of each potential safety application based on the following:

1. Estimated percentage of new vehicles in the U.S that are likely to be equipped with the application in the first deployment year (I)
2. Estimated multiplier growth factor for subsequent years after deployment (G)

No retrofitting of old vehicles with the application is assumed in these calculations. The total number of new light duty vehicles introduced in the U.S. in 2002 is approximately

17 million. The total number of registered vehicles in the U.S. in 2002 is approximately 210 million.

3.2.3.1 First Year Market Penetration (I)

This category defines the estimated percentage of new light duty vehicles in the U.S. that are likely to be equipped with the application system in the first deployment year. Factors affecting this category include cost of the application system, benefits obtained, production capacity, etc.

Possible values examined are 0.1%, 0.5 %, 1%, or 2%.

Some examples of first year market penetration of recent driver assistance systems deployed in the U.S. are the following:

- Night Vision (GM): 0.02%
- Adaptive Cruise Control (DaimlerChrysler): 0.02%
- Adaptive Cruise Control (Toyota): 0.05%

The lower bound of 0.1% is higher than in the above examples. This is because a higher level of market penetration for cooperative application systems being considered is thought to be required in order to be effective. The upper bound is chosen to be equal to a quarter of all new luxury class light duty vehicles being equipped with the application system.

As an additional reference, the case where the first year market penetration is 100% has also been examined. This would mean that all new vehicles manufactured in the deployment year would be equipped with the application.

3.2.3.2 Market Penetration Multiplier for Subsequent Years (G)

This category defines a multiplier factor for estimation of market penetration of the application system in the U.S. after first deployment year.

Possible values examined are 1, 1.5, or 2.

A value of one indicates that there is no increase in market penetration of the application system in the subsequent year. A value of two indicates that the market penetration of the application system is double in the subsequent year, and so on.

3.2.3.3 Probability of Vehicle Being Equipped with Application

In order to determine the probability that a light duty vehicle is equipped with the application in year Y after deployment year, the following simple market penetration model was used:

Number of new vehicles each year = 17 million

Total number of registered vehicles each year = 210 million

Probability that a vehicle is equipped with application in year Y after deployment

$$P_V(Y) = \frac{17}{210}(I)[1 + (G)^1 + (G)^2 + \Lambda + (G)^{Y-1}]$$

The following is an example of market penetration calculation for estimating safety benefits of the application system:

First year market penetration (I) = 0.1 %

Market penetration multiplier for subsequent years (G) = 2

Probability that a vehicle is equipped with application in year three after deployment

$$P_V(3) = \frac{17}{210}(0.1\%)[1 + (2)^1 + (2)^2] = 0.000567$$

Suppose that every new vehicle in the U.S is equipped with the application system in each year since deployment. This case would provide the best safety benefit opportunity of the application. The following is an example of market penetration calculation for estimating the benefit opportunity of the application system:

First year market penetration (I) = 100 %

Market penetration multiplier for subsequent years (G) = 1

Probability that a vehicle is equipped with application in year three after deployment

$$P_V(3) = \frac{17}{210}(3) = 0.0809$$

3.2.4 Infrastructure / Other Vehicle Cooperation Model

All the application scenarios described in Chapter 2 require cooperation from the infrastructure, other vehicles or both. Cooperation with the infrastructure and other vehicles required by the applications is in the form of relevant safety-related data exchange using infrastructure-to/from-vehicle communication, and/or vehicle-to-vehicle communication.

Communication requirements of an application also impact market penetration and deployment time frame. For example, deployment of infrastructure-to-vehicle communication capability at all intersections may be infeasible. Vehicle-to-vehicle communication architectures are being developed but an application that depends on this type of communication may not be deployable soon.

The fifth year after deployment has been used for estimating the probability that a vehicle equipped with application will get cooperative communication from other vehicles and/or the infrastructure.

It was not possible to identify future DSRC infrastructure deployment models for vehicle safety applications. Hence, an estimate for the probability of getting infrastructure cooperation and/or other vehicle cooperation in year five after deployment, $P_C(5)$, is chosen from a set of possible values given below.

Possible values examined are 0.005, 0.01, 0.015, 0.02, 0.03, 0.05, 0.1, 0.15, 0.2, 0.3, or 0.4.

3.3 Application Ranking Process

The application scenarios were first classified as near-term, mid-term or long-term applications based on expected deployment timeframe. Estimated deployment time frame of an application system depends on technical factors such as additional sensor requirements, vehicle position plus map accuracy required, and communication requirements.

The estimates of deployment time frame for the application systems shown in Table 3.1 consider these factors. It is expected that the main DSRC standards will be completed by the second quarter of 2004. It is assumed that standards, technology and cost would make it viable to deploy the applications in the timeframe stated.

Relative ranking was done separately for near-term, mid-term, and long-term application scenarios respectively. Application scenarios were primarily ranked based on estimated benefits derived with respect in crash scenarios. This analysis included identification of the relevant crash scenarios that could benefit from an application scenario. For each of the relevant crash scenarios that benefit from an application scenario, the percent effectiveness of the application system to that particular crash scenario was estimated.

Estimates for market penetration were used to determine the estimated number of vehicles in the U.S market that would be equipped with the application scenario in each year after initial deployment. The two-degree of freedom market penetration model described earlier was used to estimate the probability that a vehicle is equipped with application in year Y after deployment.

All the application scenarios described in Chapter 2 require cooperation from the infrastructure, other vehicles or both in the form of relevant safety-related data exchange using infrastructure to/from vehicle communication, and/or vehicle-to-vehicle communication. Estimates were used for the probability that a vehicle equipped with application will get cooperative communication from other vehicles and/or the infrastructure.

For each application system, engineering judgment was used in estimating the application evaluation attributes. The benefit distributions of an application system with respect to the crash scenarios were computed based on two perspectives: benefit opportunity and estimated benefits.

Table 3.1 Application Deployment Timeframe

Application Scenario	Estimated Deployment Timeframe
	(N = Near-term, M = Mid-term, L = Long-term)
Adaptive drivetrain management	N
Adaptive headlight aiming	N
Approaching emergency vehicle warning	M
Blind merge warning	M
Blind spot warning	M
Cooperative ACC	M
Cooperative collision warning	L
Cooperative FCW	M
Cooperative glare reduction	M
Cooperative vehicle-highway automation system	L
Curve speed warning	N
Emergency electronic brake lights	N
Emergency vehicle signal preemption	N
Enhanced route guidance and navigation	N
Free-Flow tolling	N
GPS correction	L
Highway merge assistant	M
Highway/rail collision warning	N
Instant messaging	L
Intelligent on-ramp metering	N
Intelligent traffic flow control	M
Intersection collision warning	L
In-Vehicle Amber Alert	N
In-vehicle signage	N
Just-in-time repair notification	M
Lane change warning	M
Left turn assistant	M
Low bridge warning	N
Low parking structure warning	N
Map downloads and updates	M
Pedestrian crossing information at designated intersections	L
Point of interest notification	N
Post-crash warning	N
Pre-crash sensing	M
Road condition warning	N
Safety recall notice	M
SOS services	N
Stop sign movement assistance	M
Stop sign violation warning	N
Traffic signal violation warning	N
Vehicle-based road condition warning	M
Vehicle-to-vehicle road feature notification	M
Visibility enhancer	M
Work zone warning	N
Wrong-way driver warning	M

Benefit Opportunity

Benefit opportunity provides an estimate of the potential benefits derived by deployment of an application scenario in all new vehicles for each year after initial deployment. The percent effectiveness of the application scenario with respect to the crash scenarios, and the probability that a vehicle equipped with application will get cooperative communication from other vehicles and/or the infrastructure is based on the VSC team estimates, i.e.

<u>Possible Values Examined for Market Penetration</u>

First Year Market Penetration: 100%

Market Penetration Multiplier for Subsequent Years: 1

<u>Possible Values Examined for 44 Crashes Percent Effectiveness</u>

0%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100%

<u>Possible Values Examined for probability of getting Infrastructure and/ or Other Vehicle Cooperation (in year 5 after deployment)</u>

0.015, 0.02, 0.03, 0.1, 0.15, 0.2, 0.3, or 0.4

Estimated Benefits

Estimated benefits indicate the potential benefits derived by deployment of an application scenario using the VSC estimates for market penetration and the market penetration model described earlier. The percent effectiveness of the application scenario with respect to the crash scenarios, and the probability that a vehicle equipped with application will get cooperative communication from other vehicles and/or the infrastructure is also based on the VSC team estimates, i.e.

<u>Possible Values Examined for Market Penetration</u>

First Year Market Penetration: 0.1%, 0.5%, 1%, or 2%

Market Penetration Multiplier for Subsequent Years: 1, 1.5, or, 2

<u>Possible Values Examined for 44 Crashes Percent Effectiveness</u>

0%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100%

<u>Possible Values Examined for probability of getting Infrastructure and/ or Other Vehicle Cooperation (in year 5 after deployment)</u>

0.005, 0.01, 0.05, 0.1, 0.2, or 0.3

In order to rank the near-term, mid-term and long-term applications, **Functional Years Saved** has been used as the most important benefits distribution. Functional Years Saved is used as a relative measure, rather than an absolute measurement, thus it is correct in a directional sense. The **fifth year after deployment** has been used for computation of benefit opportunity and estimated benefits of the application scenarios. The two degree-of-freedom market penetration model could introduce increasingly significant errors into the benefits estimation if it was used for predicting market penetration much further than five years after deployment.

The following formula is used for safety benefits calculation for the application scenarios. Let

T = Total cost of crash statistic loss metric from the crash scenario

F_i = Percent of total cost attributed to crash scenario i

E_i = Percent effectiveness of application scenario with respect to crash scenario i

$P_V(5)$ = Probability that a vehicle is equipped with application in year five after deployment (see Section 3.2.3.3)

$P_C(5)$ = Probability of getting infrastructure cooperation and/or other vehicle cooperation in year five after deployment (see Section 3.2.4)

Then the safety benefit of the application in year five after deployment can be computed as

$$\text{Safety Benefit}(5) = P_V(5)\, P_C(5)\, \text{SUM}(E_i F_i) T .$$

A spreadsheet was developed primarily as a tool for performing the application benefits analysis and ranking. The results of the application benefits analysis and ranking are discussed next.

3.4 Application Ranking

The following figures show potential safety benefits (Functional Years Saved) for **fifth year** after deployment, and the ranking for the near-term, mid-term, and long-term applications. provides ranking of near-term application scenarios based on benefit opportunity for fifth year after deployment.

The benefit opportunity and estimated benefits of Traffic Signal Violation Warning, Curve Speed Warning and Emergency Electronic Brake Lights appear to provide the best benefit opportunity as well as best estimated benefits. Note that both Traffic Signal Violation Warning and Curve Speed Warning require infrastructure to vehicle communications, while Emergency Electronic Brake Lights requires vehicle-to-vehicle communications.

The benefit opportunity appears to be significantly higher than the estimated benefits. The cooperative application systems considered here require infrastructure-to-vehicle communication and/or vehicle-to-vehicle communications. This requirement is reflected in low market penetration of the applications and hence the estimated benefits in the fifth year after deployment are significantly low.

The communication requirements for Stop Sign Violation Warning are similar to those of Curve Speed Warning. Moreover, Stop Sign Violation Warning may be best implemented using a map database, therefore, this application scenario was not considered any further. The remaining application systems provide significantly low benefit opportunity and estimated benefits in relative comparison to Traffic Signal Violation Warning, Curve Speed Warning, and Emergency Electronic Brake Lights.

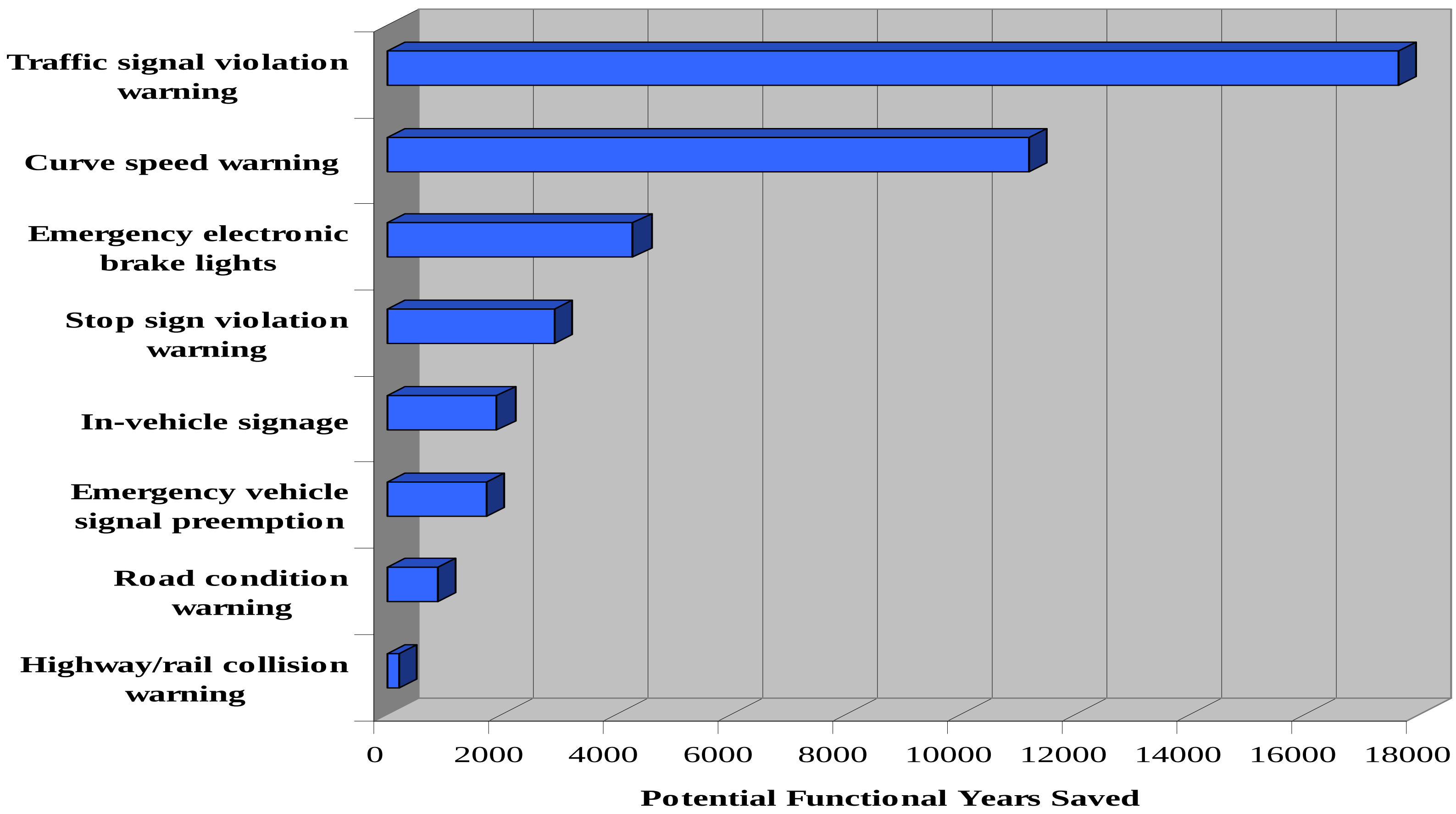


Figure 3.1 Near-term Ranking by Benefit Opportunity

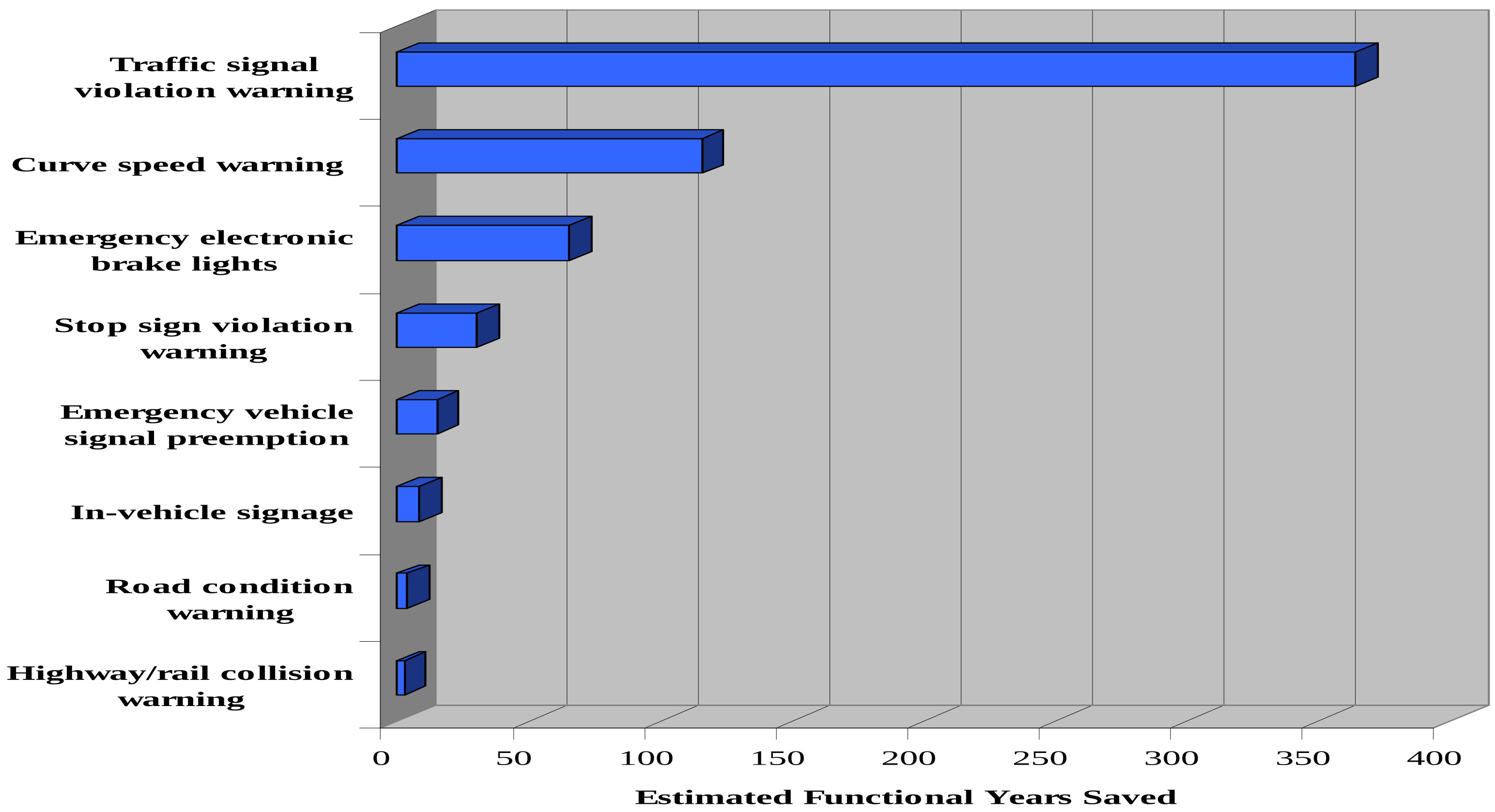


Figure 3.2 Near-term Ranking by Estimated Benefits

Based on the analysis of near-term application scenarios, Traffic Signal Violation Warning, Curve Speed Warning, and Emergency Electronic Brake Lights were selected as the high potential benefit near-term application scenarios. Table 3.2 provides the benefit opportunity and estimated benefits (i.e. Functional Years Saved based on the crash scenarios) that may be achievable with the selected application systems in the fifth year after deployment. The percentage value shown in Table 3.2 indicates the Functional Years Saved as a percentage of total functioning and life lost per year.

Table 3.2 High Potential Benefit Near-term Applications

Application System	Benefit Opportunity (Functional Years Saved)	Estimated Benefits (Functional Years Saved)
Traffic Signal Violation Warning	17,627 (0.86 %)	364
Curve Speed Warning	11,189 (0.54 %)	116
Emergency Electronic Brake Lights	4,284 (0.21 %)	66

Figure 3.3 provides ranking of mid-term application scenarios based on benefit opportunity for fifth year after deployment. Figure 3.4 provides ranking of mid-term application scenarios based on estimated benefits for fifth year after deployment.

From Figure 3.3 and Figure 3.4, the benefit opportunity and estimated benefits of Pre-Crash Warning, Cooperative Forward Collision Warning, Left Turn Assistant, Lane Change Warning and Stop Sign Movement Assistance appear to provide the best benefit opportunity as well as best estimated benefits. Note that Left Turn Assistant and Stop Sign Movement Assistance require infrastructure to vehicle communications, while Pre-Crash Warning, Cooperative Forward Collision Warning and Lane Change Warning require vehicle-to-vehicle communications.

The benefit opportunity appears to be significantly higher than the estimated benefits in this case. This is due to the fact that the cooperative application systems being considered require infrastructure-to-vehicle communication and/or vehicle-to-vehicle communications. This requirement is reflected in low market penetration of the applications and hence the estimated benefits in the fifth year after deployment are significantly low.

The communication requirements for Blind Spot Warning and Cooperative ACC are similar to that of Lane Change Warning and Cooperative FCW, respectively. Therefore, these application scenarios were not considered any further. The remaining application systems have significantly low benefits in relative comparison.

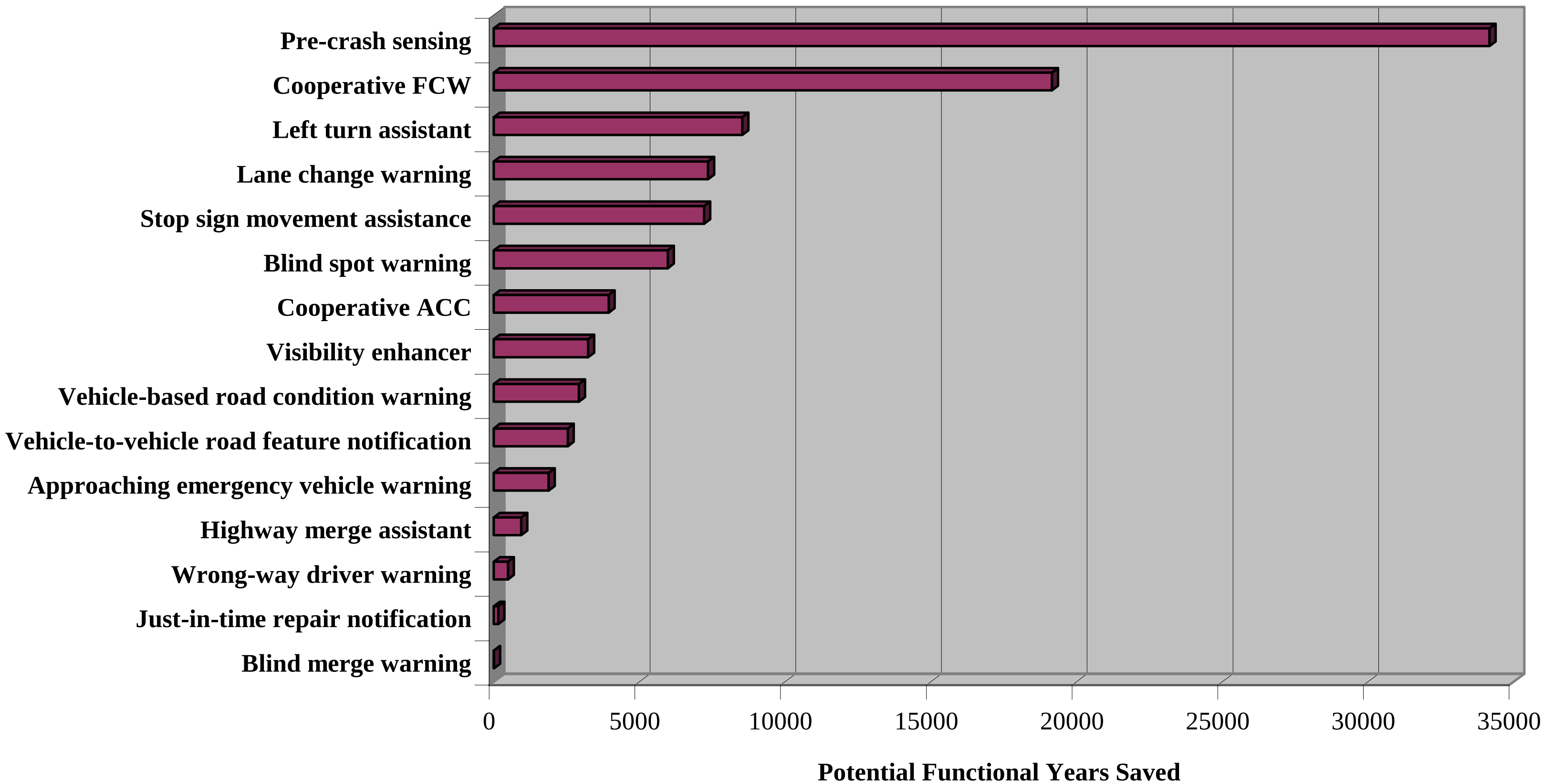


Figure 3.3 Mid-term Ranking by Benefit Opportunity

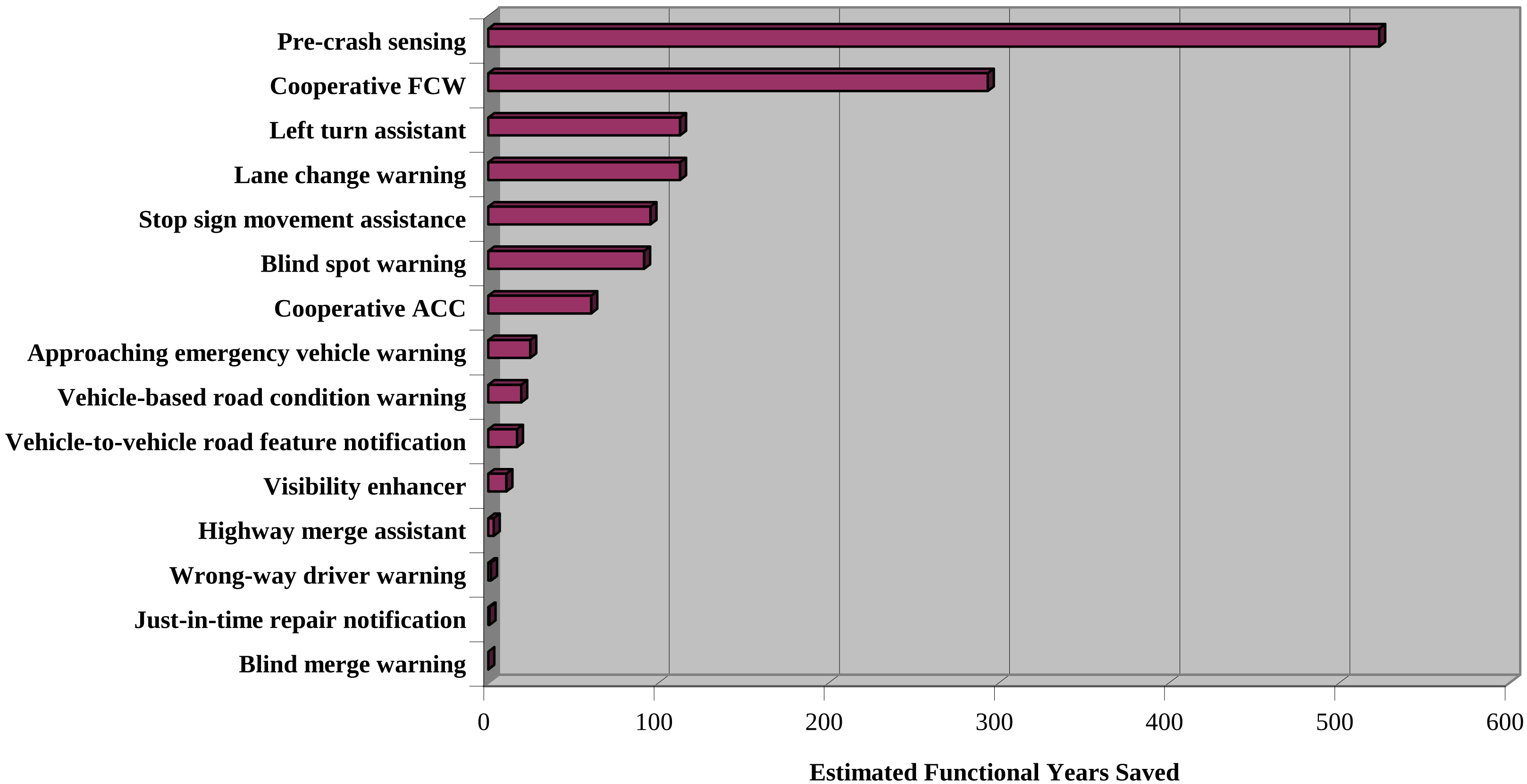


Figure 3.4 Mid-term Ranking by Estimated Benefits

Based on the analysis of mid-term application scenarios, Pre-Crash Warning, Cooperative Forward Collision Warning, Left Turn Assistant, Lane Change Warning and Stop Sign Movement Assistance were selected as the high potential benefit mid-term application scenarios. Table 3.3 provides the benefit opportunity and estimated benefits (i.e. Functional Years Saved based on the crash scenarios) that may be achievable with the selected application systems in the fifth year after deployment. The percentage value shown in Table 3.3 indicates the Functional Years Saved as a percentage of total functioning and life lost per year.

Table 3.3 High Potential Benefit Mid-term Applications

Application System	Benefit Opportunity (Functional Years Saved)	Estimated Benefits (Functional Years Saved)
Pre-Crash Warning	34,172 (1.66 %)	523
Cooperative Forward Collision Warning	19,160 (0.93 %)	294
Left Turn Assistant	8,534 (0.42 %)	113
Lane Change Warning	7,354 (0.36 %)	113
Stop Sign Movement Assistance	7,217 (0.35 %)	95

Figure 3.5 provides ranking of long-term application scenarios based on benefit opportunity for fifth year after deployment. Figure 3.6 provides ranking of long-term application scenarios based on estimated benefits for fifth year after deployment. From Figure 3.5 and Figure 3.6, it appears that the benefit opportunity and estimated benefits of Cooperative Collision Warning and Intersection Collision Warning provide the best benefit opportunity as well as best estimated benefits.

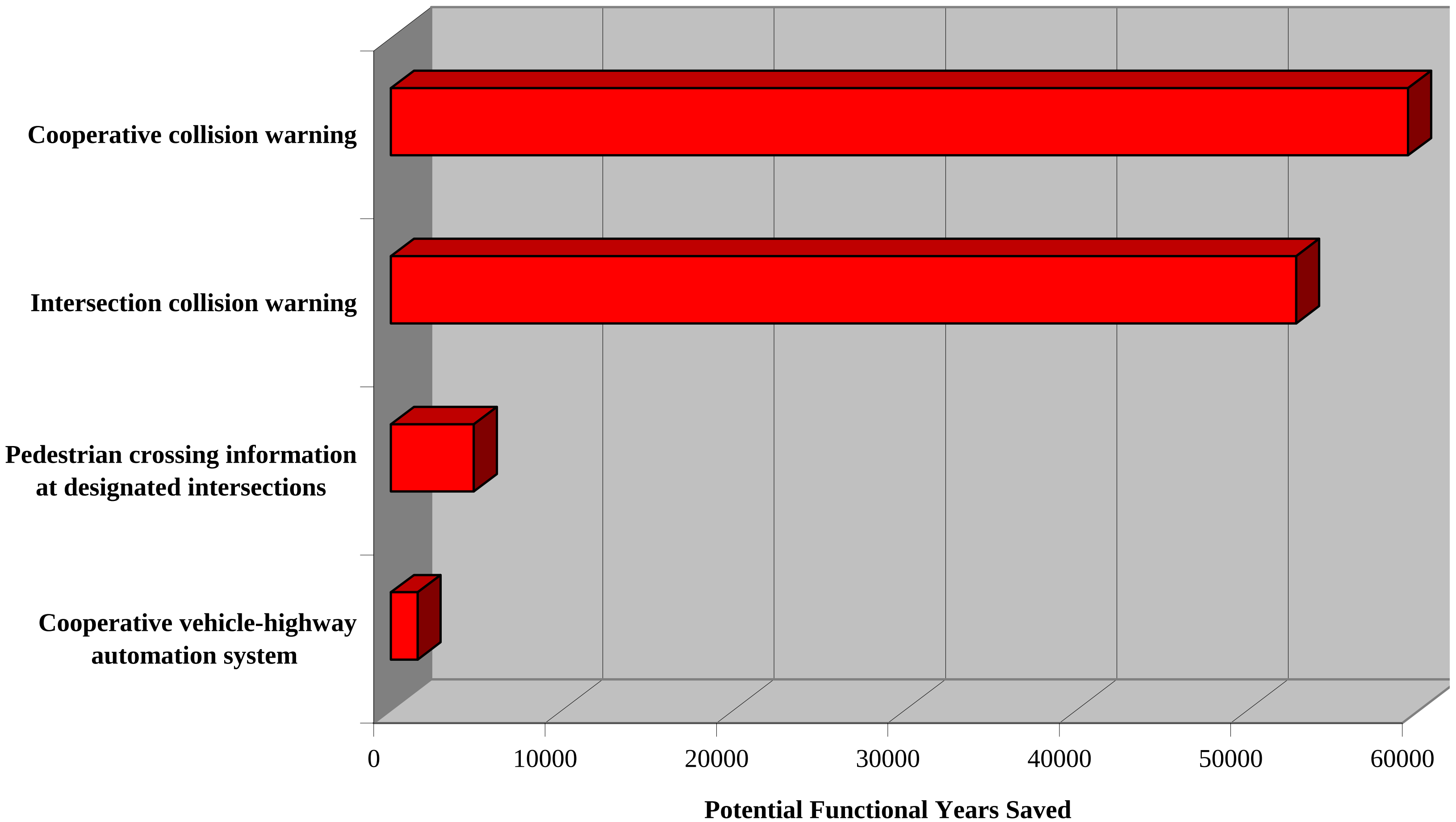


Figure 3.5 Long-term Ranking by Benefit Opportunity

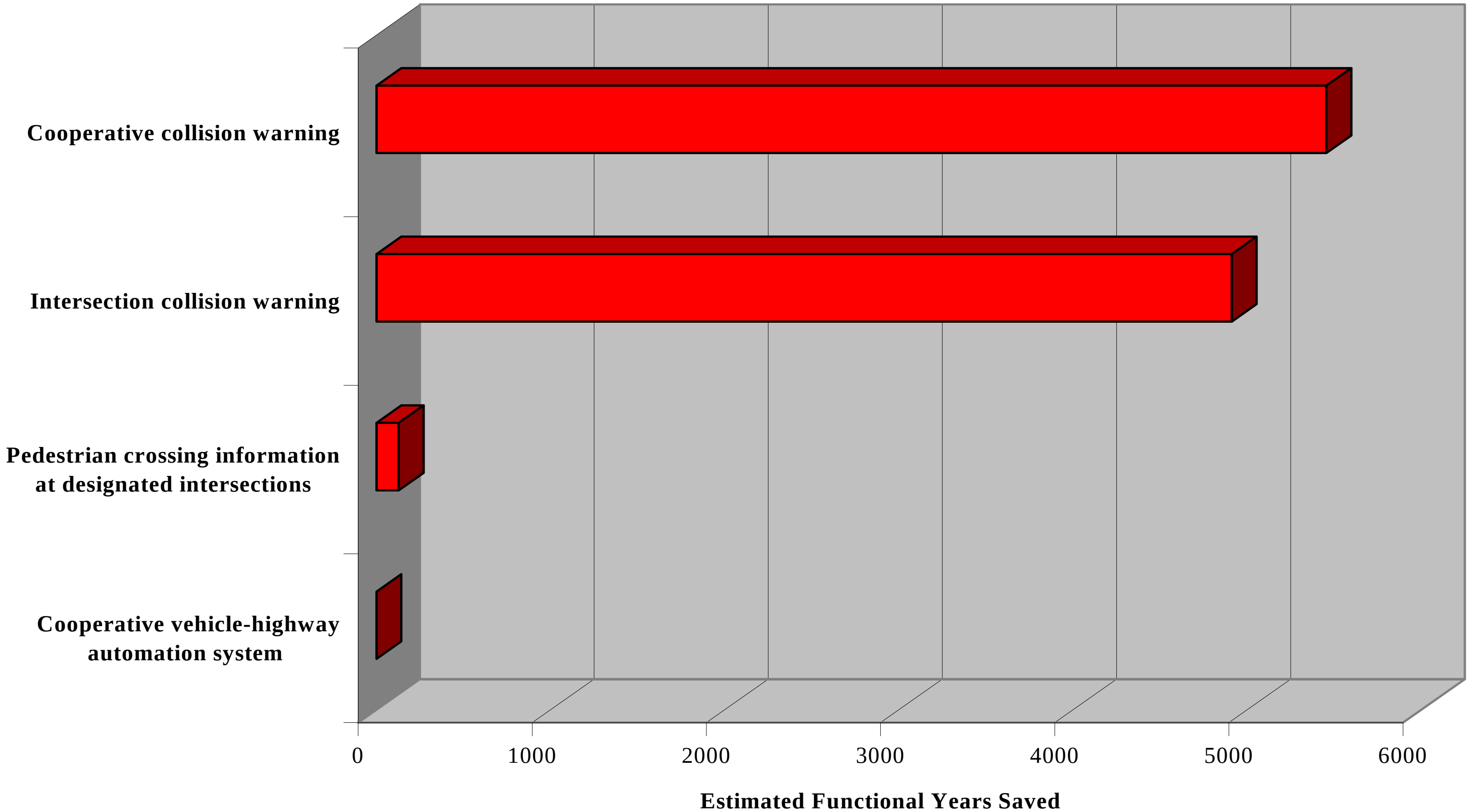


Figure 3.6 Long-term Ranking by Estimated Benefits

Table 3.4 provides the benefit opportunity and estimated benefits (i.e. Functional Years Saved based on the crash scenarios) that may be achievable with the Cooperative Collision Warning and Intersection Collision Warning application families in the fifth year after deployment. The percentage value shown in Table 3.4 indicates the Functional Years Saved as a percentage of total functioning and life lost per year.

Table 3.4 High Potential Benefit Long-term Applications

Application System	Benefit Opportunity (Functional Years Saved)	Estimated Benefits (Functional Years Saved)
Cooperative Collision Warning	59,336 (2.88 %)	5,453
Intersection Collision Warning	52,804 (2.57 %)	4,911

Cooperative collision warning is in fact an application family that includes several cooperative vehicle-to-vehicle communications based safety applications that are likely to be introduced in the near and mid-term timeframes. Intersection collision warning is in fact an application family that includes several intersection-located, infrastructure-to-vehicle communications based safety applications that seem likely to be introduced in the near and mid-term timeframes. The communication requirements for these application families are not significantly different from that of cooperative vehicle-to-vehicle communications based applications, and infrastructure-to-vehicle communications based applications that are likely to be introduced in the near-term and mid-term timeframe. Therefore, none of the long-term applications were selected for further consideration.

3.5 Summary

The primary goal in application analysis has been to develop a methodology for estimating the relative ranking of the application scenarios. Applications were primarily ranked based on potential benefits with respect to crash scenarios. A benefit distribution defined as Functional Years Saved was used to rank the applications. Estimates for market penetration were used to determine the estimated number of vehicles in the U.S market that would be equipped with the application system in each year after initial deployment. All the application scenarios require cooperation from the infrastructure, other vehicles, or both, in the form of relevant safety-related data exchange using infrastructure to/from vehicle communication, and/or vehicle-to-vehicle communication. Estimates were used for the probability that a vehicle equipped with an application will get cooperative communication from other vehicles and/or the infrastructure.

The results of the application analysis may only be used for relative comparison of benefits of the application scenarios. Determination of absolute values of benefits estimation for the application scenarios was beyond the scope of this project.

Table 3.5 provides a summary of high potential benefit application systems in the near-term and mid-term deployment timeframes.

Table 3.5 High Potential Benefit Application Systems

Near Term	Mid Term
Traffic Signal Violation Warning	Pre-Crash Warning
Curve Speed Warning	Cooperative Forward Collision Warning
Emergency Electronic Brake Lights	Left Turn Assistant
	Lane Change Warning
	Stop Sign Movement Assistance

The high potential benefit safety focused applications identified here are further developed in Chapter 4 in order to further develop the applications concept as well as more detailed communication requirements.

4 High-Priority Safety Applications: Further Development and Communication Requirements

By analyzing the communications requirements of the eight high-priority vehicle safety applications, commonalities in the latency requirements, for example, and particularly in the data payload, have been identified. The preliminary communications requirements described in Chapter 2 for each of the eight high-priority vehicle safety applications were confirmed through this further research, and are therefore not repeated in this chapter. In this chapter, the detailed communications requirements for the data payload for each application have been defined in terms of required data message sets. These data message set requirements represent applications data payload only, and do not include packet or table header information that may be specified by the DSRC standards.

The data payload commonalities evident in the data message set requirements suggest that it may be possible to establish a standard information content for each broadcast message. The broadcast messages emanating from vehicles for vehicle-to-vehicle type safety applications seem to require basically the same information. There appears to be a similar convergence toward standard information content for infrastructure-based safety application broadcasts. These findings support the intention of the DSRC Standards Writing Group to define standard broadcast tables, in terms of form and content. Further analysis in Task 4 of the VSC project is planned to better identify the information content required, and develop the specific requirements for these broadcast tables. It will be necessary to provide extensibility for these standard tables, since many more vehicle safety applications are likely to be identified and deployed in the future. As well, the requirements for data content to support security have not yet been determined. The security issues are further discussed in Section 4.9.

4.1 Traffic Signal Violation Warning

4.1.1 Introduction

Each vehicle safety application is likely to require significant safety engineering research to determine the best design for the particular application. In the case of vehicle safety applications, like traffic signal violation warning, that involve cooperation between vehicle systems and roadway infrastructure, processes will need to be initiated to design system components, message sets, and operational standards within both vehicles and roadside infrastructure to ensure interoperability. The 5.9 GHz DSRC standards development process represents a first step in this direction, by focusing on interoperability over the DSRC wireless communications link.

The specific application scenario of traffic signal violation warning falls within the overall area of intersection collision avoidance. Signal violations account for a significant portion of intersection collisions. Based upon the safety benefits analysis research, this application emerged as the highest priority vehicle safety application for the near-term.

Although more complex versions of traffic signal violation warning may be implemented further in the future, this vehicle safety application is viewed as potentially able to be implemented in the near-term (~2007-2011) in simple form, as illustrated in the example application scenario presented in this section.

4.1.2 System Architecture and Concept of Operation

This example application scenario for traffic signal violation warning uses infrastructure-to-vehicle communication to warn the driver to stop at the legally prescribed location if the traffic signal indicates a stop and it is predicted that the driver will be in violation. Please note that this application scenario DOES NOT address the human machine interface issues related to how to best present such a warning to the driver.

The in-vehicle system will use information communicated from the infrastructure located at traffic signals to determine if a warning should be given to the driver. The communicated information would include traffic signal status and timing, traffic signal stopping location or distance information, and directionality. The type of road surface and weather conditions near the traffic signal may also be communicated, as this could be used to better estimate the required braking distance.

In this application scenario, the traffic signal will broadcast a periodic wireless message that identifies the signal and its exact location. The message will indicate the current phase of the signal, as well as in which direction from the signal this phase is in effect. The message will also indicate the next phase for the signal, as well as the time until that phase change. The message may contain weather-related road surface condition information. As well, the message will contain indicators for message type, priority, and possibly other system-related information. It is most likely that the appropriate broadcast will be directed toward particular roadway approaches through directional transmission antennas.

The vehicle, in this application scenario, would receive the wireless message from the traffic signal and conduct computations to determine if a warning should be provided to the driver. The vehicle would use its knowledge of its own location, heading, speed and acceleration, in conjunction with the traffic signal location, phase and timing information, to estimate the likelihood of violating the traffic signal phase upon entering the intersection. The calculations could also use road condition information in the message from the traffic signal to adjust the decision algorithm. If the likelihood of violation was calculated to be above a certain threshold, then a warning would be given to the driver.

4.1.2.1 Illustration

Based upon the concept of operation that is described in the preceding section, this application scenario can be illustrated as shown in the following sequence of four figures (Figure 4.1 – Figure 4.4).

In Figure 4.1, a vehicle is shown approaching a traffic signal from the West. The traffic signal is broadcasting its identity, location, and appropriate phase and timing information in a directional manner along the four approach paths in the figure. In this scenario concept, directional antennas are used to direct the wireless broadcasts along the appropriate approach paths.

The vehicle, as shown in Figure 4.2, receives the appropriate traffic signal information broadcast for vehicles approaching from the West. The vehicle's computer system knows the vehicle's location, speed, heading and acceleration. This information, in conjunction with the information broadcast from the traffic signal, is used to determine that the vehicle will enter the intersection before the signal turns yellow. On the basis of this determination, no notice is provided to the driver of the vehicle.

In Figure 4.3, the traffic signal is broadcasting the information that it is currently yellow in the westerly direction, and will turn red in 2.5 seconds. This information from the traffic signal, along with the vehicle's location, speed, heading and acceleration, is used to determine that the light will be red before the vehicle enters the intersection. Under these conditions, the vehicle's computer decides that the driver should be warned to stop, as shown in Figure 4.4.

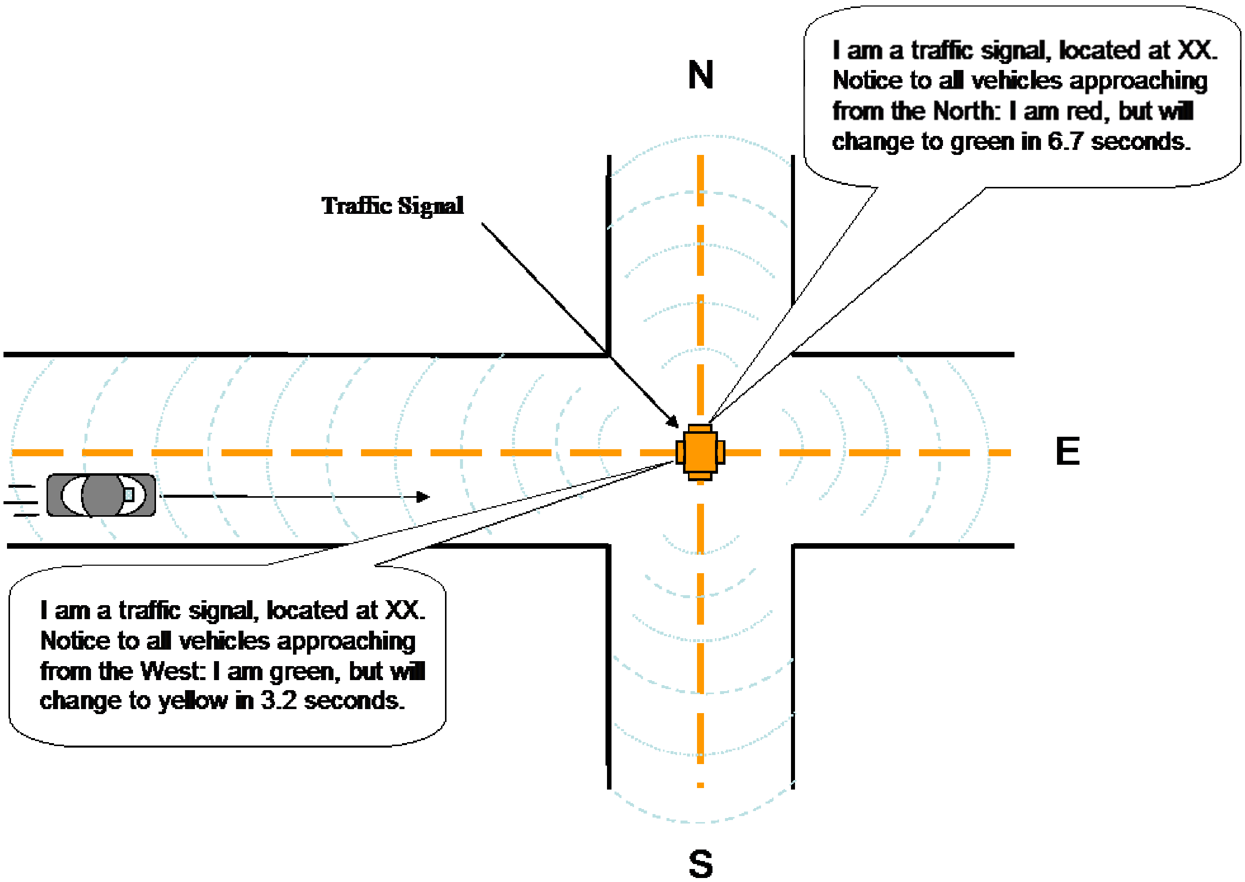


Figure 4.1 Traffic Signal Violation Warning: Directed Signal Phase Messages – Turning Yellow

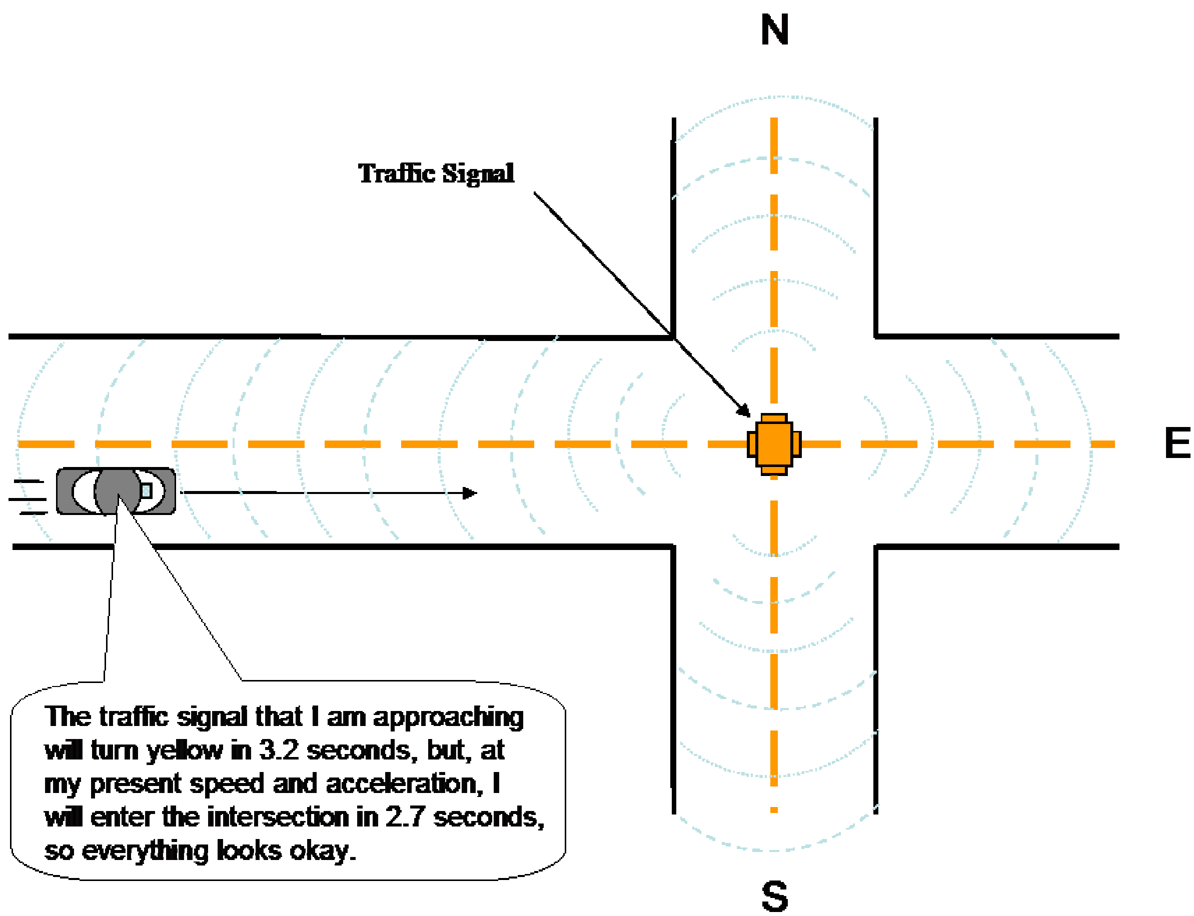


Figure 4.2 Traffic Signal Violation Warning: Vehicle Approaching - Okay to Proceed

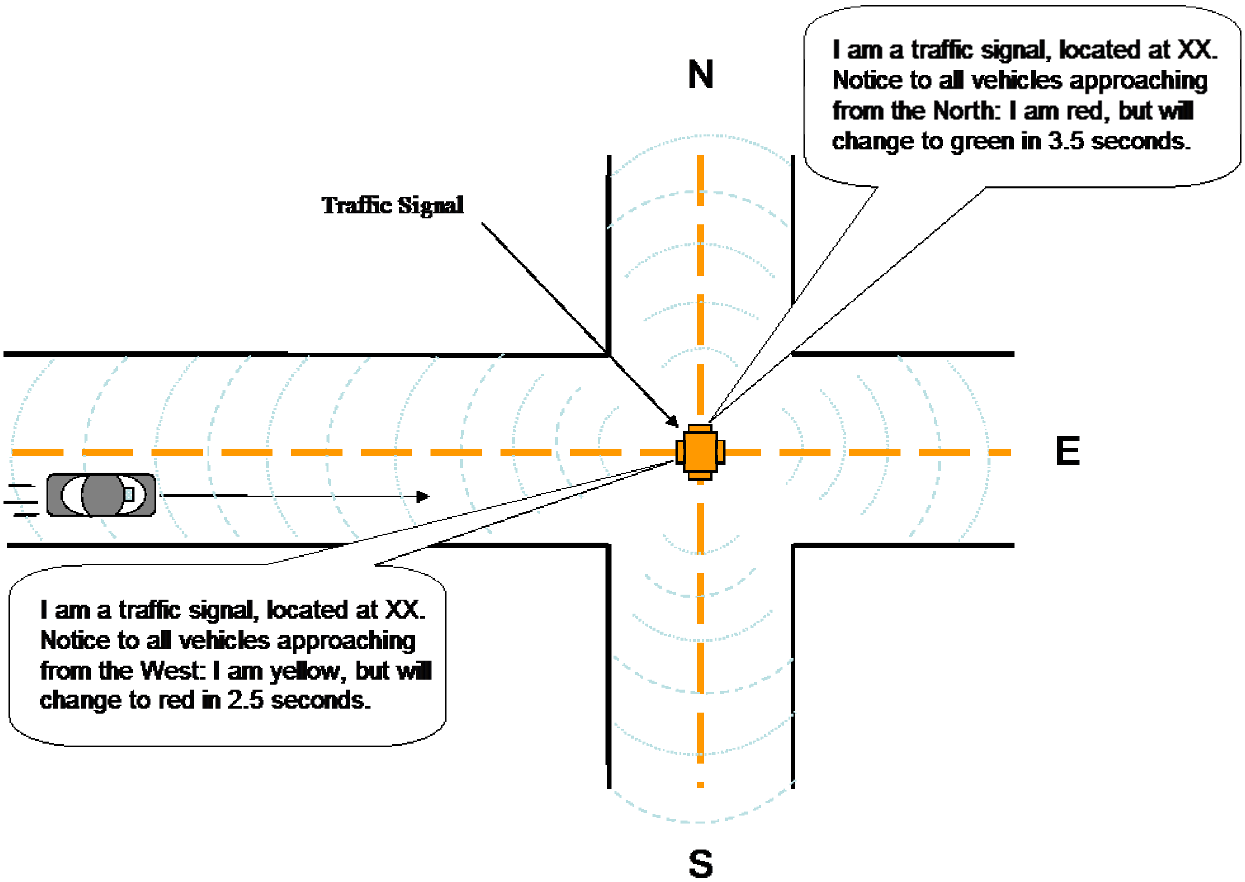


Figure 4.3 Traffic Signal Violation Warning: Directed Signal Phase Messages – Turning Red

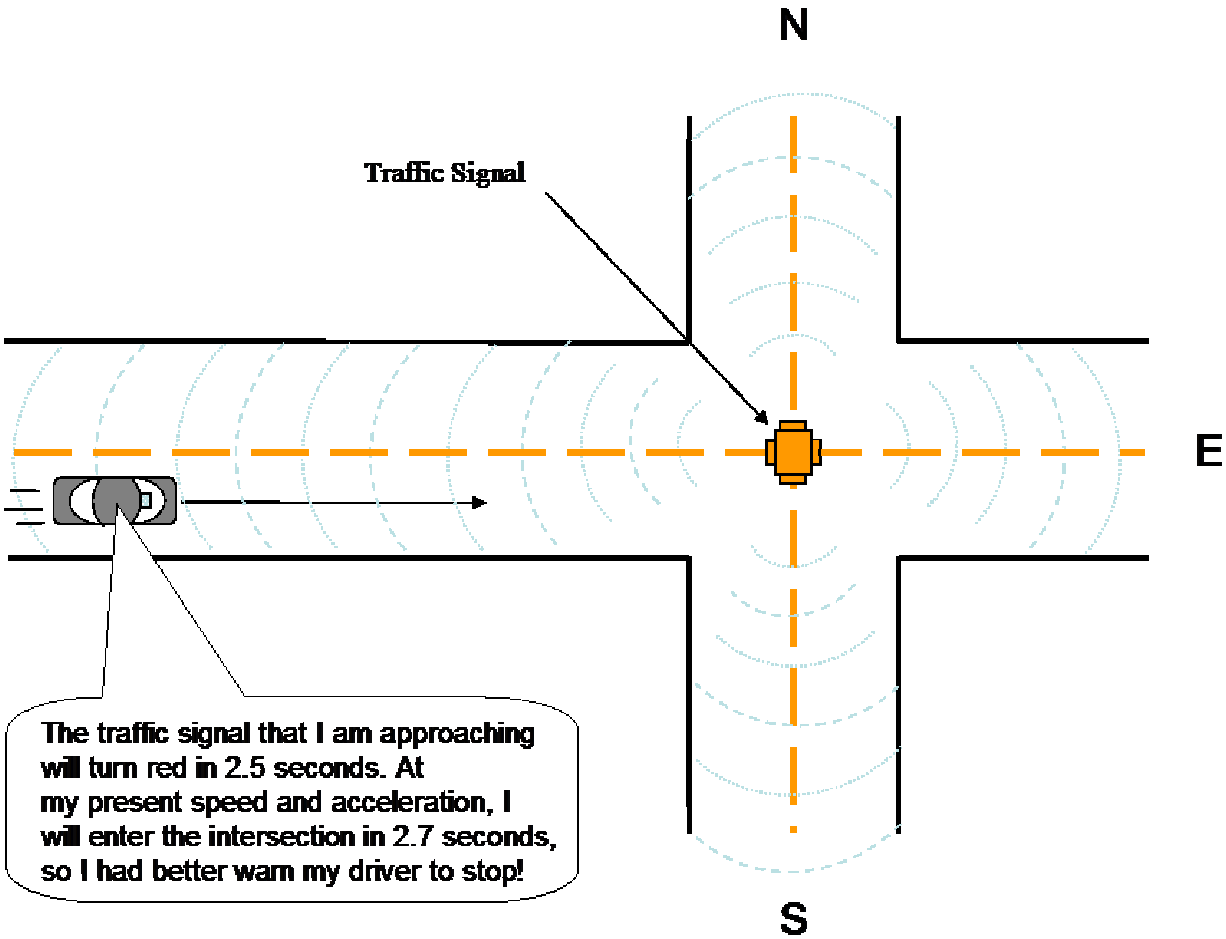


Figure 4.4 Traffic Signal Violation Warning: Vehicle Approaching – Warning Required

4.1.2.2 Block Diagram

The block diagram for the traffic signal violation warning application scenario represents a simplified view of the components necessary to operate the system as presented in this application scenario. Other enhancements may be expected to be accomplished in later implementations of this application through the addition of components to the systems. The particular scenario being illustrated has been chosen as representative of the initial systems that are likely to be deployed.

The block diagram for this application scenario includes two major divisions: the traffic signal system and the vehicle system. As shown in Figure 4.5, the traffic signal system consists of five major components. The first component takes an input signal from the traffic signaling logic and derives the instantaneous phase and timing information to be used in the traffic signal system. Another component is the database of traffic signal identification and location. This database would be populated during an initiation sequence. The processor represents another major component of the traffic signal system. The processor would be a small-scale computer that could integrate the signal phase and timing information with the identification and location, and then generate repetitive messages in the standard format. These messages would be sent to the DSRC protocol stack and radio unit component, and then over the air through the directional antenna component.

The vehicle system also includes five major components. The receive antenna may or may not be directional, while the DSRC protocol stack and radio unit are basically analogous to the same component in the traffic signal system. A GPS unit is an integral component of the vehicle system. Another major component in the vehicle system takes inputs from the vehicle sensor and network systems, and maintains an instantaneous view of the vehicle's location, speed, heading and acceleration. The processor component determines whether a signal violation warning should be issued to the driver by applying a mathematical calculation to the signal phase and timing information, in conjunction with the vehicle location, speed, heading and acceleration. The driver warning generator component provides the warning message if the processor component decides that a warning is needed. The warning is then output to the vehicle's appropriate human/machine interface.

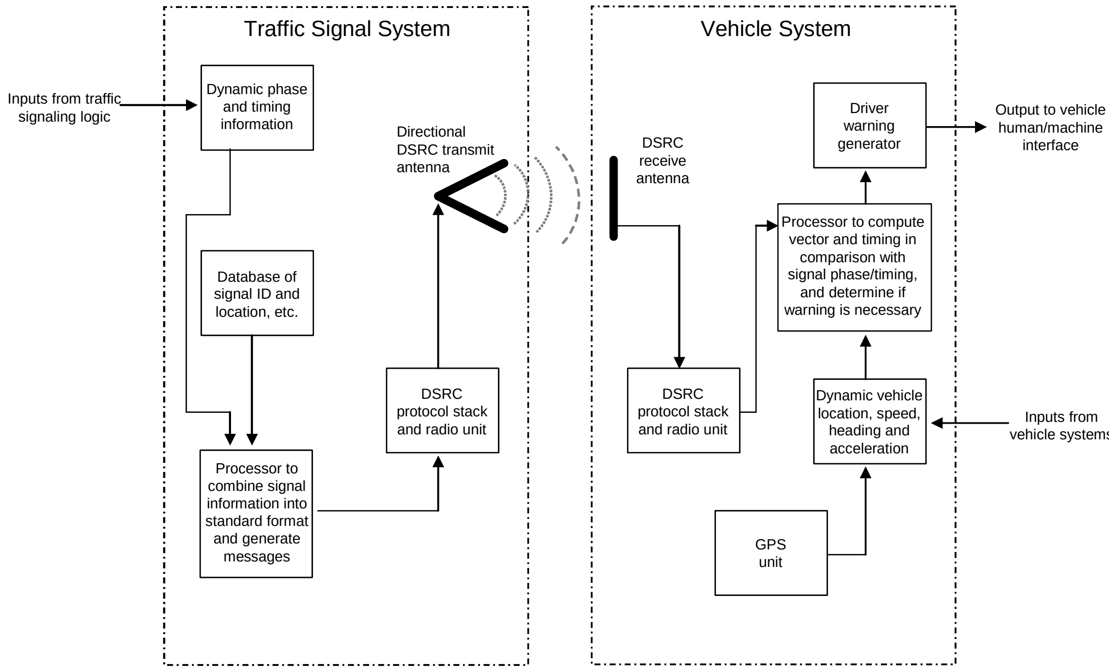


Figure 4.5 Traffic Signal Violation Warning Block Diagram

4.1.2.3 Sensors and Other System Needs

A GPS unit with accuracy of five meters represents one of the basic requirements of sensor information for the system to support this traffic signal violation warning application scenario. Accurate speed and acceleration sensor information is also required to support this application scenario. Although this application scenario could likely be enhanced through the use of an on-board map database, the simpler scenario being illustrated is more likely to be initially deployed. For alternative applications scenarios, sufficient intersection data has been specified in the communications requirements to allow potential application scenarios to be developed for vehicles without GPS capabilities.

On the output side of the system, an appropriate human/machine interface with the driver is required to delivery the warning messages effectively. This interface may be implemented differently in various vehicles according to the specific needs of the vehicle platform.

4.1.2.4 Data Message Set Requirements

It is apparent from the block diagram in Figure 4.5 that the traffic signal system has a transmit-only radio requirement. The vehicle system in this application scenario only has the requirement to receive the radio signal. This one-way communication is typical of the basic wireless communications requirements envisioned for the majority of the initial vehicle safety applications.

More specifically, the transmissions originating from the traffic signal would consist of one packet sent every 100 milliseconds. Each packet would contain at least the following information derived from the instantaneous status of the traffic signal in the appropriate approach direction.

Table 4.1 Traffic Signal Violation Warning Data Message Set Requirements

Description	Number of bits
Traffic signal status information	
Current phase	8
Date and time of current phase	56
Next phase	8
Time remaining until next phase	24
Road shape information	
Data per node	32
Data per link to node	72
Road condition/surface	8
Intersection information	
Data per link	120
Location (lat/long/elevation)	96
Stopping Location (offset)	32
Directionality	16
Traffic signal identification	48
Message type	8

4.2 Curve Speed Warning

4.2.1 Introduction

Excessive vehicle speed in curves often leads to lane departure, collision, loss of vehicle control, and/or road departure, any of which may result in some combination of vehicle or property damage or loss, injury, and death. Currently, reduced speed limits are regularly posted on the most troublesome curves, but their safe negotiation is often influenced by more factors than just road geometry.

The driver attempts to take all available factors into account, sometimes unsuccessfully, when deciding on an appropriate speed in a curve. If the vehicle were to assess vehicle dynamics, prior knowledge of curve geometry, road surface parameters, and estimated road surface conditions well in advance of a curve and notify the driver unobtrusively when speed should be reduced, the driver would be better equipped to negotiate the curve and less likely to cause an accident.

Curve speed warning would help drivers negotiate curves at safe speeds by warning them if they are approaching a curve beyond current safe limits of the road and vehicle. This application uses information communicated from roadside beacons in view of the approaching traffic to a curve. Information from the roadside beacon may include curve start and end locations, road geometry (describing road and lane widths, curvature, bank, and grade), wet/dry road surface static and sliding coefficients of friction, road shoulder/boundary conditions, maximum posted speed limit, and road surface condition. The in-vehicle system combines information from the roadside beacon with vehicle parameters and on-board sensor data to determine if the driver should be warned to reduce speed in order to safely negotiate the curve.

4.2.2 System Architecture and Concept of Operation

Curve speed warning can be accomplished in several ways. A warning could be derived using a digital map database, GPS position, vehicle speed, on-board sensor information, and vehicle handling characteristics, such as maximum allowable lateral acceleration and stability control parameters. This approach could be done without communications by inferring road surface condition from on-board temperature and rain sensors or windshield wiper setting, for example. Without actual road surface conditions, this warning may give the driver a false sense of confidence when entering a curve at an excessive speed. To counteract this possibility, the safety system designer may be compelled to increase warning tolerances and likewise the potential for false alarms.

The curve speed warning becomes much more reliable and accurate when up-to-date curve layout and actual road surface conditions are communicated from a roadside beacon to the approaching vehicle. The roadside beacon will provide road geometry parameters, which especially benefits vehicles that do not have onboard digital maps, current map updates, or GPS positioning. Changes to the curve’s geometry may be available via the beacon (possibly updated by a road maintenance crew or by digital map updates), which may be derived from probe vehicle reports. If properly equipped, an enhanced beacon may provide local sensor data to determine the actual road surface condition.

Communications from the roadside beacon to approaching vehicles should be periodic, one-way broadcasts. The broadcast message should repeat at regular intervals 24 hours a day, regardless of the presence of vehicles. Message content should change only with respect to road surface condition updates and curve geometry changes. Vehicles must be able to receive roadside messages, process the information, and provide timely warning to the driver if current speed exceeds the computed vehicle safe speed for the curve.

4.2.2.1 Illustration

Figure 4.6 illustrates a curve speed warning scenario on a mountain road. The vehicle enters the communication range of a roadside beacon. The beacon continuously transmits curve geometry for the upcoming series of turns. In addition to standard curve parameters, broadcast messages note the minimal shoulder due to a cliff at the hairpin and, if equipped with surface condition sensors, the presence and location of ice on the road. Given sensor and beacon constraints, additional beacons may provide supplemental coverage at various points along the road. The vehicle computes a safe curve speed based on broadcast message content, which contains the posted speed limit, current road geometry, shoulder characteristics, weather conditions, and, if equipped, road surface conditions, as well as the vehicle's inherent handling characteristics and any applicable vehicle sensor data. This information is compared to current vehicle speed and various driver input controls, potentially including brake and throttle positions, as well as steering wheel angle. If the current or projected vehicle speed exceeds the computed safe limit, the vehicle warns the driver to decrease speed to the safe level. This warning must be provided to the driver early enough to allow a controlled deceleration and safe negotiation of the curve.

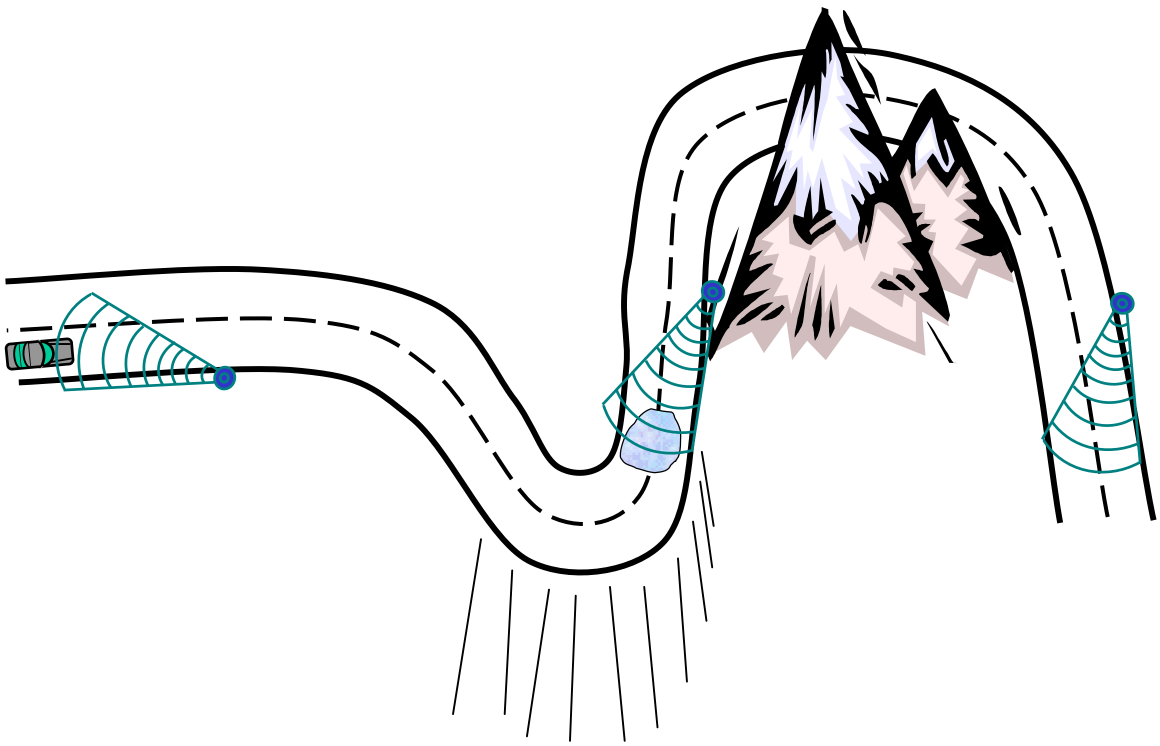


Figure 4.6 Curve Speed Warning Scenario

4.2.2.2 Block Diagram

Figure 4.7 depicts a top level block diagram for the curve speed warning logic flow. The vehicle continuously listens for messages. When it receives a message from a roadside beacon, it first determines whether the message is applicable to its current course. If so, the vehicle processes the curve data and compares this with its own vehicle data to compute a safe curve speed. The vehicle then warns the driver to slow down if the current or projected speed will exceed the computed safe curve speed.

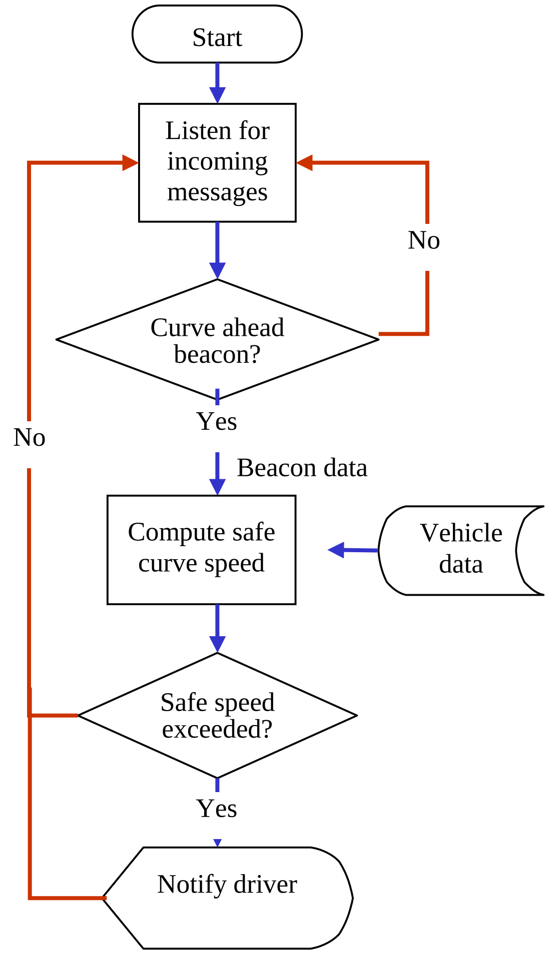


Figure 4.7 Curve Speed Warning Logic Flow

4.2.2.3 Sensors and Other System Needs

This application would work simply with roadside beacon messages, vehicle positioning and speed, and inherent vehicle characteristics like maximum lateral acceleration and stability control parameters. However, performance could benefit significantly from other data such as stored digital maps, DGPS, throttle and brake positions, steering wheel angle, outside temperature, rain sensor and/or wiper setting, turn signal setting, tire pressures, and individual wheel speeds.

Digital mapping combined with moderate resolution (~10m) positioning information would allow for vehicle speed assessment and curve speed warnings based on historical curve data prior to entering roadside beacon coverage zones. Once in the coverage zone and throughout the curve, the vehicle could continuously update the driver regarding safe curve speed based on current road data and position. Higher resolution (~1m) position knowledge could additionally offer lane level curve speed analysis and warning updates based on lane changes within a curve or position within a lane. Generally, the smaller turn radius of an inside lane causes higher lateral accelerations which may necessitate an incrementally slower speed for safe travel through a curve.

While initial systems could provide exceptional performance, further enhancements may be achieved by using additional sensor data that may be available from the vehicle. Throttle and brake positions can provide an indication of the driver's intention to accelerate or decelerate and at what rate. This information could forestall or hasten a warning to the driver. Steering wheel angle can provide information on the driver's intention to follow the curve or possibly change lanes. Turn signal settings can also help in lane change determination. External temperature readings are most important when near the freezing point of water. This could help anticipate the significant change in friction coefficients between a wet road and an icy road, especially when coupled with a rain sensor or windshield wiper setting. Tire pressure knowledge can refine tire contact patch approximations, improving estimates for maximum lateral acceleration, also when pressures are coupled with other sensor readings such as rain. Individual wheel speeds can also help determine when traction is marginal or lost on one or more tires. This last indicator may be of minimal use to the driver since the warning may come too late for any corrective actions. However, if the roadside beacon were to collect probe data, existence of traction loss could be sent to following vehicles. This function also reduces the dependence on roadside sensors.

4.2.2.4 Data Message Set Requirements

Curve speed warning communications in this scenario originate in the roadside beacon and are processed in the receiving vehicle. Note that the vehicle provides the actual warning to the driver. The roadside beacon merely sends pertinent data on the curve and current conditions. Beacon data is transmitted nominally once per second. This was arbitrarily selected as a reasonable assumption in order to assist with capacity calculations. A maximum communication range of 200m for the roadside beacon was also arbitrarily set, but could vary based on local constraints. Nominal roadside beacon message length can be approximated from the data set bit stream estimates shown in Table 4.2.

Table 4.2 Curve Speed Warning Data Message Set Requirements

Description	Number of bits
Message type	8
Roadside beacon ID	48
Maximum posted speed	7
Curve header (# of curve points)	8
Curve point counter	8
Each curve point (lat, long, el, curvature)	112
Each curve point bank angle (±30°)	6
Each curve point road width	8
Each curve point lane width	6
Each curve point shoulder width	5
Each curve point road boundary condition	3
*Each curve point road surface condition	8
*Weather conditions	8

* *Denotes roadside beacon enhanced with sensor(s)*

Note that total message length will vary depending on the number of curve points used to describe the total curve. The message structure above indicates that the number of bytes in a basic roadside beacon message equals (79 + 140X)/8, where X is the number of curve points in the total curve. If the beacon were enhanced with weather and surface condition sensors, the message structure would be (87 + 148X)/8. For example, if the curve was relatively short and simple it might only require 4 curve points. The total basic message length would then be approximately 80 bytes. If the curve included roadside sensor data and were long and complex, it might require 20 curve points. This curve would then require a message length of approximately 381 bytes.

4.3 Emergency Electronic Brake Light

4.3.1 Introduction

This is one of the vehicle-to-vehicle communication applications. This application "enhances" the driver visibility by giving an early notification of a vehicle braking hard even when the driver's visibility is limited (e.g. heavy fog, rain, snow, other large vehicle in between).

The current brakelamp goes on when the driver applies the brake. The Emergency Electronic Brake Light application might not only enhance the range of a "hard" braking message but also might provide important information such as acceleration/deceleration rate. At present, brake lamps do not differentiate level of deceleration and are only useful as far rearward as direct line of sight allows.

4.3.2 System Architecture and Concept of Operation

For this application scenario, it is assumed that the vehicle in an emergency braking situation would be equipped with a DSRC unit. It is also assumed that the message from the vehicle would be sent to the following vehicles, including the ones that are behind a much larger vehicle (e.g. a big truck).

The message sender needs to have an algorithm to decide if an "emergency braking" message delivery is necessary (For example: deceleration greater than 0.6g). If a vehicle determines that it is braking hard then it could use the On-Board Unit of DSRC to share that information with others.

In order to determine if an "emergency braking" message is relevant to the listening vehicle, the listening vehicle needs to know the relative location from which the message originated (e.g front, rear, left, right). This can be done based on its GPS information and the GPS information of the braking vehicle. In this simple near-term application scenario, an "emergency braking" message from a vehicle in lane 3 may not necessarily apply to a vehicle traveling in lane 1.

4.3.2.1 Illustration

As a near-term application, the following illustration shows a relatively simple approach.

a) Vehicles are traveling on a 3-lane highway.

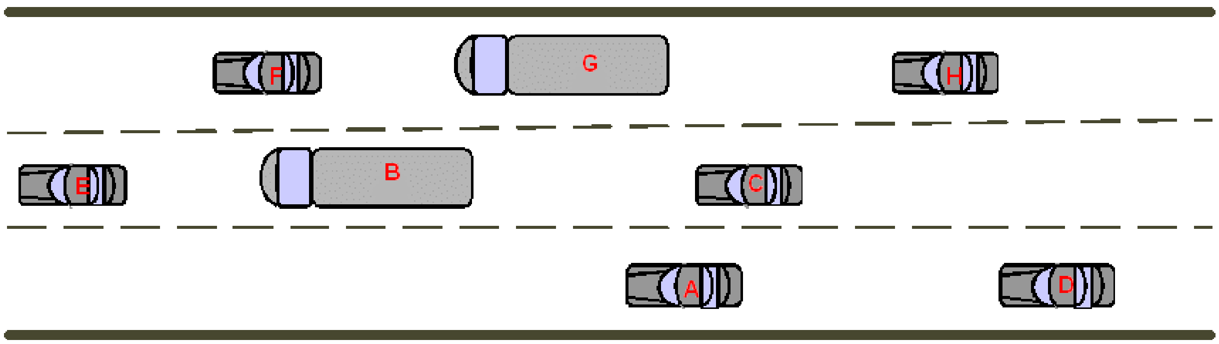


Figure 4.8 Emergency Electronic Brake Light Illustration A

b) Vehicle E brakes hard and broadcasts the message.

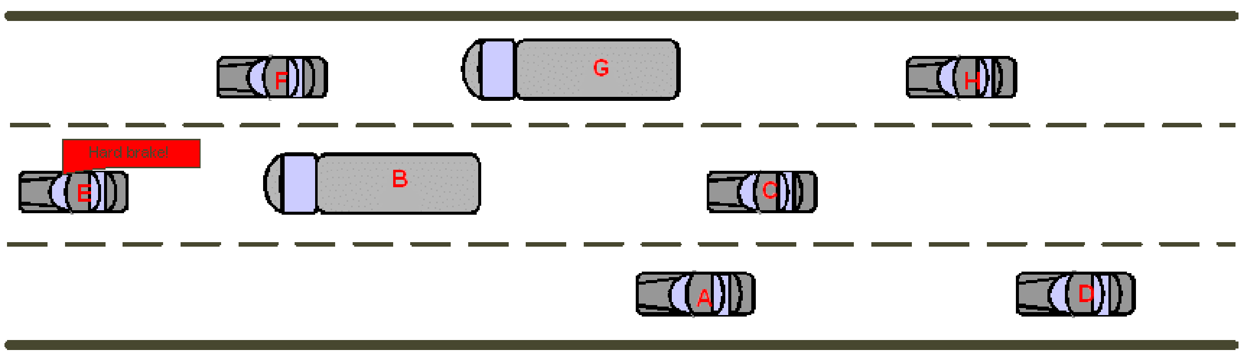


Figure 4.9 Emergency Electronic Brake Light Illustration B

c) Vehicles with DSRC radio unit will listen to the message sent by vehicle E and check to evaluate if the message is relevant (e.g. For vehicle C, a "hard brake" message from D might not be relevant). If the "hard brake" message is relevant to the application host vehicle, the driver is warned (e.g. Driver of vehicle B and C).

4.3.2.2 Block Diagram

a) Hardware architecture and information flow for application host vehicle.

"Emergency brake message" is received by DSRC radio unit. GPS unit provides host vehicle position. Host vehicle speed, acceleration, etc. could be obtained from the vehicle data bus. When the processor determines that a message is relevant, a "driver warning generator" is activated.

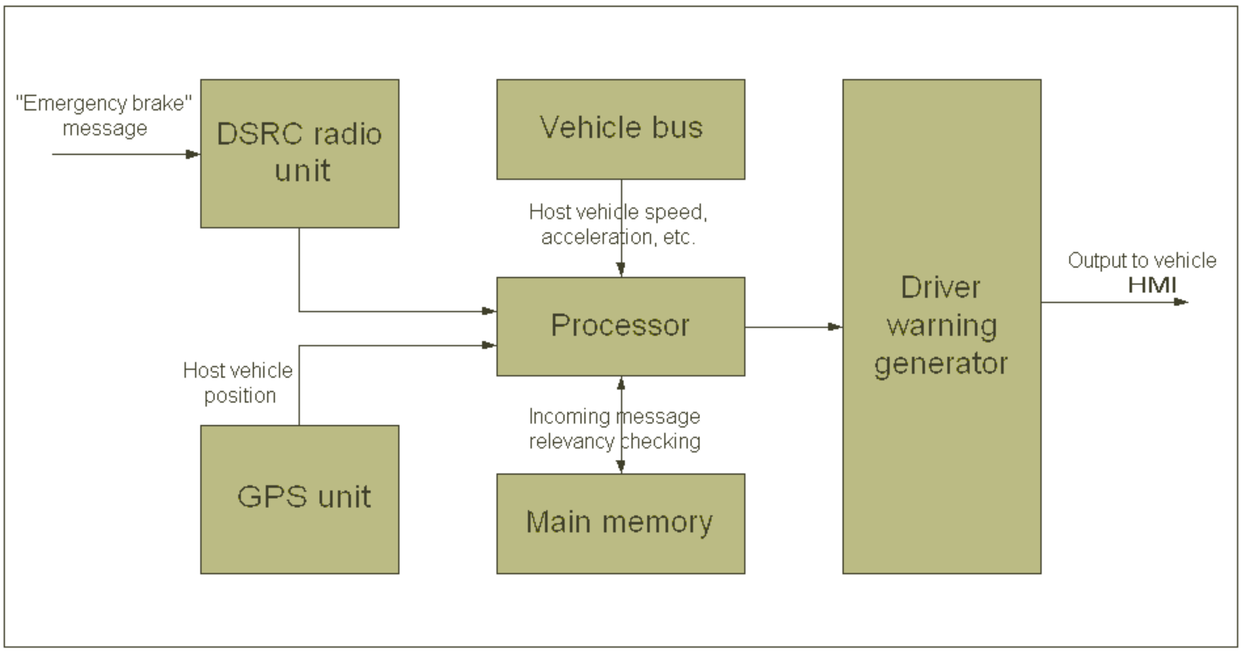


Figure 4.10 Emergency Electronic Brake Light Block Diagram I

b) Hardware architecture and information flow for vehicle-to-vehicle message sender

The processor generates a vehicle-to-vehicle type message based on the information from GPS and the vehicle data bus. An “emergency brake” message is generated when the vehicle data exceeds a threshold. On-board DSRC unit broadcasts the message.

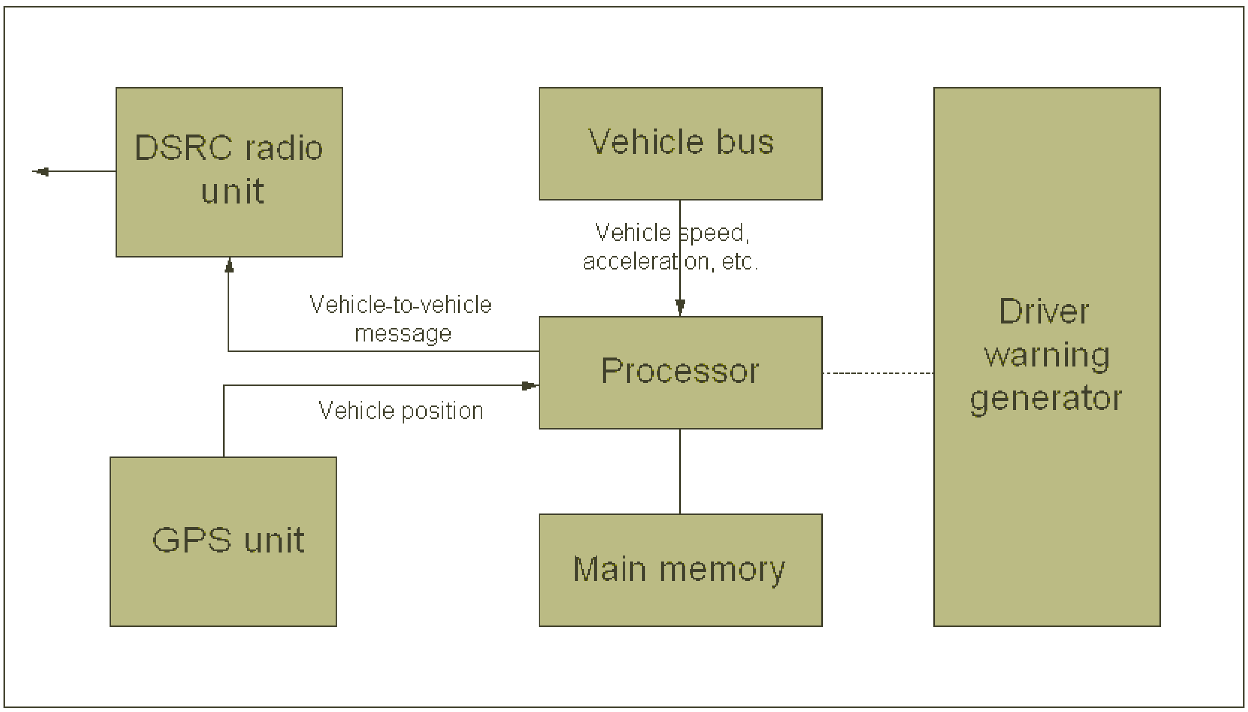


Figure 4.11 Emergency Electronic Brake Light Block Diagram II

c) Emergency Electronic Brake Light application flow chart (receiver side)

When the vehicle starts, it listens to incoming messages (as shown in Figure 4.12). As an early implementation, the vehicle simply looks for an “emergency brake message”. If the message is an “emergency brake message”, the vehicle checks if the message is relevant to itself. This filtering mechanism is necessary to avoid unnecessary warning to drivers traveling to opposite direction or different lanes from the vehicle braking “hard”. Based on this filtering mechanism, an application designer could implement the details of a warning algorithm based on different criteria. (For example: cautionary warning if any “hard brake message” is detected; imminent warning if the “hard brake message” is from a vehicle in front is the same lane; etc.)

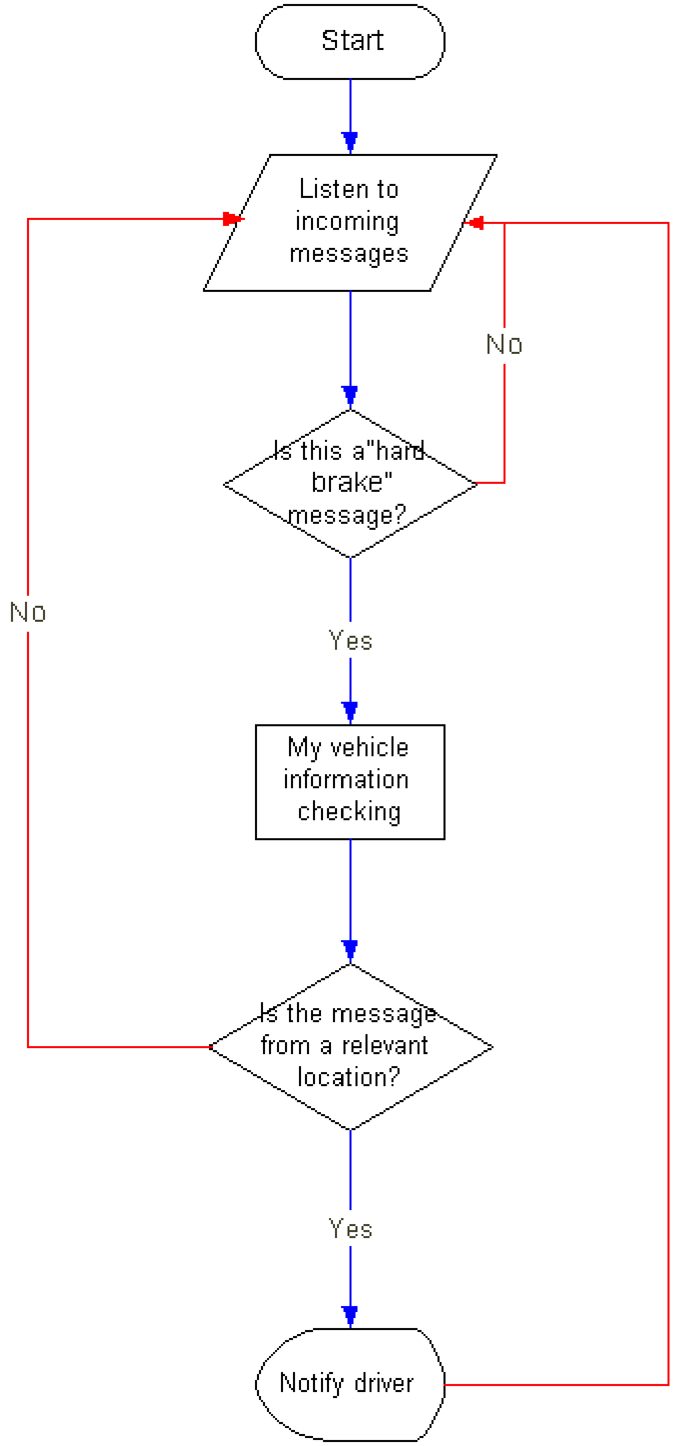


Figure 4.12 Emergency Electronic Brake Light Flow Chart

4.3.2.3 Sensors and Other System Needs

Besides the DSRC radio unit, a GPS unit and a connection to the vehicle data bus is necessary to send out the right information to other vehicles.

A map database would help to provide information such as which lane the vehicle is traveling. In addition, the road curvature can be taken into account when an application host vehicle evaluates "emergency braking message" to see if a warning to the driver is necessary.

4.3.2.4 Data Message Set Requirements

Required vehicle-to-vehicle message data set is shown in Table 4.3.

Table 4.3 Emergency Electronic Brake Light Data Message Set Requirements

Description	Size (bits)
GPS coordinates	96
Time stamp	64
Vehicle speed	16
Vehicle Acceleration/deceleration	16
Vehicle heading	16
Vehicle size (length, width, height)	48
GPS antenna offset (relative XYZ)	32

4.4 Pre-Crash Sensing for Cooperative Collision Mitigation

4.4.1 Introduction

The main objective of a pre-crash sensing system is to collect relevant information regarding an impending collision and communicate this information to the vehicle's occupant protection system. The information set may include parameters such as crash type (side/frontal/rear), impact time, impact speed, struck and striking vehicle size and mass, etc. Examples of collision counter measures enabled by pre-crash sensing include enhanced air bags, seat-belt pre-tensioning, occupant repositioning, bumper extension for increased frontal crush zone, truck/car crash compatibility counter measures and emergency brake assist among others. In contrast to collision warning technology, whose primary goal is to help the driver avoid the crash, collision mitigation based on pre-crash sensing is aimed at reducing injuries once the crash is deemed unavoidable. Figure 4.13 depicts a general chronological sequence of events and possible timing of crash counter measures. Pre-crash sensing can be viewed as a contingency counter measure for any safety warning application that may have failed to achieve its intended objective. The potential benefit impact of this application spans a number of vehicle-to-vehicle crash types.

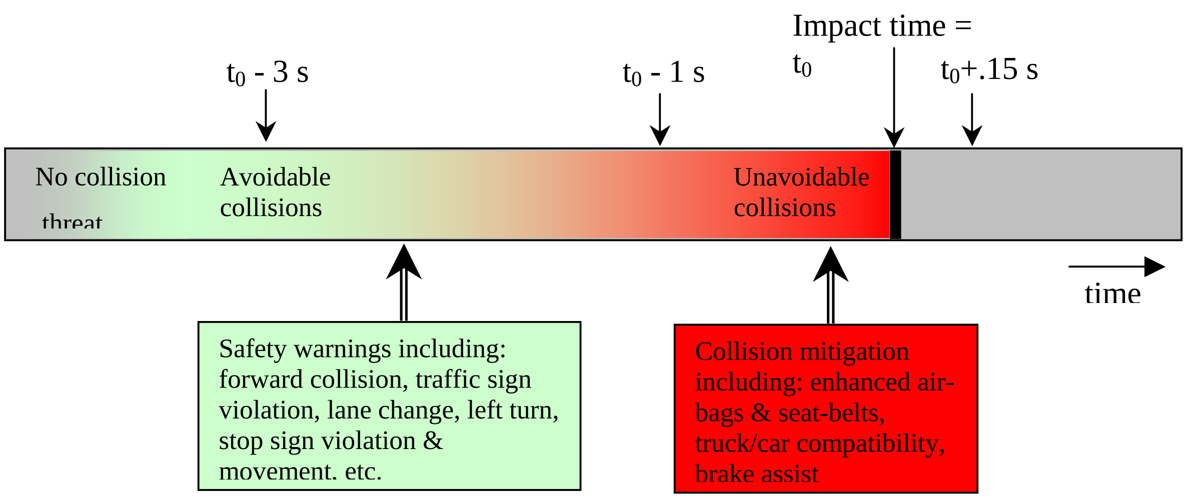


Figure 4.13 Active Safety Counter Measures Chronology before a Crash

While many important issues concerning reliability, security, etc., it may be feasible to use the communication link between two vehicles, in an unavoidable crash situation to transfer the necessary information such as target classification (truck, car, pole, etc.) and mass information to reliably assess the geometry and the crash type and subsequently deploy appropriate and even coordinated counter measures to mitigate the effects of the collision. However given the short timeframe available to deploy such counter measures, one the main technical challenges for the 5.9 GHz DSRC technology is whether it can fully support the high update rate thought to be necessary for these type of applications (between 50 and 100 Hz). An assessment regarding this issue will be made before the end of the VSC project based on real data collected in Tasks 4 and 6.

To help understand what type of pre-crash sensing scenarios and communication requirements are relevant for testing, a basic concept of the application needs to be defined. This is attempted in the following section, where, a generic implementation of pre-crash sensing for cooperative collision mitigation is presented. To make the task manageable and still have relevance for the mid-term deployment time frame, the initial concept and communication links requirements are based on the premise of enhancing radar-based pre-crash sensing.

4.4.2 System Architecture and Concept of Operation

The basic concept of a Pre-Crash Sensing System (PCSS) is to gather key information, just before impact, regarding the severity, location and type of the crash. This information can then be used by various vehicle subsystems in a coordinated effort to mitigate occupant injuries during the crash. In general, counter measures that can be activated just before a crash (say 200 ms to 800 ms) can be classified into two categories:

Reversible Counter Measures:

Features that are activated just before a potential crash but usually with the capability of being reset in case of a false alarm. They are usually referred to as *reversible* pre-crash counter-measures. The PCSS function is of a secondary nature and provides confirmation to some higher-level safety counter-measure. Such systems include:

- Air-bag pre-arming which attempts to set optimal firing thresholds based on delta velocity (provided by the PCSS) in order to provide maximum occupant protection. In this case the final firing decision still relies on the existing air-bag crash accelerometers data. Such a feature is particularly desirable in the case of side impact collision where the time budget to fire the airbag is very small when compared to a frontal crash situation.
- Seat-belt pre-tensioning which attempts to achieve optimal positioning of the occupant before the air-bag deployment.
- Bumper extension or lowering which attempts to increase crush zones to dissipate more crash energy or achieve better truck-car geometric crash compatibility.
- Sensor-based emergency brake-assist which attempts to enhance of the current panic brake system. It relies on sensor input to confirm, in addition to driver emergency braking, that a threat is in the vehicle path and therefore maximum braking is warranted and provided if the driver is not achieving it. This is considered a very effective way to mitigate the effects of a crash since the energy involved, is a quadratic function of speed.

Non-Reversible Counter Measures:

Features that are activated just before a potential crash but usually with the drawback of not being re-settable. They are usually referred to as *non-reversible* pre-crash counter-measures and are not expected to be ready until the long-term deployment time frame. For these counter measures, the PCSS function is that of primary confirmation and firing decision for the safety counter-measure. These features have the potential to provide the highest benefit in terms of injury mitigation. Example of such systems include

- Pedestrian protection: Entails the deployment of, for instance, an external air bag, to soften the impact. The PCSS system in this case has to reliably detect, locate and properly classify a person about to be struck.
- Pre-Impact braking which is yet another extension of the panic brake assist feature mentioned earlier, with the main difference being that the PCSS system could activate the brakes automatically if the necessary level of confidence in doing so is warranted.
- Truck-to-car Compatibility counter measures: Enhancements of the bumper capabilities mentioned earlier. In this case however, some other structure (yet to be fully defined) could be deployed before impact to protect the occupants of a car being struck from the side by a truck.

In the following, the focus is on the pre-crash sensing portion of a cooperative collision mitigation system and describing the most likely implementation concept, based on either existing or anticipated technologies. This will, in turn, help to gain a better understanding of the communication requirements for pre-crash sensing.

4.4.2.1 Illustration

Figure 4.14 illustrates a generic pre-crash sensing application scenario. The crash scenario considered is of an intersection type and the envisaged counter measure is a side impact air bag deployment improvement strategy. In this situation vehicle A is about to be struck on its side by vehicle B. The pre-crash sensing system on vehicle A consists of a side radar sensor that detects targets in its field of view and measures range, range rate and azimuth angle to these targets. It also predicts whether a target is a potential threat based on a time to collision calculation. Given the fast dynamics of an air bag (within 100 ms), accuracies and update rates imposed on the radar measurements are more stringent that those commonly found on radars for adaptive cruise control. The radar update frequency in this case is in the order of 100 Hz (10 ms updates) and the measurement accuracies are in the order of a few cm and cm/s for the range and the range rate data. In addition to the radar measurements, vehicles A and B are expected to transmit standardized vehicle safety messages, in broadcast mode, that include vehicle ID and a set of dynamic parameters, such as speed, location, heading, yaw rate and accelerations at an update rate of 10Hz. A DGPS unit is required for this application to provide the necessary accuracies in positioning (in the order of centimeters). Once the radar sensor identifies vehicle B as a potential threat, a message can be triggered with enough time to establish a two-way communication with vehicle B. This new communication link is expected to operate at a higher update (50Hz minimum) rate and carry the same information contained in the standard message. Schemes for minimizing the size of this message can be developed at the system design level, where for example all the static information (vehicle class, size, mass, antenna location, etc.) may only need to be sent once. The dynamic information portion of the message containing speed, location, acceleration, yaw rate and similar information would be updated at the higher rate. This is necessary to perform the required data association and threat confirmation with the radar measurements. By comparing the radar-based position, velocity and heading of vehicle B with the on-board and vehicle B DGPS information, a full confirmation of the crash and its parameters is possible. Subsequently improved deployment strategies for deploying the side air bag can be designed. For example earlier and faster deployment for severe crashes may be selected to minimize occupant injuries in vehicle A. Similar collision mitigation counter measures can be envisaged for vehicle B. In the long term, the counter measures deployed in vehicle A and B may even be expected to be coordinated to achieve maximum benefits.

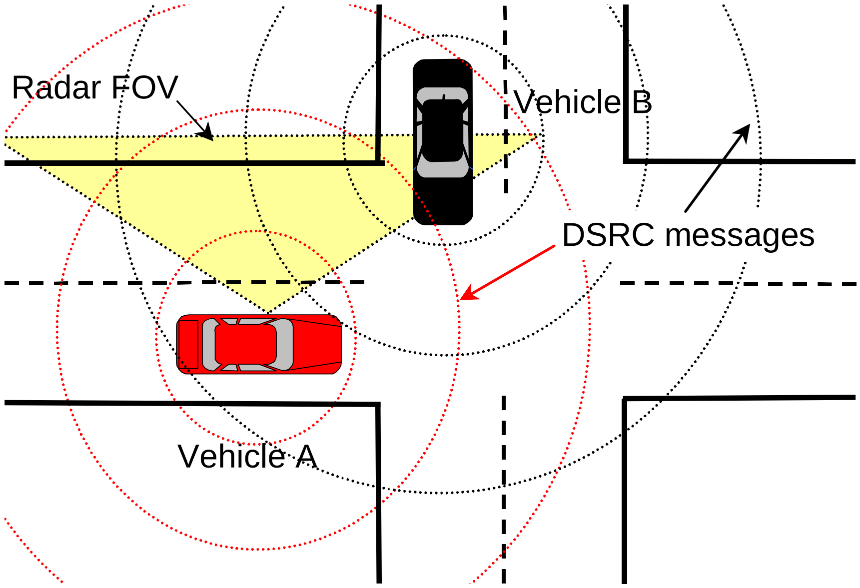


Figure 4.14 Pre-Crash Sensing for Cooperative Collision Mitigation: Side Impact Scenario

4.4.2.2 Block Diagram

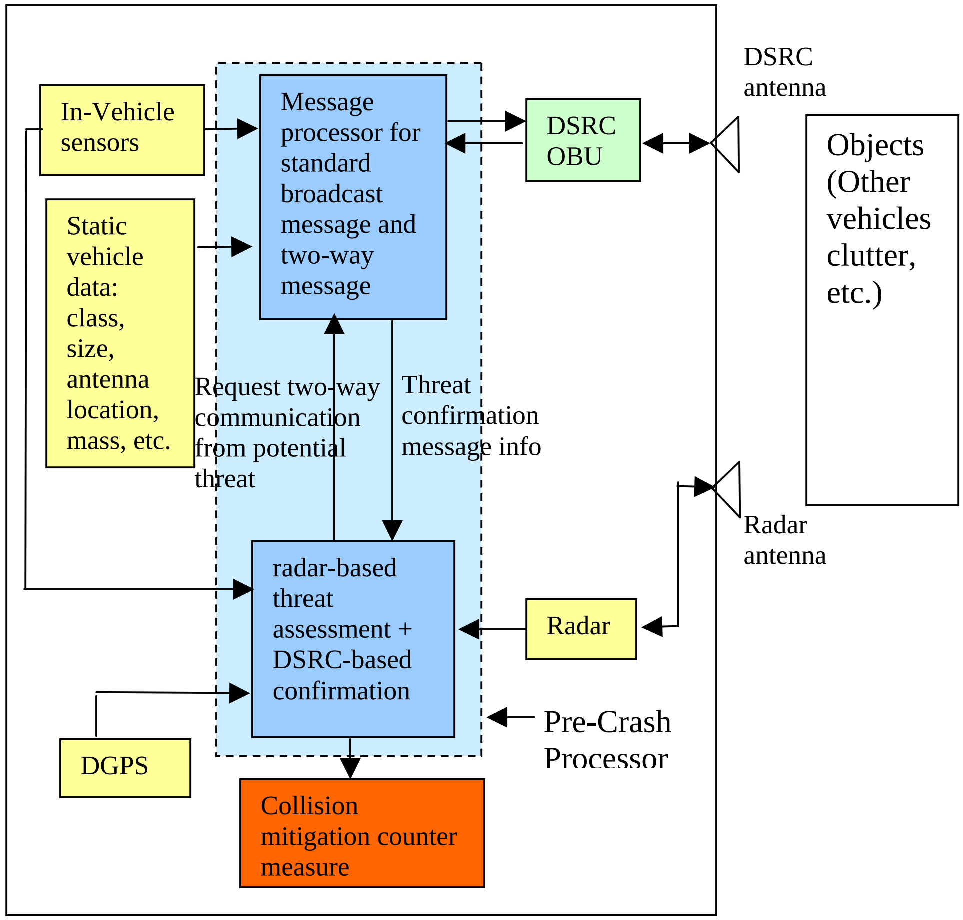


Figure 4.15 Example of Block Diagram for Cooperative Collision Mitigation System Based on Pre-Crash Sensing

Figure 4.15 depicts a generic diagram of a cooperative collision mitigation system based on pre-crash sensing. The various blocks are briefly described in the following:

- In-vehicle sensors. This is the subsystem consisting of all the sensors on the vehicle and whose information is available on the vehicle data bus. The sensors expected to be part of this subsystem are:
  - Speed, yaw rate, longitudinal acceleration, lateral acceleration, steering wheel angle, air bag crash sensors and brakes and throttle status data.

- Static vehicle data: This is the non-changing vehicle data such as:
  - Vehicle ID, class, size (length, height, width) and mass, and DSRC antenna location.
- DGPS: Differential GPS unit to provide:
  - Vehicle position (longitude, latitude, vertical) and heading and GPS time stamp.
- DSRC OBU. This is the 5.9 GHz DRSC unit to transmit both the standard vehicle message at 10 Hz in broadcast mode and the higher update rate (50 Hz) two-way communication message. The latter is only expected to be triggered based on radar data prediction of a potential threat and is not expected to last more that a second or two. It is however a high priority message since it may contain crucial confirmation regarding a crash that is about to occur.
- Radar. This is the primary source of data regarding potential threats. It detects targets in its field of view and measures at 100Hz the following parameters for each detected target: range, range rate and azimuth angle.
- Pre-Crash Processor. Divided into two blocks in the diagram:
  - A DSRC message processing unit
  - A radar processing unit to conduct the threat evaluation and confirmation based on the radar data, the host vehicle data and the DSRC message data.
- Collision counter measures. This represents the counter measure subsystem where the actuation takes effect. In the scenario being considered it consists of the side air bag subsystem.
- Objects (other vehicles, clutter, etc.). This represents the environment in which the radar attempts to detect and classify collision threats, including other vehicles and non-threatening radar reflecting objects on the road.

4.4.2.3 Sensors and Other System Needs

From the previous section it appears that a suite of sensors are needed in order for the pre-crash application to be feasible. Some of these sensors are currently available on most vehicles, but a majority of these sensors are not yet widely used. This is one of the main reasons for having ranked pre-crash sensing for cooperative collision mitigation systems in the mid-term deployment time frame as defined in Chapter 3. The requirements for acceleration information, yaw rate, steering and especially DGPS (with centimeter level accuracies) make the prospect for short-term deployment very unlikely. The required short-range radar sensor technology for some limited pre-crash sensing is currently available and will make its introduction in the automotive market in the next two years. The specifications for future radar cooperative pre-crash systems are essentially met with current technology. Typically the maximum detection range is about 25 meters, ranging capability is within a few centimeters of accuracy, and doppler measurement and fast update rates (around 100 HZ) are achievable.

Other system needs may include integration of pre-crash sensing with other safety warning applications since they logically complement each other. Also, this type of approach is probably the most economically viable approach to a safety-integrated system on a vehicle.

4.4.2.4 Data Message Set Requirements

DSRC-equipped vehicles are expected to have the ability to transmit and receive standard vehicle messages at 10 Hz. Each message would contain a packet of data with the following parameters:

Table 4.4 Data Message Set Requirements for Cooperative Pre-Crash Sensing

Description		**Number of bits**
Static Vehicle Data	Message Type	8
	Vehicle ID / Communication Address	48
	Vehicle Type / Class	4
	Vehicle Size and Mass (length, width, height, mass)	64
	Position Antenna Offset (relative X, Y, Z)	48
Dynamic Vehicle Data	Time Stamp – GPS Milliseconds in week	32
	Time Stamp – GPS week number	16
	Vehicle Speed	16
	Vehicle Acceleration - longitudinal	16
	Vehicle Acceleration - lateral	16
	Vehicle Acceleration - vertical	16
	Vehicle Heading	8
	Vehicle Yaw-rate	16
	Vehicle Position - Longitude	32
	Vehicle Position - Latitude	32
	Vehicle Position - Elevation	32
	Turn Signal Status - Right	1
	Turn Signal Status - Left	1
	Brake Position	1
	Throttle Position	8
	Steering Wheel Angle	16
	System Health	4

The communication range expected is around 25 meters for most pre-crash sensing applications. Some long-term applications, such as mitigation by braking based on pr-crash information, may require up to 50 meters in the worst case scenarios (head on collisions). The standard vehicle message is expected to be in a broadcast mode only. However for cooperative pre-crash sensing, a two-way communication may be required once the radar sensor predicts the eventuality of a collision. In that case, a two-way communication message is requested from the DSRC units. This message would contain the same data mentioned earlier in the standard message. The update rate however is expected to be around 50 Hz, which should provide updated DSRC ranging data every other radar updates. This should be enough in the case where the DSRC ranging information is used only to confirm the type of target that the radar has detected. The stringent two-way communication requirement and fast update rate is unique to this application. However, it is only activated in the eventuality of a crash and does not last more than a second or two. The message size could potentially be reduced since most of the static vehicle data can be transmitted just once for proper system functionality.

4.5 Cooperative Forward Collision Warning (FCW) System

4.5.1 Introduction

A rear-end collision is defined as an on-road, two vehicle collision in which both vehicles are moving forward in the same direction prior to the collision or a collision in which the vehicle in the forward path has stopped. The objective of a forward collision warning system is to increase driver awareness and subsequently reduce deaths, injuries and economic losses resulting from vehicular rear-end collisions. A forward collision warning system is designed to aid the driver in avoiding or mitigating collisions with rear-end of vehicles in the forward path of travel through driver notification or warning of the impending collision. The system does not attempt to control the host vehicle in order to avoid an impending collision.

A forward collision warning system will typically use a forward-looking sensor mounted at the front of the host vehicle that detects targets (other vehicles or objects) ahead of the host vehicle and in its field of view. An accurate prediction of the forward lane geometry ahead of the host vehicle (up to 150 meters) is necessary in order to properly classify the targets as in-path or out-of-path, and thereby identify potential threats of rear-end collision. For FCW, incorrect classification of in-path and out-of-path targets leads to false alarms and missed detections in the system, which may limit deployment and user acceptance. To predict the forward road geometry ahead of the host vehicle, the system may also use a GPS receiver for vehicle position measurement, a map database, a vision system that detects lane markers, a vehicle speed sensor, and a yaw-rate sensor. However, each of these approaches have limitations. Yaw-rate sensors do not possess the capability to determine the forward road geometry up to 150 m since the prediction is based on extrapolation of curvature of the road at the current host vehicle position. The limitations of using yaw-rate to determine forward road geometry are easily demonstrated as a host vehicle travels on a straight section of road into a curve. Lane markings tracker based on a vision system can also be used to provide a forward road geometry estimate but they have been unable to do so at distances required by FCW. Vision systems also have difficulties under varying weather and light conditions. Map databases have the characteristic of being able to provide forward geometry and other information under all weather and light conditions and at distances capable of supporting FCW. However, current map databases, based on the needs of navigation systems, have not been shown to provide the accuracy required in order to estimate forward geometry reliably and do not possess other important roadway attributes.

A cooperative forward collision warning system would use information communicated from neighboring vehicles via vehicle-to-vehicle communication in addition to forward looking sensor data to address these shortcomings.

4.5.2 System Architecture and Concept of Operation

4.5.2.1 Illustration

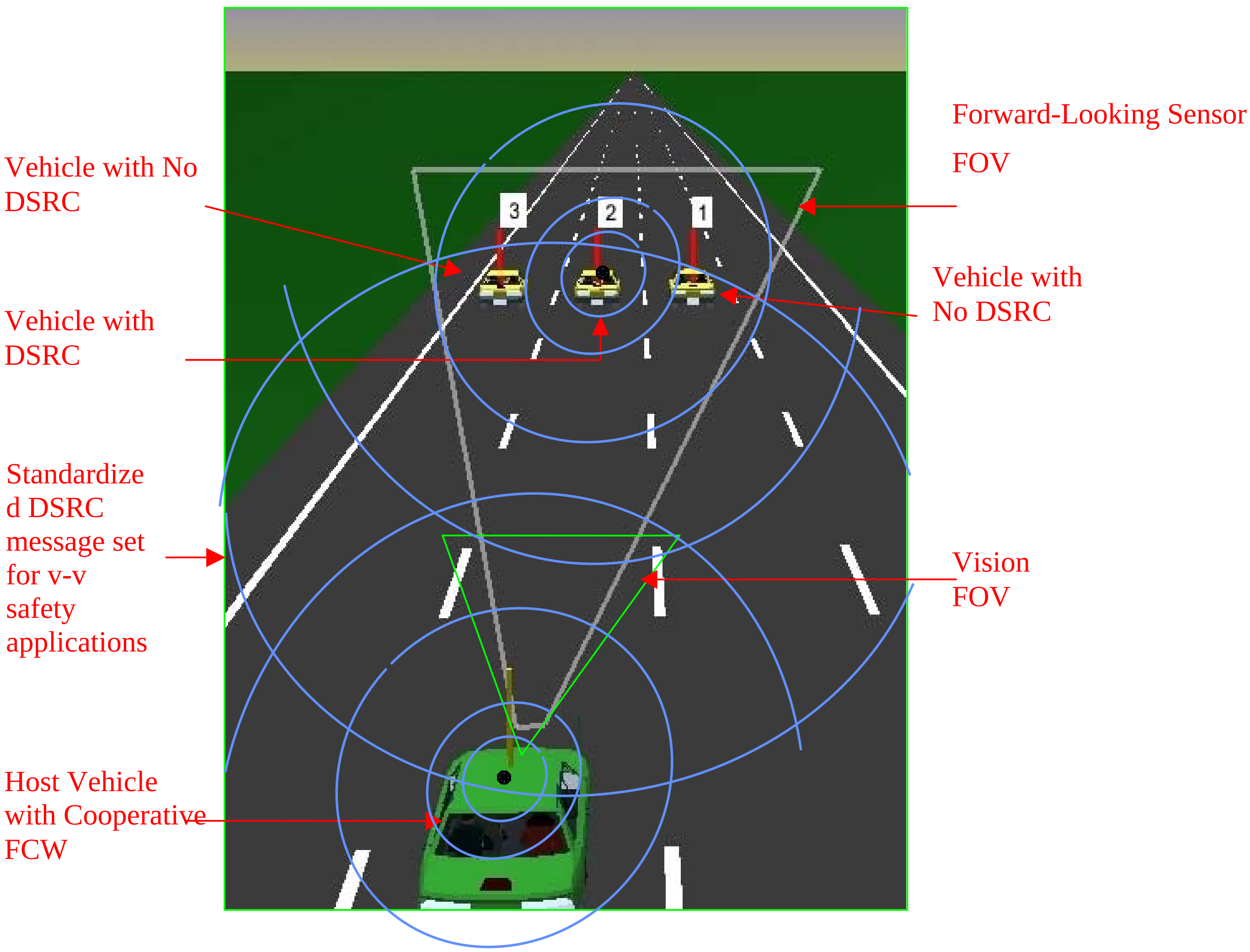


Figure 4.16 Illustration of Cooperative Forward Collision Warning

Figure 4.16 is an illustration of a cooperative forward collision warning application scenario. The host vehicle is assumed to have a cooperative forward collision warning system that implies, among other things, that the host vehicle is able to transmit and receive standardized DSRC messages designed for vehicle-to-vehicle safety applications. However it is assumed that not all target vehicles will be equipped with DSRC on-board units. In the figure three targets are shown corresponding to three vehicles. Target 2 is shown to have a DSRC on-board unit and transmits standardized DSRC messages designed for vehicle-to-vehicle safety applications periodically, while targets 1 and 3 do not have DSRC on-board units. The communication range for the DSRC message sets should be chosen to take into account the requirements of a forward collision warning system.

The cooperative forward collision warning system in the host vehicle will process all the targets and classify them as in-path or out-of-path targets. The system will then select the closest-in-path target and process the target's dynamics information and provide a warning to the driver if the threat assessment algorithm indicates a threat. The performance of the system is enhanced by vehicle-to-vehicle communication received from DSRC-equipped target vehicles in the following ways:

- Provides additional redundancy in target vehicle detection thereby increasing reliability of detection

  Although forward-looking sensor has a high probability of detection of targets in its field of view, there are occasional missed detections. The probability of missed detections increases with environmental factors such as rain, snow, dirt, etc. Moreover, such a sensor cannot detect target vehicles that are blocked by other vehicles. Therefore, cooperative vehicle-to-vehicle communication from neighboring vehicles would increase the reliability of target vehicle detection required for forward collision warning.

- Provides accurate dynamics information with low latency from target vehicles

  Since the standardized message sets from DSRC-equipped target vehicles include GPS information, it is possible to correlate the received communication from neighboring vehicles with corresponding forward-looking sensor targets. The host vehicle is able to get significantly detailed dynamics information about DSRC-equipped target vehicles that is not possible with the sensor alone. Such information includes vehicle size, vehicle type, position (from GPS), velocity, acceleration, heading, yaw-rate, turn-signal status, brake position, throttle position, steering wheel position, etc. Furthermore, this information is received with low latency. Using the additional information, the system will be able to make accurate determination of imminent threats and provide the warning at the most appropriate time. This would reduce false alarms and missed detections significantly thereby improving the performance and user acceptance of the system.

- Provides early detection of vehicle cut-in into host vehicle path

  Since the standardized message sets from DSRC-equipped target vehicles include turn-signal status, steering wheel position, yaw-rate information the host vehicle is able to predict target vehicle cut-in into its path, early. This is not possible with the sensor alone since the radar's lateral vehicle movement tracking is quite poor. Furthermore, this information is received with low latency. Using the additional information, the system will be able to make accurate determination of target vehicle cut-ins and provide early warning if necessary.

- Provides early detection of vehicles leaving host vehicle path

  Since the standardized message sets from DSRC-equipped target vehicles include turn-signal status, steering wheel position, yaw-rate information the host vehicle is able to predict target vehicle leaving the host path, early. This would reduce false alarms from target vehicles moving away from the host path thereby improving the performance and user acceptance of the system.

- Provides early detection of stopped vehicles

  One of the present limitations of forward-looking sensors is the limited ability to differentiate stopped vehicle targets from other stationary targets such as bridges, lamp-posts, trees, sign-boards, etc. This is typically only possible at short ranges. When the host vehicle travels at highway speed and encounters a stopped vehicle, this range is not sufficient for providing adequate warning to the driver so as to prevent the crash. If the host vehicle obtains standardized message sets from DSRC equipped stopped vehicles, it is possible to evaluate the threat early enough and provide the warning at the appropriate time so that a collision with the stopped vehicle may be prevented.

- Provides better warning algorithms that includes target vehicle type and size

  The severity of a crash depends on the target vehicle type and size. The warning algorithm can be improved to include the target vehicle type and size from DSRC-equipped target vehicles.

- Provides an opportunity for deploying cooperative forward collision warning purely based on vehicle-to-vehicle communication

  If DSRC proves to be a very reliable vehicle-to-vehicle communication link for vehicle safety applications, and if all vehicles are equipped with DSRC OBUs capable of communicating standardized message sets needed by vehicle safety applications, it may be possible to deploy forward collision warning systems purely based on cooperative vehicle-to-vehicle communications.

4.5.2.2 Block Diagram

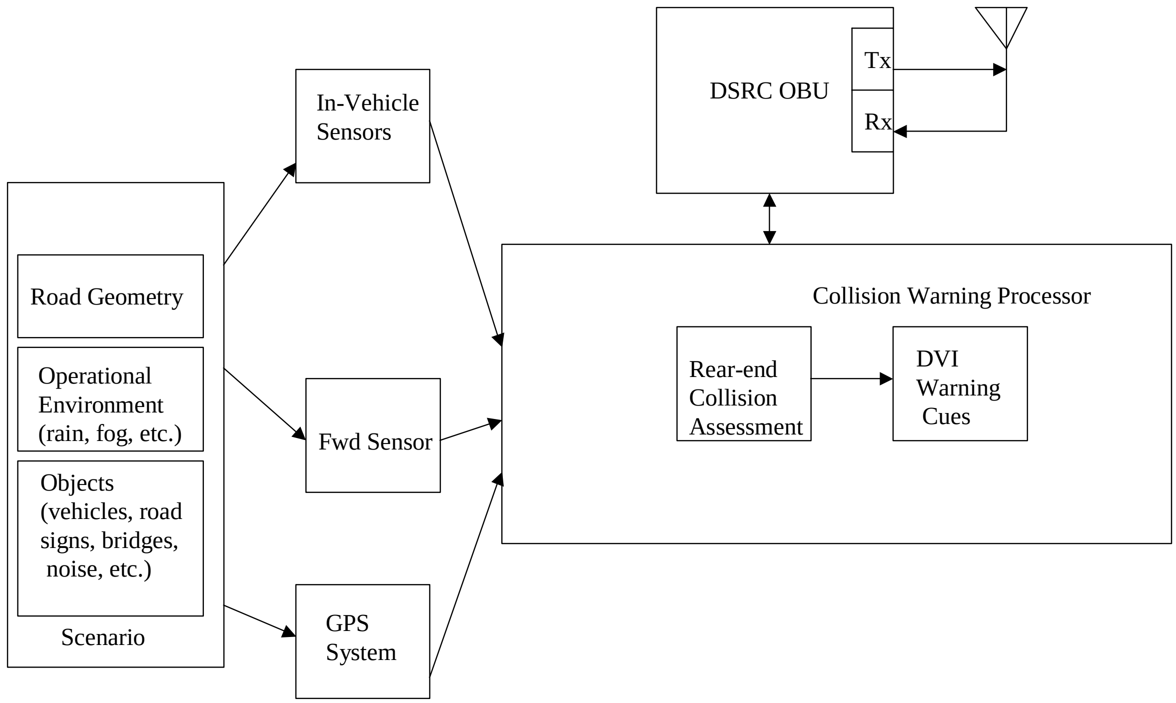


Figure 4.17 Block Diagram of Cooperative Forward Collision Warning System

A block diagram of cooperative forward collision warning system is shown in

Figure 4.17. The operational scenario of the vehicle affects all the sensor systems as shown in the figure.

The DSRC OBU and antenna can transmit and receive standardized vehicle-to-vehicle message sets, periodically, as required by vehicle safety applications. The host vehicle uses the communicated information from other vehicle to maintain situational awareness of vehicles in the forward path and to assess the threat of a conflict with other vehicles.

In-vehicle sensors consists of a suite of sensors and associated I/O Interface functions that include filters for the vehicle kinematics sensors to provide engineering units and to reduce noise in these measurements.

The forward sensor may be used to track vehicles and objects that are not equipped with DSRC, and also to obtain forward road geometry.

The GPS system provides absolute vehicle positioning that is a required data for the standardized vehicle-to-vehicle message set.

The rear-end collision assessment function uses the host vehicle dynamics, the target dynamics, and the expected driver response to determine what level of warning should be generated.

The Driver-Vehicle Interface functions control all of the devices that transmit information to the driver. These may include audio and visual outputs.

4.5.2.3 Sensors and Other System Needs

The application would need a fairly accurate DGPS system that would limit the vehicles' longitudinal and lateral position error to small values. The update rate for vehicle positioning should be at least 10 Hz for good performance. The DSRC OBU can be easily integrated to a cooperative forward collision warning system by interfacing to a standard vehicle bus such as the CAN bus.

The sensor-based system for forward collision warning is already fairly well developed.
A map database would help to provide information such as which lane the vehicle is traveling. In addition, the road curvature can be taken into account when an application host vehicle evaluates target information to see if a warning to the driver is necessary.

4.5.2.4 Data Message Set Requirements

It is expected that vehicles equipped with a 5.9 GHz DSRC OBU and antenna will be capable of transmitting and receiving a standardized DSRC message set that would be required by vehicle safety applications. This is easily done by interfacing the DSRC OBU to a standard vehicle bus such as the CAN bus.

Table 4.5 shows a preliminary version of the message content that may be required to implement a cooperative forward collision warning system.

Table 4.5 Data Message Set Requirements for Cooperative FCW

Description	Number of bits
Message Type	8
Vehicle ID / Communication Address	48
Vehicle Type / Class	4
Vehicle Size (length, width, height)	48
Position Antenna Offset (relative X, Y, Z)	48
Time Stamp – GPS Milliseconds in week	32
Time Stamp – GPS week number	16
Vehicle Speed	16
Vehicle Acceleration - longitudinal	16
Vehicle Acceleration - lateral	16
Vehicle Acceleration - vertical	16
Vehicle Heading	8
Vehicle Yaw-rate	16
Vehicle Position - Longitude	32
Vehicle Position - Latitude	32
Vehicle Position - Elevation	32
Turn Signal Status - Right	1
Turn Signal Status - Left	1
Brake Position	1
Throttle Position	8
Steering Wheel Angle	16
System Health	4

It is expected that the DSRC equipped vehicles would periodically broadcast the standard message set to neighboring vehicles within a certain desired range. Current automotive radars used in FCW systems are capable of track updates at an update rate of 100 ms and have a range of coverage 150 m. Hence, the update rate for vehicle-to-vehicle communication is expected to be at least 100 ms, and the communication range is expected to be at least 150 m.

4.6 Left Turn Assistant

4.6.1 Introduction

The Left Turn Assistant provides information to drivers about oncoming traffic to help them make a left turn at a signalized intersection without a phasing left turn arrow. Information is obtained by the infrastructure system, which uses sensors and/or DSRC communications to detect vehicles approaching from the opposite direction. After the infrastructure system collects the status of oncoming traffic, the information is transmitted to the in-vehicle system via DSRC, or provided to the driver through infrastructure equipment such as a traffic signal. The key options for implementing the Left Turn Assistant can be differentiated based on the following criteria:

- whether or not DSRC technology is used to locate approaching vehicles,
- whether or not there is application intelligence (judgment of collision potential) in the infrastructure or in the vehicle,
- whether or not the information is provided through infrastructure equipment (e.g. a left turn arrow that changes between yellow and red depending on the situation),
- whether or not the information is provided through an in-vehicle application,
- whether or not an in-vehicle system needs to request information that is particular to the left turn maneuver (in cases where the infrastructure can download many different types of information)

The Left Turn Assistant scenario that is described in this section identifies one potential combination of the elements listed above. In this scenario, the in-vehicle system determines that there is a need for information about approaching traffic based upon the driver's intention to make a left turn near an intersection. The traffic data is gathered automatically by the infrastructure system, which detects the location and movement patterns of oncoming vehicles using vehicle detection sensors. The infrastructure system transmits the data to vehicles at regular intervals via DSRC, and the said in-vehicle system provides the relevant information to the driver.

4.6.2 System Architecture and Concept of Operation

The operational concept in this scenario is similar to an application being tested in Japan under the Advanced Cruise Assist Highway System (AHS) program. The AHS approach to this application allows vehicles without GPS capability to use the system, and this particular version of the concept adds the provision of traffic signal phase and timing to the traffic data that is sent to the vehicle. Two DSRC antennas are needed for each right-of-way that offers left turn assistance: one to establish a point of reference (Reference DSRC Antenna), and the other to transmit the information gathered by the infrastructure (Communication DSRC Antenna).

4.6.2.1 Illustration

As the vehicle passes the Reference DSRC Antenna, the in-vehicle application is instructed to initialize the dead reckoning function (start counting the odometer). The communication zone of the Reference DSRC Antenna is small to allow a relative location reference for vehicles without GPS capability (Figure 4.18).

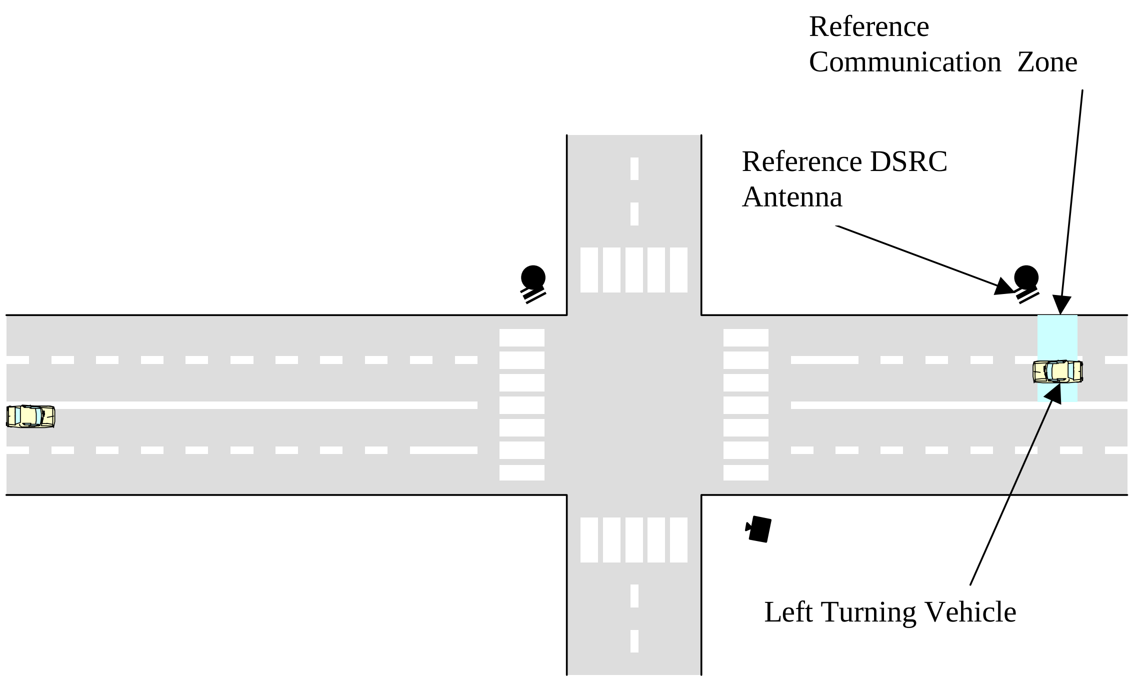


Figure 4.18 Reference DSRC Communications

The vehicle detection sensor(s) identify vehicles approaching from the opposite direction (Figure 4.19). The detection of vehicles preferably takes place at an angle that allows a clearer definition of on-coming traffic than what the driver's view is limited to.

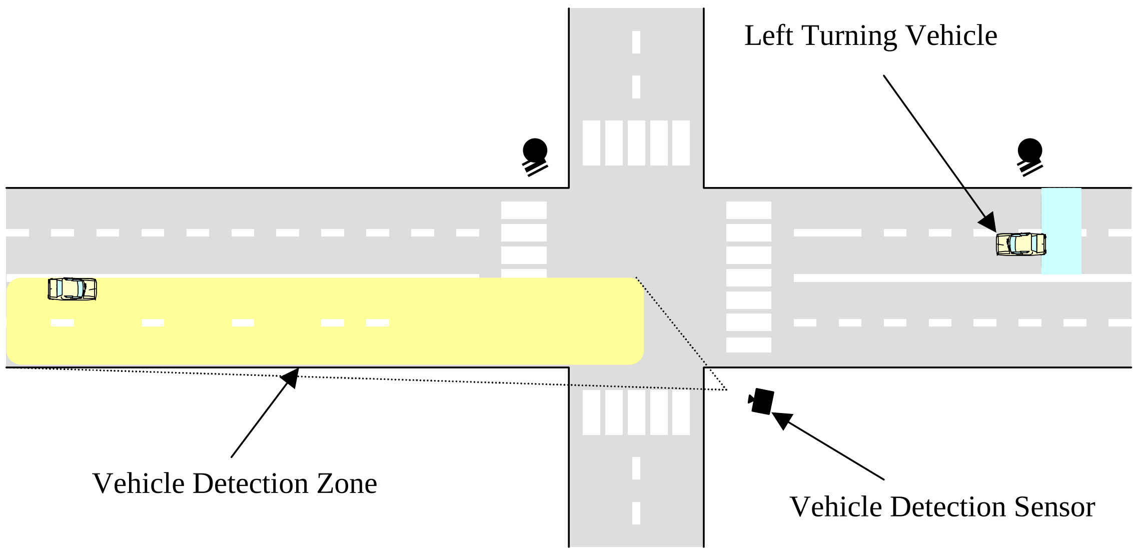


Figure 4.19 Detection of Approaching Vehicles

The driver activates the in-vehicle application through the traffic status request mechanism – the turn signal switch in this scenario. Shifting the switch to the left-hand turn position causes the application to search whether or not appropriate information has been sent from an intersection RSU. Applicable intersections will send information through the Data DSRC antenna (Figure 4.20). The order in which the vehicle passes by the Reference and Data DSRC antennas helps the in-vehicle application to determine the applicability of the information that is received (the direction of travel on the road).

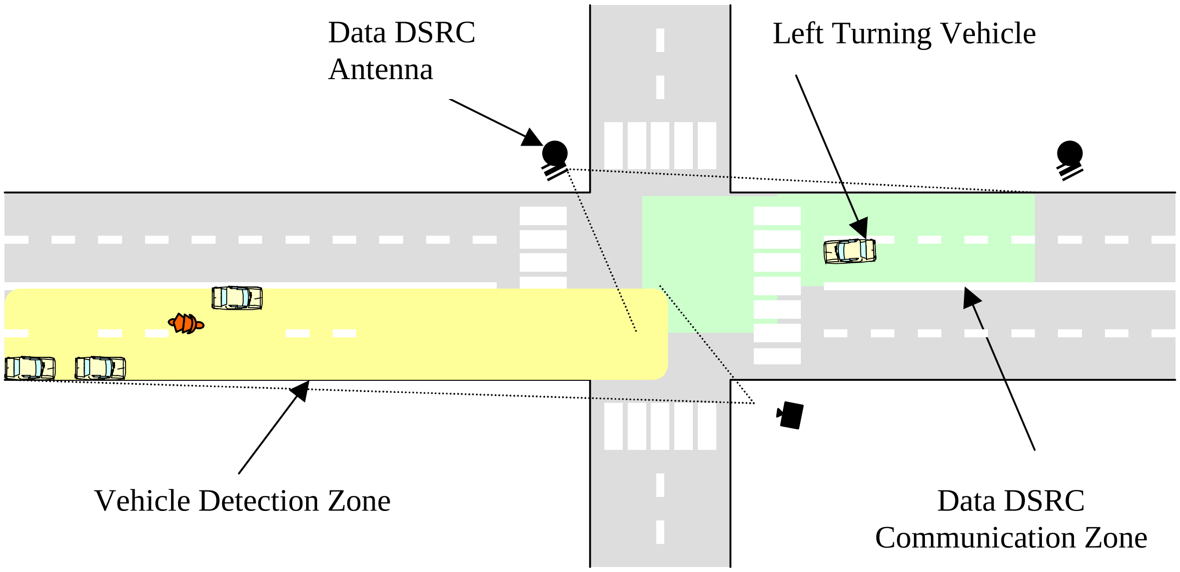


Figure 4.20 Data DSRC Communications

Information received from the Data DSRC antenna includes intersection and road shape information, traffic signal status, and traffic location and movement data.

The presentation of information on an in-vehicle display can help the driver to see vehicles that are obstructed from the normal field of view, as well as thin-width vehicles that can travel in-between lanes and squeeze through traffic. Drivers can watch the traffic signal phase change on the in-vehicle screen when the outdoor signals are hidden by the glare of the sun (Figure 4.21).

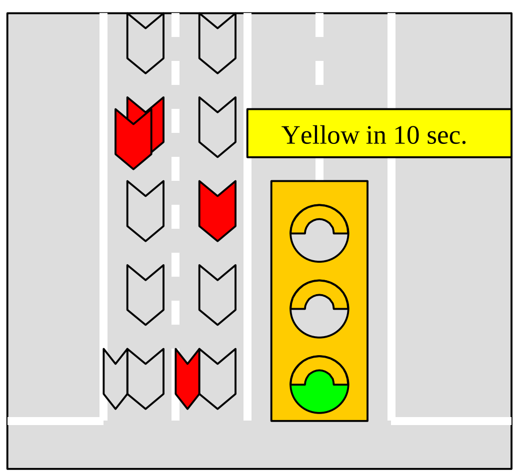


Figure 4.21 In-Vehicle Display Example

4.6.2.2 Block Diagram

The Left Turn Assistant consists of the following major components:

<u>In-Vehicle Components</u>

- Application Processing
- DSRC On-Board Unit (OBU)
- DSRC Antenna
- Traffic Status Request Mechanism (Turn Signal Switch)
- Driver Feedback Devices

<u>Infrastructure Components</u>

- Vehicle Detection Sensors
- Application Processing
- DSRC Roadside Unit (RSU)
- DSRC Antenna

Figure 4.22 is a block diagram of the Left Turn Assistant system. It shows the major components and subsystems needed for the application scenario to function properly in its mode of operation.

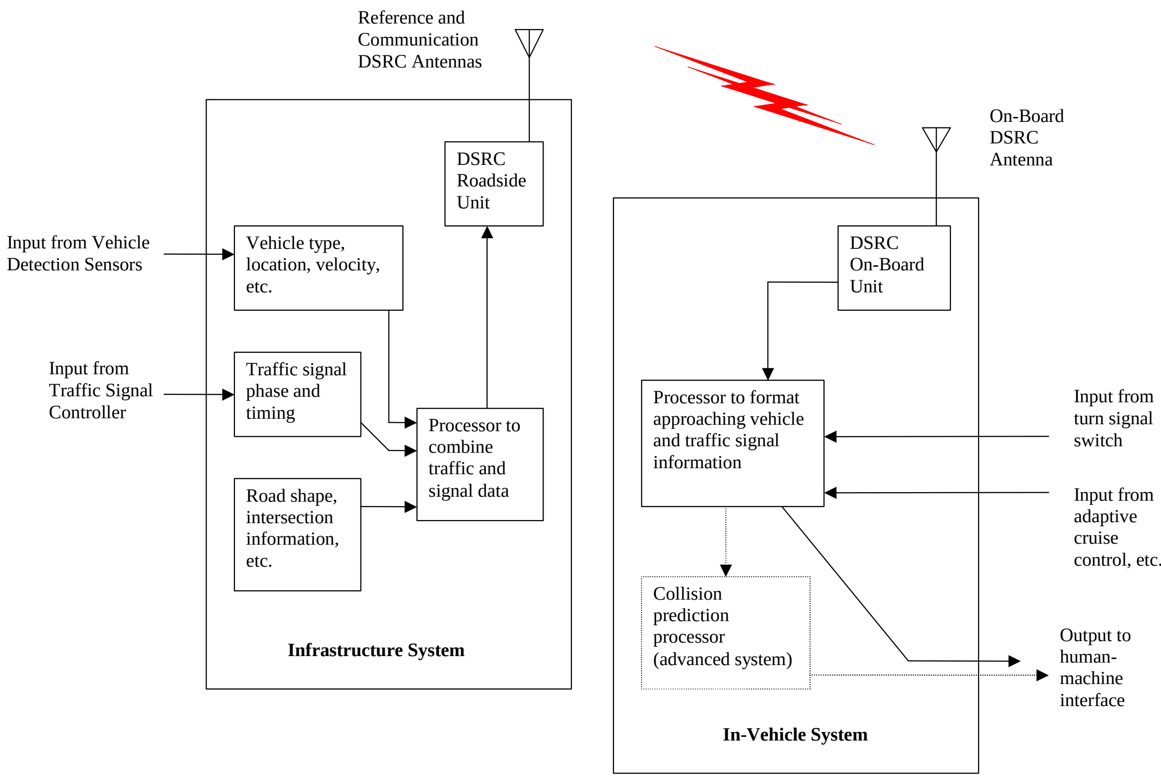


Figure 4.22 Block Diagram of the Left Turn Assistant

Infrastructure System

Vehicle Detection Sensors

The sensing requirements for the vehicle detection sensors are based upon the need to identify the movement patterns of each vehicle approaching the intersection from the opposite direction of those being serviced by the application. The sensing can be accomplished through radar, laser, image-based sensors, etc. In advanced in-vehicle systems with precise locating capabilities (DGPS, etc.), this data could be supplemented by information collected from approaching vehicles through DSRC communications. In the case of a DSRC-based approach to vehicle location, the information would need to be based upon a location referencing standard that is agreed upon by all public and private sector organizations involved in this aspect of DSRC.

Application Processor / RSU

The application processor interfaces with the vehicle detection sensors and the traffic signal controller and provides information to the RSU. The RSU identifies that it can provide left turn input to approaching vehicles through its Roadside Service Table. In this scenario, intersection RSUs have a limited number of services to offer and can therefore broadcast all service data periodically without receiving a request for particular information from an in-vehicle OBU.

In-Vehicle System

Human-Machine Interface (HMI)

The HMI for the Left Turn Assistant consists of a turn signal and those feedback devices that provide information to the driver. Activation of the turn signal causes the in-vehicle application to determine whether or not a nearby RSU has provided the necessary information. If data regarding on-coming traffic has been sent to the vehicle, this information can be provided to the driver through audible, haptic and visual display methods. In more advanced systems, a warning can be provided if the system incorporates collision prediction software.

Application Processing

The left turn application processing unit receives the location and movement patterns of approaching vehicles and provides the information to the driver feedback devices. In more advanced systems, a collision avoidance processing unit would calculate if a left turn is likely to cause an accident. If the parameters of the approaching vehicles fell within a threshold determined by the collision avoidance algorithm, the processing unit would send the appropriate warning to the driver interface. Such a unit would require extremely precise location data, as well as high-speed processing capability in order to complete its determination while the vehicle is approaching the intersection.

4.6.2.3 Sensors and Other System Needs

In-vehicle sensors can supplement and verify the location information that is sent from the infrastructure. Laser, millimeter-wave radar, and vision-based technologies that support applications like adaptive cruise control can be applied to a data fusion process that improves the quality of information presented to the driver.

In this scenario, the in-vehicle system identifies the presence of approaching traffic without explicitly warning the driver of a potential collision. In more advanced systems, a warning could be provided to the driver if the system incorporates collision prediction software. Such a system could apply force feedback to the steering wheel if the driver attempts to turn with oncoming vehicles in close proximity. Yet more advanced systems could initiate either partial control (e.g. automatic braking) or full control of the vehicle in response to the collision avoidance algorithm.

4.6.2.4 Data Message Set Requirements

Infrastructure-to-Vehicle Communications

Transmissions from the infrastructure consist of one packet sent every 100 milliseconds. Each packet could contain at least the information shown in Table 4.6 for a system that supports vehicles with and without GPS capability.

Table 4.6 Infrastructure-to-Vehicle Data Message Set Requirements

Description	Number of bits
Traffic signal status information	
Current phase	8
Date and time of current phase	64
Next phase	8
Time remaining until next phase	24
Road shape information	
Data per node	32
Data per link to node	72
Intersection information	
Data per link	120
Oncoming vehicle information	
Date and time vehicles detected	64
Link information for in-lane vehicles	48
Data per lane	16
Data per vehicle:	
Position	96
Speed	16
Acceleration	16
Directionality	16
Distance from intersection	16
Link information for between-lane vehicles (motorcycle, etc.)	48
Data per lane	16
Data per vehicle:	
Position	96
Speed	16
Acceleration	16
Directionality	16
Distance from intersection	16

Note that total message length will vary depending on the number of nodes, links, lanes, and detected vehicles that are used to support the application.

Road shape and intersection information provides data that allows vehicles without GPS capability to utilize the system and to present road and intersection characteristics on an in-vehicle display. Road shape information includes the ID and position of nodes, and the lengths and connection angles of links along the roadway. Intersection information includes the connection angles and widths of roadway links, and the location of the crosswalks and stopping lines.

Oncoming vehicle information includes the monitoring range of the detection system, the number of lanes monitored, and the location, movement and detection time of oncoming vehicles.

Vehicle-to-Infrastructure Communications

Supplementary vehicle location data could be collected from approaching vehicles through DSRC communications using the following message set shown in Table 4.7.

Table 4.7 Vehicle-to-Infrastructure Data Message Set Requirements

Description	Number of bits
GPS coordinates	96
Date and time of current location	64
Vehicle speed	16
Vehicle acceleration	16
Vehicle directionality	16

4.7 Lane Change Warning

4.7.1 Introduction

This application provides a warning to the driver if an intended lane change may cause a collision with a nearby vehicle. The application receives periodic updates of the position, heading and speed of surrounding vehicles via vehicle-to-vehicle communication. When the driver signals a lane change intention, the application uses this communication to predict whether or not there is an adequate gap for a safe lane change, based on the position of vehicles in the adjacent lane. If the gap between vehicles in the adjacent lane will not be sufficient, the application determines that a safe lane change is not possible and will provide a warning to the driver.

A lane change warning application could be realized in the mid-term, since it relies on high penetration of DSRC units but is otherwise straight-forward. To decrease the dependence on penetration, such a lane change warning application could also be realized using radar sensors or cameras in combination with DSRC communication. This possibility is further explained in Section 4.7.2.3. The biggest challenge for this application is in designing a system that can determine the exact location of a vehicle in tightly-packed traffic, so that the system doesn't provide false warnings to the driver. Of the applications described in detail in this report, the lane change warning has one of the highest position accuracy requirements. Using additional sensor such as radar or cameras could make the application more accurate.

Though the general concept of a DSRC lane change warning system is defined, the exact implementation, including the human-machine interface (how the driver will be warned, whether the driver is given ok/not ok signals or just not ok signals, etc.), is not specified.

4.7.2 System Architecture and Concept of Operation

A DSRC lane change warning system will use information sent from other vehicles to determine whether its vehicle is making an unsafe lane change maneuver.

Keeping track of the locations of surrounding vehicles is essential to this application. For this purpose, a table of vehicle locations is kept in memory. At the initialization point, no nearby vehicles will be in the table. The vehicle then listens to incoming messages and continuously keeps a list of other vehicles in the area. As messages are received, they are stored into a memory space in the form of a table. If a message from the same vehicle is already present in the table, the most recent message is retained. Each entry set (row) in the table has a finite expiration period. If no new messages are received from the same vehicle within that period, the entry set (row) is deleted.

The system notes when the driver intends to make a lane change, either by monitoring the status of the turn signals or by another method. Options include using a camera-based lane position recognition system or a highly-accurate map database that can determine the position of the vehicle in its lane. When a lane change is intended, the system looks at the table of nearby vehicles to determine if the lane change is dangerous. The current location of each nearby vehicle is extrapolated from the most recent message sent by that vehicle. If a vehicle is found at the intended merge point, the driver is warned.

4.7.2.1 Illustration

a) Vehicles are traveling on a 3-lane highway.

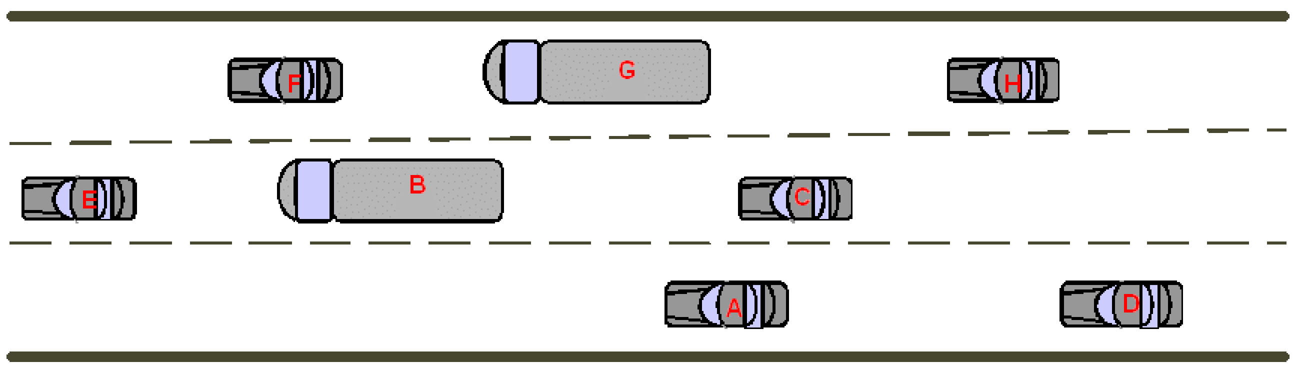


Figure 4.23 Lane Change Warning Illustration A

b) Vehicles equipped with DSRC OBUs transmit standardized periodic messages with their position, heading, acceleration, etc.

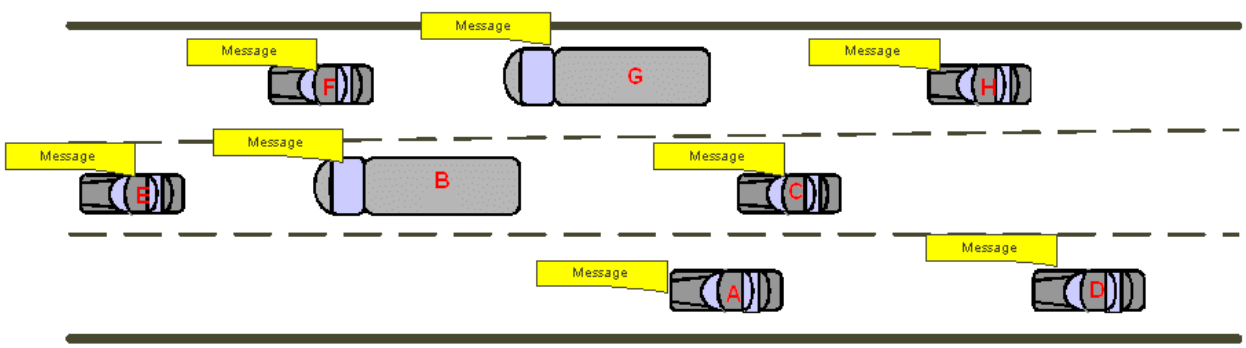


Figure 4.24 Lane Change Warning Illustration B

c) All vehicles, including vehicle A (which is used in this example), receive messages from surrounding DSRC-equipped vehicles.

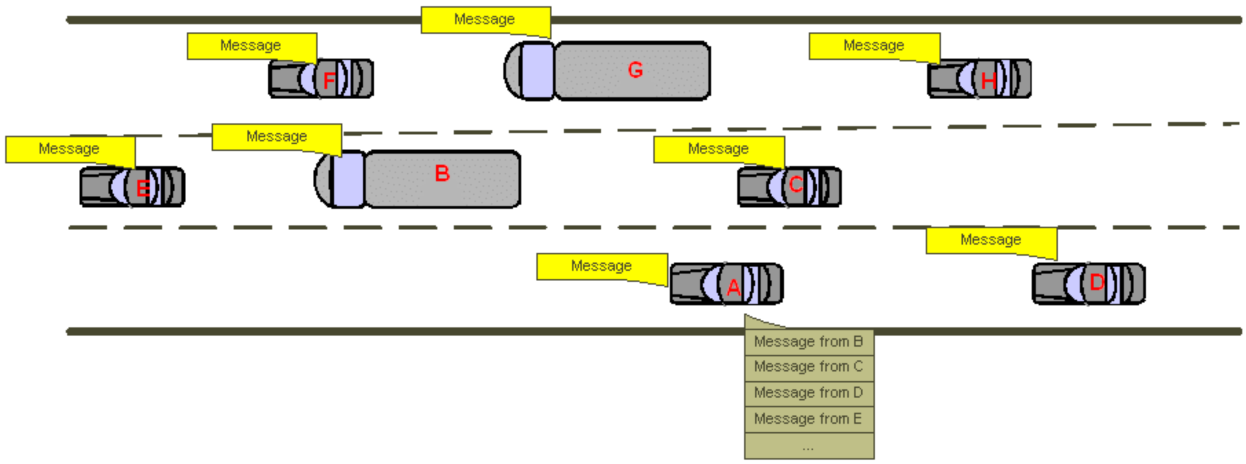


Figure 4.25 Lane Change Warning Illustration C

d) Vehicle A keeps a table with a list of nearby vehicles relevant to itself.

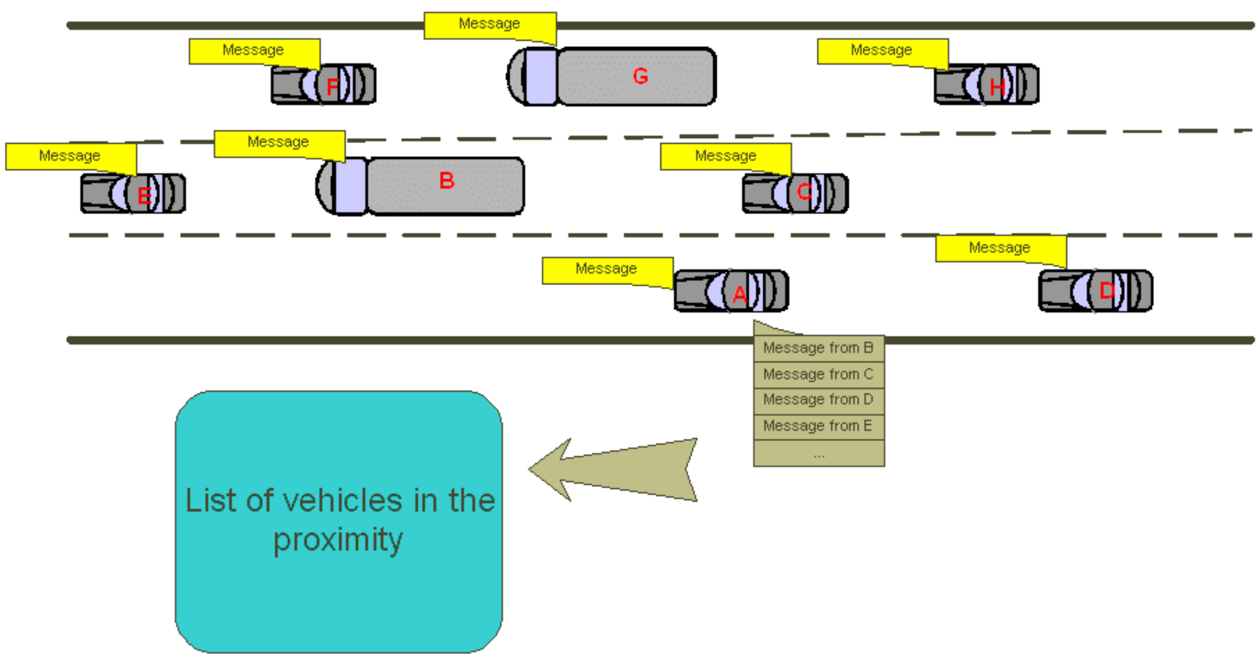
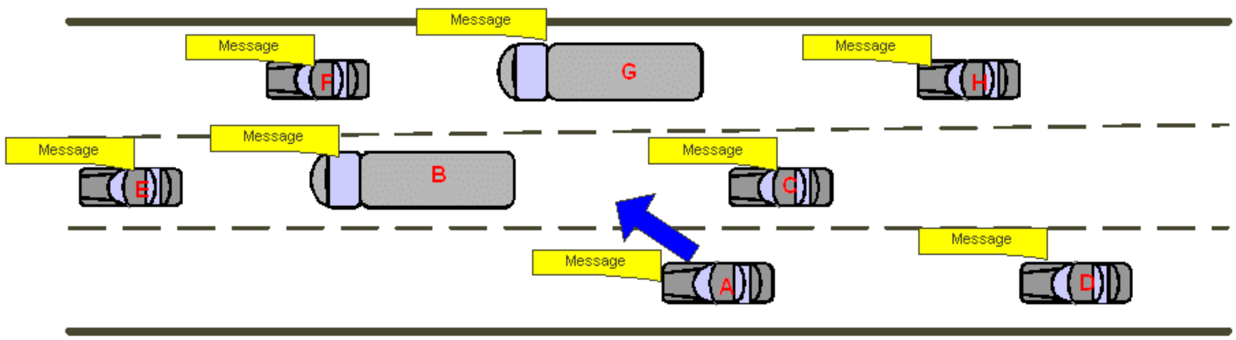


Figure 4.26 Lane Change Warning Illustration D

e) When vehicle A intends to change lanes, its list of nearby vehicles is checked. If a vehicle is found at the intended merge point, the driver of vehicle A is warned.



Vehicle	Velocity	Accel	Projected position	Time stamp	Distance	Time to expire	Relative position
B	60	1	Xx:xx:xx ; xx:xx:xx	Hh:mm:ss.ss	3	2	45
C	62	0	Yy:yy:yy yy:yy:yy	Hh:mm:ss.ss	2.5	2	95
D	64	0	Zz:zz:zz ; zz:zz:zz	Hh:mm:ss.ss	4	1	180
E	61	0.5	Xy:xy:xy ; xy:xy:xy	Hh:mm:ss.ss	8	2	5
...	...	...	...	...	...	...	...

Figure 4.27 Lane Change Warning Illustration E

A more detailed view of the "nearby vehicle table" is shown in Table 4.8.

Table 4.8 Nearby Vehicle Table

Vehicle	Velocity (mph)	Accel (m/s^2)	Projected position	Time stamp	Distance (m)	Time to expire (count)	Relative azimuth angle (deg)
B	60	1	Xx:xx:xx ; xx:xx:xx	Hh:mm: ss.ss	3	2	45
C	62	0	Yy:yy:yy ; yy:yy:yy	Hh:mm: ss.ss	2.5	2	95
D	64	0	Zz:zz:zz ; zz:zz:zz	Hh:mm: ss.ss	4	1	180
E	61	0.5	Xy:xy:xy ; xy:xy:xy	Hh:mm: ss.ss	8	2	5
…	…	…	…	…	…	…	…

<u>Column heading descriptions:</u>

Vehicle: identification of the sender (e.g. MAC address)

Velocity

Acceleration

Projected current position: extrapolated from other values

Time stamp: time when the message was received

Time to expire: the row with this entry will be removed if time expires

Distance: relative distance from host vehicle

Relative azimuth angle: relative position from the host vehicle

4.7.2.2 Block Diagram

Hardware architecture and information flow for the application host vehicle are shown in Figure 4.28.

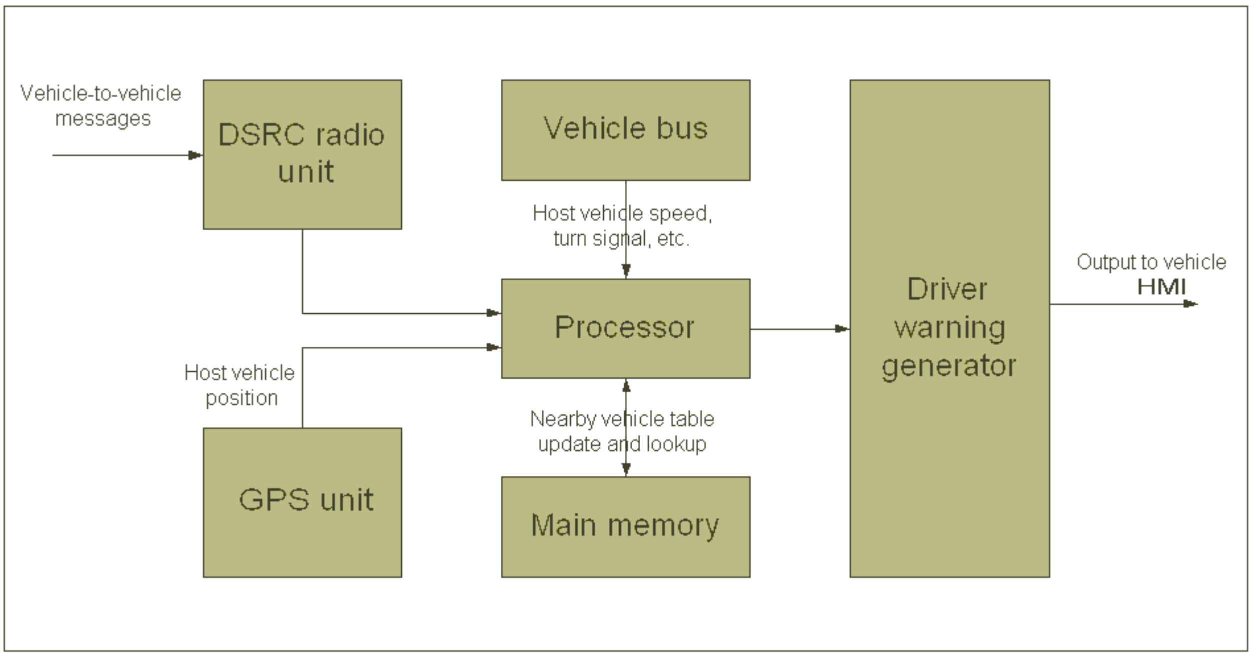


Figure 4.28 Application Host Vehicle Architecture and Information Flow

The hardware architecture and information flow for the vehicle-to-vehicle message sender are shown in Figure 4.29.

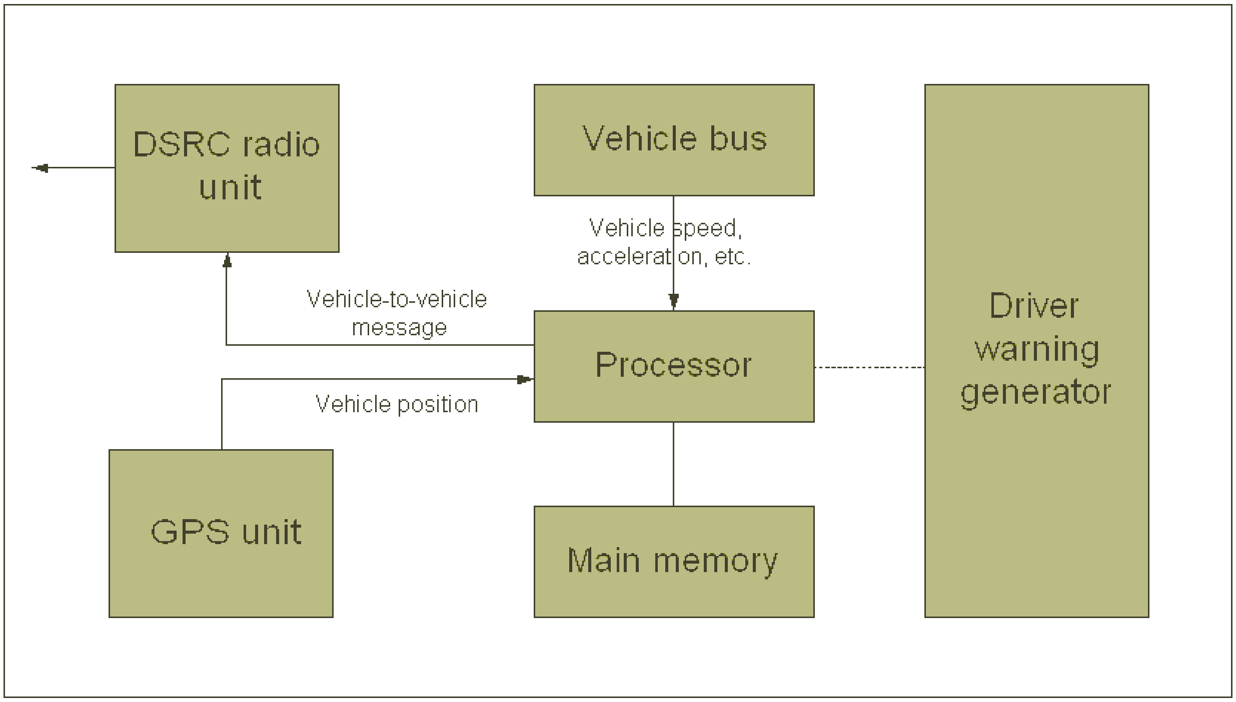


Figure 4.29 Vehicle-to-Vehicle Message Sender Architecture and Information Flow

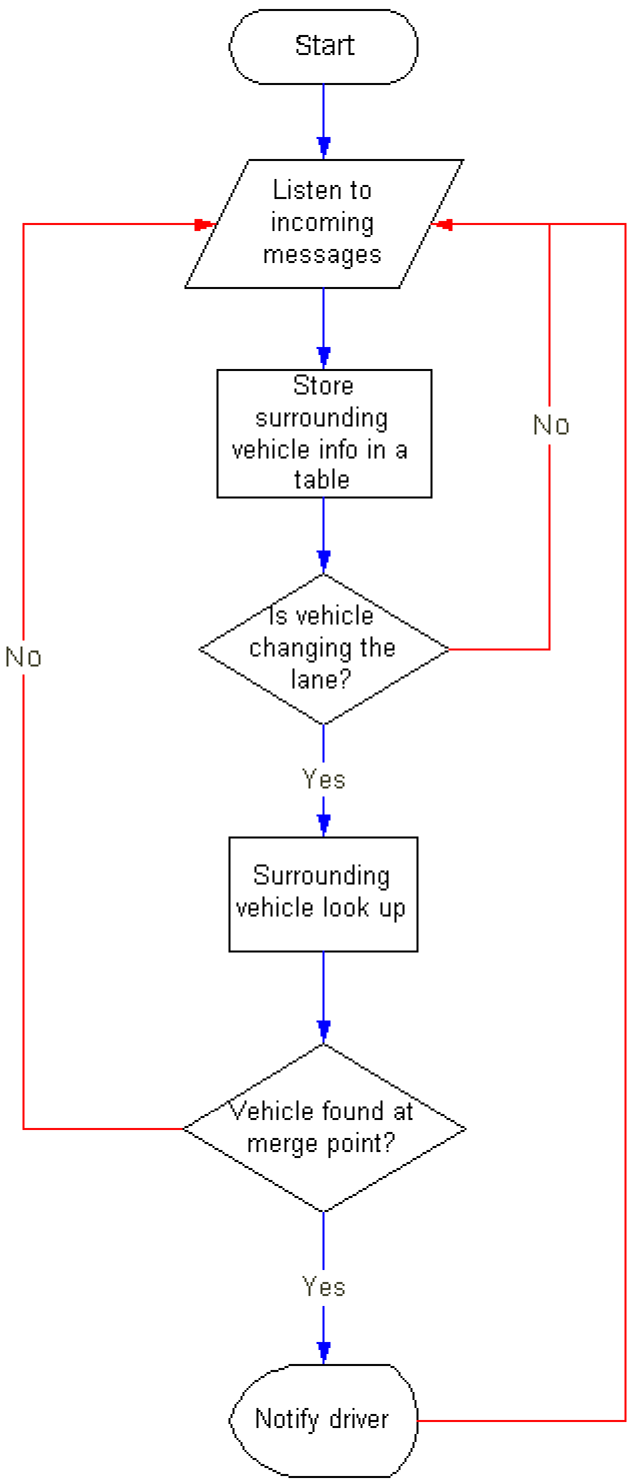


Figure 4.30 Lane Change Warning Application Flow Chart

4.7.2.3 Sensors and Other System Needs

Besides the DSRC unit itself, information from other sources is necessary for the lane change warning application to operate. A DGPS unit, a map database, and a vehicle bus connection that provides vehicle speed are all required.

DGPS is necessary for this application to function correctly. Because the safety of a lane change is determined by measurements of several meters (and not several tens of meters), the resolution of the distance between the host vehicle and the surrounding vehicles must be small. A GPS receiver with high accuracy is thus required.

A map database is also necessary, so that vehicles can determine whether other vehicles are traveling on the same road, which lane they are in, and so that road curvature can be taken into account in the calculations.

Each vehicle must broadcast its dynamic location, velocity, heading, and acceleration. The DGPS unit can provide the location and heading. The velocity and acceleration that could be calculated by the DGPS is relatively inaccurate when compared to the velocity (and possibly acceleration) that is available on most vehicle busses. If the vehicle does not have a longitudinal accelerometer or otherwise doesn't have longitudinal acceleration available on a vehicle bus, then such a value must be calculated from the vehicle velocity or GPS signals.

A vehicle equipped with radar or cameras sensing both sides of the vehicle could perform this application in addition to or without DSRC. If either radar or cameras is available, however, they could be used to double-check the DSRC location data. A system that uses only one way of sensing vehicles (DSRC, radar, or cameras) may not be accurate enough to create a reliable system without false-positives. In that case, other sensing mechanisms should be added.

4.7.2.4 Data Message Set Requirements

Vehicle-to-vehicle data message set requirements are shown in Table 4.9.

Table 4.9 Vehicle-to-Vehicle Data Message Set Requirements

Description	Size (bits)
GPS coordinates	96
Time stamp	64
Vehicle speed	16
Vehicle Acceleration	16
Vehicle heading	16
Vehicle size (length, width, height)	48
GPS antenna offset (relative XYZ)	32

4.8 Stop Sign Movement Assistant

4.8.1 Introduction

This application provides a warning to a vehicle that is about to cross through an intersection after having stopped at a stop sign. The warning is provided in order to avoid a collision with traffic approaching the intersection. Information is obtained from the infrastructure system, which uses sensors or DSRC communications to detect vehicles moving through an intersection. When the infrastructure or the in-vehicle application determines that proceeding through the intersection is unsafe, it provides a warning to the driver.

A stop sign movement assistant application may not be realized until at least the mid-term, since it is only effective when there is a large penetration of stop sign intersections equipped with this application. Each stop sign intersection must have a DSRC unit as well as back-up sensors (such as radar or cameras), so that vehicles without DSRC will be also be sensed.

Though the general concept of a DSRC stop sign movement assistant system is defined, the exact implementation, including the human-machine interface (how the driver will be warned, whether the driver is given ok/not ok signals or just not ok signals, etc.), is not specified. The system can be designed to work with vehicles that do or do not have GPS units. The illustration below shows how the system might work for vehicles that are equipped with GPS.

4.8.2 System Architecture and Concept of Operation

A DSRC stop sign movement assistant application might use information sent from vehicles as well as information from additional sensors to alert vehicles stopped at stop signs if they enter the intersection at an unsafe time.

The road-side unit is required to send out vehicle information that it receives, either from the other vehicles themselves (via DSRC) or from other sensors, such as radar or cameras. For this purpose, a table of vehicle information is kept in a memory table. As it receives information from vehicles via DSRC or from its sensors, the RSU keeps a list of vehicles in the area of the stop sign. As messages are received, they are stored into a memory space in the form of a table. If a message from the same vehicle is already present in the table, the most recent message is retained. Each entry set (row) in the table has a finite expiration period. If no new messages are received from the same vehicle within that period, the entry set is deleted. The RSU constantly sends out the information in its table, one entry per message. When no vehicles are in the vicinity of the intersection, the RSU will be idle.

The vehicle at the stop sign must keep track of the information sent to it from the road-side unit (RSU). For this purpose, a table of vehicle information is kept in a memory table. At the initialization point, no nearby vehicles will be in the table. When the vehicle stops at a stop sign, it listens to incoming messages from the RSU and thereby keeps a list of other vehicles in the area of the stop sign. As messages are received, they are stored into a memory table, in the same manner that messages are stored in the RSU. After the vehicle successfully passes through the intersection, the table is cleared.

The system notes when the driver intends move from the stop sign into the intersection, either by monitoring vehicle velocity or by some other method. When entry into the intersection is intended, the system looks at the table to of nearby vehicles determine if the movement is dangerous. The current location of each nearby vehicle is extrapolated from the most recent message sent by that vehicle. If another vehicle is found in a dangerous location, the driver is warned.

4.8.2.1 Illustration

a) Vehicle A is stopped at an intersection with a 2-way stop sign. Vehicles B and C are approaching the intersection and do not have stop signs.

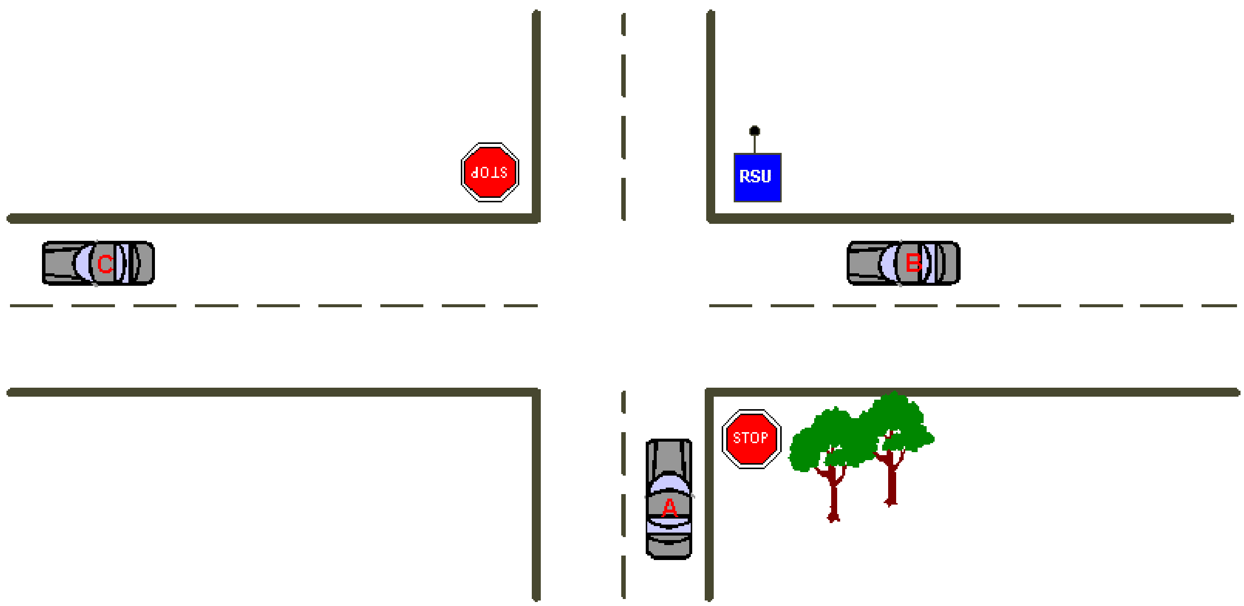


Figure 4.31 Stop Sign Movement Assistant Illustration A

b) Vehicles A and B have DSRC, though vehicle C does not. All vehicles equipped with DSRC transmit standardized periodic messages with their position, heading, acceleration, etc.

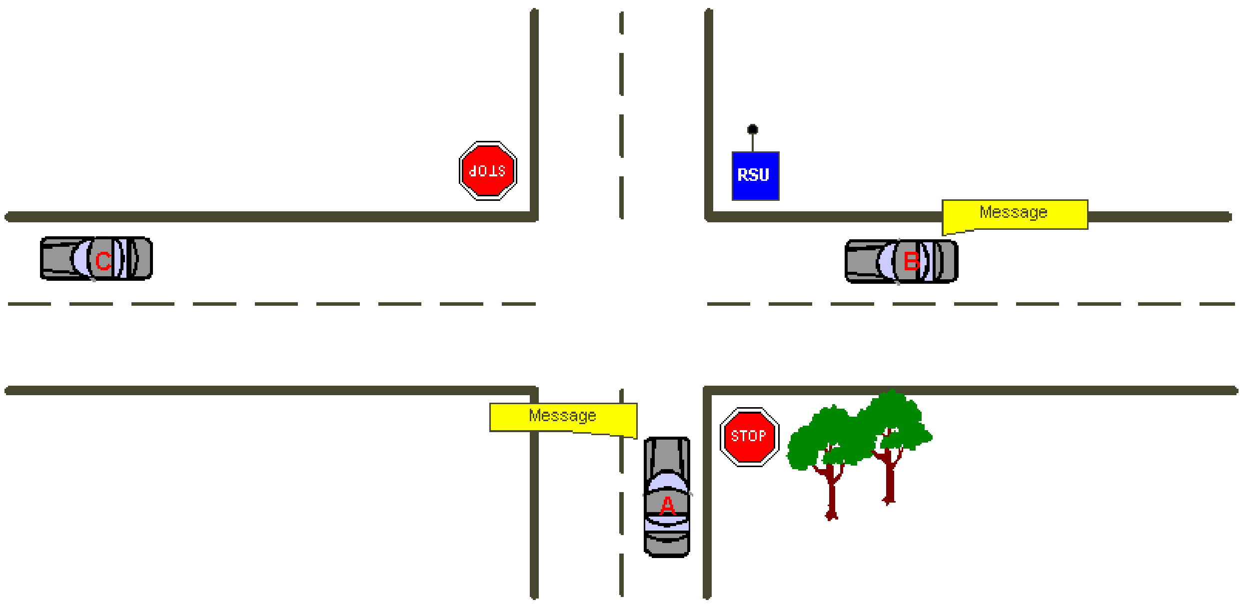


Figure 4.32 Stop Sign Movement Assistant Illustration B

c) A road-side unit (RSU), 1, is located at the intersection. RSU 1 is also equipped with radar sensors which look in all four directions. RSU 1 collects information about the vehicles near the intersection using radar and DSRC and transmits information about them to the surrounding area.

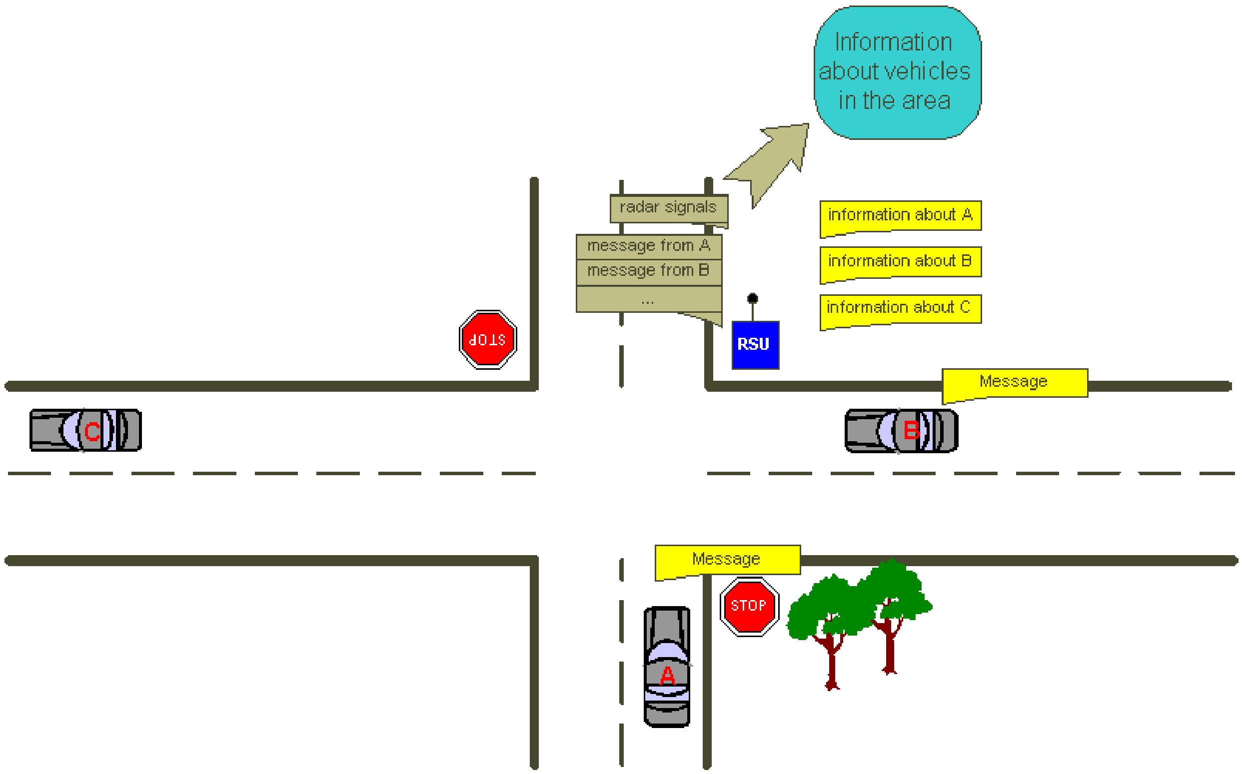


Figure 4.33 Stop Sign Movement Assistant Illustration C

d) Because vehicle A is at a stop sign, it listens for messages from the RSU and stores them in a memory table.

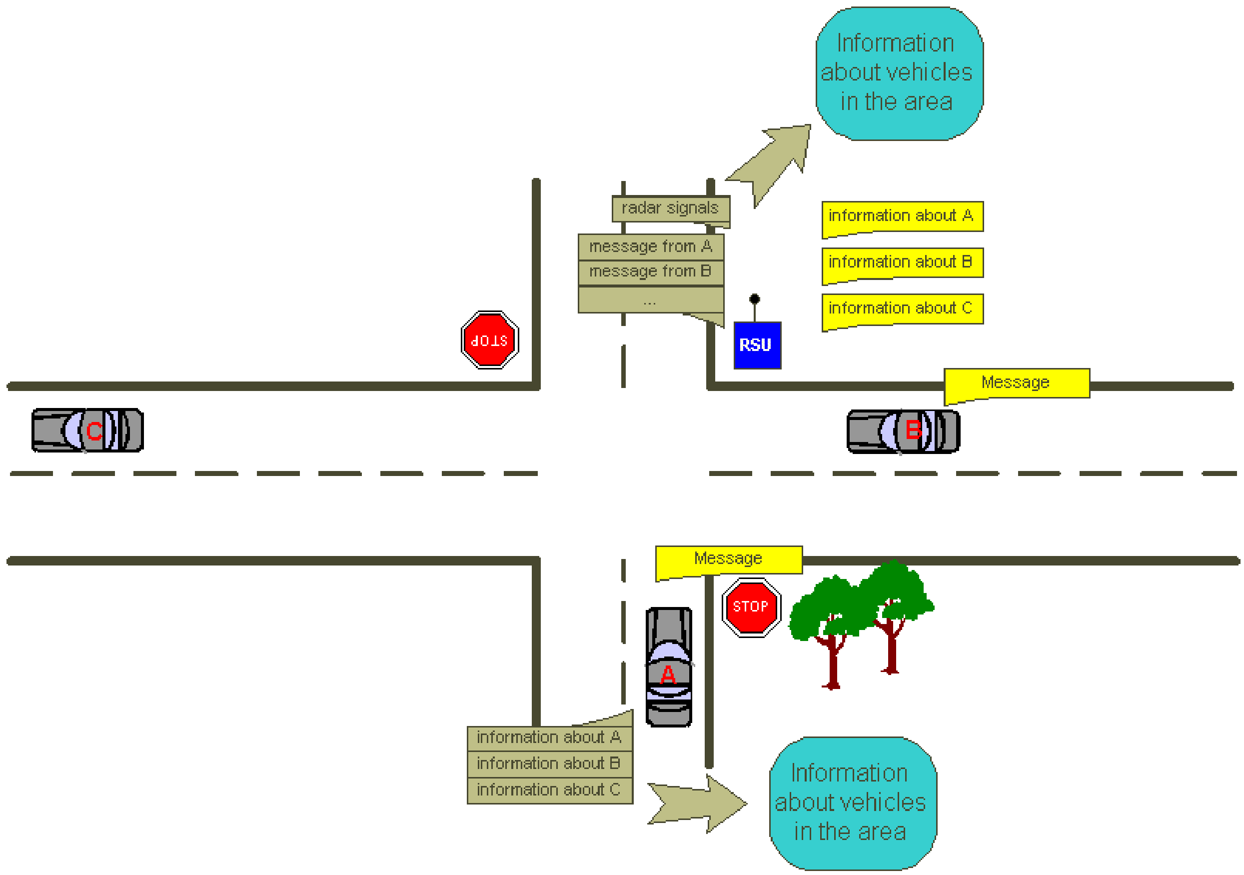
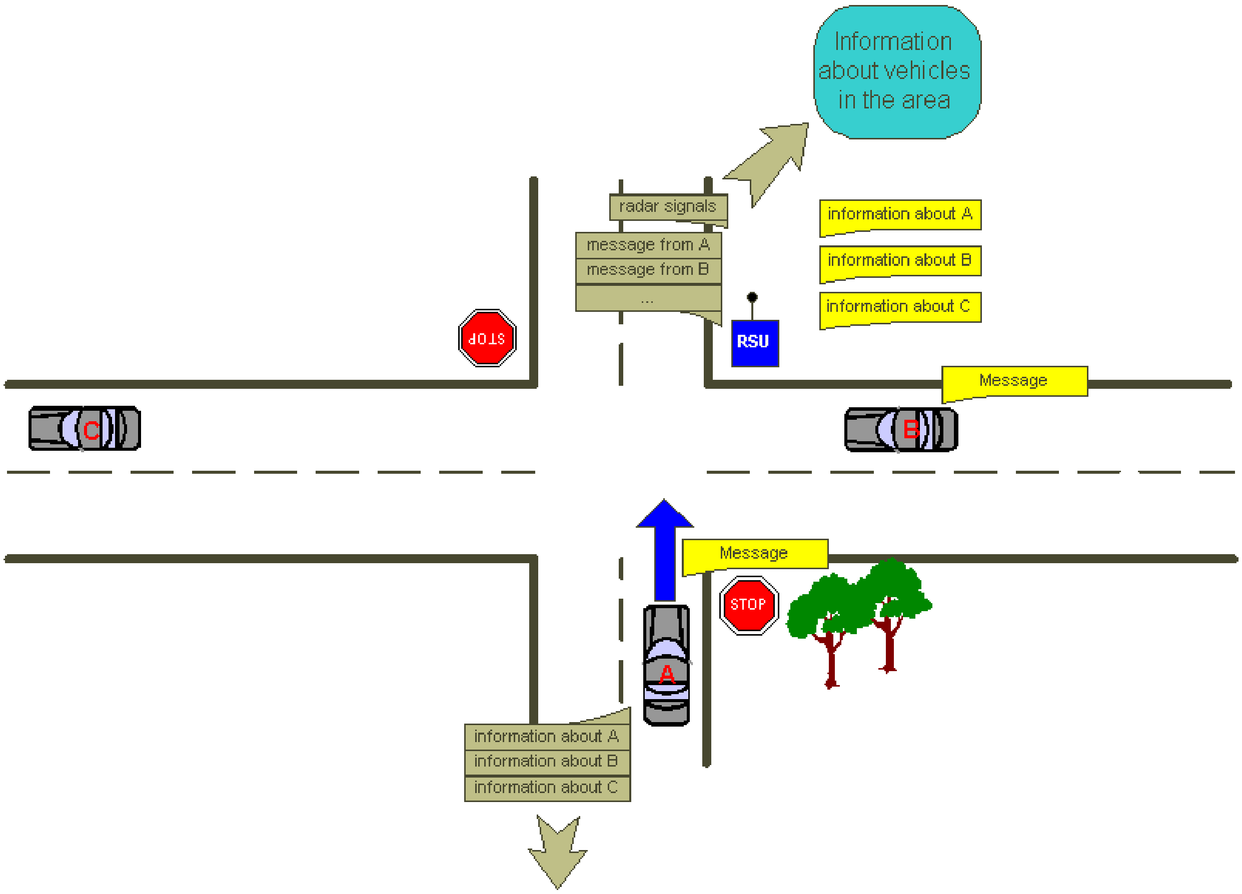


Figure 4.34 Stop Sign Movement Assistant Illustration D

e) When vehicle A intends to move from the intersection, its list of nearby vehicles is checked. If another vehicle is entering the intersection and a collision is possible, the driver of vehicle A is warned.



Vehicle	Velocity	Accel	Projected position	Time stamp	Distance	Time to expire	Relative position
B	60	1	Xx:xx:xx ; xx:xx:xx	Hh:mm:ss.ss	10	3	45
C	62	0	Yy:yy:yy yy:yy:yy	Hh:mm:ss.ss	45	2	300
...	...	...	...	...	...	...	...

Figure 4.35 Stop Sign Movement Assistant Illustration E

A more detailed view of the "nearby vehicle table" is provided in Table 4.10.

Table 4.10 Nearby Vehicle Table

Vehicle	Velocity (m/s)	Accel (m/s^2)	Projected position	Time stamp	Distance (m)	Time to expire (count)	Relative azimuth angle (deg)
B	20	1	Xx:xx:xx ; xx:xx:xx	Hh:mm :ss.ss	10	3	45
C	22	0	Yy:yy:yy ; yy:yy:yy	Hh:mm :ss.ss	45	2	300
…	…	…	…	…	…	…	…

Column heading descriptions:

Vehicle: identification of the sender (e.g. MAC address)

Velocity

Acceleration

Projected current position: extrapolated from other values

Time stamp: time when the message was received

Time to expire: the row with this entry will be removed if time expires

Distance: relative distance from host vehicle

Relative azimuth angle: relative position from the host vehicle

4.8.2.2 Block Diagram

The hardware architecture and information flow for the application host vehicle are shown in Figure 4.36.

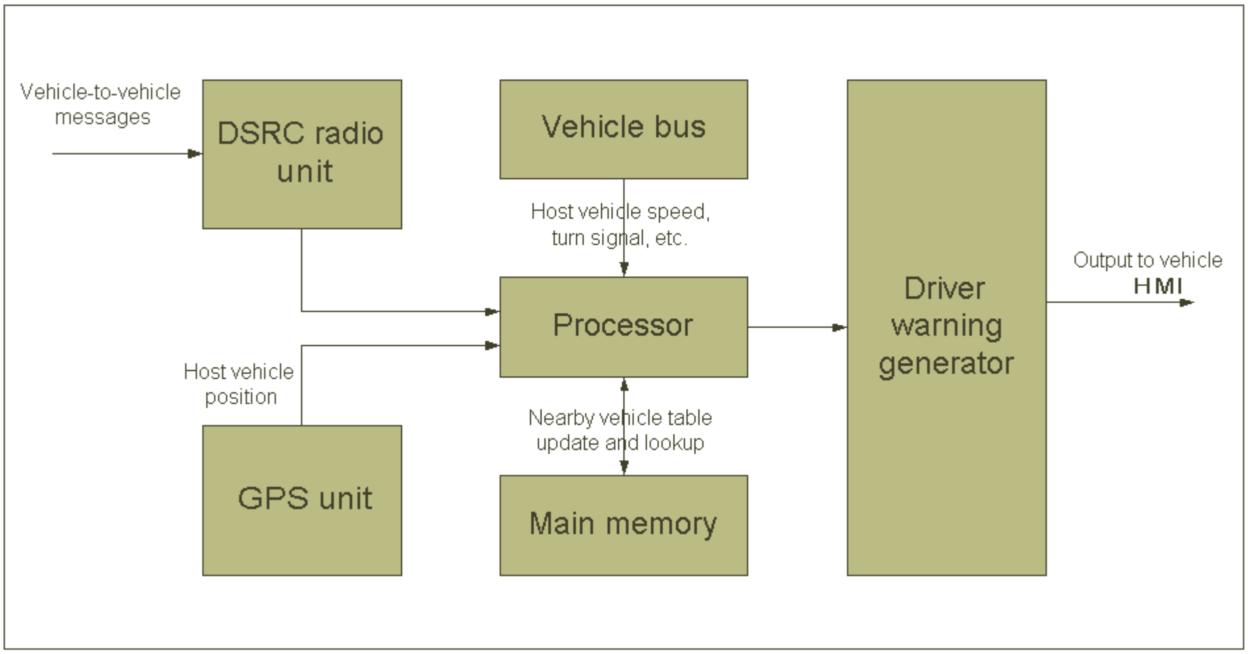


Figure 4.36 Application Host Vehicle Architecture and Information Flow

The hardware architecture and information flow for the vehicle-to-vehicle message sender are shown in Figure 4.37.

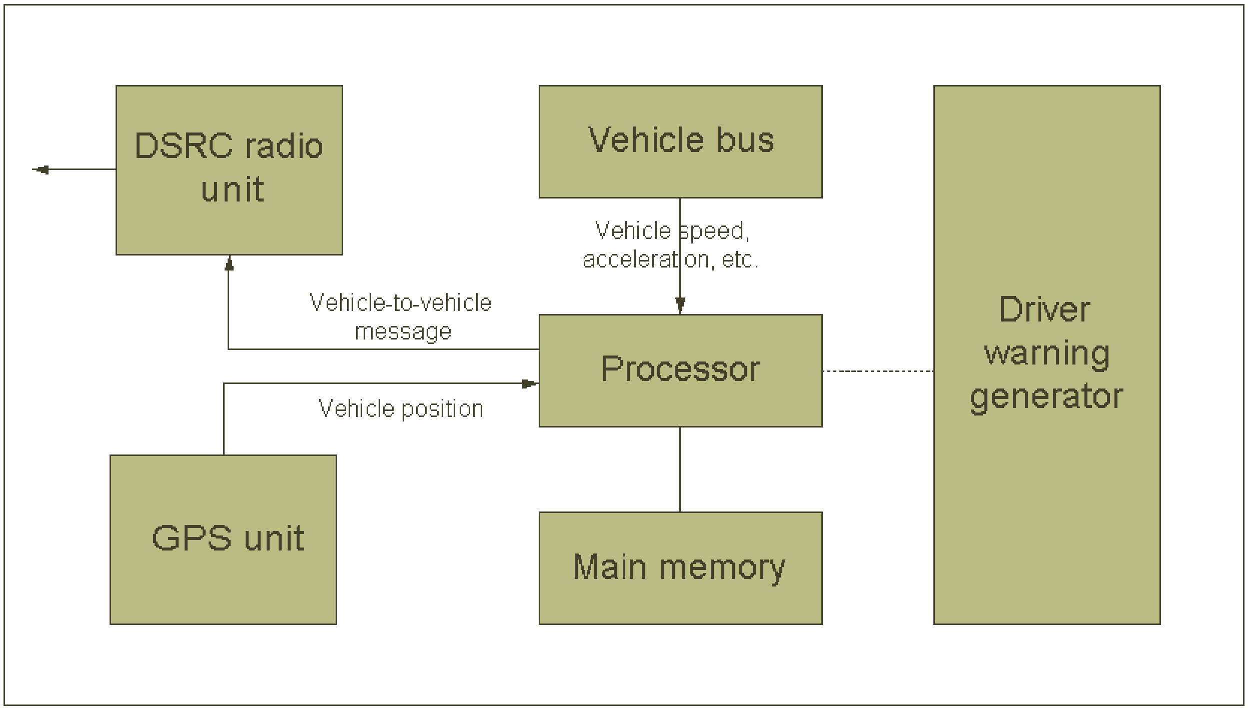


Figure 4.37 Vehicle-to-Vehicle Message Sender Architecture and Information Flow

The hardware architecture and information flow for the road-side unit are illustrated in Figure 4.38.

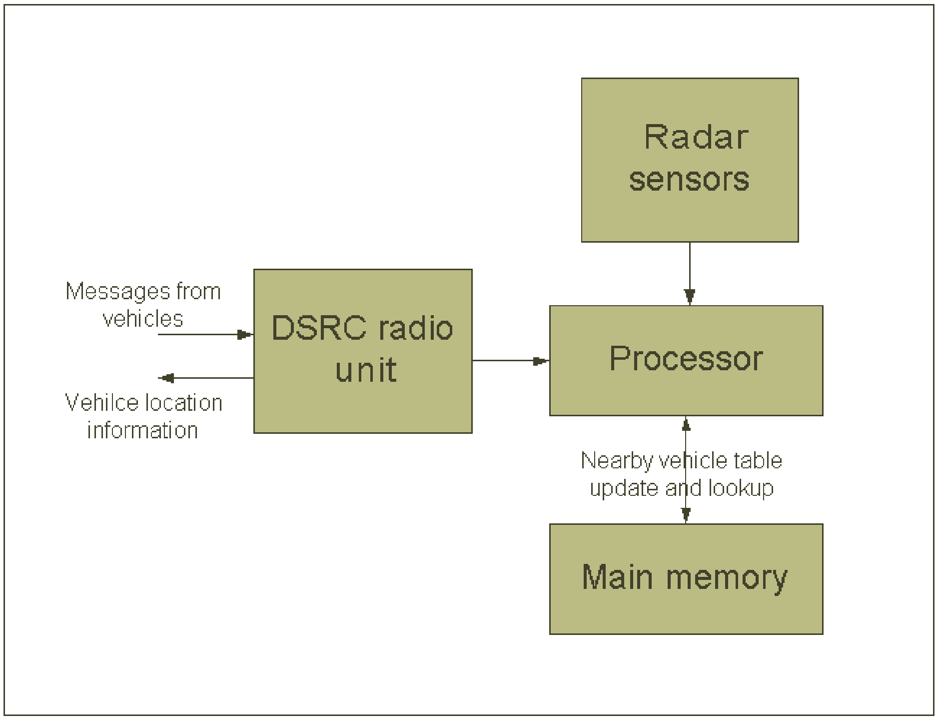


Figure 4.38 Roadside Unit Hardware Architecture and Information Flow

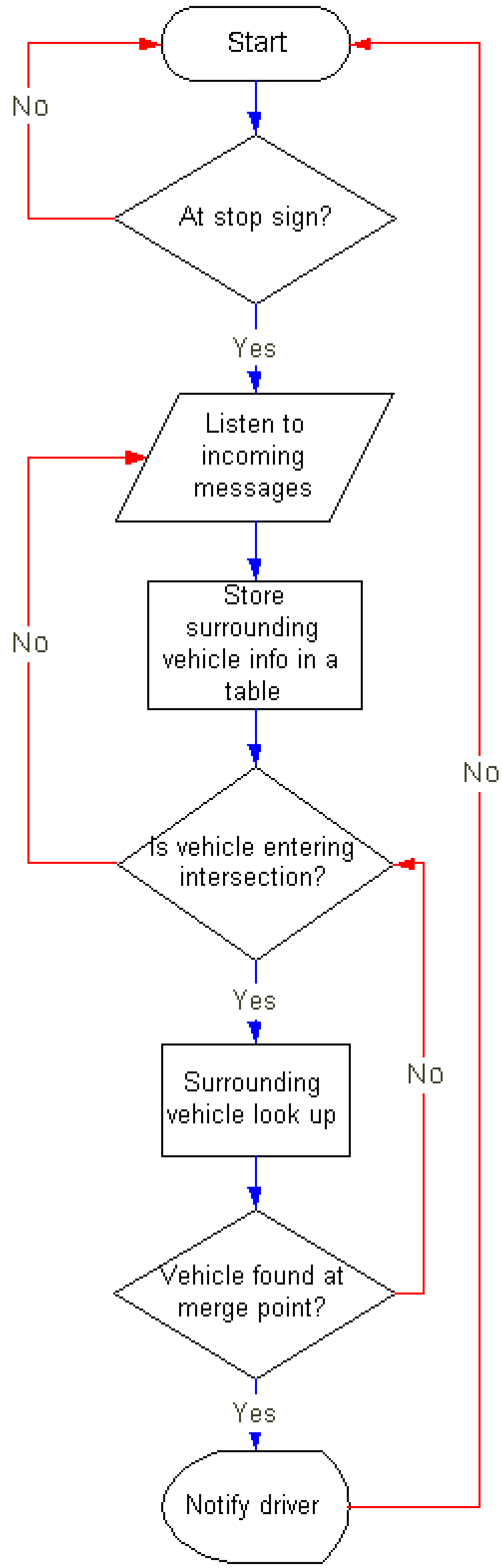


Figure 4.39 Stop Sign Movement Assistant Application Flow Chart

4.8.2.3 Sensors and Other System Needs

Besides the DSRC units themselves, information from other sources is necessary for the stop sign movement assistant application to operate. For the illustrated example, a DGPS unit, a map database, and a vehicle bus connection that provides vehicle speed are required in each vehicle. In the RSU, radar sensors or cameras are necessary.

DGPS is necessary for this application to function as illustrated. Because the separation between vehicles at an intersection can be small, the resolution of the distance between the host vehicle and the surrounding vehicles must be small. The host vehicle must also be accurately placed in relation to the intersection. A GPS receiver with high accuracy is thus required. A map database is also necessary, so that vehicles can determine whether other vehicles are traveling on the same road and whether they are in fact approaching the same intersection.

Each vehicle must broadcast its dynamic location, velocity, heading, and acceleration, so that the RSU can collect the information. The DGPS unit can provide the location and heading. The velocity and acceleration that could be calculated by the DGPS is relatively inaccurate when compared to the velocity (and possibly acceleration) that is available on most vehicle busses, and thus the version supplied on the bus is preferable. If the vehicle does not have a longitudinal accelerometer or otherwise doesn't have longitudinal acceleration available on a vehicle bus, then such a value must be calculated from the vehicle velocity or GPS signals.

As an alternative to the illustrated scenario, roadside units could be configured so that vehicles do not need GPS or a map database. If the roadside units have a small transmit area and multiple units are used at each intersection, they could send the vehicle information about the intersection and about other vehicles in the area, and the vehicle could position itself in relation to the intersection and other vehicles using dead-reckoning. The roadside units would determine the position of vehicles based on other sensors, such as cameras or radar. Though this alternative scenario is not illustrated here, allowances have been made in the communication section for the appropriate data to be sent.

The RSU must be equipped with radar or cameras to sense traffic approaching the intersection. These sensors are necessary to detect vehicles that do not have DSRC, as well as to provide a backup check for vehicles that do have DSRC. For both radar and cameras, signal processing would be used to provide accurate information regarding the location and velocity of vehicles in the vicinity of the intersection.

4.8.2.4 Data Message Set Requirements

The required vehicle-to-infrastructure data message set is shown in Table 4.11.

Table 4.11 Required Vehicle-to-Infrastructure Message Data

Description	**Size (bits)**
GPS coordinates	96
Time stamp	64
Vehicle speed	16
Vehicle acceleration	16
Vehicle heading	16

The infrastructure-to-vehicle message data required for this application scenario is shown in Table 4.12. Information about a pre-determined maximum number of vehicles will be sent, based on the maximum message length. This data includes information that would be required for a system that supports vehicles with or without GPS capability.

Table 4.12 Required Infrastructure-to-Vehicle Message Data

Description	**Size (bits)**
Intersection information, per link*	120
Time stamp	64
Link information, per link	48
Data per lane	16
Data per vehicle:	
Temporary vehicle ID	8
GPS coordinates	96
Vehicle speed	16
Vehicle acceleration	16
Vehicle heading	16
Distance from intersection	16

* A link is a right-of-way on a street: one-way streets consist of one link and two-way streets consist of two links, regardless of how many lanes they contain.

4.9 Security Requirements for High-Priority Applications

As stated in Section 2.1, various communications and/or system-level security measures may be employed for each of the applications listed. Potential security measures could include a method of assuring that the packet/data was generated by a trusted source, as well as a method of assuring that the packet/data was not tampered with or altered after it was generated.

For applications in which a road-side unit generates messages, a security scheme that assures that the message came from a trusted RSU is necessary. The scheme must also assure that the RSU cannot be compromised and false data then be sent. These applications include Traffic Signal Violation Warning, Curve Speed Warning, Left Turn Assistant, and Stop Sign Movement Assistant.

For applications in which an on-board unit generates messages, a security scheme that assures that the message came from a trusted OBU is necessary. The scheme must also assure that the OBU cannot be compromised and false data then be sent. These applications include Emergency Electronic Brake Light, Pre-Crash Sensing for Cooperative Collision Mitigation, Forward Collision Warning (FCW) System, Left Turn Assistant, Lane Change Warning, and Stop Sign Movement Assistant.

In all cases, the systems must have the capability to reject messages from known-compromised units. The security scheme also must be able to guarantee that messages have not been tampered with after they were sent.

At the present time, it is not clear whether appropriate security techniques will be implemented within the lower layers of the entire DSRC system, or will be implemented in the upper layers. It is possible that the security solution for vehicle safety applications may depend upon the DSRC system security solution, or, at the other extreme, that security for the vehicle safety applications may be implemented on an application-by-application basis within the upper protocol layers.

5 Conclusions

A number of conclusions can be drawn from this research. At the highest level of abstraction, the main conclusion is that DSRC is potentially an important enabler of a large number of vehicle safety applications, and that many of these applications offer significant potential safety benefits in the longer term.

5.1 Potential Vehicle Safety Applications Enabled by DSRC

Over eighty applications that are potentially enabled by DSRC have been identified just within the scope of this project. Having such a range of potentially enabled safety applications means that the installed cost of DSRC (and other required) hardware in vehicles may be able to be balanced by the benefits of the multiple applications, thus substantially reducing the effective cost-per-application.

5.2 Unique Capabilities of DSRC

The 5.9 GHz DSRC has a maximum range of 1000 meters within the current standards. Under most operating conditions, DSRC will be limited to less than 200 meters. This distance limitation is well-suited for many vehicle safety applications, since the other vehicles, or infrastructure, of interest for relevant safety-related communications seem to be generally within these kinds of ranges.

DSRC offers the capability of broadcast messages. This is a significant advantage over point-to-point wireless communications, like cellular, for vehicle safety applications. With cellular technology, for example, it would be difficult to know in advance the cell phone numbers of other vehicles that may come in close proximity.

One of the most significant potential advantages of DSRC technology is the capability for very low latency communications. Latencies of less than 100 milliseconds seem to be possible with DSRC, and many of the vehicle safety applications have latency requirements in this range. Latencies in this range do not appear to be achievable with other wireless communications technologies that are widely available or currently being planned for wide deployment.

Another major benefit of 5.9 GHz DSRC is the potential for high-availability communications. Portions of the 5.9 GHz DSRC spectrum can be designated for high-availability access, and used, for example, for two vehicles on an imminent collision course to exchange vital information during the last 500 milliseconds before impact. This vital information exchange could potentially allow the vehicles to better prepare to protect the occupants from the impact. On most other wireless communications systems, voice services have priority, and data has a secondary role.

5.3 Vehicle-to-Vehicle versus Vehicle-to/from-Infrastructure

The vehicle safety applications identified in this report fall into two communications categories: vehicle-to-vehicle and vehicle-to/from-infrastructure. The identified applications, as envisioned in the various scenarios described in this report, are almost evenly divided between these categories. The implication is that the wireless communications system chosen to support vehicle safety applications must include capabilities for both categories of communications. DSRC appears to have the potential to support both categories of communications with a single transceiver installed in the vehicle.

5.4 Estimated Potential Safety Benefits

Evaluation of the estimated potential safety benefits of the envisioned vehicle safety applications, based upon the crash scenarios, indicates that there could be a reasonable expectation of safety benefits from the deployment of a number of the vehicle safety applications. Since the estimated potential safety benefits were scaled only in relative terms among the applications being evaluated, no potential safety benefit estimates in absolute terms were developed.

5.5 Deployment Time Scale

With the expected completion of ASTM and IEEE core DSRC standards in the first half of 2004, the earliest possible deployment of DSRC vehicle safety applications on production vehicles is likely to be in 2007. Since many of the potential safety benefits of the vehicle safety applications derive from a wide deployment in vehicles and relevant roadway infrastructure, it is likely to take more than a decade to begin realizing significant safety benefits.

5.6 High-Priority Vehicle Safety Applications

The evaluation of estimated potential safety benefits produced a relative ranking of the identified vehicle safety applications. Eight vehicle safety applications were selected as high-priority applications for further evaluation based upon this ranking: Traffic Signal Violation Warning, Curve Speed Warning, and Emergency Electronic Brake Lights were selected as the highest rated near-term applications; Pre-Crash Warning, Cooperative Forward Collision Warning, Left Turn Assistant, Lane Change Warning and Stop Sign Movement Assistance were selected as the highest rated mid-term applications. These eight applications were viewed as representative of the vehicle safety applications from the standpoint of determination of communications requirements. As well, three of the selected applications relate to intersection collision avoidance, which is an explicit focus of this research project.

5.7 Communications Requirements for High-Priority Vehicle Safety Applications

The eight high-priority vehicle safety applications were further analyzed, and more detailed communications requirements were developed. This more detailed view of communications requirements reinforced the general 100 millisecond latency requirement, and the broadcast nature of the communications required. In addition, the data packets to support most vehicle-to-vehicle communications were determined to be less than 100 bytes. Infrastructure-to-vehicle packets were generally a bit larger, with a maximum size of around 430 bytes required for the left turn assistant application scenario.

5.8 Security Issues

The general requirements for broadcast-based communications, including the need to make sure that the transmission comes from a trusted source (and has not been tampered with), have been input into the DSRC standards process. However, the solutions are not obvious. Most security solutions being discussed in the standards process have been designed for wired networks, or, at least, two-way communications on a point-to-point basis. Additionally, a threat assessment must be completed for the various vehicle safety applications before the necessary level of security required can be determined. If a significant level of security is determined to be required for the vehicle safety applications, then the necessary security overhead may seriously degrade the system capabilities in terms of latency and/or channel capacity. There is clearly a need to better understand these issues.

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