NISTIR 5444

Recommendations on Selection of Vehicle-to-Roadside Communications Standards for Commercial Vehicle Operations

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U.S. DEPARTMENT OF COMMERCE
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Recommendations on Selection of Commercial Vehicle-to-Roadside Communications Standards

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1. Executive Summary

The National Institute of Standards and Technology (NIST) Robot Systems Division is participating in a Federal Highway Administration (FHWA) program that is to lead to the recommendation of standards in Vehicle-to-Roadside Communications (VRC) equipment used in commercial vehicle operations (CVO). There is substantial motivation to develop these standards, both on the part of the government and the CVO community. A standardized VRC system will allow states to check credentials, weight, and safety parameters while commercial vehicles travel at highway speeds of up to 160 km/h This will improve the current situation in which substantial time and productivity is lost while commercial vehicles stop and wait for inspections. More sophisticated systems may employ weigh-in-motion equipment, on-vehicle sensors to determine brake temperature and other parameters in real-time, and other subsystems (navigation, etc.) capable of generating relevant data. This communications link will serve an important role in passing data between various on-board intelligent control system computers and the roadside systems.

Numerous incompatible VRC designs and protocols exist, or are being developed. The deployment of incompatible systems will not result in transparent borders, where a truck can pass, for example, from one state to another without stopping. A standard is to be developed or chosen that will meet current and projected requirements, such as those of the Intelligent Vehicle Highway System (IVHS).

This is an intensive program, intended to yield results early enough to reduce the current proliferation of incompatible systems. The standards of interest are associated with the transponder on the vehicle. One such standard will specify the interface between the transponder and the roadside communications equipment (the RF interface). The other standard of interest will specify the interface between the transponder and an On-Board Computer (OBC).

While this program focuses on the transponder technology and interfaces, development of these standards requires an understanding of the impact which they will have on roadside communication components and infrastructure as well as an understanding of the transactions to be conducted through the VRC system. The specified interfaces must be capable of supporting the present needs of CVOs in all states, and anticipated future uses. To understand the scope of the problem, consider that each state currently maintains data bases on operating authority, vehicle registration, motor fuel taxes, oversize and overweight permits and motor carrier safety inspections. Typically, these are independent data bases maintained by separate state agencies that include public service commissions, departments of motor vehicles, departments of revenue, departments of transportation and state police or highway patrols. Information specific to the driver is also important. The states vary widely in the current level of automation, if any, of these data bases. As a result, many important issues must be considered. These include the issues of data distribution (How much information is on-board the vehicle? How much does a driver carry on a smart card?), performance (How frequently must the data be updated? What

transactions need to occur in real-time as the vehicle passes a VRC reader at highway speed?), and security (prevention of tampering with the information).
NIST interacted with various CVO user bodies, VRC equipment manufacturers, state Department of Transportations (DOTs), IVHS planners, Lawrence Livermore National Laboratory (LLNL), and other government agencies to determine the current and projected VRC requirements for CVO and the current and expected near-term capabilities of numerous systems and protocols. Fifteen systems and six protocols were examined in this study, which began in April 1993 and concluded in December 1993.

As a result of this effort , we have been able to:

1. Identify the requirements of a system that would support CVO.

2. Identify the current and expected near-term capabilities of applicable VRC technology and standards.

3. Determine that the present and expected near-term CVO requirements can be met by existing or very near-term systems.

4. Determine that a standard protocol can be defined that is based largely on existing public domain protocol specifications which will have the capabilities required for CVO functions.

5. Provide specific recommendations for protocol and technical characteristics to FHWA for inclusion in a CVO VRC standard.

2. Introduction

2.1 Background

Under the sponsorship of the Federal Highway Administration (FHWA), the National Institute of Standards and Technology (NIST) and Lawrence Livermore National Laboratory (LLNL) began a program in April 1993 to examine Vehicle-to-Roadside Communications (VRC) systems and standards in an effort to reduce incompatibilities through recommendations for interface standards for Commercial Vehicle Operations (CVO). A typical VRC system employs a roadside communication element, an on-vehicle transponder or tag, possibly an interface between the on-vehicle transponder and the on-vehicle computer, and an on-vehicle operator interface that may contain a display or smart card type device. NIST's Robot Systems Division was tasked to perform a rapid determination of CVO requirements, examine the available technologies and their expected performance and capabilities, and present recommendations to FHWA for standardization of the VRC protocol and characteristics of the transponder to On-Board Computer (OBC) interface.

This has been an intensive program, intended to yield results early enough to reduce the current proliferation of incompatible systems. The standards of interest are associated with the transponder on the vehicle. One such standard will specify the interface between the transponder and the roadside communications equipment (the RF interface). The other standard of interest specifies the interface between the transponder and an on-vehicle computer.

While this program focused on the transponder technology and interfaces, development of these standards requires understanding the impact on the roadside communication components and infrastructure as well as an understanding of the transactions to be conducted through the VRC system. The specified interfaces must be capable of supporting the needs of CVOs in all states, and anticipated future uses. To understand the scope of the problem, consider that each state currently maintains data bases on operating authority, vehicle registration, motor fuel taxes, oversize and overweight permits and motor carrier safety inspections. Typically, these are independent data bases maintained by separate state agencies that include public service commissions, departments of motor vehicles, departments of revenue, departments of transportation and state police or highway patrols. Information specific to the driver is also important. The states vary widely in the current level of automation, if any, of these data bases. As a result, many important issues must be considered. These include the issues of data distribution (How much information is on-board the vehicle? How much does a driver carry on a smart card?), performance (How frequently must the data be updated? What transactions need to occur in real-time as the vehicle passes a VRC reader at highway speed?), and security (prevention of tampering with the information).

2.2 Description of Problem

Numerous incompatible VRC designs and protocols exist, or are being developed. The deployment of incompatible systems will not result in transparent borders, where a truck can pass, for example, from one state to another without stopping. A standard is to be developed or chosen that will meet current and projected requirements, such as those of the Intelligent Vehicle Highway System (IVHS).

There is substantial motivation to develop these standards, both on the part of the government and the CVO community. A standardized VRC system will allow states to check credentials, weight, and safety parameters, while commercial vehicles travel at highway speeds of up to 160 km/h. This will improve the current situation in which substantial time and productivity is lost while commercial vehicles stop and wait for inspections. More sophisticated systems may employ weigh-in-motion equipment, on-vehicle sensors to determine brake temperature and other parameters in real-time, and other subsystems (navigation, etc.) capable of generating relevant data. This communications link will serve an important role in passing data between various on-board intelligent control system computers and the roadside.

2.3 Previous Related Work

Several groups have been meeting to address the VRC incompatibility issue. An ASTM group has been working to develop a standard for short range, two-way VRC equipment. This group consists of members from FHWA, state DOTs and vendor representatives. An Electronic Toll and Traffic Management (ETTM) User's group, which consists of toll authority representatives, state DOTs and members from FHWA, has also met to specify ETTM user requirements for future national compatibility. Lawrence Livermore National Labs, working with the California Department of Transportation (CALTRANS), has also developed a VRC standard for toll collection which is, at the present time, the standard VRC protocol for the state of California.

2.4 Approach

NIST interacted with various CVO user bodies, VRC equipment manufacturers and vendors, state DOTs, IVHS planners, Lawrence Livermore National Laboratory, and other government agencies to determine the current and projected VRC requirements for CVO and the current and expected near-term capabilities of numerous systems and protocols. Fifteen systems and six protocols were examined in this study. The results of this study are reported in this document.

In Section 3 we document the necessary technical attributes of a VRC system that are required for it to perform specific CVO functions. Further, attributes which might be needed for future IVHS functions were considered in an effort to determine the future demands on a VRC system. Three data models are defined that essentially form three different groupings of CVO functions. These models provide a means to compare system capabilities to three possible, and increasingly sophisticated, implementation configurations. The models represent the possible evolution of CVO VRC systems from the present into the future. The CVO (and future IVHS) user services that were determined were then documented in a matrix which indicates the technical characteristics or requirements that must be present to perform each service.

In Section 4 we document the technologies that are available or expected to be available in the near future for VRC implementations. First, we examine a number of communications protocols for the tag-to-reader RF interface and document their important characteristics. The most important parameters of each protocol are summarized in a matrix. Similarly, the capabilities of currently used on-board computer interfaces and of other standard communication interfaces that might be considered for use as an on-board computer interface are presented. Numerous VRC systems were examined in order to obtain an understanding of the current capabilities of VRC for CVO, and to determine what capabilities might be reasonably expected in the near future. The characteristics of the examined systems are documented.

In Section 5 we evaluate the information presented in Sections 3 and 4 and provide conclusions and recommendations. Section 6 includes a reference list for the resources used in this study and Section 7 contains an Appendix of supporting information.

3. Identification of Requirements

Many uses of tag technology have been implemented, planned or considered. Each potential use places certain requirements on the VRC system. This section reviews these services or functions, and presents the technical requirements that would likely to be needed to implement each. In an effort to gather enough information to guide the selection of the best type of VRC system, three types of information have been considered. First, in order to best estimate the needs of the future and to increase the potential application areas of a standardized CVO VRC, services envisioned under the IVHS program which are not CVO services have been examined. Second, several sources were studied to determine CVO- specific services and their requirements. Finally, a number of requirements that are not related to specific services, and are known in advance were also studied. These include characteristics of the VRC system such as its necessary ruggedness, weather resistance, etc. These are all described, but only those that might differentiate possible implementations are included in the requirements matrix which is presented later.

3.1 Relevant IVHS Services

Numerous services that could use tag technology are envisioned under IVHS outside of those being considered for CVO operations. The Vehicle-to-Roadside Communications subcommittee of ASTM (E17.51) has documented many of these as part of its standardization effort [1]. This section briefly describes these services. It is useful to keep these services in mind in the selection of a VRC solution for CVO. An ideal VRC solution would support these services as well. If this is not reasonable, a VRC solution can be selected which does not exclude these capabilities simply through lack of consideration. Most require capabilities that are quite similar to those needed for CVO activities. These services all require a reader/tag system in which the tagged vehicle passes through the operational field of the reader and data is exchanged. Differences lie in the nature of the transactions and the amount of data to be exchanged. Instances where significant differences in requirements exist are pointed out.

3.1.1 Electronic Toll Collection (ETC)

Several variations on ETC systems exist or have been described [2, 3, 4, 5, 6, 7]. The most common is a open road application where the tag sends an ID to the roadside reader. The vehicle is instructed to proceed via signs or lights. Transaction processing is handled off-line. This requires only a read-only tag system. Additional vehicle classification equipment may also be used. Systems intended to record toll road entry location information (as in the case of a closed road application) or value information (stored-value tags) in the vehicle tag require read-write tag technologies. Current tag technologies support ETC with a small amount of data (128 to 256 bit tags).

3.1.2 Airport Applications, Commercial Vehicle Fee Collection (CVFC)

These systems are used for the automated collection of fees from commercial vehicles when they enter and leave airports with customers. Examples include taxis, limousines, and hotel and rental car shuttles. Various accounting methods are used to determine cost, with the vehicle owner typically being billed for each month's charges. The information exchanged includes: transaction information, lane information, and detection of a violation (based on time-of-day, etc.). Processing is performed off-line and a read-only tag is sufficient. Data quantities are comparable to the ETC service.

3.1.3 Airport Applications, Restricted-Access Roadways (RAR)

RAR systems provide access control for restricted roads within airports. The tag simply provides the proper authorization to allow passage. Vehicles with invalid tags or no tags will not be allowed to pass. Operation in multiple-tag environments may be required, for example, where trains of containers or personnel carry the tags. Data requirements are minimal and read-only capability is sufficient.

3.1.4 Transit and Intermodal Operations

Numerous applications for tag technology are envisioned for transit operations. They include:

Position Location

Vehicle position along a route can be monitored in terms of the location of the last reader contacted and the time since that contact. Location resolution is determined by reader spacing. Read-only capability is sufficient and data quantity is small, consisting of a vehicle identification.

Schedule Monitoring and Control

A two-way VRC (read-write tag technology) equipped vehicle could, on the basis of schedule monitoring information, be directed to adjust its behavior through by-passing stops, or waiting at stops in order to more accurately comply with the schedule. Only small amounts of data should be necessary to convey these schedule adherence adjustments.

Dynamic Dispatching

Dynamic dispatching activities might include the uploading of schedules, and routing and assignment data through the VRC system to a vehicle on-board computer. This service is more demanding of the VRC system than those previously described in two ways. First, it entails the communication of what are probably the largest data records among the proposed transit uses of VRC, and second, it requires the existence of an interface between the tag and an on-board computer. The route data (perhaps on the order of hundreds of bytes) must be exchanged during a pass by the reader, which dictates the required performance of the VRC system. The transfer of this information to the on-board computer should be timely, but is not required to be completed at the reader location. Therefore, the transfer rate of this interface can be considerably slower. Completion within a minute or so is probably sufficient to keep pace with the rate of information update.

Vehicle Condition Monitoring

The ability to obtain vehicle operational and maintenance information on-route and at terminals is envisioned through the use of VRC technology. An on-board computer would likely collect the information and provide it to the tag through an interface. Provisions for engine and vehicle diagnostics, fuel and fluid levels, odometer reading and other information has been suggested. Clearly, the set of potentially useful information is nearly endless. However, the amount of critical information which is needed from the vehicle, at operating speed, is probably a small subset. Other more detailed information could be available to systems at the terminal, avoiding the exchange of these longer records at highway speed.

Priority treatment at intersections, HOV lanes

A transit vehicle can make its presence known at access points along HOV lanes or at intersections capable of providing priority treatment through signaling. A read-only capability and the transmission of an identification would be sufficient for this service.

Automatic Switching

Train contents, route, trip and special information can be used by rail switching stations. However, information beyond an ID could require lengthy data records that must be exchanged at train speed.

Automatic next stop announcements

Next stop announcements can be performed automatically if the identity of the present stop is known. This requires two-way communication and only a small amount of information.

Toll Collection (see ETC above)

Passenger Count

Schedule adherence and dynamic dispatching decisions can be improved with passenger count information from the vehicle. This requires only a small amount of data and probably would be included with some other vehicle status message.

Intermodal Operations

In addition to providing more current and accurate schedule information, hand-carried transponders may be used to pay transit fares, indicate destinations and to gain access to schedule information systems. These applications seem similar to toll applications in that only small amounts of information need be carried and the hand-carried unit may or may not contain "stored-value." On the other hand, they need not operate at highway speeds, and a premium would be placed on small size, light weight and low power consumption.

Safety/Environmental Monitoring

Failures of emission-critical vehicle components can be detected by on-board diagnostic systems. It may be feasible for vehicles with such a failure to report their identification and fault codes.

Waste Management

Waste management involves the identification of the carrier and any hazardous material on the vehicle while at the landfill site. This is a relatively simple application requiring only read-only tag technology, with the hazardous waste information adding somewhat to the amount of data required. A reasonable assumption would be that data would not exceed on the order of 100 bytes.

Hazardous Material Transportation

Equipping hazardous material transporting vehicles and hazardous material containers with VRC tags will enable automatic monitoring for regulatory compliance, fee payment, electronic bills of lading and other related services. This will enhance the effectiveness of enforcement and emergency response operations. Because of the importance of controlling and monitoring the movement of hazardous materials, it is probably reasonable to assume that the amount of information, even if it only identifies the cargo in detail, could be quite large, perhaps several thousand bytes. It is not clear what quantity of information would need to be exchanged at highway speeds.

Traveler Information (TI)

Traveler Information is a term used to cover a wide variety of information types that could be sent from the roadside to vehicle to assist the driver. This includes information on congestion, alternate routes, navigation and vehicle location. This type of information could be expected to exceed several hundred bytes, and require transmission at highway speeds. More accurate traveler information can be provided if more traffic information is available to traffic management centers. Use of two-way communication would allow traffic management centers to receive information from the vehicles.

Commercial Services (CS)

This service category covers another wide range of services including travel service information, restaurant and hotel reservations, automobile service center information, personal voice mail and faxing, and entertainment services. While many services could be provided that require only small amounts of data, some have been estimated to require 100K bytes of data. Two-way communication would also be required.

Traffic Management (TM)

VRC equipped vehicles may be used as probes for traffic management purposes. A single vehicle, tracked through a series of readers, provides information necessary to infer traffic flow rate. If the VRC system can discriminate between lanes, incident detection capability is enhanced. This service requires only a unique vehicle identifier and read-only technology.

Emergency Messaging (EM)

The ability to generate an SOS type message would be very useful in a number of emergency situations. The message itself would likely be short and not place a great demand on the system. The practicality of this approach rests on how likely it is that a short-range transmission from a vehicle would be picked up by an appropriate receiver, be it another vehicle or a reader. In any event, since the vehicle must initiate the message, two-way communication would be required.

3.2 CVO Requirements

The following section is a list of Commercial Vehicle Operations (CVO) services that would be supported by Vehicle to Roadway Communications (VRC) and a description of each service. Several sources of information were use in compiling this list [8, 9, 10]. In addition, documentation describing current and planned testbed programs, such as the HELP program were reviewed for their contributions to the requirements definition [11, 12, 13]. We have provided here what we believe to be reasonable estimates for the amounts of data required for each service. Specific implementations may vary, but based on a few assumptions, these numbers should be reasonable. One assumption is that the information that is typically text, such as Carrier Name, is stored as text (that is, one 6-bit byte per character) rather than as some more compact encoded form. Appendix A provides the details of how each estimated field size was determined.

3.2.1 Automated Safety Verification

The Automated Safety Verification service is aimed at significantly enhancing the safety of commercial vehicle operation. This service can be divided into three areas:

Roadside Access to Safety Records

This function will develop safety record systems to allow enforcement officers to access selected safety records on the commercial vehicle, motor carrier, and driver from the roadside. The safety records will include: 1) safety fitness and performance of the motor carrier, 2) vehicle-specific safety records such as the date and violations since the last inspection, and 3) the safety record of the driver. This information would provide an inspector with additional information to make a decision about which drivers and vehicles to perform a detailed inspection on and which to let pass an inspection facility.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• License plate number and state for each vehicle unit	50 bits

• Driver name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS)	32 bits

Estimated Message Length: 520 bits

Roadside Safety Records and Status Verification

This function will use advanced technology devices to quickly and accurately check the vehicle's and driver's safety condition. This includes 1) data entry and information access; 2) automated vehicle inspection; 3) driver safety status; and 4) covert monitoring of Out Of Service vehicles (OOS).

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• License plate number and state for each vehicle unit	50 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS)	32 bits

Estimated Message Length: 520 bits

On-board Safety Monitoring

This function would enable enforcement officers, motor carrier logistics, safety, dispatch personnel, and drivers to review vehicle, cargo, and operator safety status while the Commercial Motor Vehicles (CMVs) are traveling at highway speeds.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• Whether or not cargo is hazardous materials	4 bits
• Driver ID Number (CDL number & state of license)	86 bits

Estimated Message Length: 294 bits

3.2.2 Cross-border

The concept of this service is to extend the technologies for preclearing commercial vehicles at state borders to North American border crossings.

Automating the international border crossing process will require the involvement and cooperation of safety enforcement, registration, fuel tax, immigration and customs agencies of the three countries as well as local transportation officials from the various states and provinces.

The service as envisioned would allow automated clearance of regular cross-border commercial vehicle operations. This would likely involve the use of transponder-equipped trucks, smart cards for driver identification and clearance, electronic data interchange between certified shippers or customs agents or an electronic bill of lading on the vehicle; the ability to check carrier safety and credential records; and two-way communications to the vehicle signaling the driver to pass the checkpoint or to come in for further inspection.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits
• Whether or not cargo is hazardous materials	4 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS)	32 bits
Estimated Message Length:	560 bits

3.2.3 Electronic Credentials

By the year 2000 a nationwide electronic network could be created which would allow commercial vehicles to travel from one state to another without stopping at state borders to check paperwork for fuel, registration, etc. This electronic network will also help to more efficiently comply with state tax report preparation, auditing, and insurance requirements.

Electronic Purchase of Credentials

The electronic purchase of credentials would allow a motor carrier to apply for, pay for, and receive a variety of credentials electronically from a base state. Under this system a trucking company could apply for and obtain annual state credentials (e.g., registration, fuel tax, trip, oversize/ overweight, hazardous materials etc.) via a computer hook-up to the base state for annual credentials and to individual states for temporary credentials (e.g. trip permits).

This is an off-line function.

Pre-Travel Verification of Credentials

Another major function of the electronic credentials service is the pre-travel verification of credentials. This function would provide carriers with the ability to verify state credentials/ requirements prior to the start of a trip. The carrier could then access individual state licensing databases or a bulletin board and check the registration and permitting requirements for the trip or the status of a particular vehicle or fleet of vehicles prior to dispatching. With this capability, a carrier could put its vehicles on the road and be assured that they would be legal in every state in which they travel.

This is an off-line function.

Nationwide Motor Carrier Advisory Bulletin

Another way to improve the credential process is the establishment of a nationwide Motor Carrier Advisory Bulletin Board. Such a bulletin board program would provide carriers with up-to-date information on credential and permitting requirements in each state, including information on whether new requirements or procedures have been added or existing requirements have been changed or eliminated.

This is an off-line function.

Mainline Verification of Credentials

Mainline verification of credentials requires the capability to identify a vehicle and to check its credentials without having to stop it. This can be done by either transmitting credential information stored in an on-board computer through a transponder mounted on the truck to a roadside reader for evaluation by state enforcement officials or by the official accessing a database elsewhere. Readers at the Port Of Entry (POE) for a state would query the truck's transponder for the credential information and determine whether the carrier is in compliance with state requirements. If the carrier's credentials are in order, the driver would be signaled not to stop. Weight information from weigh-in-motion devices could also be provided to the POE computer at the same time. In this way, the computer could compare the actual weight of the vehicle against the registered axle weights and determine if the vehicle is traveling legally.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits
• Whether or not cargo is hazardous materials	4 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS)	32 bits

Estimated Message Length: 560 bits

Electronic Mileage and Fuel Reporting

Another credential-related service that would benefit both states and the motor carrier industry is electronic mileage and fuel reporting. Even with greater standardization stemming from the International Registration Plan (IRP) and the International Fuel Tax Agreement (IFTA), compliance with state tax reporting and record keeping requirements is still a major effort for the motor carrier industry. For registration and auditing purposes, a carrier is required to maintain accurate mileage and vehicle information. This information is captured for each trip on an Individual Vehicle Mileage Record (IVMR). Information including location, date, time, mileage, and fuel purchase from credit or smart cards could be captured at state crossings. This information could replace the manual trip log which is typically prepared by the driver. The mileage information could be recorded either/both in an on-board computer or in a remote computer location managed at the state or national level. This data would then provide the means to automatically create tax reports. A fleet management software package could be developed to calculate tax liabilities and prepare tax reports. Such software would match fuel purchased with mileage data to calculate a carrier's tax liability.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits

Estimated Message Length: 278 bits

3.2.4 Fleet Management

Fleet management has primarily been a private sector activity. However, the FHWA is asking whether there is a need for public or DOT involvement to: l) facilitate intermodal transfer, 2) provide real-time traffic information to dispatchers and, 3) provide information to carriers on the benefits of improved terminal operations. Also this service would support and complement public sector initiatives in safety and regulatory enforcement and DOT initiatives in intermodal transportation.

This service would provide real-time communications between commercial vehicle drivers, dispatchers, and intermodal transportation providers which would: l) reduce delays for drivers and 2) provide commercial drivers and dispatchers with real-time routing information in response to congestion or incidents.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• License plate number and state for each vehicle unit	50 bits

Estimated Message Length: 266 bits

3.2.5 Hazardous Materials

This service is aimed at enhancing the safety of shipments of hazardous materials by truck. Hazardous material shipments might include paint being transported to the local hardware store, truckloads of gasoline being delivered to local service stations, and nuclear weapons or weapons-grade plutonium being delivered to military installations.

This service focuses on being able to determine when an incident involving a truck carrying hazardous materials occurs, the nature and location of the incident, and the material involved so that it can be handled properly. While these functions are all related, an integrated low-cost system that can be used by local responders is needed.

It may not be cost-effective to track all hazardous material shipments. For some types and amounts of hazardous materials it may only be important to locate these trucks when they are involved in a serious accident and then provide specific cargo information through electronic placard or other technology on the vehicle.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not cargo is hazardous materials	4 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
Estimated Message Length:	458 bits

3.2.6 Size And Weight - Mainline Weigh-In-Motion

Trucks which are legal from a size-and-weight or permit standpoint can be checked at highway speeds and allowed to bypass weigh stations and ports of entry.

The four main parts of this service are:

1. Technologies for mainline checking of axle and gross vehicle weights:
   - High-Speed Weigh-In-Motion (HSWIM)
   - Automatic Vehicle Classification (AVC)
   - Automatic Vehicle Identification (AVI)

2. Oversize/overweight permit data bases to determine whether vehicles exceeding statutory weight or linear dimension limits have a permit and are thus operating legally.

3. Model instrumented weigh station design.

4. Mobile weight enforcement. In addition, this service will research and test alternatives to screening at fixed sites including high-speed portable WIM and on-board weighing systems.

Vehicle weight enforcement is an activity which all states have historically conducted to protect pavements and bridges and develop a record for planning construction needs in accordance with the weights that are moving on the highway system. In 1974, the Congress made active weight enforcement a condition to be met in order for a state to be eligible to receive its full annual apportionment of Federal-aid highway construction funds. All states actively enforce vehicle weight limits. IVHS technologies can significantly increase the efficiency of the activity.

Mainline Screening of Weight

Mainline WIM installation and attendant technologies (AVI, AVC, and roadside/vehicle 2-way communication) are considered the key elements to providing the desired service.

Oversize and Overweight Permit screening

Vehicles can legally exceed statutory weight limits through the use of an oversize/overweight permit. Therefore, there must be the capability to determine within a few seconds the existence of a permit authorizing the movement. Permit conditions and availability vary by state, however, and is the type of information which would readily lend itself to electronic encoding onto a transponder or a credential data base if it were accessible in real time.

Instrumented Weigh Station Design

As existing weigh stations/ports-of-entry are rehabilitated or replaced, redesign should be based on the motor carrier services that are expected to be available at the site and the anticipated commercial motor vehicle volumes. A research project to help optimize site usage is about to begin. The output of this project will be guidelines for maximizing operational efficiency both for new locations and existing locations where right-of-way availability or some other constraints may force prioritization of services that can be provided. This should save each state money that it would have to spend for weigh station design and result in some degree of nationwide compatibility for carriers that desire to use the available services.

Mobile Weight Enforcement

Mobile weight enforcement operations are a very important element of each states overall weight enforcement plan. They allow states to more efficiently schedule human resources and patrol those routes used to evade permanent scales. Portable and semi-portable HSWIM will be more important in the future as the major highways are instrumented and intentionally illegal vehicles from a weight and/or size standpoint attempt to evade detection.

The data requirements for WIM technology can be summarized below:

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits
Estimated Message Length:	290 bits

3.2.7 Carrier Safety Fitness

This service would access the carrier's "safety rating" and would allow the enforcement officials a basis to make a decision about which drivers and vehicles to perform a detailed inspection on and which to let pass an inspection facility.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits

Estimated Message Length: 204 bits

3.2.8 Vehicle Registration

This service would be used to determine what base state the carrier is registered in, if the registration is current, and the vehicle's registered weight.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• License plate number and state for each vehicle unit	50 bits

Estimated Message Length: 266 bits

3.2.9 Fuel Tax

This service would be used to determine the base state for fuel tax reporting and whether or not the fuel tax payments are current.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits

Estimated Message Length: 216 bits

3.2.10 Permits

This service would be used to access and determine the existence of and how current the necessary permits are including temporary vehicle registration (trip permit), hazardous materials (HM) permit based on cargo carried, oversize/overweight permit, etc.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not cargo is hazardous materials	4 bits

Estimated Message Length: 224 bits

3.2.11 Accident Rate

With the mileage from the registration database and the accidents reported to the Office of Motor Carriers (OMC) by the states, the accident rate could be calculated to determine whether the carrier is within some predefined criteria for acceptability.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• Base state for vehicle registration (IRP)	8 bits
• License plate number and state for each vehicle unit	50 bits
• Driver Name	120 bits
• Driver ID Number (CDL number & state of license)	86 bits
Estimated Message Length:	468 bits

3.2.12 Roadside Inspections

This service could be used to determine: 1) When the vehicle was last inspected to prevent the vehicle from being stopped multiple times along the same route when unnecessary, 2) Whether or not vehicle was placed out-of-service during last inspection, and 3) License plate number on individual vehicle units (to determine whether a particular vehicle unit had defects detected during a previous inspection)

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• License plate number and state for each vehicle unit	50 bits
Estimated Message Length:	254 bits

3.2.13 Cargo Data

This service could be used to determine which types of hazardous materials and amounts should be monitored and a unique identification for each.

Data required:

• Carrier Name	120 bits
• Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not cargo is hazardous materials	4 bits
Estimated Message Length:	224 bits

3.2.14 Summary - Required Information For CVO Services

The minimum information that must be stored on the vehicle to perform the described CVO transactions or to access the information required for the aforementioned CVO services from a remote database is:

• Carrier Name	120 bits
• Interstate/Intrastate Carrier ID Number	84 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits
• Whether or not cargo is hazardous materials	4 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS?)	32 bits
Estimated Message Length:	560 bits

3.3 Analysis of CVO Requirements

The estimate presented above, of somewhat less than a thousand bits of information to support CVO transactions, helps to clarify the scale of the VRC for CVO application. However, this estimate alone does not provide enough information to determine the data requirements for a VRC tag. It does not consider where data is stored or how the data is acquired. Different system designs, each capable of supporting the described CVO transactions, can have very different requirements for the amount of information that needs to be carried on the tag. In order to provide a structure for the evaluation of the various possible implementation technologies, three VRC system models are described below. Each system will be evaluated with respect to its ability to perform within each of these models.

3.3.1 Model 1

Model 1 represents a system requiring a read-only tag carrying a single piece of information, an identification number. This model can employ the simplest form of tag. Read/write capability is not required, since the tag stores only the ID number. Roadside systems are required to obtain any desired information from data bases using the ID number as the only key. Although many transactions can be performed in this way, this is not a likely candidate since it lacks the ability to provide information to the driver, and because it demands very high performance in the retrieval of information from the remote data bases.

3.3.2 Model 2

Model 2 assumes support of data elements on the tag, in addition to the ID number, that permit the completion of a subset of the CVO transactions. The transactions selected can be completed through the use of a read/write tag without the need for extraction of information from a remote data base. These transactions are directly aimed at main-line screening type activities. The data elements and examples of the transactions are described below. This model is intended to represent a system that could be implemented quickly with existing technology and still provide valuable functionality. Transactions not directly supported through the use of tag data can be performed through the remote data base if necessary, using the ID number, as in Model 1.

Data required on tag:

• ID	32 bits
• Weight at last weighing	12 bits
• Time of last weighing	28 bits
• Safety flags	4 bits
• Time of last safety inspection	28 bits
• Temporary Permits	120 bits

Estimated Message Length: 224 bits

A read-write tag with only this small set of information could permit the following mainline functions:

Retrieval of weight from the truck for purposes of calculation of fees without stopping or re-weighing the truck.

Determination of need to weigh, based on age of weight data on tag. Permits passing acceptable vehicles without stopping them.

Examination of some form of safety indicator or flag that indicates that some safety item required attention at last inspection. This could be examined to see if correction was made. Time of last inspection could be used to determine if truck should be stopped or allowed to pass.

Short-term temporary permits could be issued and their possession indicated on the tag for easy and timely verification. Such permits might provide authorization for only a few days, making entering and tracking them through a remote data base impractical.

Note that the information selected for inclusion on the tag in this model is the type of information that changes frequently. The tag is a better location for this type of information since it can be changed at any weigh station. This permits the information to be more timely and accurate than if it was maintained in some remote central data base. Employing this model places no additional performance demands on the remote data bases.

For these reasons, a system following this type of data distribution model, may be a sensible first step toward CVO/VRC improvements.

An additional class of frequently changing, or perishable, information might be included as well under Model 2 if a smart card type user interface is available. This class would contain various driver specific information, which would need to be changed each time a driver operated a different vehicle. It could include the following:

• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	84 bits

• Driver Social Security Number (to access NLETS?)	32 bits
Estimated Additional Message Length:	264 bits

3.3.3 Model 3

Model 3 represents the most far reaching of the models presented. It represents a system in which all of the CVO transactions described are intended to be supported by the tag, with an absolute minimum of reliance on any remote data bases. While the exact nature of such a VRC system is not yet defined, it clearly would require the most sophisticated tag solution of the three models. Such a system would require greater on-tag memory, and be flexible enough to handle all possible CVO transactions, as well as support toll activities and the various functions envisioned under IVHS. Support of these advanced functions would almost certainly require a user interface such as a smart card as well as read/write capability. The data requirements to support CVO alone would consist of all of the data elements described under CVO Requirements as well as those used for the handling of frequently updated information described for a Model 2 type system. Together they are the following:

Required Information For CVO Services

The minimum information that must be stored on the vehicle to perform the described CVO transactions or to access the information required for CVO services from a remote database is:

Infrequently changed data:

• ID	32 bits
• Carrier Name	120 bits
• Interstate/Intrastate Carrier ID Number	86 bits
• What permits, if any, the vehicle is operating under	16 bits
• Whether or not carrier is registered in a "base state"	4 bits
• Base state for vehicle registration (IRP)	8 bits
• Base state for fuel tax reporting (IFTA, RFTA)	8 bits
• License plate number and state for each vehicle unit	50 bits
• Whether or not cargo is hazardous materials	4 bits

Frequently changed data:

• Weight at last weighing	12 bits
• Time of last weighing	28 bits
• Safety flags	4 bits
• Time of last safety inspection	28 bits
• Temporary Permits	120 bits
• Driver Name	120 bits
• Time driver came on duty	28 bits
• Driver ID Number (CDL number & state of license)	86 bits
• Driver Social Security Number (to access NLETS?)	32 bits

Estimated Message Length:	786 bits

Model 3 is clearly the most ambitious, and may require design decisions that go beyond our current understanding of how to implement an effective VRC system. For this reason, it is probably most useful as a long-term goal, designed to keep VRC progress headed in the right direction, rather than as a current system definition.

3.4 VRC Functional Requirements

In addition to simply providing the capability to perform the services described above, the VRC system must do this in the particular environment of a public roadway. This implies certain functional requirements for the system [14]. A list of the functional requirements necessary to implement the various IVHS and CVO services are detailed in this section. Not all of these requirements are needed to implement many of the services listed. Rather, this is a complete summary of the requirements for all the IVHS and CVO services. The requirements may be divided up into two sections: those of the overall system which include the reader, communication between the reader and transponder, etc., and those of the transponder itself.

3.4.1 Overall System

Multilane Capabilities

The reader should have the ability to monitor vehicle activities on multilane highways. The communication between the reader and the vehicle should be two-way. Furthermore, the reader should be able to determine which traffic lane it is communicating with and distinguish between transponders in different lanes passing the reader site simultaneously. The reader should also be able to actively select which transponder it wishes to communicate with.

Single or Multiple Reads

As the vehicle passes through the read zone, a single read record should result. The reader could also have the option to take multiple reads proportional to the amount of time the transponder is in the read zone. This feature may be used for future system enhancements such as congestion monitoring.

Transponder Spacing

The reader should be able to discriminate individual transponders passing through the read zone separated by a minimum distance of 1.5 m.

Communication Data Rate

The rate of data communication must be high enough to allow the vehicle to transmit all relevant data while traveling at speeds up to and including 160 km/h. For some of the services mentioned, the reader should also have the capability to write to the transponder to update the individual vehicle's records. Both read and write must occur while the vehicle is in the communication zone. Therefore, the communication rate must be high enough to allow the vehicle to both transmit and receive all relevant data depending on the type of application or service that is in use.

Memory Storage

Nonvolatile memory is needed either on the transponder or on an in-vehicle computer to store the information. The size of the memory must be adequate to store all pertinent records and data that will be communicated to and received from the reader. If the data is stored in an on-board device, then the transponder must have sufficient storage capacity to act as a temporary buffer for the received and transmitted data.

Data Encryption and Fraud Detection

The stored data should be encrypted to insure the data is not easily understood or modified by unauthorized parties. The reader system should also be able to detect fraudulent transactions and unauthorized information that is written to the memory.

Data Accuracy

The system must be able to transmit data accurately. A system with high accuracy will not allow transactions to appear valid when in reality they are not (i.e., collecting funds from the wrong account).

Communication Reliability

Finally, the communication between reader and transponder must be reliable. The maximum number to transponders that fail to be read as they pass through the read zone should not be more than 1 in 10^6.

3.4.2 Transponder

RF Interference

The transponder should not produce any RF interference or be susceptible to local RF interference such as electrical generators, cellular telephones, mobile pager units, two-way radios, etc. which may disrupt communications. For example, the transponder may be frequency agile which would adjust the frequency used to send or receive information. Radiated radio frequency power levels should conform to federal standards.

Communication Activation and Deactivation

The transponder should be capable of selectively activating or deactivating communication with the reader depending on commands received from the reader or site controller.

Interface to On-Board Computer (OBC)

The transponder should have a standard external interface to on-board computers and devices on the vehicle through which it would communicate up-linked data. Such on-board devices would be used for data storage, dynamic dispatching, vehicle condition monitoring, etc.

Power Supply

The transponder's power supply should be independent of the vehicle's electrical system. While certain features on the transponder may utilize the vehicle's power supply, the basic default operation should be independent.

External Displays

The transponder should have an external display which indicates if it is faulty. The display would also indicate if the transponder has been tampered with or removed by unauthorized personnel.

Physical Requirements

The transponder should be able to function under all ambient climatic conditions, operating environments, and in the presence of normally occurring substances such as sand, salt, dirt, precipitation, etc. It should meet the requirements for shock, vibration, contaminants, etc. as defined by Military Standard 810D. The transponder should operate and maintain the integrity of its stored data in temperatures ranging from -60 °C to 85 °C. Finally, the transponder should operate reliably under prolonged physical, radio frequency, thermal and ultraviolet exposure.

Mounting

The transponder should be easily mounted to the vehicle, bearing in mind the roadway environment and life expectancy of the transponder. If possible, it should conform to preexisting standards (i.e. license plate patterns).

Cost

The transponder unit should not be overly expensive when mass produced. A good cost goal is under $50.

Life Span

In normal use, 90% of transponders should remain functional after 5 years and 80% functional after 10 years.

3.5 VRC Technical Requirements

In order for a VRC system to perform the services described earlier, and to meet the functional requirements identified above, it must possess certain technical characteristics. These required technical characteristics, or technical requirements, are described here. Not all of the intended services require the existence of all of these technical requirements. To help manage this complex requirements analysis, a matrix has been constructed that maps appropriate technical requirements to the desired services.

3.5.1 Technical Requirement Descriptions

The following is a description of each of the technical requirements used in the requirements matrix.

Off-line Function

This is a transaction that does not take place as the vehicle passes an RF beacon in mainline motion. This function would be performed through the interaction of roadside computers or terminals with a national database. Any data that must be resident on the vehicle transponder would then be written to the vehicle.

One-way Sufficient

One-way communication with the vehicle is sufficient for this service. There is no need to write any information to the vehicle tag. An example of such a service would be electronic toll collection where the roadside beacon queries that tag on the vehicle for an ID.

Two-way Enhancement

One-way communication with the vehicle is sufficient for this service, but the service would be enhanced if there was two-way communication with the vehicle. The added writeability of the tag would allow additional data to be kept on the tag and could be used to provide extra information to the driver of the vehicle.

Two-way Required

Two-way communication with the vehicle is required for this service. There is information which must be updated on the tag and information which the driver must have in order to determine what action he must take.

Lane Distinction

The lane in which the vehicle resides must be known to direct its next action (toll collection, border crossing, or bypassing a weigh station.)

Transponder Memory Size

Refers to the total amount of data storage (in bits) that is resident within the transponder and/or which may reside in other devices connected to the transponder (onboard computers, etc.) If the transponder is connected to an onboard device, it can be assumed that the data storage within the transponder is only required for temporary buffering purposes and other uses not associated with the onboard device.

OBC Enhancement

The use of an On-Board Computer (OBC) would allow enhanced or more sophisticated implementation of this service.

OBC Required

The use of an On-Board Computer (OBC) is required to make the required transactions and store/retrieve the required data.

Data Encryption

Encryption consists of an algorithm residing in the fixed equipment which encodes data sent to the transponder and decodes data received from the transponder. This helps to prevent any unauthorized use of the data.

Multilevel Security

The data should have additional multilevel security when involving confidential or value (monetary) information.

Minimum Data Rate

Specifies the minimum data rate, in Kilobits per second (KBS), required to transfer the information between the fixed equipment and the transponder on the vehicle while the vehicle is in the capture zone of the antenna.

3.5.2 Requirements Matrix

The following matrix (Table 1) has been constructed to simplify the evaluation of various VRC approaches. It maps various technical requirements for a VRC implementation against CVO services and potential IVHS services.

VRC Technical Requirements vs. User Services	Off-line	Read only	Read/write	Read/write	Lane	Transponder Memory Size				OBC	OBC	Multi-level	Minimum Data Rate (KBS)		
	Function	Sufficient	Enhancement	Required	Distinction	128	<500	<2K	>2K	Enhancement	Required	Security	10	100	400
IVHS Services															
Electronic Toll Collection - Open		X	X		X	X						X	X		
Electronic Toll Collection - Closed				X	X		X			X		X	X		
Comm. Vehicle Fee Collection		X	X		X	X						X	X		
Restricted-Access Roads		X	X		X	X							X		
Transit & Intermodal:															
Position Location		X				X							X		
Schedule Monitoring				X		X							X		
Dynamic Dispatching				X					X	X					X
Vehicle Condition				X			X				X		X		
Priority Treatment, HOV		X	X		X	X							X		
Automatic Switching		X	X			X							X		
Next Stop Announcements				X		X							X		
Passenger Count				X	X	X							X		
Intermodal Operations		X	X				X						X		
Safety/Environment Monitoring				X		X							X		
Waste Management		X							X		X				X
Hazmat Transport				X				X		X				X	
Traveler Information		X	X					X			X			X	
Commercial Services				X				X		X				X	
Traffic Management		X				X							X		
Emergency Messages				X		X							X		
CVO Services															
Automated Safety Verification:															
Access to Safety Records		X							X						X
Safety Records & Status Verification		X	X						X						X
Safety Monitoring				X				X						X	
Cross-border				X	X				X						X
Electronic Credentials:		X						X				X		X	
Electronic Purchase of Credentials	X														
Pre-Travel Verification of Credentials	X														
Nationwide Advisory Bulletin Board	X														
Mainline Verification of Credentials				X	X				X						X
Mileage & Fuel Reporting				X				X			X	X		X	
Fleet Management				X				X						X	
Hazardous Materials		X	X						X						X
Weigh-In-Motion				X	X			X						X	
Carrier Safety				X				X						X	
Vehicle Registration		X						X						X	
Fuel Tax		X						X			X	X		X	
Permits		X						X				X		X	
Accident Rate		X							X						X
Roadside Inspection		X						X						X	
Cargo Data		X						X				X		X	

Table 1: VRC Technical Requirements vs. User Services

3.6 Site Specific Requirements

There are a number of VRC system characteristics that cannot be viewed as required to accomplish any particular service. However, in certain installations, it may be found that they are important in obtaining successful system operation. These include the following:

Frequency Agility

Systems with this feature are better able to accommodate sources of intentional or unintentional electromagnetic interference by changing the roadside equipment's frequency to a clear channel. Interference occurs, even with dedicated frequency authorization. Interference often results from high power transmitters tuned near the authorized frequency or harmonically related.

Polarization Type

Refers to the RF polarization type that sends the best signal. The signal is usually polarized in the horizontal or vertical directions. Circular polarization is also available.

Field Strength

Refers to RF signal strength required to make the communication link between the roadside beacon and the vehicle transponder (this can vary from a few milliwatts to 2 watts).

Inpavement Antenna

The data required for the service can be transmitted to the vehicle satisfactorily using an inpavement type antenna.

Overhead Antenna

The data required for the service can be transmitted to the vehicle satisfactorily using an overhead type antenna.

Since the need for a particular polarization type, antenna type, frequency agility, etc. is not dictated by the user service, and is, in fact, dependent on local site variables (such as the nature of local RF interference), no general statement can be made about their applicability for all installations. Since site characteristics vary, it is clear that systems offering flexibility in these characteristics (that is, choice of antenna types, etc.) have an advantage.

4. Identification of Alternative Approaches

Numerous concepts, protocols, designs and components exist or are planned that embody characteristics desirable in a VRC system. The need for the specification of a standard in as short a time as possible dictates that existing technologies be used where available and where they meet the requirements presented earlier. The purpose of this section is to present the existing, planned or currently proposed standards that may be applicable, in whole or in part, to CVO VRC requirements.

Further, since the practicality of employing a standard depends, in part, on the ability to actually implement it in real components using existing technology, a broad survey of VRC systems and components was performed to determine present capabilities and planned near-term capabilities of various VRC technologies. It is important not to define a communication standard that calls for performance of its required components which is beyond the capability of systems that can be fielded.

Numerous documents [3-7, 15-27, 30-32] and conversations with developers [28, 29, 33-38] were used in compiling the information in this survey. The results of this survey follow. Based on the number of protocols, technologies, and component specifications examined, we believe the information accurately reflects the types of alternatives currently available. An attempt has been made to present a representative set of approaches. It cannot be guaranteed that every approach has been examined, especially since new approaches are continuously being developed.

4.1 RF Interface Protocols

The following standards, proposed standards, or techniques have been identified as candidates for VRC protocol standardization. They are described here in no particular order. In most cases, use of the particular method implies use of a particular type of hardware (though not necessarily a particular vendor). For this reason, the different techniques are described in the context of an installation described by the developer. Where the method is flexible across hardware types, it is noted. Some protocols are considered proprietary by their developers. The nonproprietary aspects of these are presented because they give some insight into other possible approaches, because licensing may be pursued, and since proprietary techniques are sometimes eventually released into the public domain.

4.1.1 CALTRANS - Public Domain

Communications Protocol

The CALTRANS protocol (Figure 1) for Vehicle-to-Roadside Communications (VRC) equipment uses a half-duplex modulated backscatter approach to permit two-way communications with a transponder [4, 6]. The protocol is designed to handle only one (the most dominant) transponder per reader at a time. The protocol does not address multiple transponder responses (no multiplexing). The reader transmits a 33 microsecond RF pulse of 10 “1” bits to activate the transponder. The reader then transmits a polling message which provides information to the transponder including the type of transaction to take place. The reader then transmits an unmodulated continuous wave RF signal for the transponder to modulate with a data message while backscattering to the reader. When an error free message is obtained, the reader transmits an encoded Acknowledgment message to the transponder providing status information and requesting that the transponder not respond to the same polling message again for ten seconds. This silencing of correctly read transponders reduces the interference from multiple transponders responding simultaneously to the same reader.

The CALTRANS standard is not proprietary and has been placed in the public domain.

RF Characteristics

The reader and transponders transmit in the 902-928 MHz frequency band. Specific frequency and bandwidth depend on FCC assignment. Transponders will be able to operate at any frequency in this band.

The reader-to-transponder data is encoded in the RF signal using the methodology of Manchester Encoding. The binary bit 1 is represented by a positive pulse followed by a negative pulse. The binary bit 0 is represented by a negative pulse followed by a positive pulse.

The transponder-to-reader data is encoded in the RF signal using a methodology called Frequency Shift Keying (FSK). The transponder baseband message signal modulates the subcarrier with a center frequency of 900 kHz and a frequency deviation of ± 300 kHz. The lower frequency (600 kHz) corresponds to a 0 bit and the upper frequency (1200 kHz) corresponds to a 1 bit.

The data rate of data messages is 300 Kbits per second for both the reader-to-transponder and transponder-to-reader links.

Security Capabilities

The protocol employs a 32 bit random number that is used by the transponder as part of an encryption algorithm for secure data communications.

Error Checking Capabilities

The protocol uses a 16 bit Cyclic Redundancy Check (CRC) based on the polynomial $X^{16} + X^{12} + X^5 + 1$ to detect errors in the transmitted data.

Vehicle Location Capabilities

The protocol does not specify how to determine vehicle location for the purposes of enforcement, although it could likely be accomplished using a one reader per lane configuration.

Application Description: Vehicle Transponder

The CALTRANS specified transponder is an RF two-way modulated backscatter device which is encoded with a unique identification code. The transponder must be able to be turned on and off. The memory size of the transponder is not specified, as it is application specific. The transponder modulation scheme is amplitude modulation of an RF carrier backscatter and Frequency Shift Key modulation of the subcarrier. The transponder must be positioned at the front of the vehicle with a clear line of sight to the reader antenna.

Application Description: Roadside Reader

The reader is the protocol master to trigger or activate a transponder, read from or write to a transponder, and assure message delivery and validity. The reader is intended to be installed at a fixed location on the roadway.

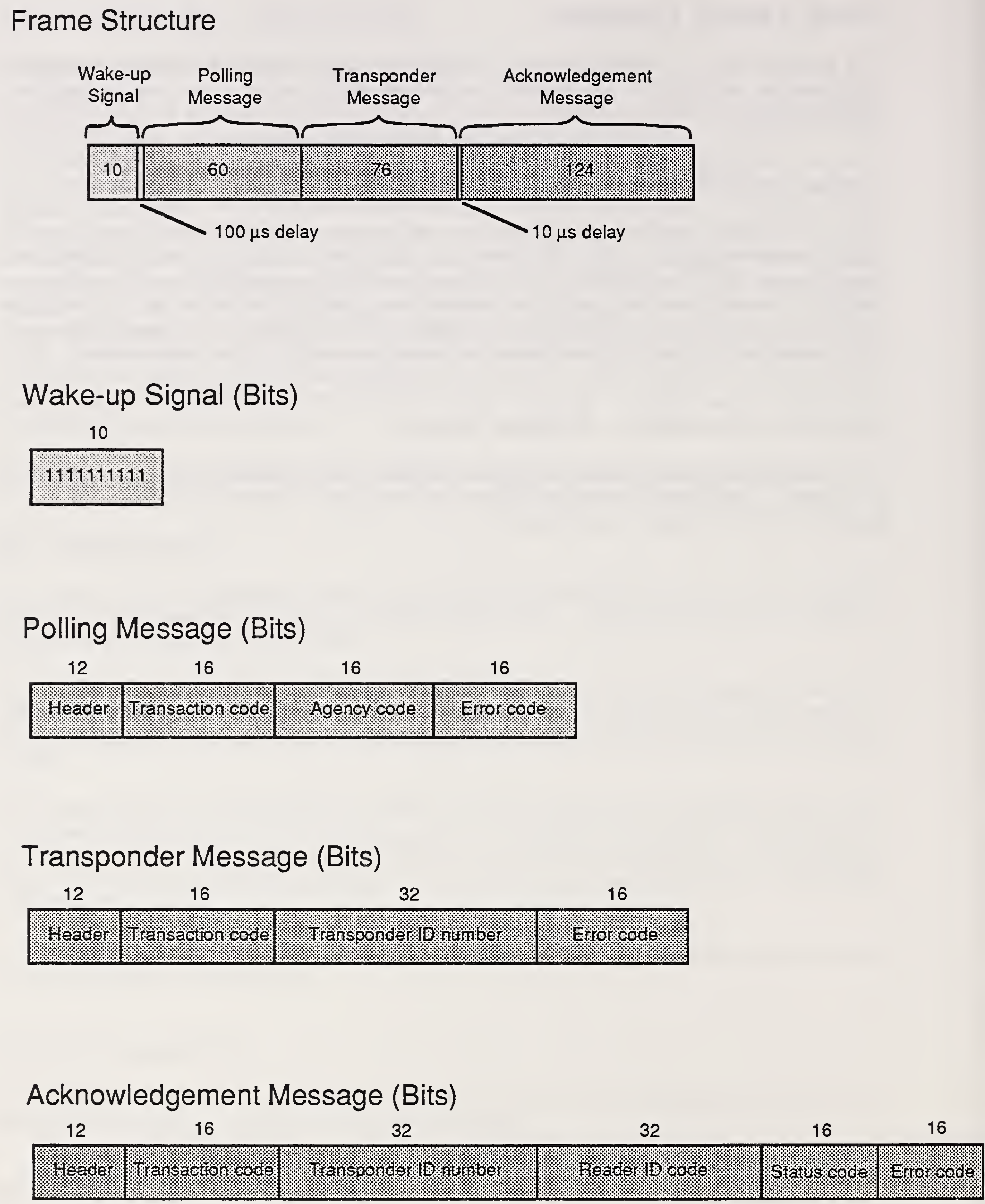


Figure 1. CALTRANS Format

4.1.2 Proposed Standard A - Public Domain

Communications Protocol

This proposed standard consists of two protocol specifications. One is for wide-area operation and is described here. The other is for lane-based application and is described in 4.1.3.

This proposed standard for Vehicle-to-Roadside Communications (VRC) equipment uses a Slotted Aloha Time Division Multiple Access (TDMA) protocol to permit two-way communications with many vehicles simultaneously (Figure 2). The Slotted Aloha protocol is a priority slot system consisting of several request slots and data slots that comprise a data frame. The protocol frame structure consists of a Reader Control Message, 4 Data Message Slots, an Acknowledgment Message after each Data Message Slot, and 16 Aloha Request Slots. Each vehicle transponder within the communication area of the reader antenna competes to capture an Aloha Request Slot. After the transponder has successfully captured a slot, the reader then commands it to transmit its data in one of the four Data Message Slots. At the conclusion of each transaction, a positive confirmation is performed. If the transaction failed for any reason, a mechanism to repeat the transaction is initiated. If a collision occurs between transponders in trying to capture an Aloha Request Slot, each transponder in the collision is required to wait a random period of time before attempting to seize an Aloha slot for retransmission. The protocol is also being extended to permit communication with HELP and CALTRANS type tags during otherwise unused guard time periods. The standard defines the structure of the communications protocol and equipment performance requirements. Message content (data) and equipment design is application specific and is not in the scope of the proposed standard.

This protocol has been placed in the Public Domain to help encourage standardization.

The protocol frame structure is described in more detail below:

<u>Reader Control Message</u>

The Reader Control Message assigns Data Message Slots for up to four requesting transponders and issues a transaction command to each of the four selected transponders.

<u>Data Message Slots</u>

The Data Message Slots contain a data packet to or from the transponder. Content of the Data Message Slot is application specific. Unused bits in the slot are set to zero.

<u>Aloha Request Slots</u>

The Aloha Request Slots are used by the transponder to notify the reader that it is present in the communication zone and is requesting to send information to the reader.

<u>Acknowledgment Message</u>

The Acknowledgment Message indicates whether or not the prior Data Message Slot was received properly. All Data Message Slots either have a positive or negative Acknowledgment Message.

RF Characteristics

This protocol is currently implemented using an active technology, with the transponder incorporating an active transmitter. The use of an active transmitter allows for lower RF power, wide area of coverage, and high speed data rates. Carrier frequency for the wide-area protocol is country and application specific, as well as subject to FCC assignment in the U.S. The lane-based carrier is specified as ±915 MHz, subject to FCC assignment. There are currently three RF versions: 915 MHz (North America and Australia), 2.45 GHz (Asia), and 5.8 GHz (Europe and Asia).

Security Capabilities

The protocol uses a 64 bit validation algorithm to protect against counterfeiting or tampering with the transmitted data.

Error Checking Capabilities

The protocol uses a 16 bit Cyclic Redundancy Check (CRC) of the form $X^{16} + X^{12} + X^5 + 1$ to detect errors in the transmitted data.

Vehicle Location Capabilities

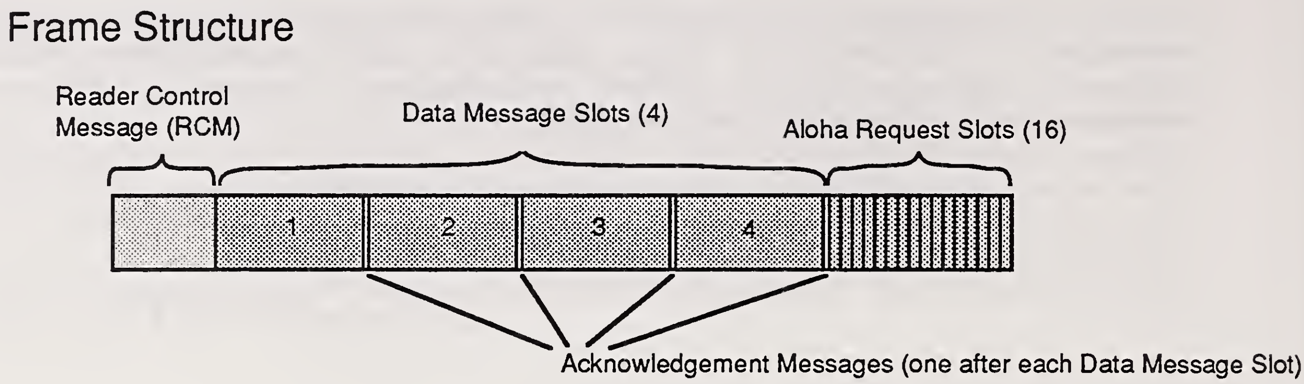
A proprietary system for tracking and determining the location of the vehicle has been developed and tested. It makes use of the normal message traffic and some additional off-vehicle hardware to make determinations of vehicle position. This could provide the data required to perform toll enforcement.

Application Description: Vehicle Transponder

A transponder using this protocol is being manufactured for the Advantage I-75 project and described below. The transponder has 512 bits of memory of which 64 bits are factory programmed with a 32 bit public ID and a 32 bit private ID, 192 bits are agency programmed, and 256 bits are read/write. The transponder incorporates a driver interface through the use of 2 LED signal lights and a beeper annunciator. There is also a 9600 baud RS-232 serial link that can be interfaced to an On-Board Computer (OBC), a smart card device, the existing J-bus connection (SAE and/or ISO), driver displays such as an LCD, and a voice annunciator. This interface allows for driver audio/visual messaging, safety/road sensing and monitoring, and diagnostic monitoring of the vehicle's condition.

Application Description: Roadside Reader

The reader is the protocol master to trigger or activate a transponder, read from or write to a transponder, and assure message delivery and validity. The reader is intended to be installed at a fixed location on the roadway. The roadside reader can be integrated into existing infrastructure such as toll collection systems, truck weigh station systems, and commercial fleet computers. The same reader can operate in the following RF frequency bands: 915 MHz (North America and Australia), 2.45 GHz (Asia), and 5.8 GHz (Europe and Asia). The reader has an RS-232/RS-422 interface for application specific computer systems and is VME form factor. Simple applications can be handled directly without additional computing power, but if additional computing power is required, the reader can be integrated with additional computer processing.



Reader Control Message (Bits)

Header	Type	Cmd 1	ID #1	Cmd 2	ID #2	Cmd 3	ID #3	Cmd 4	ID #4	Seed	CRC
16	8	8	32	8	32	8	32	8	32	64	16

Data Message (Bits)

Header	Type	Message Data	Valid	CRC
16	8	512	8	16

Acknowledgement Message (Bits)

Header	Type	CRC
16	8	16

Aloha Request Message (Bits)

Header	Type	ID #	CRC
16	8	32	16

Figure 2. Proposed Standard A Format

4.1.3 Proposed Standard B - Public Domain

Communications Protocol

This protocol for Vehicle-to-Roadside Communications (VRC) equipment uses a Time Division Multiple Access (TDMA) protocol to permit two-way communications with many vehicles simultaneously in a lane-based application. The reader transmits a 20 μs triggering pulse, at a rapid periodic rate, at a frequency of 910 MHz. The vehicle mounted transponder is activated by this pulse and in turn transmits its identification and other stored data to the reader antenna. This VRC system is a lane-based system. It is the lane-based system that is specified as the lane-based component of the protocol described in Section 4.1.2

The TDMA protocol uses in-pavement antennas for lane-based applications.

The protocol and system described is installed on the HELP Crescent project [11, 12, 26] that runs up and down the west coast from Washington state to California.

This protocol has been placed in the Public Domain to help encourage standardization.

RF Characteristics

This protocol uses an active technology to communicate between the vehicle's transponder and the roadside reader. The use of an active transmitter allows for large data rates. The system is capable of a 500 Kbits per second data rate. The inpavement antenna has a read range of approximately 1.2 m in the direction of travel.

The reader and transponders transmit in the 902-928 MHz frequency band (tuned at 910 MHz), subject to FCC assignment.

The data is encoded in the RF signal using the methodology of Manchester Encoding. The binary bit 1 is represented by a positive pulse followed by a negative pulse. The binary bit 0 is represented by a negative pulse followed by a positive pulse.

Security Capabilities

The protocol uses encryption in the transmitted data to secure the information and prevent counterfeiting.

Error Checking Capabilities

The protocol uses a 16 bit Cyclic Redundancy Check (CRC) to detect errors in the communication data.

Vehicle Location Capabilities

The location of the vehicle can be determined using time multiplexing with the in-pavement antennas. Only one antenna is reading at a time and therefore only the vehicle that is in the lane of the active antenna is read. If a violation occurs, the lane that the vehicle is in is determined.

Application Description: Vehicle Transponder

The protocol is used in three types of transponders. These are exterior transponders, interior transponders, and one with an on-board smart card reader.

The external transponder is a read/write Type II transponder used with the in-pavement antennas and has 256 bits of memory. The partition between the fixed (read only) and reprogrammable (read/write) data fields is flexible. An interface for an on-board computer or smart card reader is available with the external transponder (Type III interface). The RF communications rate for the external transponder is 500 Kbits per second.

The internal transponder is read/write Type II transponder used with overhead antennas. The internal transponder is mounted to either the dashboard or windshield. An interface for an on-board computer or smart card reader is available with the internal transponder (Type III interface). The RF communications rate for the internal transponder is 500 Kbits per second.

The smart card reader is designed to mount on or above the dash-board of the vehicle. A Type III transponder is included in the smart card reader's housing when overhead antenna's are used. The smart card reader has an optional serial port for connection to other devices. The RF communications rate for the smart card reader is 500 Kbits per second. Access to the information on the smart card is 9600 baud.

Application Description: Roadside Reader

The reader is the protocol master to trigger or activate a transponder, read from or write to a transponder, and assure message delivery and validity. The reader is intended to be installed at a fixed location on the roadway. A single reader using time multiplexed antennas (in-pavement) can interface simultaneously with up to eight lanes of traffic. The reader can be tuned to operate in the 902-928 MHz frequency band (set at 915 MHz). The reader has an RS-232 interface and an optional RS-422 interface with up to 4 MB of RAM. The reading speed of the reader is 500 Kbits per second and can have up to 5 reads per transponder at 160 km/h with vehicles present in 8 lanes simultaneously.

4.1.4 Proposed Standard C - Public Domain

Communications Protocol

This protocol for Vehicle-to-Roadside Communications (VRC) equipment supports the CALTRANS open protocol and other protocols. The system uses a principle called modulated backscatter to permit two-way communications with tags. Note: The developer uses the term "tag" for the vehicle mounted equipment rather than the term "transponder." The principle of modulated backscatter will be described in more detail in the RF Characteristics section. Three programmable modes of operation are provided in the system. These include the CALTRANS/ETC mode, the ATA/ISO mode, and extended command mode. The extended command mode includes: frame specific read/write access, 600 Kbits per second uplink communications rate, Time Division Multiple Access (TDMA), and information/status access.

Open Road Operation - (Wide Area)

For the open road application, a TDMA protocol has been derived (Figure 3). A triggering pulse consisting of a stream of 10 "1" bits followed by a 100 μs delay is used as a wake-up signal. A polling message is sent by the reader to inform the tags how many activation slots are available in the activation cycle. The number of activation slots can be varied to adjust for the traffic conditions at each reader site. Each tag then calculates a random number to determine which activation slot to transmit its ID number in. If two or more tags transmit in the same activation slot, a collision occurs, but because of the sensitivity of the reader, the reader is usually expected to capture the closer tag ID. The remaining tags that transmitted in the same activation slot will transmit again when the polling message in repeated during the next communication frame. After the reader has received the ID numbers for the tags that transmitted their ID's in the activation slots, the reader goes into a direct communications mode with each of the specified tags, one at a time. The number of direct communication exchanges is determined by the number of tag IDs that were captured in the previous activation cycle. After the direct communications with each tag is completed, each tag is commanded to "sleep" for a specified time to prevent multiple transactions with one tag and to reduce the noise level. After the reader has communicated with the last tag, it issues another trigger and poll message and another batch of tag ID numbers are obtained in another activation cycle.

Lane-based Operation

For lane-based operations, such as Electronic Toll Collection (ETC), one reader is installed per lane of roadway. Therefore, there is a dedicated link between the vehicle in the lane and the reader in that lane. The readers must be carefully tuned to avoid "cross lane reads" and still cover enough area so that no tags can slip by without being read. As the tag approaches the roadside reader, a presence detector signals the system to turn on and the reader sends out a single frequency RF signal into the designated area called the capture zone. Inside the capture zone, the tag first enters a read envelope which is as large as the capture zone itself. The RF signal reflects off the tag and returns to the reader with the tag's ID and other data encoded in a modulation of the original RF signal. As the tag enters the smaller write envelope within the read envelope, the strength of the RF signal reaching the tag exceeds a preset threshold and a switch in the tag flips to permit the write transaction to occur to the tag. Each lane on the roadway has a reader that operates at a separate frequency. After the transaction is completed and validated, the tag is issued a command to sleep for a period of time.

The protocol is in the process of being placed in the public domain.

RF Characteristics

This protocol uses a backscatter technology to communicate between the vehicle's tag and the roadside reader. The tag does not actively generate and transmit an RF signal. The tag is a field disturbance device that sends information to the reader by changing or modulating the signal transmitted by the reader. This modification of the signal includes the unique identification code of the tag and the data that must be exchanged for the required transaction. This method of communication is called modulated backscatter.

The data is encoded in the RF signal using a methodology called Frequency Shift Keying (FSK). Each of the tags bits are data that are composed of 8 sub-bits, with a 0 represented by a 20 kHz square wave signal, and a 1 represented by a 40 kHz square wave signal.

The usable data rate that is attained using the modulated backscatter approach with this system is 300 Kbits per second on the downlink (reader to tag link) and 600 Kbits per second on the uplink (tag to reader link).

In open road operation the reader requires approximately 6 MHz of bandwidth to cover multiple lanes of highway.

In lane-based operation, each reader requires a 2 MHz of separation from the reader in the adjacent lane to perform communications without interference.

Security Capabilities

Several security features, including unique ID addressing, are used to ensure that a given data message only effects the designated tag. Read and write password protection and off-line authentication provide operational security.

Error Checking Capabilities

The protocol uses a check sum to detect any errors that may occur during the transmission or the receiving of data. If an error occurs, data must be retransmitted.

Vehicle Location Capabilities

The location of the vehicle (lane detection) is accomplished by installing one reader per lane of roadway. Therefore, there is a dedicated link between the vehicle in the lane and the reader in that lane. The readers must be carefully tuned to avoid "cross lane reads" and still cover enough area so that no tags can slip by without being read.

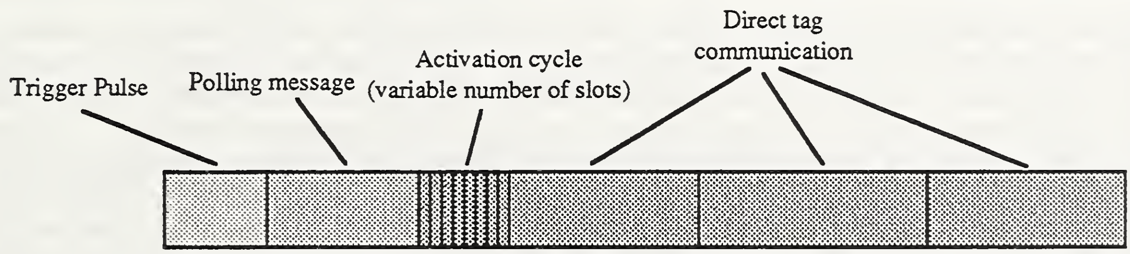
Application Description: Vehicle Transponder

The tag is composed of the modulator, power, code generator, clock, memory and antenna circuits located on a single printed circuit board. The tag has 19 general data frames of 128 bits each for the storage of information. The tag is powered by a 3 AA size batteries. Battery life is specified to be 10 years and range is specified to be up to 30 m. There are no external interfaces with the tag. The tag may be attached to the vehicle windshield.

Application Description: Roadside Reader

The reader is intended to be installed at a fixed location on the roadway. The reader receives a demodulated signal from the RF module, decodes the ID information, confirms message integrity, and transmits the code along with any appended information to the host computer system. The reader operates in the 850-950 MHz frequency band and has a SCSI-2 communications interface. The reader has 32K of memory, controls two RF channels (for two lanes of roadway in a lane-based application) and supports two serial ports and six I/O control channels.

Frame Structure



Trigger pulse - Stream of 10 "1" bits to wake up the tags within range of the reader

Polling message - Provides operating instructions which direct the tags' response

Activation cycle - Tags transmit their ID number to the reader during a random time slot

Direct communication - Reader communicates directly with each tag using ID addressing
The number of communications depends on the number of tag ID's captured during the previous activation cycle.

Figure 3. Proposed Standard C Format

4.1.5 Proprietary Technique A

Communications Protocol

This protocol for Vehicle-to-Roadside Communications (VRC) equipment uses a Code Division Multiple Access (CDMA) protocol to permit two-way communications with many vehicles simultaneously.

There are two roadside antennas for the system. One antenna is a long-range (1.6 km) broadcast antenna and the other antenna is a short-range lane-based two-way communication antenna. The transactions are as follows:

The long-range antenna initializes contact with the transponder and communicates the entire toll schedule. The transponder then determines if there are sufficient funds for the required transaction. In the toll lane, the second antenna communicates with the transponder to debit the toll amount in the transponder and create a record of the transaction. The account information is stored in the transponder (decentralized data base) and transaction information is sent back to the antenna for audit purposes.

Each transponder is shipped from the factory with a permanent Electronic Serial Number (ESN) identifying it uniquely in a potential universe of 16 billion units. This ESN is the identifying code that is used in the CDMA protocol.

There are 24 memory locations for toll or other account balances, a 25th memory location is used for closed tollway applications (temporary retention of the entry point of the vehicle) and a 26th memory location is used to record every transaction that occurs (circular data base of 150 transaction). CVO applications use two variable memory locations. The first location of 32 bytes can only be modified by an authorized agent and contains identification information such as commercial account number, ICC registration number, license plate number, or other usable ID. This ID along with the ESN is part of every transaction between the reader and the transponder. The second variable memory location of 32 bytes may be written to at highway speed through an RF link. This memory can be used to write CVO information such as transport data for interstate registration clearance, Weigh In Motion (WIM) data, or other traffic management purposes.

This protocol keeps all data decentralized, but is capable of employing a more centralized approach if desired.

Further details are not available because the protocol is currently proprietary. Several parts are being considered for release to the public domain in the future.

RF Characteristics

The reader transmits in the 902-928 MHz frequency band (tuned at 904.5 MHz), subject to FCC assignment.

The transponder receiver frequency is 904.5 MHz and the transponder transmit frequency is 49.86 MHz, Part 15 type accepted. The 904.5 MHz communication is AM and the 49.86 MHz communication is FM to take advantage of capture effect and pulse noise rejection. Both of the antennas are etched on the printed circuit board of the transponder. Other frequencies can be accommodated where necessary.

The data rate for both the reader and the transponder is 9600 baud.

The data is encoded in the RF signal using the methodology of Manchester Encoding. The binary bit 1 is represented by a positive pulse followed by a negative pulse. The binary bit 0 is represented by a negative pulse followed by a positive pulse.

Security Capabilities

The protocol uses encrypted messages in both directions to provide security capabilities.

Error Checking Capabilities

The protocol uses a 16 bit Cyclic Redundancy Check (CRC) to detect errors in the communication transmissions.

Vehicle Location Capabilities

The location of the vehicle can be determined by using one short range antenna per lane. The microprocessor in the transponder measures the field strength from each antenna to determine its position on the roadway. In automatic ticket issuing lanes for a closed ticketing system, a valid signal will occur prior to the ticket issuing machine so the lane controller will prevent issuing a ticket.

Application Description: Vehicle Transponder

The transponder is a read/write Type III transponder with a built in microprocessor (on-board computer). The transponder has separate receiver/transmitter for read and write ranges of up to one mile. The CVO transponder has a built in 2 line LCD display and audio speaker for in-cab notification. The transponder has a large memory storage (16 Kbits with expandability up to 1 Mbits). The transponder has an on-board transponder interface, two keys for programming and 4 data input ports.

Application Description: Roadside Reader

The reader is the protocol master to trigger or activate a transponder, read from or write to a transponder, and assure message delivery and validity. The reader is intended to be installed at a fixed location on the roadway. The reader can control either 4 or 8 lanes of traffic.

4.1.6 Proprietary Technique B

Communications Protocol

This protocol for Vehicle-to-Roadside Communications (VRC) equipment uses frequency division among several readers to permit two-way communications with many vehicles simultaneously using a specific type of tag. The system uses a principle called modulated backscatter to permit two-way communications with tags. Note: the developer uses the term "tag" for the vehicle mounted equipment rather than the term "transponder." The principle of modulated backscatter will be described in more detail in the Communications Link section. As the tag approaches the roadside reader, a presence detector signals the system to turn on and the reader sends out a single frequency RF signal into the designated area called the capture zone. Inside the capture zone, the tag first enters a read envelope which is as large as the capture zone itself. The RF signal reflects off the tag and returns to the reader with the tag's ID and other data encoded in a modulation of the original RF signal. As the tag enters the smaller write envelope within the read envelope, the strength of the RF signal reaching the tag exceeds a preset threshold and a switch in the tag flips to permit the write transaction to occur to the tag. Each lane on the roadway has a reader that operates at a separate frequency. After the transaction is completed and validated, the tag is issued a command to sleep for a period of time.

Two RF modules can be controlled by each reader and can be time multiplexed so that two lanes can be controlled by one reader. This multiplexing will cause a reduction in a particular lane's maximum data rate below the already somewhat low 9600 baud rate.

The protocol is currently proprietary.

RF Characteristics

The protocol uses a backscatter technology to communicate between the vehicle's tag and the roadside reader. The tag does not actively generate and transmit an RF signal. The tag is merely a field disturbance device that sends information to the reader by changing or modulating the signal transmitted by the reader. This slight modification of the signal includes the unique identification code of the tag. This method of communication is called modulated backscatter.

The data is encoded in the RF signal using a methodology called Frequency Shift Keying (FSK). Each of the tags bits are data that are composed of 8 sub-bits, with a 0 represented by a 20 kHz square wave signal, and a 1 represented by a 40 kHz square wave signal.

The data rate that is attained using the modulated backscatter approach is 9600 baud.

The frequency separation between adjacent readers for typical highway applications must be at least 2 MHz to prevent interference. The preferred frequency band of operation for maximum user operating performance and flexibility at minimum cost is a 10 MHz wide band in the 850-950 MHz band (and specifically, the 902-928 MHz band).

Security Capabilities

The protocol uses a 12 bit security field to protect that data that is being written to and read from the tag

Error Checking Capabilities

The protocol uses a check sum to catch any errors that may occur during the transmission or the receiving of data. If an error occurs, data must be retransmitted.

Vehicle Location Capabilities

The location of the vehicle (lane detection) is accomplished by installing one reader per lane of roadway. Therefore there is a dedicated link between the vehicle in the lane and the reader in that lane. The readers must be carefully tuned to avoid "cross lane reads" and still cover enough area so that no tags can slip by without being read.

Application Description: Vehicle Transponder

The tag is composed of the modulator, power, code generator, clock, memory and antenna circuits located on a single printed circuit board. The tag has two 128 bit data frames of memory for the storage of information. One of the frames is fixed (read only) and the other frame is variable (read/write). The tag is powered by a small lithium battery and can be read at distances up to 25 m. There are no external interfaces with the tag. The tag may be attached to the vehicle windshield.

Application Description: Roadside Reader

The reader is intended to be installed at a fixed location on the roadway. The reader receives a demodulated signal from the RF module, decodes the ID information, confirms message integrity, and transmits the code along with any appended information to the host computer system. The reader operates in the 850-950 MHz frequency band and has an RS-232 communications interface. The reader has 32K of memory, controls two RF channels (for two lanes of roadway) and supports two serial ports and six I/O control channels.

4.1.7 Protocol Summary Matrix

The following matrix (Table 2) summarizes the information presented above for the known protocols that may be applicable to a VRC system.

VRC Protocol Summary

	Proposed Standard A	Proposed Standard B	Proposed Standard C	CALTRANS	Proprietary Technique A	Proprietary Technique B
Technology Type	Active	Active	Backscatter	Backscatter	Active	Backscatter
Communications Protocol	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex
Downlink Modulation	Unipolar AM	AM	Unmodulated	Unipolar AM	AM	Unmodulated
Uplink Modulation	Unipolar AM	AM	Modulated	Subcarrier AM	FM	Modulated
Binary Coding Scheme	ASK - Manchester	ASK - Manchester	FSK	ASK - down, FSK - up	ASK - Manchester	FSK
Multiplexing Protocol	TDMA	TDMA	TDMA	None	CDMA	Frequency Division
Lane Based Protocol	Yes	Yes	No	Yes	No	Yes
Wide Area Protocol	Yes	No	Yes	No	Yes	No
Data Rate	500 Kbits per sec	500 Kbits per sec	300K - 600K bits per sec	300 Kbits per sec	9600 baud	9600 baud
Security	64 bit validation seed	Encryption	Password and encryption	Encryption with 32 bit field	24 bit security field	12 bit security field
Error Checking	16 bit CRC	16 bit CRC	Check Sum	16 bit CRC	16 bit CRC	Check Sum

4.2 On-Board Computer Interface

An on-board computer interface provides a means for the tag to send or receive information over a hardwire connection to/from some device on the vehicle. This interface will be used to connect the tag with a computer on-board the vehicle. These interfaces have been used for connection to devices such as smart-card readers and driver displays as well. Several manufacturers produce tags with an interface of this type, but there is no standard protocol.

This section presents a summary of potentially useful communication protocols for this purpose.

CAN

The Controller Area Network (CAN) is a serial communications protocol which supports distributed real-time control with a very high level of security. Its domain of applications ranges from high speed networks to low cost multiplexing wiring. In automotive electronics, engine control units, sensors, etc. are connected using CAN with data rates up to 1 Mbyte per second. CAN has the following properties: prioritization of messages, guarantee of latency times, configuration flexibility, multicast reception with time synchronization, system wide data consistency, multimaster, error detection and signaling, automatic retransmission of corrupted messages as soon as the bus is idle again, and distinction between temporary errors and permanent failures of nodes and autonomous switching off of defective nodes. Error checking is performed with a 16 bit CRC of the form $X^{15} + X^{14} + X^{10} + X^{8} + X^{7} + X^{4} + X^{3} + 1$.

SAE J1850

The Society of Automotive Engineers (SAE) J1850 is a serial communications protocol which focuses on the network layer, data link layer and the physical layer of the OSI seven layer model. The data rate is either 10.4 Kbits per second or 41.6 Kbits per second dependent on the physical layer. The maximum length of the network through the vehicle is 40 m and the maximum number of nodes on the network is 32. Error checking is performed with an 8 bit CRC of the form $X^{8} + X^{4} + X^{3} + X^{2} + 1$.

The following table (Table 3) summarizes the two protocols just described as well as others that should be examined for applicability to the VRC on-board computer interface. Various standards and other resources have been used to compile this matrix [39,40]. Not all are typically thought of as automotive busses, however they provide a good indicator of the state of the art in cost and performance, which will aid in determining an appropriate standard for VRC. Other protocols exist, but these provide a good representation of the spectrum of capabilities available.

Existing Serial Interfaces

	SP50	CAN	SERCOS	I3NET	BACnet	SAE J1850
Maximum number of nodes supported on the network	255 on a link, can be extended through bridges	2032	254	100	10,000 (Ethernet), 255 (ARCNET), 32 masters and 222 slaves (MS/TP)	32
Maximum distance between nodes	750 m	50 m @ 1Mbyte/s	1 km, limited by fiber	2 km	1 km	40 m network length
Types of physical media supported	Twister pair, coax, fiber, RF	Not specified	Fiber	Twisted pair	Twisted pair, coax, fiber	single wire, parallel pair, twisted pair
Availability of sensor power from bus	Yes	Yes	No	Yes (slaves)	No	Yes
Minimum message	1 byte	0 bytes	1-16 bytes	1 byte		1 byte
Maximum raw data rate on network	2.5 Mbyte/s, 1 Mbyte/s, 31.25 Kbytes/s	1.6 Mbyte/s	2 Mbyte/s	9.6 Kbyte/s	10 Mbyte/s	10.4 Kbits/s, 41.6 Kbits/s dependent on physical layer
Support for deterministic and nondeterministic media access by nodes	Both are possible through a token access mechanism	Nondeterministic media access through a nondestructive bit-by-bit multiple access-arbitration method	Both are available through master synchro-nization pulses	Deterministic access through single master	Deterministic media available through MS/TP and ARCNET, only nondeterministic through Ethernet	
Estimated latency between transmission of a request and receipt of its response	<100 μs for selected messages	200 μs	62.5 μs	<5 μs for selected messages	<1 μs for selected messages	< 300 μs
Support for event-driven communication	Yes	Yes	No	No	Yes	Yes
Support for datagram service	Yes	Yes	Yes	Yes	Yes	
Support for connections-oriented, in-sequence services	Yes	No	No	No	No	
Support for periodic invocation of application functions	Yes	No	No	No	No	Yes
Maximum permitted applications data in a single network frame	256 octets	8 octets	16 octets	Unspecified	510 octets (MS/TP), 1500 octets (Ethernet)	
Support for multiple priorities	Yes	Yes	Yes	No	Yes	Yes
Support for multicast services	Yes	Yes	Broadcast only	No	Yes	

Protocol complexity	High, protocol supports several quality of service parameters and application layer services	Simple, but the protocol lacks the definition of application-layer services	Medium, 403 application messages are defined and initialization sequence is complex	Simple, supports digital I/O, analog I/O, parameter index, parameter read/write, and totalization	Medium, protocol supports operations on digital I/O, analog I/O, text string, schedule alarm, event, file, and control logic	Simple, addresses all OSI 7 layers, focuses on Network, Data Link and Physical layers
Reliability against loss of nodes	Network will continue to operate if there is at least one node on the network that is capable of operating as a link active scheduler	Network will continue to operate with the affected node disconnected	Loss of any slave system will still permit network operation	Loss of any slave will still permit network operation; also, the master node has a redundant bus interface circuit	Network will continue to operate with the affected node disconnected	Network will continue to operate with remaining nodes
Reliability against loss or corruption of information	16-bit CRC	16-bit CRC	16-bit CRC	8-bit CRC	16-bit CRC (MS/TP) 32-bit CRC (Ethernet)	8-bit CRC
Error rate	Low	Low	Low	Low	Low	Low
Cost	High	Low	Medium	Low	Medium	Low

Table 3: Overview of Existing Serial Interfaces

4.3 FCC Regulations

In the U.S., the Federal Communications Commission (FCC) governs assignments relevant to these types of systems. It is beyond the scope of this document to describe in detail all of the applicable regulations, however we will point out the regulations of interest. Part 90 of the Code of Federal Regulations describes the regulations for this type of system. A proposed change in the Part 90 regulations [41] is currently being evaluated by the FCC.

The current proposed changes in FCC regulations under 47 CFR Part 90 for the 902-928 MHz frequency band include the following new assignments:

Short Range Vehicle Identification	Automatic Vehicle Location
902 - 904 MHz	904 - 912 MHz
912- 918 MHz	918 - 926 MHz
926 - 928 MHz	

It is important to note the small number of assignments for Short Range Vehicle Identification and the limited bandwidth available in each. Two assignments with 2 MHz bandwidth and one assignment with 6 MHz bandwidth are proposed for this function.

Also of interest is 47 CFR Part 15 which governs other uses of the 902-928 band for operation without a license on a secondary basis. Many commercial and consumer products operate under Part 15.

4.4 Existing Systems

The purpose of the examination of existing VRC systems, specifications and equipment is to determine the level of capability currently available. This information is considered in the evaluation phase in determining what should be included in the standard and in evaluating if a candidate standard can be implemented successfully.

A description of relevant technical attributes is presented. A chart follows documenting the attributes of each surveyed component.

4.4.1 Technical Attributes

Technology Type

This is the physical method in which the data is transmitted or received from the transponder. The two major technologies that are used in the Vehicle-to-Roadside Communications (VRC) equipment are:

Active: There is an active transmitter in the transponder that transmits the transponder's information back to the reader.

Backscatter: The transponder reflects and modulates the incoming signal to carry the transponder's information back to the reader. There is no active transmitter in the transponder.

Communication Protocol

This is the method in which communications traffic is sent between the reader and the transponder. A Simplex transmission is in one direction only. A Half-Duplex transmission is in both directions, but only one direction at a time. A Full-Duplex transmission is simultaneous in both directions. A Half-Duplex transmission is found in most transponder/reader communications which use an inquiry/response protocol.

Downlink Modulation

This is the modulation scheme from the reader to the transponder. In Amplitude Modulation (AM), the amplitude varies to represent 1's and 0's. In Frequency Modulation (FM), the amplitude remains constant, while the frequency varies to represent 1's and 0's.

Uplink Modulation

This is the modulation scheme from the transponder to the reader. In Amplitude Modulation (AM), the amplitude varies to represent 1's and 0's. In Frequency Modulation (FM), the amplitude remains constant, while the frequency varies.

Binary Coding Scheme

This is the method in which the data is carried on the RF signal. There are two main coding schemes of concern, Frequency Shift Key (FSK) and Manchester Encoding.

Frequency Shift Keying

Using Frequency Shift Keying, the data is represented by a subcarrier modulation for each bit. For example, a 0 bit can be represented by a 20 kHz square wave signal and a 1 bit as a 40 kHz square wave signal. These signals are carried on the carrier frequency of 902-928 MHz.

Manchester Encoding

Using Manchester Encoding, the data bits are represented by signal pulses. The 0 bit is represented by a negative pulse followed by a positive pulse and the 1 bit is represented by a positive pulse followed by a negative pulse.

Protocol Proprietary

Is the RF protocol that is used to pass the information between the reader and the transponder proprietary, or is it accessible to vendors to manufacture compatible equipment?

Lane-based Protocol

Does the system have the capability to perform lane-based applications.

Wide-area Protocol

Does the system have the capability to perform wide-area applications such as communications with several vehicles over a wide area (several lanes) simultaneously.

Multiplexing Protocol

This is the multiplexing scheme that is used so that the reader can communicate with the many transponders that are in the antenna beam. The three multiplexing schemes that are of concern are Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) and Frequency Division. A single transponder response (no multiplexing) can also be used.

Time Division Multiple Access

In Time Division Multiple Access, transponders in the communications area take turns (in a round robin), each one periodically getting the entire bandwidth for a short time. The reader is only communicating with one specific transponder at a time during a specific time slot.

Frequency Division

In Frequency Division, the frequency spectrum is divided into smaller allocations so that each lane of traffic is equipped with a reader that communicates at a different frequency from the neighboring readers. This allows the several readers to communicate with transponders simultaneously without interference between readers. For adjacent lanes of traffic, the readers typically need to be separated by a band of at least 2 MHz to prevent interference from occurring.

Code Division Multiple Access

In Code Division Multiple Access, an identifying code is used to separate a desired signal at the receiver from other signals that simultaneously occupy the same frequency band. Unlike TDMA or FD networks, a CDMA network will accommodate an additional system without revising the signal formats, although some performance degradation results.

Single Transponder Response (No Multiplexing)

The single transponder response method of communications operates under the assumption that the reader will communicate only with the transponder sending the strongest signal back to the reader (the closest and most dominant transponder). The transaction is completed with that transponder and a command is issued to the transponder to remain silent for a period of time (usually 10 seconds) to allow communications with other transponders in the read area.

Lanes per reader

This is the number of lanes that each reader can control. If the reader controls more than one lane, there has to be a multiplexing scheme involved, this is usually Time Division Multiple Access (TDMA). This allows communication with one lane of traffic at a time.

Data rate

This is the rate in which the data is transferred by the radio frequency signal. The data rate is usually expressed in Kbits per second or baud (bits per second)

Transponder Memory Size

This is the amount of data storage (in bits) that is resident within the transponder and/or which may reside on other devices connected to the transponder such as on-board computers and smart card readers. If the transponder is connected to an on-board computer, it can be assumed that the data storage within the transponder is only required for temporary buffering purposes and other uses not associated with the on-board device. The first number in parentheses is the amount of read only memory on the transponder. The second number in parentheses is the amount of memory that can be written to via the RF link (writeable).

Transponder Size

This is the physical size of the transponder. The numbers correspond to length, width and height and is expressed in centimeters. The transponder should not be of a size so large that it is cumbersome and difficult to mount correctly.

Transponder Weight

This is the physical weight of the transponder in grams.

Price of Transponder

This is the price of the transponder as it is currently produced by the manufacturer. A good cost goal for the transponder should be less than $50 when mass produced.

Transponder Mounting Location

This is the location that the transponder must be mounted in order to operate correctly. Transponders are usually mounted either on the front bumper of the vehicle or on the vehicle dash.

Transponder Type

Type I, Type II, and Type III are labels commonly used to differentiate transponder capabilities.

A Type I transponder is capable of only transmitting data (has fixed code only).

A Type II transponder can store new data received from the roadside reader (has fixed and reprogrammable fields).

A Type III transponder is capable of full two-way communications with the roadside via a link to an on-board computer or smart card reader (capable of bi-directional communications between the roadside and an on-board computer or smart card reader).

Visual Display on Transponder

A visual display on the transponder (be it a LCD display or LED light display) allows direct communication with the driver of the vehicle.
Audio on Transponder

An audio signal that is generated by the transponder allows direct communication with the driver of the vehicle.

Optional Ports on Transponder

Optional ports on the transponder allow the transponder to interface with other devices on the vehicle such as on on-board computer, a smart card reader, or the vehicle's J-bus.

Power Supply

This is the method in which the transponder chip receives its power. The transponder may be battery powered, be powered by the vehicles power, or be powered by the energy in the signal generated by the reader (some backscatter transponders use this method of powering the transponder).

Battery Life

This is the life expectancy of the internal battery that powers the transponder's circuitry.

Battery replaceable by user

If the transponder is powered by an internal battery, can it be accessed and replaced by the owner of the transponder.

Nominal RF Power - Reader

This is the maximum power output of the reader at the reader antenna. This is limited by the FCC regulations for Radio Frequency devices. Most readers have to be FCC licensed for the site.

Security

This is the method in which the data is secured within the transponder and over the RF link to prevent tampering, falsification and unauthorized access of data.

Error Checking

This is the method that is employed to assure that the data transfer between the reader and the transponder occurs without error. The methods of error checking include Cyclic Redundancy Checks (CRC) and Checksums.

Operating Temperatures

This is the temperature range at which the transponder will function properly and maintain the integrity of its stored data.

Operating Range

This is the range at which communications can accurately take place between the stationary roadside reader and the mobile transponder that is mounted on the vehicle. The operating range may dictate the data rate which is required for the RF communications. If the operating range is small (1.2 m for some in-pavement antenna configurations) the data rate needs to be large (500 Kbits per second) to accomplish the required data transaction between the roadside reader and the vehicle while the vehicle is in range. In actual installations, range may be affected by many factors including antenna design and orientation, terrain characteristics, and presence of interfering signals or noise.

Operating Speed

This is the maximum vehicle speed supported by the system.

Polarization

This is the transponder polarization technique.

RF Frequency

This is the carrier frequency that is used to transmit the data between the roadside reader and the vehicle transponder. This is usually accomplished in the 902-928 MHz frequency band.

Frequency Agility

This is the ability for the reader to adjust the frequency in which it transmits to the transponder and the frequency that the transponder transmits to the reader. This is normally only accomplished with a backscatter system in which the transponder reflects the incoming signal from the reader back to the reader. A frequency agile system allows the reader to make adjustments if there is local interference in another frequency.

Bandwidth of Signal

This is the required amount of frequency bandwidth that is required to transmit the data at the specified data rate.

Frequency separation per lane

This is the frequency separation required between adjacent readers so that there is no interface between them. Normally this is only required in a backscatter system where Frequency Division is required to operate multiple lanes on a tollway.

Lane detection

This is the ability of the system to detect in which lane a specific vehicle is located. This is required for toll systems and for enforcement. There are several methods for determining which lane a specific vehicle is located. One dedicated reader per lane, the use of inpavement antennas, and calculations from several incoming signals can be used to located the vehicle. This is not as important for CVO capabilities as it is for ETC capabilities.

Type of Data Base

This is the type of data base that the transponder uses. If the transponder only holds an identification number, this number must be used to located the required information from a central database. If the transponder holds the required data for the transaction, there is no need to go to a centralized data base for information. This is called a decentralized system

Overhead Antenna Available

Overhead antennas can be used with transponders which are mounted on the vehicle's dash board or on the front bumper. Copper coated windows, used for instant defrost in some modern automobiles, can prevent communications between an overhead antenna and a dash mounted transponder.

Inpavement Antenna Available

Inpavement antennas can be used with transponders that are mounted on either the front bumper or under the vehicle.

4.4.2 Technical Attributes Matrix

The following matrix (Table 4) presents the relevant technical attributes for the systems examined in this survey.

VRC Systems Technical Summary

	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
Protocol	Proprietary Technique B	Proprietary Technique B	Proprietary Technique B	Proprietary Technique B	Proposed Standard C	Proprietary Technique A	CALTRANS	Proprietary
Protocol Proprietary	Yes	Yes	Yes	Yes	No	Partially	No	Yes
Technology Type	Backscatter	Backscatter	Backscatter	Backscatter	Backscatter	Active	Backscatter	Active
Communication Protocol	half duplex	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex	half duplex	half-duplex
Downlink Modulation	Unmodulated	Unmodulated	Unmodulated	Unmodulated	Unmodulated	Amplitude Modulation (AM)	Unipolar AM	
Uplink Modulation	Modulated	Modulated	Modulated	Modulated	Modulated	Frequency Modulation (FM)	Subcarrier AM	
Binary Coding Scheme	Frequency Shift Key (FSK)	FSK	FSK	FSK	FSK	Amplitude Shift Key (ASK)	ASK - down, FSK - up	FSK
Wide Area Protocol	No	No	No	No	Yes	Yes	No	No
Lane Based Protocol	Yes	Yes	Yes	Yes	No	No	Yes	Yes
Multiplexing Protocol	Frequency Division	Frequency Division	Frequency Division	Frequency Division	Time Division (TDMA)	Code Division (CDMA)	None	
Lanes per reader	2	2	2	2		4 or 8	Not specified	
Data rate	9600 baud	9600 baud	9800 baud	300 - 19,200 baud	300K - 600 Kbits per sec	9600 baud	300 Kbits per sec	40 Kbits per sec
Transponder Memory Size	128 bits	258 bits (128/128)	128 bits	256 bits (140/118)	2584 bits (128 bit frames)	18000 bits	Application specific	up to 8000 bits
Transponder Size	9.2 x 5.9 x 1.1 cm	9.2 x 5.9 x 1.1 cm	23.6 x 8.0 x 1.75 cm	23.6 x 8.0 x 1.75 cm	12.7 x 6.4 x 3 cm	12.7 x 7.8 x 2.5 cm	Not specified	9.7 x 8.2 x 0.8 cm
Transponder Weight	50 grams	50 grams	160 grams	170 grams	140 grams		Not specified	35 grams
Price of Transponder	$35	$49	$35			$38	Not specified	$40
Transponder Mounting Location	Vehicle dash	Vehicle dash	Vehicle bumper	Vehicle bumper	Vehicle dash or bumper	Vehicle dash	Front of vehicle	Vehicle dash
Transponder Type (I, II, III)	Type I	Type II	Type I	Type III (sensor interface)	Type III	Type III	Type II	Type I
Visual Display on Transponder	No	No	No	No	Yes (LCD)	Yes (LCD)	Not specified	No
Audio on Transponder	No	No	No	No	Yes	Yes	Not specified	No
External Communications ports	No	No	No	No		Yes - 4 ports	Not specified	
Power Supply	Battery powered	Battery powered	Beam powered	Vehicle powered	Battery powered	Battery powered	Battery powered	Battery 2 x 3V
Battery Life	10 years	5 years	Indefinite	Indefinite	10 years	1 year	Not specified	3 years
Battery replaceable by user	No	No	-	-	No	Yes	Not specified	Yes
Nominal RF Power - Reader	2 W max at transmitter	2 W max at transmitter	2 W max at transmitter	2 W max at transmitter	30 - 300 mW	20 - 600 mW	500 mV/m	600 mW
Security	12 bit security field	12 bit security field	12 bit security field	12 bit security field	Password and encryption	24 bit security field	Not specified	Encryption
Error Checking	Check Sum	Check Sum	Check Sum	Check Sum	Check Sum	18 bit CRC	18 bit CRC	CRC
Operating Temperatures	85 to -40 C	85 to -40 C	85 to -40 C	85 to -40 C	85 to -40 C	Not specified	Not specified	
Operating Range	up to 50 m	up to 25 m	up to 18 m	up to 15 m	up to 30 m	up to 1600 m	Not specified	up to 2 m
Operating Speed	up to 160 km/h	up to 80 km/h (10/91)	up to 160 km/h	up to 160 km/h	up to 160 km/h	up to 160 km/h	Not specified	up to 25 km/h
Polarization	Parallel to longer side	Parallel to longer side	Parallel to longer side	Parallel to longer side	Parallel to longer side	Predominantly horiz	Predominantly horiz	
RF Frequency	902 - 928 MHz	902 - 928 MHz	902 - 928 MHz	845 - 950 MHz	902 - 928 MHz	904.5 and 49.88 MHz	902 - 928 MHz	1.99 MHz
Frequency Agility	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Bandwidth of Signal	5 KHz	5 KHz	5 KHz	5 KHz	6 MHz	500 KHz	Not specified	
Frequency separation per lane	2 MHz	2 MHz	2 MHz	2 MHz	-	None	Not specified	None
Lane detection	Yes - 1 reader/lane	Yes - 1 reader/lane	Yes - 1 reader/lane	Yes - 1 reader/lane	Yes - 1 reader/lane	Yes 1 antenna/lane	Yes - 1 reader/lane	
Type of Data Base	Centralized	Centralized	Centralized	Centralized	Decentralized	Decentralized	Not specified	Decentralized
Overhead Antenna Available	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inpavement Antenna Available	No	No	Yes	Yes	Yes	No	Not specified	No

Table 4-1: VRC Systems Technical Summary

VRC Systems Technical Summary	System 9	System 10	System 11	System 12	System 13	System 14	System 15
Protocol	Proprietary	Proposed Standard A	Proposed Standard B	Proposed Standard B	Proposed Standard B	Proprietary	CALTRANS
Protocol Proprietary	Yes	No	No	No	No	Yes	No
Technology Type	Active	Active	Active	Active	Active	Active	Backscatter
Communication Protocol	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex	half-duplex
Downlink Modulation		Unipolar AM	AM	AM	AM		Unipolar AM
Uplink Modulation		Unipolar AM	AM	AM	AM		Subcarrier AM
Binary Coding Scheme	FSK	ASK - Manchester	ASK - Manchester	ASK - Manchester	ASK - Manchester		ASK - down, FSK - up
Wide Area Protocol	No	Yes	No	No	No	Yes	No
Lane Based Protocol	Yes	Yes	Yes	Yes	Yes	Planned	Yes
Multiplexing Protocol		TDMA	TDMA	TDMA	TDMA	None	None
Lanes per reader			8	8	8	-	1
Data rate	40 Kbits per sec	500 Kbits per sec	500 Kbits per sec	500 Kbits per sec	500 Kbits per sec	9600 baud	300 Kbits per sec
Transponder Memory Size	up to 8000 bits	512 bits	128 bits	128 or 256 bits	24000 bits		512 bits
Transponder Size	9.7 x 8.2 x 0.8 cm		10 x 6 x 1 cm	19.8 x 4.5 x 2.2 cm	14.2 x 8.4 x 2.3 cm		9.49 x 8.74 x 1.09 cm
Transponder Weight	35 grams			140 grams			18.44 grams
Price of Transponder	$50	$75 for Type III	$30	$30	$150		
Transponder Mounting Location	Vehicle dash	Vehicle dash	Vehicle dash	Vehicle bumper	Vehicle dash		Vehicle center line
Transponder Type (I, II, III)	Type II	Type III	Type I or II	Type I or II	Type III	Type II	Type II
Visual Display on Transponder	Optional LCD	Yes (2 LED, stop & go)	No	No	Yes (LED)	No	No
Audio on Transponder	Optional buzzer	Yes	No	No	Yes	Yes	No
Optional Ports on Transponder		Yes - RS232	No	No	Yes - 1 serial port	No	
Power Supply	Battery 2 x 3V	Vehicle powered	Lithium battery	Lithium battery	9V battery	Battery	Battery
Battery Life	3 years	Indefinite	5 years	10 years	1 year		8 years
Battery replaceable by user	Yes	-	No	No	Yes	Yes	No
Nominal RF Power - Reader	600 mW	4 W max at transmitter	1 mW	1 mW			500 mV/m
Security	Encryption	64 bit validation seed					Encryption
Error Checking	CRC	16 bit CRC	16 bit CRC	16 bit CRC	16 bit CRC		16 bit CRC
Operating Temperatures		Not specified	160 to -40 F	70 to -40 C	70 to -40 C		70 to -25 C
Operating Range	up to 4 m	Not specified		1.5 m			
Operating Speed	up to 40 km/h	up to 160 km/h	up to 160 km/h	up to 160 km/h	up to 160 km/h		up to 160 km/h
Polarization		Predominantly horiz	Predominantly horiz	Predominantly horiz	Predominantly horiz		Predominantly horiz
RF Frequency	1.8 MHz	915 MHz	915 MHz	915 MHz	910 MHz		902 - 928 MHz
Frequency Agility	No	No	No	No	No	No	Yes
Bandwidth of Signal		1.5 MHz	750 KHz	750 KHz	750 KHz		
Frequency separation per lane	None	None	None	None	None		2 MHz
Lane detection		Yes - Angle Of Arrival		Yes - Inpavement antenna			Yes - 1 antenna/lane
Type of Data Base	Decentralized	Centralized	Centralized	Centralized	Decentralized	Decentralized	Centralized
Overhead Antenna Available	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Inpavement Antenna Available	No	No	No	Yes (4 foot range)	No	No	

Table 4-2: VRC Systems Technical Summary

5. Recommendations

5.1 Evaluation

In this section we address the issues requiring resolution in order to form useful recommendations for VRC for CVO. In this effort we draw on the requirements documented in Section 3 and on the available alternative approaches documented in Section 4 in identifying the issues and potential solutions. The various issue areas presented are those that became evident to us in the process of examining both the requirements and the alternative approaches. Resolution of these issues in the context of CVO is the basis for our recommendations presented in Section 5.2. After describing some important assumptions, we consider the various issues and present the strengths and weaknesses of possible solutions.

5.1.1 Assumptions

Several assumptions have been made that serve to bound this evaluation effort, establish the priorities of evaluation criteria and help to ensure that the resulting recommendations will clearly address the problems in the VRC for CVO domain that are of the greatest concern to the FHWA.

A major area of concern for the FHWA is the deployment of incompatible VRC systems. It is a goal that VRC incompatibilities due to technology must be eliminated and therefore the recommendations provided must support eliminating these incompatibilities.

It is also a goal of FHWA to act as quickly as possible in addressing the compatibility problems. For this reason, a priority is placed on standards, protocols and technologies that are available immediately, or to a somewhat lesser extent, that will be available soon.

Another assumption is that the recommendations for standardization must support the User Services for CVO and other requirements documented in Section 3, with additional consideration given to standards, protocols and technologies that can address future needs (such as IVHS functions) as well.

Where other, more specific, assumptions are made they will be pointed out in the evaluation.

5.1.2 User Requirements

Table 5 presents a matrix of user requirements versus the numerous systems examined. The purpose of this table is not to support a recommendation of any particular system or type of system, but rather to document the ability of the current state of VRC technology to address the requirements of CVO, and to some extent, other IVHS services. It serves to help determine what capabilities or characteristics are reasonable to include in recommendations for standardization. Further, it can be used to verify that the recommendations made can be addressed by existing technology and systems.

5.1.3 RF Technology

Table 4 presents the characteristics of a great number of VRC systems. Two distinctly different approaches are used in implementing the tag's ability to send data to a reader. One approach used is the modulated backscatter technique and the other is the on-tag active transmitter approach. These two approaches are fundamentally incompatible. That is,

VRC System Capabilities vs. CVO User Services

	System 1	System 2	System 3	System 4	System 5*	System 6	System 7	System 8	System 9	System 10*	System 11	System 12	System 13	System 14	System 15
Automated Safety Verification:															
Access to Safety Records	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	No (4)	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Safety Records & Status Verification	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	No (4)	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Safety Monitoring	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Cross-border	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	No (4)	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Electronic Credentials:	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	Yes	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Electronic Purchase of Credentials															
Pre-Travel Verification of Credentials						OFF	LINE	FUNCTIONS							
Nationwide Advisory Bulletin Board															
Mainline Verification of Credentials	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	No (4)	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Mileage & Fuel Reporting	No (1,2,3,4)	No (2,3,4)	No (1,2,3,4)	No (2,3,4)	Yes	No (3,4)	No (3)	No (1,4,5)	No (4,5)	Yes	No (2,3)	No (2,3)	Yes	No (3,4)	No (3)
Fleet Management	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Hazardous Materials	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	No (4)	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Weigh-In-Motion	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Carrier Safety	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Vehicle Registration	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	Yes	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Fuel Tax	No (2,3,4)	No (2,3,4)	No (2,3,4)	No (2,3,4)	Yes	No (3,4)	No (3)	No (4,5)	No (4,5)	Yes	No (2,3)	No (2,3)	Yes	No (3,4)	No (3)
Permits	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	Yes	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Accident Rate	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	No (4)	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	No (2,4)
Roadside Inspection	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	Yes	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
Cargo Data	No (2,4)	No (2,4)	No (2,4)	No (2,4)	Yes	No (4)	Yes	No (4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (4)	Yes
CVO Data Model Support:															
Model 1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Model 2	No (1,2)	Yes	No (1,2)	Yes	Yes	Yes	Yes	No (1)	Yes	Yes	No (2)	Yes	Yes	Yes	Yes
Model 3	No (1,2,3,4)	No (2,3,4)	No (1,2,3,4)	No (2,3,4)	Yes	No (3,4)	No (3,4)	No (1,4,5)	No (4,5)	Yes	No (2,4)	No (2,4)	Yes	No (2,3,4)	No (2,3,4)

VRC System Capabilities vs. IVHS User Services

	System 1	System 2	System 3	System 4	System 5*	System 6	System 7	System 8	System 9	System 10*	System 11	System 12	System 13	System 14	System 15
Toll Collection - Open	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Toll Collection - Closed	No (1,2)	Yes	No (1,2)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	No (2)	Yes	Yes	Yes	Yes
Comm. Vehicle Fee Collection	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Restricted-Access Roads	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Transit & Intermodal:															
Position Location	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Schedule Monitoring	No (1)	Yes	No (1)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Dynamic Dispatching	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	No (4)	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (2,4)	No (2,4)
Vehicle Condition	No (1,2,3)	No (3)	No (1,2,3)	Yes	Yes	No (3)	No (3)	No (1,5)	No (5)	Yes	No (2,3)	No (3)	Yes	No (3)	No (3)
Priority Treatment, HOV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Automatic Switching	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
	No (1)	Yes	No (1)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Passenger Count	No (1)	Yes	No (1)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Intermodal Operations	No (2)	Yes	No (2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (2)	Yes	Yes	Yes	Yes
Safety/Environment Monitoring	No (1)	Yes	No (1)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Waste Management	No (2,3,4)	No (2,3,4)	No (2,3,4)	No (2,3,4)	Yes	No (3,4)	No (3,4)	No (4,5)	No (4,5)	Yes	No (2,3)	No (2,3)	Yes	No (2,3,4)	No (2,3,4)
Hazmat Transportation	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (2,4)	Yes
Traveler Information	No (2,3,4)	No (2,3,4)	No (2,3,4)	No (2,3,4)	Yes	No (3,4)	No (3)	No (4,5)	No (4,5)	Yes	No (2,3)	No (2,3)	Yes	No (2,3,4)	No (3)
Commercial Services	No (1,2,4)	No (2,4)	No (1,2,4)	No (2,4)	Yes	No (4)	Yes	No (1,4,5)	No (4,5)	Yes	No (2)	No (2)	Yes	No (2,4)	Yes
Traffic Management	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No (5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes
Emergency Messages	No (1)	Yes	No (1)	Yes	Yes	Yes	Yes	No (1,5)	No (5)	Yes	Yes	Yes	Yes	Yes	Yes

1 - Read/write transponder required for this service
2 - Larger transponder memory required for this service
3 - On Board Computer interface (ie Smart card reader) required for this service
4 - Insuffiecient data rate for this service
5 - System can not support required vehicle speeds

* Preliminary - Information based on prototype testing

Table 5: VRC Systems vs. User Services

backscatter and active components (tags or readers) cannot communicate with each other, since they each employ different principles of operation. Some consideration has been given to employing both technologies in a single system, but we are aware of no existing devices that currently employ this technique and its overall practicality is not clear. We present here what we feel are the most important and relevant strengths and weaknesses for each of these techniques for CVO.

Backscatter

Because a backscatter system's tag sends its data by modulating it onto its reflection of a continuous wave received from the reader, the frequency of the signal received by the reader is exactly the same as that sent by the reader. This means that within some bounds, the reader can select the frequency for operation. Thus, a degree of frequency agility is offered by employing this technique. Frequency agility has the potential for allowing different frequencies to be selected to avoid interfering signals as well as to avoid frequencies used by other similar systems, without requiring a change in the vehicle tag. This is an advantage not shared by tags containing an active transmitter designed to transmit on a single frequency, as are all the active systems examined here.

However, several related issues need to be considered in determining just how much of an advantage this is for near term CVO VRC adoption. First, backscatter tags deployed for U.S. operation typically operate in the 902-908 MHz frequency range, with the inherent agility permitting them to operate anywhere within that band. The ability to use this agility, though, is partly dependent on FCC rules, some of which are under consideration for change (see Section 4.3). As an example of the problem, Proposed Standard C (Section 4.1.4) for a wide-area implementation using backscatter requires 6 MHz of bandwidth. The proposed FCC rules only allocate one assignment for short range vehicle identification that can accommodate this (912-918 MHz). Since under the proposed rules, no other assignment is available for a move, the agility advantage is largely lost. It should also be noted even under the present rules, it is not guaranteed that one can avoid interference by moving within the 902-928 MHz band. Many commercial unlicensed spread spectrum devices are available that operate in this band, some using the entire 26 MHz bandwidth for high data rate communications. If a different band altogether becomes available for VRC, it could help the congestion problem, but even a backscatter system would require new tags, since the agility does not provide for a change to another band.

Another advantage of the backscatter technology stems again from the fact that the signal received by the reader is a reflection of a signal sent by the reader. Because of this, the signal will have experienced an attenuation over twice as much distance as it would have had it originated from a transmitter on the tag. Since received power drops as the fourth power of the distance, this distance is significant. This effect has been exploited in differentiating between tags in different lanes in lane-based toll applications, where lane determination is important for enforcement. How this effect can be used in wide-area implementations in a way that results in an advantage over active systems is not clear.

In considering standards, it is a strength that the backscatter technique for lane-based operation has already been adopted as a standard by the state of California. Known as the CALTRANS standard, it is formally documented and in the public domain.

For implementation of wide-area backscatter systems, Proposed Standard C (Section 4.1.4) is being placed in the public domain by its developer. This is not yet formally described in public documents, nor has it been submitted to any formal standards body.

This appears to be a very flexible protocol for wide-area use. According to the developer, testing at the prototype stage has been performed. No fielded implementations exist.

Because of the use of reflected signals, the reader for a backscatter system must transmit more power than is required for an active system. In general, requiring more power is a disadvantage, in that it increases the likelihood of interference with other systems and adds more energy to an already very crowded band.

Active

Active tags use a transmitter on the tag that produces an RF signal that carries information to the reader. (Reception of data by the tags is performed in the same way for both active and backscatter systems, using an on-tag receiver.) Since this transmission originates on the tag, the communications path for carrying data from the tag to the reader is the vehicle to reader distance. A path from the reader to the tag and back to the reader is not required as with backscatter. The result is a lower power requirement for reader transmissions.

Since the tag to reader signal originates on the tag, rather than being a reflection of a reader signal, its frequency is determined by the tag. Active tags are viewed as fixed-frequency devices, without the frequency agility advantage of backscatter tags.

The inclusion of a transmitter on the tag adds complexity, however this has not been reflected in the tag cost data.

Lane distinction methods have been developed for both lane-based and wide-area modes of operation of active systems, using characteristics of the signals received from the tags to deduce position.

In considering standards, ASTM is currently working on a standard that includes Public Domain Standard A (Section 4.1.2) to specify wide-area operation. Public Domain Standard B (Section 4.1.3) for lane-based operation is supported within Public Domain Standard A to support communications with tags that operate with that protocol. It is an advantage that both of these are associated with CVO implementations, Public Domain Standard B with the HELP program, and Public Domain Standard A with the I-75 program. Further, effort is being made under the ASTM group to accommodate communications with both active and CALTRANS type backscatter tags within the protocol. This could lead to commonalty between the CVO hardware and the much greater number of ETTM applications.

In their respective wide-area configurations, the active approach yields a bandwidth advantage, with its developer claiming a bandwidth requirement of 1.5 MHz for a wide-area implementation. The developer of Public Domain Standard C for wide-area backscatter specifies a 6 MHz bandwidth requirement.

Finally, because an active tag has all the hardware on it necessary to transmit, it can send a message without requiring a reader to provide the CW signal. Though all the examined protocols place the reader in charge of the data exchange, and in fact currently require the reader to activate the tag, the active tag itself has the capability for future, vehicle initiated communications, such as emergency messaging.

5.1.4 Protocols

Section 4 includes descriptions of communications protocols that are in use, being tested, or are proposed for use at the RF interface in the CVO application, each possessing strengths and weaknesses. As we evaluate these in the context of the FHWA requirements and CVO needs, we are able to identify advantages and disadvantages of various approaches which will be considered in our recommendations.

Two different types of communication are represented in the various protocols. These are lane-based and wide-area techniques.

Lane-based

Lane-based protocols are designed to communicate with a single vehicle in a particular lane using, at a minimum, an antenna installed in each lane. Multilane implementations rely on coordination of the readers activities and physical properties of the installation (lane separating barriers, antenna pattern and range control, etc. to avoid cross-lane reads, since the protocol itself operates independently in each lane. A multilane configuration operates as multiple, point-to-point links.

One advantage of a lane-based system is that a clear line-of-sight path between a vehicle and a lane's antenna is easy to obtain, since each vehicle will pass the lane's antenna without any shadowing problems caused by other vehicles.

Another strength is that protocols exist for communication in a lane-based topology for both backscatter (CALTRANS) and active systems (Public Domain B).

A disadvantage of lane-based systems is the requirement for dedicated equipment required for each lane. An antenna must be able to communicate with each lane, and multiple readers may be required to cover all lanes. Addition of lanes requires addition of equipment. Additions or modifications to roadways are required for lane-based installations.

The physical zone in which vehicle to reader communication can take place is small by design, in order to minimize cross-lane reads. This has the negative side effect of limiting the time available for communication as a vehicle passes at high speed.

Minimizing cross lane reads typically involves examining each incoming signal at the reader and selecting, by various algorithms, the one believed to be from the nearest vehicle. This adds complexity and is subject to some error. On the other hand, the conclusion that the message, and the identification within it, came from the vehicle in a specific lane can be used for enforcement purposes.

Wide-area

Wide-area protocols are designed to communicate with multiple vehicles in any lane in their coverage area using, at a minimum, a single antenna typically installed at the side of the roadway. Coordination of the message traffic is based on information in the protocol itself, with provisions made for dynamically assigning communication time slots and dealing with message collisions.

An advantage of a wide-area system is the minimal impact on the roadway. Multiple vehicles can communicate with a single roadside antenna location without requiring modifications to the road or use of antennas in each lane. An additional lane can be included for use without addition of hardware, providing the range of the roadside system is sufficient.

The size of the communications zone is typically over 30 m and could be more depending on the frequency and power used. This provides for longer possible communications times that could be needed for transfer of large data files with multiple vehicles at high speed.

Protocols exist for wide-area topologies under both active and backscatter technologies.

A disadvantage of a wide-area system is the possibility of a vehicle being shadowed from the reader antenna by another vehicle. More than one antenna or reader might be needed in some situations.

Since the protocol handles communications with any vehicle in any lane and does not force a determination of the lane occupied by a communicating vehicle, lane determination, if required, must be determined by some other means. Several mechanisms have been employed by various developers. None are in the public domain.

5.1.5 Data Models

Section 3.3 introduced the use of three different models of CVO VRC implementations to help evaluate the capabilities of alternative approaches. Table 5 includes an indication of the ability of each currently available alternative system to support each of the three data models for VRC implementation.

All systems are capable of supporting the requirements of a Model 1 scenario. Many, but not all systems can support Model 2 operation. This is important since this is the likely near-term implementation model. Those that could not support Model 2 fell short because they lacked read/write capability or had insufficient on-tag memory. In evaluating the ability to support future CVO needs, it is encouraging to note that a small but significant number of systems are able to support Model 3 requirements. It is also important to note that the few systems that can support Model 3 behavior are not all the same type, for example, both active and backscatter systems are represented.

5.1.6 On-Board Computer Interface

The performance requirements of this interface are not yet clear. An upper limit on performance is the tag-to-reader data rate, since there is probably no need to communicate with the tag at a rate greater than that. At the lower end, there are certainly functions that could be performed using a very simple RS-232 link operating at 9600 baud. However, if one considers transferring files of considerable length while a vehicle is in communication with a reader, faster techniques are necessary. It is possible that only a small incremental cost over that of lower performance systems will provide enough performance to permit the higher data rates that will likely be needed for future IVHS applications.

At this time no strong preference for a particular technique is being put forth by any developer. Common among currently available tags are simple serial RS-232 interfaces and the higher performance SAE J1850 interface. RS-232 interfaces supporting up to 19.2

kbaud are easily available. J1850 offers a current rate of up to 41.6 Kbits per second. A future 125 Kbits per second version is being pursued. Well beyond these in performance are other standard interface techniques currently being used or planned for fieldbus communications, typically among controllers and industrial devices. The CAN bus for example can support communications at rates to 1.6 Mbytes per second. A rate such as this would allow real-time communication with the on-board computer at the maximum tag RF data rate.

5.2 Conclusions and Recommendations

In Section 3 we utilized numerous sources of information to document the necessary technical attributes of a VRC system that are required for it to perform specific CVO functions. Further, attributes which might be needed for future IVHS functions were considered in an effort to determine the future demands on a VRC system. Three data models were defined that essentially form three different groupings of CVO functions. These models provide a means to compare system capabilities to three possible and increasingly sophisticated implementation configurations. The models represent the possible evolution of CVO VRC systems from the present into the future. The CVO (and future IVHS) user services that were determined were then documented in a matrix (Table 1) that indicates technical characteristics or requirements that must be present to perform each service.

In Section 4 we documented the technologies that are available or expected to be available soon for VRC implementations. First, we examined a number of communications protocols for the tag-to-reader RF interface and documented their important characteristics. The most important parameters of each protocol were summarized in Table 2. Similarly, the capabilities of currently used on-board computer interfaces and of other standard communication interfaces that might be considered for use as an on-board computer interface were presented in Table 3.

Numerous VRC systems were examined in order to obtain an understanding of the current abilities of VRC for CVO, and to determine what capabilities might be reasonably expected in the near future. The characteristics of the examined systems were documented in Table 4.

We began our analysis in this section, with a statement of assumptions and a description of specific areas which require resolution in order to eliminate incompatible VRC systems within CVO. With the information just described, documenting the user services and their technical requirements, and the technical characteristics of available systems, we are able to present here, in Table 5, a matrix showing the degree to which current and expected near-term systems can provide the required CVO services. In addition, the ability of the examined systems to accommodate the needs of the three implementation Data Models is included. Similarly, the ability to perform future IVHS services is also documented. With this information as a foundation we present our conclusions and recommendations.

Table 5 indicates a situation in which standardization can be helpful. Notice that several existing or prototype systems have the capabilities to perform all the listed CVO user services. These systems also can support the activities implied by the three data models defined earlier. In addition, they have the basic ability to perform the functions expected to be needed for the listed IVHS services. It is our view that a standard should not be adopted that calls for less capability than these systems already provide. We say this because these systems provide capabilities for supporting future IVHS services and because the systems with lesser capability are not significantly less costly.

However, among the systems with these capabilities, the different developers employ different communications protocols and different RF technologies, making all incompatible with each other.

The existence of several possible solutions and the FHWA interest in standardizing as quickly as possible, make creating a new solution unnecessary and undesirable. It is our view that a suitable standard can be obtained that specifies methods used in those systems that are most capable. The technical aspects that we believe are appropriate for CVO and should be specified for standardization are explained next.

FHWA has specified as a technical requirement that the CVO VRC standard shall provide for multilane operation. We recommend that a wide-area protocol and system configuration be used to accomplish this rather than a lane-based approach. There are several reasons for this. First, a wide-area approach minimizes that impact on the roadway infrastructure compared to lane-based techniques. This is important since future installations will include retrofits to existing weigh-stations. Further, a wide-area approach permits operation of a right-lane only type of configuration (such as that planned for I-75) and still allows for expansion to coverage of other lanes without addition of equipment for additional lanes. We feel the advantage of lane-determination in lane-based configurations is outweighed by the need to handle cross-lane reads and the fact that techniques are being developed for lane determination in wide-area systems. We also feel that the fact that a vehicle is in the communication zone longer in a wide-area system makes it possible to consider longer messages and more complicated transactions in the future.

Of the three systems that were found to meet the CVO user services requirements, data model, and IVHS needs, two support both wide-area and lane-based protocols and one supports only a lane-based protocol. The two wide-area protocols are Proposed Standard A and Proposed Standard C. These were discussed in Section 4.1.2 and 4.1.4 respectively. We recommend Proposed Standard A for CVO VRC for several reasons. While both protocols have been placed in the public domain by their developers, Proposed Standard A is much farther along in the process of review and standardization. It has been available in the public domain longer, and has been subject to review by an ASTM working group that includes participants from multiple VRC system vendors and interested users. As such, it has achieved a level of formal definition and documentation that is not available with any other public domain wide-area protocol. While not yet complete, this "head-start" is in line with the FHWA goal of attaining a standard as soon as possible.

This protocol includes features that will enhance its ability to carry out CVO and other functions. The protocol incorporates a mechanism for the reader to access vehicle devices external to the tag. This will be needed for access to smart card readers and external memory or computing systems. The protocol is also being extended to permit communication with HELP and CALTRANS type tags during otherwise unused guard time periods.

Proposed Standard A is designed for use with 2-way active RF technology. For this reason, and because of the smaller bandwidth requirement of this wide-area active configuration (1.5 MHz) compared to the larger bandwidth requirement of the proposed wide-area backscatter configuration (6 MHz), we recommend use of active tag technology for VRC. In addition, we feel it is an advantage that there are multiple developers of active tags that could support Proposed Standard A. It should also be noted that existing (HELP) and planned (I-75) CVO mainline bypass programs employ active technologies and that the I-75 program will employ an early version of Proposed Standard A. This protocol's allowance for communication with CALTRANS and HELP devices during protocol guard times will nonetheless provide coordination of communication with CALTRANS backscatter technology devices.

We also recommend consideration of the use of variable length frames. This capability is supported by Proposed Standard C but not by Proposed Standard A. Given the developing nature of VRC communications, it is hard to predict the optimum frame length or best number of activation slots. The ability to specify these dynamically could prove useful.

Our examination of the requirements for an on-board computer interface found that few specific requirements have been identified by users and that developers have not strongly proposed any particular interface. This has not lead us to any definitive position on the related issues, but we are able to make a few observations and recommendations. The primary use for the on-board computer interface at this time is for support of a smart-card device to be used with a card that contains driver specific information. This requires only a relatively low data rate interface, and can therefore easily be handled through an RS-232 or J-1850 interface. With both of these currently available on tags, we recommend using the J-1850 interface because of its greater data rate. For future applications in which the modest data rate of J-1850 (41.6 Kbits per second) is insufficient, we must look elsewhere. This is a very active area in communications system development. A number of protocols have been developed or are being developed for use in distributed control, most aimed at fieldbus communications for manufacturing systems. Of those protocols presented in Section 4.2, the CAN bus has seen application in vehicle implementations. Its data rate of up to 1 Mbyte per second is in line with the 500 Kbits per second data rates of current tag technology. We recommend further examination of CAN for evaluation of cost, performance and implementation considerations.

Finally, we remind the reader that few operational CVO mainline bypass installations exist, and none employ wide-area communications. The recommendations presented here are not the result of any performance history for installed systems, but on an analysis of the best available information we could obtain at the time of this study. Multiple sources were used in developing the requirements and in determining the current and expected near-term capabilities of various technologies. In many cases, the available information from developers is sketchy and not well documented, and of course, always subject to change. Nonetheless, we feel our recommendations have been reached through a careful analysis and weighing of what we believe to be likely technical capabilities and necessary user services.

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7. Appendix: Data Element Size Estimates

The following provides additional insight into how we estimated the lengths of the various data elements for CVO VRC applications. When alphanumeric characters are represented, a 6-bit ASCII code is used. A table for the 6-bit ASCII code follows.

- Carrier Name — 120 bits
  (20 characters * 6 bits/character)
- Carrier ID Number — 84 bits
  (14 characters * 6 bits/character)
- What permits, if any, the vehicle is operating under — 16 bits
  (16 bit bit-mapped storage area for 16 permits)
  (1 - valid permit, 0 - no permit)
- Whether or not carrier is registered in a "base state" — 4 bits
  (0001 - yes, 0000 - no)
- Base state for vehicle registration (IRP) — 8 bits
  (using a state code 0 - 49)
- Base state for fuel tax reporting (IFTA, RFTA) — 8 bits
  (a state code 0 - 49)
- License plate number and state for each vehicle unit — 50 bits
  (7 characters for plate and 8 bits for state code)
- Whether or not cargo is hazardous materials — 4 bits
  (0001 - yes, 0000 - no)
- Tag ID — 32 bits
  (32 bit factory installed number that is unique to the tag)
- Weight of the vehicle at last weighing — 12 bits
  (Weight of vehicle in 100's of kgs)
- Safety flags — 4 bits
  (4 bit value to signify recent safety violations)
- Temporary permits — 120 bits
  4 bit permit code
  8 bit state code
  12 bit permit expiration date

  5 slots for temporary permits

The following is driver related data that could be stored on a smart card device and loaded onto the truck when the driver comes on duty. Each driver would have a smart card that would contain the information about him/her.

• Driver Name (20 characters * 6 bits/character)	120 bits
• Time driver came on duty	28 bits
(based on: 6 bits for minutes (60) 5 bits for hour (24) 4 bits for month (12) 6 bits for day (31) 7 bits for year (99)	
• Driver ID Number (CDL number & state of license) (13 characters. i.e. S316465040976) (and 8 bits for the state code)	86 bits
• Driver Social Security Number (to access NLETS) (9 digit numeric value)	32 bits
TOTAL:	560 bits

6-Bit ASCII Table

Six-Bit ASCII Character	Decimal Value	Six-Bit ASCII Character	Decimal Value	Six-Bit ASCII Character	Decimal Value
(space)	0	6	22	L	44
!	1	7	23	M	45
"	2	8	24	N	46
#	3	9	25	O	47
$	4	:	26	P	48
%	5	;	27	Q	49
&	6	<	28	R	50
'	7	=	29	S	51
(	8	>	30	T	52
)	9	?	31	U	53
*	10	@	32	V	54
+	11	A	33	W	55
,	12	B	34	X	56
-	13	C	35	Y	57
.	14	D	36	Z	58
/	15	E	37	[	59
0	16	F	38	\	60
1	17	G	39	]	61
2	18	H	40	^	62
3	19	I	41	_(underline)	63
4	20	J	42		
5	21	K	43		