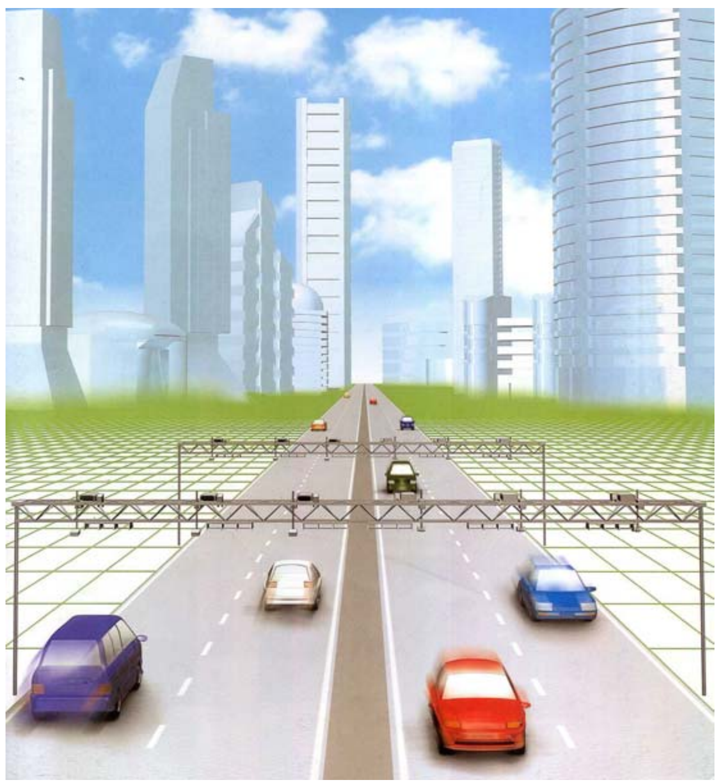
The Golden Ears Bridge

Greater Vancouver Transportation Authority

Contract 0214-45
The Golden Ears Bridge
Tolling Technology / Operations Technical Advisor

Toll Technology Assessment Final Report



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EXECUTIVE SUMMARY

The Greater Vancouver Transportation Authority (GVTA) will be implementing a toll system on the Golden Ears Bridge (GEB) in order to finance the construction, operation and maintenance of the GEB facility. The toll system will provide free flow toll collection at the facility's design speed, without requiring patrons to stop at toll booths. The facility will utilize technology to provide "open road" operations without the need for lane based toll collection.

In order to implement and operate the toll collection system, the GVTA will issue a design-build-operate contract to a toll system company or consortium of companies. Although the contract will be awarded based upon a functional specification, the toll technology needs to be considered in order to establish appropriate tolling policy and develop achievable performance specifications, both in terms of technology and cost.

The technology evaluation considered the technology required to implement the toll policy framework as presented to the public and the GVTA board. There are a number of aspects of the framework which influence the toll technology.

The four vehicle classes need to be accurately identified by the toll system to apply the correct toll tariff. The four classes are:

a) Cars – Cars include most passenger vehicles, vans, sport utility vehicles, pick-up trucks and taxis.

b) Small Trucks – Small trucks are defined to consist of "cars" towing a trailer, light duty commercial vehicles with less than five axles (with or without a trailer), school buses, intercity buses and non-exempt transit buses.

c) Large Trucks – Large trucks consist of all other vehicles (typically with five or more axles) with or without a trailer.

d) Motorcycles – Motorcycles are defined to consist of mechanized, licensed two-wheel vehicles. Note that this category does not include bicycles.

Vehicles can be classified through axle counting devices and profiling devices mounted above ground and in the road surface. The vehicle classifications identified can be determined through a variety of technologies. Since the toll system and equipment will be located on the structure, consideration needs to be made within the system specifications to limit the impact on the structure. It is recommended that preference be given to proponents whose technologies have minimal impact. An example of non-intrusive detectors is gantry mounted scanning laser vehicle detectors and classifiers. Minor adjustments to the classifications definition should be permitted if required to limit the impact on the structure.

The toll policy framework also stated that customers could be identified through the use of on-board units (OBU), toll transponders which communicate with complementary roadside equipment, or through the vehicle license plate and vehicle registration information. Customers who chose to be identified through the vehicle license plate are charged a surcharge of one dollar per trip, but are considered valid users and not violators as in other jurisdictions. The toll technology needs to address both types of customers.

In addition, the technology evaluation looks to the future. It is necessary to consider:

- Geographical expansion of the toll system through incorporation of future sections of toll road in the future;
- Functional expansion to take advantage of a fleet of OBU equipped vehicles for other ITS initiatives in the Greater Vancouver Region; and
- Future technological advances, in particular, the development of the new dedicated short range communications (DSRC) standards associated with IEEE 802.11p, also called the wireless wide area network standard (WiFi).

Automatic vehicle identification (AVI) and dedicated short range communications (DSRC) will be utilized to identify customers who opt to lease or purchase an on-board unit (OBU) and enter into a contract for use of the facility. There is a variety of different DSRC protocols utilized in North America, both public domain and proprietary. Public domain protocols include the ASTM v6 standard used in the Norpass and Prepass commercial vehicle programs and the Title 21 mandated for use on toll roads in California. As well, there are proprietary protocols which are widely used. In the future, likely starting in 2008, OBU's will be incorporated into vehicles by the manufacturers and will use the new IEEE 802.11p DSRC standard. Regarding the selection of AVI / DSRC technology, it is recommended that:

1. In order to provide for future procurement, OBU's be available from multiple sources, an open standard be used or a contractual method be adopted to control future costs;

2. Support for commercial users be provided to avoid multiple transponders on trucks, either initially if warranted or in the future when warranted;

3. OBU's be suitable to serve multiple toll facilities, provide for distance based tolling and support additional ITS functions, such as vehicular probes; and

4. Contractor be required to demonstrate a migration path to future IEEE 802.11p and associated new DSRC standards.

The toll system will utilize a bank of cameras to identify vehicles by reading the vehicle license plate. An image of the vehicle license plate will be captured as each vehicle enters the detection zone. The license plate of those vehicles not equipped with a valid OBU will be decoded by optical character recognition software, confirmed by operator intervention when necessary, and the registered vehicle owner identified from Insurance Corporation of British Columbia's (ICBC) database.

As part of the technology evaluation, the potential to utilize an all video system, using license plate recognition only without OBU's and DSRC was considered. However, video license plate recognition will not necessarily capture all vehicle license plates successfully. This will result in revenue loss or leakage. In addition, since there are additional manual operations required to process video users, the operating cost for an all video system is higher. Therefore, it has been recommended that a hybrid, OBU and video toll collection scheme be utilized.

In other jurisdictions, trucks are required to use an OBU to use the facility. However in British Columbia, the toll legislation does not require this, so truckers may decide to use the GEB and pay the toll as a video user. In order to identify the registered owner of a tractor trailer, it is necessary to capture the front license plate of the cab. This requires that both front and rear license plate capture systems be utilized. The use of front and rear license plate capture will increase the capital cost of the system, but should reduce the number of plates which are illegible.

Traditional account management back office systems are also required to provide customer service, process billings, and assist in the follow up of delinquent accounts. In addition, the back office systems need to have a link to ICBC's systems in order to obtain contact information from the license plate registry and to co-ordinate "refusal to issue" requests when the accounts are in default.

Automatic systems and electronic payment need to be encouraged in order to manage the ongoing operational costs. This includes the use of optical character recognition systems to automate as much possible the process of determining license plate numbers. In developing the back office systems specification, future requirements to toll additional roadways and distance based tolling need to be considered.

1. INTRODUCTION

The Golden Ears Bridge (GEB) will be the first tolled bridge in the lower mainland of British Columbia and as such will introduce roadway users to the concept of roadway tolls. The GEB toll system will be designed to provide motorists with non-stop, free flow automatic toll collection at normal highway speeds. The toll system must provide reliable collection of tolls as well as being perceived by the public to be fair and equitable to all users.

The toll system will be built and operated by a design–build–operate Contractor. At the end of the operations period, the facilities will be transferred back to the Greater Vancouver Transportation Authority (GVTA). The procurement process for the toll system will be independent of the procurement, construction and operation of the bridge itself and adjoining roadways.

In order to select a Toll System Contractor, procurement documents are required which detail the performance requirements for toll collection and customer service, and identify enforcement requirements. The approach to tolling and the toll specifications need to be developed with an understanding of the applicable toll technology and the limitations of this technology.

The Greater Vancouver Transportation Authority (GVTA) engaged Delcan Corporation as its Tolling Technology / Operations Technical Advisor to provide technical assistance to the Tolling Team. The Toll Technology Assessment Report has been prepared as part of this assignment to provide relevant information of toll technology with specific relevance to the GEB.

1.1 Objectives of the Document

The objectives of this document are to:

- Describe open road, free flow tolling technology which are directly applicable to the Golden Ears Bridge;
- Identify the potential performance which can be expected, conditions under which this performance can be expected, and conditions under which performance could be jeopardized;
- Relate the identified user requirements, both initially and potentially in the future, to required technology decisions; and
- Provide recommendations regarding technology choices and related performance expectations.

1.2 Organization of the Document

Section 2 through Section 4 of this document provides an overview of the toll technologies located in the field. Section 5 describes the technological systems required at the toll control centre, namely the back office systems required for billings, customer service, etc. The communications requirements associated with connecting the toll plaza location with the backend office is described in Section 6. The final section provides overall conclusions and recommendations.

1.3 Assessment Process

The technology assessment is based upon the needs of the GEB and considers inter-operational requirements with regional ITS systems as well as future expansion requirements. In recognition that the toll system procurement will be based upon performance specifications, specific design details are not considered. Technological solutions are evaluated to determine if they are practical and can meet performance requirements.

Factors considered in the evaluation process are:

- Technology maturity – is the technology proven elsewhere or derived from proven technology;
- Expansion and upgrade potential, particularly important in the choice of on-board devices (toll transponders);
- Inter-operable standards and potential for inter-operable arrangements in the areas of Automatic Vehicle Identification (AVI) and Dedicated Short Range Communications (DSRC);
- Initial costs and ongoing maintenance costs;
- Operational issues; and
- Performance and reliability impact on toll capture rates.

The assessment also considers different toll scenarios and discusses the impact of different technology choices and toll policies.

2. AUTOMATIC VEHICLE IDENTIFICATION (AVI) AND DEDICATED SHORT RANGE COMMUNICATIONS (DSRC) TECHNOLOGY

AVI technology provides an electronic method for the identification of vehicles using the GEB. It utilizes DSRC to communicate between an on-board unit (OBU) and roadside equipment or roadside unit (RSU). The OBU, which is also known as a transponder or tag, provides in the simplest case, a unique identification number which can be utilized to provide individualized information. In a toll application, this provides highly reliable and accurate identification of the client. It can also be used to provide other information to confirm vehicle classification or special status, such as a high occupancy vehicle, registered car pool or other information.

AVI and DSRC are also extensively used to support commercial vehicle operations (CVO), specifically the CVSIN (Commercial Vehicle Information System and Network) program which allows automatic bypass of vehicle inspection stations by registered commercial vehicles. In the CVO applications, a more significant amount of data is transferred to and from the transponder, including information on the driver and load. DSRC is also being used at border locations to assist in customs and immigration processing to speed the processing of pre-registered users.

In the wider context of Intelligent Transportation Systems (ITS), AVI using DSRC is also being used to support traffic probes, transit vehicle traffic signal priority and intersection safety systems.

As well as the use of DSRC for AVI, this section of the report also discusses technology associated with vehicle identification, location and related technologies, such as Smart cards and the so called electronic purse.

2.1 Overview of AVI Systems

This section of the report provides an overview of the technology used for automatic vehicle identification in North America. Current technology utilizes radio communications between roadside equipment and on-board equipment. The DSRC provides two way communications and allows data on the OBU to be stored and retrieved.

Radio Frequency Identification (RFID) is used for a variety of non-transportation related purposes, such as theft protection in retail stores, automatic payment for gasoline and convenience store items, goods shipping and logistics. Usually, RFID applications use different radio frequency bands than AVI. Although AVI could be considered to be a form of RFID and DSRC is used by both, the term RFID will only be used in this document to refer to applications which are not ITS applications. Another term which is commonly used is Electronic Vehicle Identification (EVI) which encompasses AVI.

Throughout this document, the term AVI refers to the identification of vehicles through the use of DSRC to communicate the vehicle identification from an OBU to associated RSU. Historically, automatic vehicle identification systems did just that; identify a vehicle by reading an encoded number. However, the terminology is currently also used to include systems where data can be read or written to the transponder / OBU and even transferred to connected devices in the vehicle.

2.1.1 System Components

The roadside equipment or roadside unit (RSU), also referred to as a reader, consists of a hardened computer, a radio transceiver and one or more directional antennas. The roadside equipment has a communications link to the operations centre and necessary inter-connections to the other toll field equipment. The other field equipment is required for vehicle classification and license plate recognition subsystems, which are described in subsequent sections of this report. The communications link is required to provide transaction information, license plate data and images, status of equipment, lists of invalid transponders and other information dependent upon the design.

Transponders or OBU's are usually installed on the wind screen of the vehicle or mounted internally to the vehicle. In most cases, it contains a microprocessor or ASIC (Application Specific Integrated Circuit) and usually consists of a battery or connection to vehicular power. In the event that the transponder is not powered, then the functionality will be reduced. However, it is still possible to actively transmit messages and store a limited amount of data.

The transponder may be equipped with lights which are used to indicate when successful communications have occurred, to indicate low account balances, failures or other simple functions. The transponder may have a connection to an external device, such as an on-board computer in commercial vehicles or devices to support enhanced functions. In most ETC systems, external devices are not utilized. They are currently used primarily to support commercial vehicle operations. However, in the future with the development of new DSRC standards, these interfaces will be used more widely. In toll applications, the interface could be used to interface with electronic purse or smart cards. In practice however, this is not done since simpler and more secure payment methods are possible. The transponder is usually equipped with a limited amount of write-able memory. Certain memory locations and programming is only done by the vendor or agency, however some memory may be used for application data. Application data could include location of where and when a vehicle entered a facility for distance based tolling, remaining account balance, low account balance indicator, vehicle classification, special toll characteristics or other implementation specific data.

2.1.2 Dedicated Short Range Communications

DSRC, as the name implies, is designed to provide application specific communication messages between roadside equipment and individual vehicles. Each antenna has a coverage pattern, or footprint, which can be as large as 300 m or as small as 0.5 m.

Current North American toll systems operate in the Industrial, Scientific and Medical (ISM) band of 902-928 MHz. This band is also used for low power license exempt radio communications purposes and is heavily utilized. In the future, spectrum in the 5.9 GHz range will be available for transportation DSRC to partially address this concern. Different frequency bands and other technologies, including infra-red communications, have been used in different part of the world.

A variety of communications protocols have been developed over many years for DSRC and the current status will be discussed in the subsequent sections. However, the fundamental characteristics are that communications are activated when the vehicle enters the communications zone, and communications between the OBU and RSU are dedicated. The RSU is constantly polling for OBU's, when the OBU enters the zone, it responds and the RSU establishes a point-to-point communications using the OBU's unique address. In this manner, the user can be identified and other relevant data transferred.

2.1.3 Considerations for Open Road Tolling

There are a variety of fundamental issues associated with the use of DSRC for open road tolling where there are no physical barriers between lanes and vehicles could be changing lanes or straddling lanes. These issues have been addressed through a variety of means by systems integrators and manufacturers over the years.

It is necessary to establish communications with a single OBU at a time as each enters the communications zone to avoid collisions of the responses. It is also necessary to establish the location of the vehicle being communicated with, to co-ordinate with the license plate capture system and the vehicle classification system. This can be accomplished by controlling the size of the radio communications footprint and addressing radio frequency cross talk by adjacent channel co-ordination and synchronization of polls and carrier signals. The location of the vehicle is known by the footprint.

Another method uses a wide area DSRC (e.g., 407 ETR and CVSIN) to establish communications with each transponder early as it enters the larger communications zone, re-broadcasting if necessary to overcome collisions, and then establish a temporary dedicated time slot for communications with each OBU. This method however needs another technique to identify the location of the vehicle, such as the Angle of Arrival system which tracks the vehicle using the signal received from the OBU as it passes through the communications zone and through the license plate capture system. The methods used to solve these issues are not simple. However, solutions have been developed and proven to work in a variety of systems.

2.2 Deployed AVI Technology and Suppliers

AVI has been utilized in North America for tolling applications for several decades. It has also been effectively utilized to support the CVSIN program and more recently to provide more effective crossing of the USA, Canada and Mexican borders. Inter-operable toll systems are also deployed in Europe and in fact around the world. This report will deal with North American deployments and methods employed to procure and implement these systems.

2.2.1 Caltrans Title 21

California was one of the early North American agencies to implement AVI systems for tolling. The early systems were installed on bridges and, in order to provide compatibility, a DSRC standard was mandated through a bill in the State legislature, known as Title 21. This resulted in multiple sources for OBU's and systems. Two vendors developed the Title 21 market, namely SIRIT and Amtech. Amtech technology is now supplied through TransCore.

The standard provides for a simple read only OBU. The systems use small radio frequency footprints to resolve the location of vehicles. The DSRC uses a simple poll response protocol with an activation signal. The technology can provide for a simple write operation, but is primarily designed for read only.

Title 21 technology is well proven and used extensively throughout the United States. It is best suited for toll systems using dedicated lanes, although it can be configured for open road arrangements.

It will only support other ITS applications which require read only, and is not well suited for other ITS applications which require a wide communications zone.

2.2.2 Time Division Multiple Access (TDMA) Systems

The TDMA vehicle to roadside communications protocol was developed by Hughes Aerospace to provide wide area DRSC communications. It was derived from the slotted ALOHA protocol used for early satellite communications. The advantage of the protocol is that the wide area of reception will allow the transfer of more data since multiple packets can be transmitted as the vehicle passes through the larger communications zone. Once communications are established between the OBU and RSU, a reliable collision free communication path is available. The TDMA protocol has been extended through the standardization process and is publicly available, although never formally released.

The TDMA protocol formed the basis for the open toll road on Highway 407 Express Toll Route (ETR) in Toronto, Cross Israel Highway, and the CVSIN programs of Advantage I75 AVION, Prepass and Norpass. The TDMA protocol also provided a model for the Japanese national standard, however operating at 5.8 GHz. The CVSIN programs and

Highway 407 ETR utilize DSRC standards that were developed through the ASTM, and a de-facto standard known as ASTM v6 has been deployed for these systems.

TDMA transponders are available from Raytheon, MARK IV and Telematics. TransCore also provides a TDMA transponder, however it is different from the CVSIN transponder. The manufacturers each have different types of transponders and different forms of TDMA protocols. Inter-operability between systems is a serious issue which needs to be carefully addressed during the procurement process.

2.2.3 Interagency Group (IAG) and E-Zpass

The IAG was established by toll agencies and port authorities in the north-eastern United States in order to provide inter-operability and a single invoice for their clients when using the toll facilities of member agencies. This was accomplished through interagency agreements with a clearinghouse for billings, and through the use of a common transponder and DSRC standards. This program has been extremely successful and over ten million IAG transponders are in use.

The transponders are supplied by MARK IV Industries and utilize a proprietary DSRC protocol. The protocol is compatible with the ASTM v6 protocol in that the MARK IV protocol utilizes the same frame structure with proprietary protocol and timing considerations. However, the protocols are not inter-operable.

The IAG protocol was designed for lane based toll operations, as opposed to open road, applications. In open road applications, it is necessary to use other techniques, such as identification matching through license plate recognition for lane differentiation.

2.2.4 Sunpass / E-PASS

In Florida, a program is well established using toll transponders from Amtech (TransCore) which utilizes an extension of the Caltrans Title 21 protocol supporting both read and write capabilities, as well as a somewhat wider zone of communications. The programs in Florida, depending upon the agencies, are known as Sunpass and E-Pass. The programs have supported the concept of storing cash "value" on the card. However, in light of security concerns and to support inter-operability with other compatible systems, the agencies are moving toward centralized billing and accounting, eliminating the stored value concept.

The American Trucking Associate (ATA) and American Association of Railways (AAR) have developed standards of identification of cargo and vehicles. The products developed by Amtech to support Sunpass and E-Pass are also compatible with these legacy standards.

The Sunpass OBU's can be identified by RSU's from TransCore and SIRIT, although the write capability is limited to TransCore.

These systems utilize a lane based approach and the infrastructure consists of both manual and automatic lanes.

2.2.5 Multi-Protocol OBU's and RSU's

Vendors have developed transponders and OBU's which support more than one protocol. These include:

- MARK IV Fusion OBU supports ASTM v6 used for CVSIN and Highway 407 ETR and the IAG protocol; and
- TransCore provides support for the Caltrans Title 21 protocol plus the variable TDMA protocol compatible with the E-Pass systems.

Dual purpose RSU's can be integrated either by synchronizing two readers or through dual purpose readers. MARK IV's dual purpose RSU reads both CVSIN (serial number only) and ASTM v6 plus the IAG transponders.

TransCore also can integrate readers for Title 21, E-Pass and CVSIN equipment.

Multi-purpose RSU allows existing OBU's to be utilized for identifying vehicles without requiring additional transponders on commercial vehicles. They also enable support to other ITS applications.

2.3 DSRC Standardization

2.3.1 North American Standards for DSRC at 915 MHz

In North America, the 902-928 MHz frequency band has been available for DSRC and other purposes. As described previously, a wide variety of transportation systems, in particular toll roads, high occupancy vehicle toll roads (HOT), commercial vehicle pre-clearance and border crossing systems have utilized DSRC.

It was recognized from the early days that standardization would be required. These standards need to address:

- Non-interference – Multiple transponders mounted in a vehicle must not interfere with each other. In this case, each transponder must respond only to RSU with which it is associated to avoid interference.
- Compatibility – Compatible transponders recognize RSU's from different agencies and respond in an appropriate fashion. Compatible DSRC protocols may share common frame structure and header information.
- Inter-operability – Inter-operable transponders, RSU and system enable clients to roam between toll systems and receive a single invoice. Inter-operability also enables OBU's to serve multiple applications (tolling, customs pre-clearance, commercial vehicle permits, etc.).

The use of radio spectrum is the responsibility of Industry Canada (IC) and the American Federal Communications Commission (FCC). However, the transportation industry recognized the need to develop standards to support toll operations and ITS applications. There is also recognition of the need to address international standard development activities in the area of DSRC and ETC within CEN (European Standard Organization) and ISO (International Standard Organization).

An ASTM Committee (17.51) was established to develop an industry standard for DSRC standards to address issues of inter-operability. The committee, composed of industry agencies and government, developed the ASTM v6 standard and co-ordinated with the ISO TC 208 working group for international ETC and DSRC standards. The ASTM Committee worked with the IEEE (Institute of Electrical and Electronic Engineers) standards committees that are responsible for the development of the application layer of the DSRC standard. A variety of commercial and institutional issues resulted in a lengthy process. The Federal Highways Administration (FHWA), Transport Canada, ITS America and ITS Canada worked to promote the development of a model standard which addressed multiple applications as well as the legacy systems.

In parallel with these standardization efforts, new spectrum was made available in Canada and the United States in the 5.9 GHz band for vehicular safety and ITS applications. The available spectrum plus renewed emphasis by agencies and government resulted in a much more application based process to develop new standards for DSRC in the 5.9 GHz band. This is discussed in subsequent section of the report.

The standardization efforts of ASTM and IEEE for DSRC in the 915 MHz band resulted in the ASTM v6 standard which is the de-facto standard for the CVSIN and the development of the so called “sandwich model”, which provides a level of inter-operability between the existing available systems. In addition, the concept of the Applications Manager was introduced to provide a mechanism to manage the resources of the OBU / transponder. The Application Manager was endorsed by both the IEEE and ISO standards setting bodies for DSRC and has been carried forward to the new standards for 5.9 GHz.

The ASTM v6 standard is used for commercial vehicles for the CVSIN program and is mandated for Highway 407 ETR. Highway 407 ETR can identify CVSIN transponders and inter-agency agreements require that the operator also register as an ETR customer since client information is not shared.

Agencies that wish to establish inter-operability with other agencies can and have adopted the following models:

- Joint Procurement – The IAG have agreed to procure proprietary transponders from MARK IV and a similar situation exists between Florida and adjacent States with TransCore.

- Legislature – The state of California through Title 21 mandated that all transponders have a common protocol to ensure that they can be read by any agency and the protocol is in the public domain.
- Standards – Agencies can demand that supplier provides equipment meeting specified and open standards, such as ASTM v6.
- Multi-protocol Roadside Equipment – The roadside equipment can be configured to read more than one type of transponder. However, there are issues associated with proprietary information and incremental cost with this approach.

The technical issues associated with inter-operability can be addressed. However, commercial interests may still prevent inter-operability. For example, the ASTM v6 transponders used by 407 ETR were used for a taxi staging application at Pearson International Airport, and attempts were made to use them to develop a travel time system in the Toronto area. However, the owners of 407 ETR objected and new transponders were procured which encrypted the transponder identification specifically to preclude inter-operability. Similarly, Prepass requires users agree not to register their OBU identification for other applications, such as tolling.

2.3.2 DSRC Designs for the 5.9 GHz ITS Radio Services Band

2.3.2.1 Introduction

This section of the report presents an overview of the Federal Communications Commission's (FCC) and Industry Canada's allocation of 75 MHz bandwidth in the 5.9 GHz band for the intended goal of improving highway safety. The Institute of Electrical and Electronic Engineers (IEEE) Standards that are being developed to provide compatibility and inter-operability of equipment in this frequency band are discussed. This 75 MHz band is referred to as the Intelligent Transportation Systems (ITS) Radio Services Band and the IEEE Standards as the Dedicated Short Range Communications / Wireless Access in a Mobile Environment (DSRC / WAVE) Standards. This section of the report also discusses the government and non-government organizations that are supporting the new ITS Radio Services Band allocation, the DSRC / WAVE Standards, equipment development and related activities. Following these discussion areas, a description of the communications services and features that will be offered in the ITS Radio Services Band is provided. As part of this discussion, it is explained how non-safety applications can utilize these services and still provide the required safety priority communications capabilities. Next, the report will discuss how backward capability is provided for legacy 915 MHz DSRC systems and the migration path to the DSRC / WAVE option that is being provided for these legacy systems. Finally, a discussion of the ITS projects and DSRC / WAVE Standards that are being executed is provided. It illustrates how these activities will help assure that the new ITS Radio Services Band and its DSRC / WAVE Standards will result in the successful deployment of systems using the DSRC / WAVE technology.

2.3.2.2 Background

In 1997, the Intelligent Transportation Society of America (ITS America) submitted a Petition for Rule Making to the Federal Communications Commission (FCC). The petition called for the allocation of a band of frequencies for Intelligent Transportation Systems (ITS) communications that would support highway safety and various other ITS user services. In June 1998, the FCC unanimously voted to consider the allocation of a 75 MHz band of frequencies in the 5.9 GHz band for ITS Radio Services. In November 1998, as part of the allocation process, the FCC issued a Notice of Proposed Rule Making (NPRM). The NPRM requested comments from communications stakeholders on the proposed ITS Radio Services allocation. The FCC received mostly positive comments and proceeded with the ITS Radio Services Band allocation.

The FCC allocation in this frequency band is beneficial since it provides Dedicated Short Range Communications (DSRC) systems with co-primary status along with the government operated Fixed Satellite System (FSS) stations. This frequency allocation and its co-primary status are in sharp contrast to the 915 MHz band. In this FCC allocation, DSRC holds a secondary status, has only a 12 MHz bandwidth, and is restricted from growth by surrounding cellular telephone, paging and multi-lateration communication systems. Figure 2.1 shows a diagram of the ITS Radio Services Band and its seven operating channels.

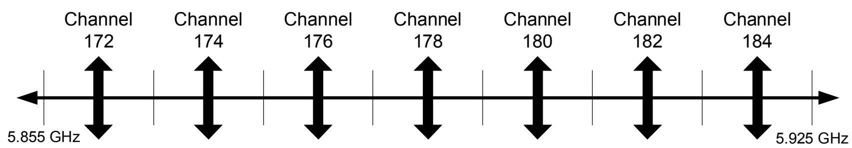

Figure 2.1 : Band Plan

The ITS Radio Services band is divided into seven 10 MHz channels.

In Canada, Industry Canada has been petitioned to allocate the same channels for the use of DSRC with a similar co-primary status. However, in some geographic locations, channels 176, 182 and 184 have been previously licensed to cellular companies. The use of these channels will be avoided when necessary.

The Institute of Electrical and Electronic Engineers (IEEE) formed several DSRC Standards writing groups and chartered them with the task of writing standards for this new ITS Radio Services Band. The Standard's writing groups evaluated several communications technologies and then selected the IEEE 802.11 Wireless Local Area Network technology. This technology is commonly referred as WiFi and is the dominant technology worldwide in wireless computer networking. An IEEE 802.11 Study Group was formed to determine the modifications that would be required to existing IEEE 802.11 technology to meet the high vehicle speed requirements of the physical layer and the low time latency processing requirements of highway vehicle transactions. The Task Group effort took the name Wireless Access in a Mobile Environment (WAVE) and resulted in an IEEE 802.11p Work Group. This IEEE 802.11p WAVE Work Group developed standards that defined the lower two layers (Physical and Data Link) of a standard communication stack. In support of these activities, IEEE formed another Standard's Writing Group that was tasked with developing standards for the other layers of the standard seven layer communication stack. This Standard's Writing Group has developed a set of standards identified as IEEE 1609. This set of standards defines the management of the communication stack and is built around the use of existing Internet Protocol (IP) Communication Standards. The IEEE 1609 Standards utilizes standardized IP interfaces and using these interfaces, anyone familiar with Information Technology (IT) and IP methods can write applications that will directly interface with the DSRC / WAVE communications devices. In addition, the management and configuration of the DSRC communication stack uses a Simple Network Management Protocol (SNMP) methodology that is also an IT Standard. Figure 2.2 shows a diagram of the DSRC / WAVE communication stack and how it utilized existing standards in its development.

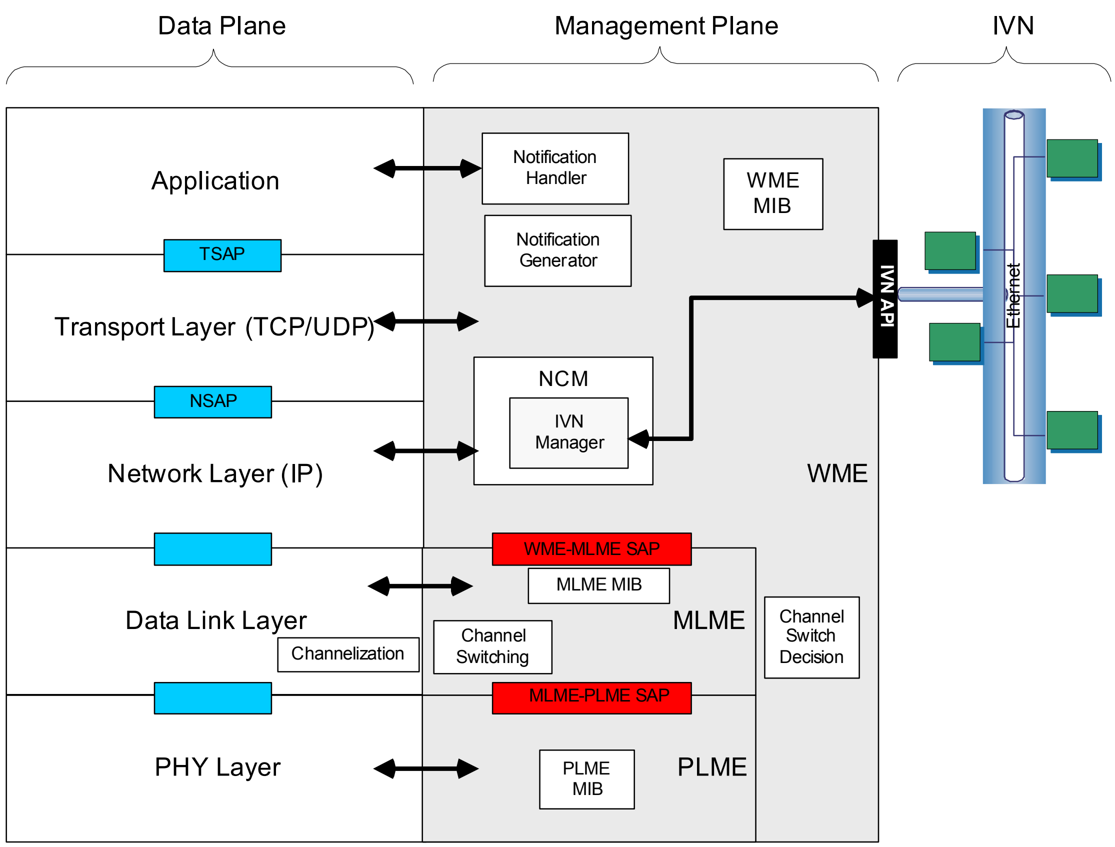

Figure 2.2 : DSRC / WAVE Communication Stack
The communication stack is based on existing IEEE 802.11 Wireless Local Area Network Standards and existing IP technologies.

The third DSRC standard being developed was IEEE 1556. This is a DSRC Security Standard that defines the security requirements for Vehicle Safety, Public Safety, and Non-Safety Applications that use the DSRC / WAVE communication stack. The IEEE 1556 Standard provides authentication services to validate the credentials for roadside units (RSU), previously called “readers”, and the ITS Applications that it offers to on-board units (OBU), previously called “tags”. Following the credential validation, the IEEE 1556 Standard provides link level encryption that is based on the IEEE 802.11i Security Standard. One of the significant features of the IEEE 1556 Standard is that it provides these security services without breaking the anonymity of the OBU. The IEEE 1556 Standard’s security method prevents unauthorized RSU’s (called Rogue RSU’s) from determining the identity of an OBU and also prevents unauthorized tracking of an OBU equipped vehicle as it travels the highways.

2.3.2.3 ITS Radio Services Features

The ITS Radio Services Band contains seven 10 MHz wide channels. Each channel is capable of supporting transmission bit rate of 27 Mbps. All communications exchanges begin on the Control Channel (Channel 178). The Control Channel is the “default channel” and, unless an RSU or an OBU is engaged in a transaction, they monitor communications on the Control Channel. RSU’s operate in the same manner as a WiFi Access Point sending timing transmissions, called “beacons”, at periodic intervals. In the DSRC / RSU, these beacons are called WAVE Beacons. The WAVE Beacons are similar to the Frame Control Message transmissions that are used in existing 915 MHz reader based systems. The WAVE Beacon provides the communication timing information and also includes a Provider Service Table (PST). The PST contents are used by ITS Applications to announce the services that they provide, and the Service Channel where the transaction will occur. Service Channels are the remaining six ITS Radio Services Band channels (excluding the Control Channel). When an OBU receives the WAVE Beacon, it processes the PST to see if it contains any ITS Applications that are of interest to the OBU. If the OBU finds an application of interest, it uses the timing information within the WAVE Beacon and switches to the Service Channel that is identified in the PST. The RSU and OBU then conduct communication exchanges on this Service Channel. In this manner, the RSU Service Provider executes its ITS Application transaction with the OBU Service User. The ITS Application transactions are not defined by the IEEE Standards. As will be discussed later, a standardized general purpose ITS Application is defined by an IEEE DSRC / WAVE Standard and will be installed in every OBU. The DSRC / WAVE system uses IP addresses to exchange IP Datagrams between an RSU Service Provider port and an OBU Service User port. The DSRC / WAVE system provides a communication capability for the delivery of these IP Datagrams. Since the DSRC / WAVE system uses IP v6 Addressing, the ITS Application does not have to reside on the RSU. The RSU can act as a router and deliver the OBU originated IP addressed Datagram to any Internet location. By the same token, the RSU originated IP addressed Datagram can be delivered to an ITS Application connected to the OBU using an “In Vehicle Network” (IVN). The use of Internet Protocols, IP v6 Addressing and the support of IVN delivery provides ITS Application creators with a powerful communications tool. No longer are ITS Application creators burdened with designing systems using proprietary reader protocols and operating systems. Standardized IP design techniques and existing Internet software packages can be used with DSRC / WAVE systems. Even more importantly, ITS Applications can be used with any DSRC manufacturer's equipment provided the equipment is "standard compliant".

The FCC allocated the ITS Radio Services Band with the understanding that it would be used to support highway safety communications. The IEEE Standards provide a framework that supports the non-safety communications discussed above, but also provides priority services for safety applications. When OBU's are not executing transactions on Service Channels, they monitor transmissions on the Control Channel. In addition to the WAVE Beacon transmissions discussed previously, the Control Channel also supports the transmission of WAVE Short Messages (WSM). These WAVE Short Messages are used by safety applications to transmit safety messages to all OBU's within range of an RSU. They are processed by the WAVE Management Entity as Ethernet Frames to provide priority delivery service even when an OBU and an RSU are executing a non-safety based transaction. The WSM are very short messages, typically less than 1 millisecond in duration, and their transmission and reception do not require the termination or interruption of an OBU and an RSU transaction.

The ITS Radio Service DSRC / WAVE systems offer a number of additional communication services that can be used by ITS Application developers. These services provide design tools that can be used to customize the DSRC / WAVE communications to meet particular system or installation requirements. The DSRC / WAVE's longer communication range ability is one important tool. The ITS Radio Services Band supports communication ranges up to 300 meters (1,000 meters for safety applications) and supports eight levels of priority. The DSRC system also provides tools for controlling the communications zone size using RF controls. The RF controls are used to adjust the size of the communications zone by inhibiting communications until the RF signal strength exceeds a specific value. The DSRC / WAVE protocol can use polling transmissions to precisely measure RF signal strength. Finally, the ITS Radio Service DSRC system also offers tools for OBU to OBU communications so that vehicles can exchange safety messages when no RSU is present.

2.3.2.4 Backward Compatibility with Legacy Systems Using DSRC

The DSRC / WAVE system does not provide backward compatibility by reproducing the 915 MHz reader / tag communication exchange. However, it does provide a backward compatibility and a migration path that can be used for backward compatibility of existing 915 MHz DSRC infrastructures. The following paragraphs discuss the compatibility provided and the migration path that is recommended. The DSRC / WAVE system addresses backward compatibility using two methods:

a) **Infrastructure Compatibility** – The DSRC / WAVE standards utilized requirements defined by the International Bridges, Tunnels, and Turnpike

Association (IBTTA) requirements document entitled “Next Generation DSRC Requirements”. The Next Generation Requirements document, with contributions and editing by Highway Electronics, was developed over a two-year period by a task force that investigated backward compatibility requirements. The Next Generation Requirements document was used by the IEEE Standard’s writers to establish DSRC / WAVE communication performance and management requirements. Using this requirements document would assure that the new DSRC / WAVE systems could be used by toll operators and commercial vehicle operations (CVO) while still maintaining the use of a majority of the existing highway equipment and the backroom infrastructure. The document defined requirements so that 915 MHz DSRC systems could continue to operate with DSRC / WAVE systems at the same installation sites. The document defined system level requirements for DSRC / WAVE so that it would directly interface with the existing infrastructure (loop, treadles, light curtains, coin machines, gantries, etc.), reproduce reader coverage communications zones and violation enforcement systems, and provide standardized interfaces that could be used by Lane Controller processors for control of the DSRC / WAVE systems.

b) **Backroom Processing Compatibility** – The set of IEEE 1609 Standards includes the definition of an ITS Application that will be installed in all OBU’s. This IEEE Standard is called the Resource Manager (IEEE 1609.1). It provides a secure memory storage feature that can be used to emulate the transactions performed by existing 915 MHz DSRC systems. The Resource Manager provides services that make the use of the DSRC / WAVE system transparent to the 915 MHz DSRC backroom processing systems that are currently deployed across North America. To understand how this is accomplished we need to first discuss the current use of 915 MHz DSRC information in tolling, CVO, and other backroom and roadside processing systems. The toll and CVO processing uses one of two techniques. The first technique uses “tag” identification (ID) numbers. In a majority of systems, the 915 MHz DSRC system “reads” ID numbers of “tags” that pass through its communications zone. The roadside processor, usually called a Lane Controller, compares the “tag” ID with a “White List” or “Black List”. These are valid “tag” IDs or invalid “tag” IDs respectively. The Lane Controller then executes transactions with the “White List” IDs and considers the “Black List” IDs as violators. When the “White List” ID transactions are received by the backroom processing, they are used to identify Customer Accounts and the “White List” transactions are then used by billing or tracking systems to execute the system processing functions. The “Black List” and non-tagged equipped vehicles are processed as system violators. The heart of these systems is the unique “tag” ID number that is used to execute the backroom transactions. Even systems that exchange transactions between toll agencies or between States utilize these “tag” IDs to exchange data or tolling fees. The second technique uses “read” commands to interrogate “tag” memory storage information and “write” commands to update or replace memory storage information. These “read / write” commands, along with the “tag” ID, are then used to execute the 915 MHz DSRC transactions. These “read / write” systems also use the “White” and “Black” list information for the processing of valid and invalid “tag” IDs. The backroom processing systems use the “tag” IDs and the memory contents of the “tag” to execute their transactions or tracking functions. The techniques discussed in this paragraph, or some variation of them, are the basis for all existing 915 MHz DSRC systems.

The Resource Manager Application (IEEE 1609.1) uses these common 915 MHz DSRC threads to provide backward compatibility. The Resource Manager contains memory space that is divided into memory “pages”. Each page has Access Credentials that allow an authorized RSU to access memory pages and also provides the RSU with privileges, such as “Read Only” or “Read / Write”. The Resource Manager can also provide pages that contain “Read Only” areas and “Read / Write” areas. An existing 915 MHz DSRC system user can, via RF commands, establish a memory page in an OBU and assign access credentials to that page so that only its RSU’s will be able to gain access to this page. The 915 MHz DSRC system user would then place the “ID” number associated with that Customer’s Account into the memory page. This “ID” number can be identical to the previous “tag” ID or can be a customer unique DSRC / WAVE OBU ID. If the 915 MHz DSRC system required the use of “Read” and “Write” processing, a separate or partitioned part of the page can be used for the “Read / Write” memory storage. The 915 MHz DSRC system then adds DSRC / WAVE equipment to its infrastructure sites and when an OBU enters the DSRC / WAVE communications zone, the system executes a Resource Manager transaction that provides the Lane Controller with the “tag” ID and any “Read / Write” information that was required. The backroom processing then receives a transaction with the same type of information that was obtained from the previous 915 MHz DSRC system. The backroom processing can continue to utilize its current processes since the type of information it receives from the DSRC / WAVE system is identical to the information it receives from the 915 MHz DSRC system. Therefore, no backroom processing changes are required in the utilization of the DSRC / WAVE technology.

The DSRC / WAVE system provides significantly more processing power than the 915 MHz “tag” and, as the population of the OBU customers increase, the 915 MHz system will at some point be removed and all customers will be switched to OBU’s. When this event occurs, the DSRC / WAVE system can be used to execute more sophisticated transactions. This migration and ultimate switch over will be driven by business decisions, and the system operator can maintain the current 915 MHz DSRC system or the dual 915 MHz DSRC and DSRC / WAVE system until they no longer meet the business and system needs.

2.3.2.5 Will the ITS Radio Services Band be Successful?

Following the frustrating and unsuccessful attempts to achieve DSRC system compatibility and inter-operability, why will success be achieved with DSRC / WAVE? This is an interesting question and answering it reveals the differences in the approaches used. The DSRC / WAVE Standards utilized the co-operation of DSRC equipment designers and system integrators, the automobile manufacturer’s interest, a variety of government funded projects, and requirements from different types of end system users to create a co-operative effort. The following paragraphs discuss each of these areas and explain the new approach being used by DSRC / WAVE:

a) **DSRC / WAVE Standards** – The DSRC / WAVE Standards are based on a study of a variety of ITS Application's communication requirements. The DSRC / WAVE Standard's writers contacted many potential users of the DSRC communication systems and determined a core set of requirements. Using these requirements, the Standard's writers evaluated a number of potential technologies and selected the best technology. The Standard's writers selected the IEEE 802.11 Wireless Local Area Network technology and the DSRC / WAVE Standards were then built on this technology base. The selected technology was agreed to by all DSRC Standard contributors and only one technology was carried forward. This is compared to the two technologies (active versus backscatter) that were utilized at 915 MHz. At 915 MHz, there were two camps that attempted to direct the DSRC Standards to their technology of choice.

b) **Co-operation between the DSRC / WAVE Equipment Designers and System Integrators** – The DSRC / WAVE equipment designers and system integrators decided that they did not want to waste their efforts in another frustrating standardization effort. To avert this possibility, they formed a DSRC Industry Consortium (DIC). The DIC studied each communication and standardization issue, and reached a consortium agreement that was then presented at the DSRC / WAVE Standard meetings as a single united voice. This approach increased the DIC's influence in the standardization process and generated sound technical decisions on standardization issues. The DSRC Industry Consortium has four manufacturing and system integration members, namely MARK IV, SIRIT Technologies, TransCore and Raytheon. It also has two IEEE 802.11 chip manufacturers, namely Atheros and Conexant.

c) **Automobile Manufacturer's Interest** – The DSRC / WAVE technology is being supported by a consortium of automobile manufacturers called CAMP. The words that formed the acronym CAMP have lost their significance, but the consortium continues to use the acronym name. CAMP is composed of fourteen automobile manufacturers. CAMP has formed a number of study groups that focus on specific communication needs that can utilize the DSRC / WAVE technology. One of the major study groups is the Vehicle Safety Communications Consortium that focuses on roadside to vehicle and vehicle to vehicle safety communication requirements. Since the ITS Radio Services Band must address highway safety, this study group provides definitions for a number of requirements. Even more important than this technical support, the automobile manufacturer's commitment to adding OBU's to all vehicles in the near future has had a major influence on maintaining standardization momentum. The automobile manufacturers are planning to start the "roll out" of OBU equipped vehicles in the 2008 year models.

d) **Numerous Department of Transportation Funded Projects** – The Department of Transportation (DOT) is currently funding a number of projects that are either developing DSRC / WAVE systems or are studying ITS Applications that will utilize the DSRC / WAVE technology. The DSRC Industry Consortium has been funded to develop DSRC / WAVE Prototype Units by mid 2005. This Prototype Project will be used to verify the DSRC / WAVE Standard and also produce a quantity of units that will be utilized by other DOT funded ITS Application Projects. The DOT is also funding the VSCC in the testing and evaluation of safety applications using DSRC / WAVE technology. In addition to these projects, the DOT is working with several State DOT's with the goal of deploying 400,000 RSU's across the nation's highways to broadcast safety alerts and road hazard warnings to OBU equipped vehicles.

e) **Variety of DSRC / WAVE End Users** – In the 915 MHz band, the initial DSRC end users were toll roads. The DSRC manufacturers built "Reader and Tag" systems that addressed the specific needs of a toll road. The toll road DSRC systems utilized were developed by different manufacturers and were not compatible or inter-operable. The DSRC / WAVE systems are more varied. Since so many ITS Applications are being addressed by the DSRC / WAVE Standards with so many different end users, a custom design for each ITS Application user is not possible. Therefore, as discussed above, it is in the best interest of the DSRC / WAVE manufacturers to develop a standardized design. In addition, the interest shown by the automobile manufacturers will result in Original Equipment Manufacturer (OEM) devices being installed in new vehicles. Since no single manufacturer can control the OEM process, standardization is an absolute requirement.

Based on these five reasons, the DSRC / WAVE technology has a much higher probability of success than the DSRC efforts at 915 MHz. The commitment of resources by so many different manufactures, ITS users, and government agencies will facilitate the adoption and utilization of the DSRC / WAVE Standards and the associated equipment and systems.

2.4 Overview of Current OBU and Smart Card Technology

2.4.1 Communication Types

The functionality of OBU's have traditionally been classified as Type 1, 2 or 3 based upon type of data communicated between the roadside equipment and the OBU. These types referred to are loosely defined as:

Type 1: The OBU is a Read Only transponder which communicates pre-programmed information to the RSU. This consists of transponder identification and agency information.

Type 2: The OBU has Read / Write capability which allows the RSU to not only read information but write and store data onto the OBU.

Type 2+: In addition to the Read / Write capability, the OBU has limited functions which can be initiated by the RSU. This includes switching audible or visible indications.

Type 3: Type 3 OBU's have enhanced computing capabilities and can transfer data to and from external devices on the vehicle.

Toll systems typically use Type 1 or Type 2 OBU's whereas CVO applications may require Type 3 transponders to communicate with special purpose devices on the vehicle to support driver logs, clearance information, etc.

The OBU identification code has historically been readable by any compatible RSU. However more recently, to control the use of the OBU, some systems dynamically encode the identification number to limit the use of the OBU identification for non-authorized applications.

2.4.2 Physical Characteristics

OBU's need to be mounted in positions visible to the RSU antennas. Typically, this requires that they be internally mountable in a vehicle wind screen. However, alternative mounting arrangements are necessary for vehicles with metallic wind screens, motorcycles and commercial vehicles if vehicular power is required.

The OBU is typically hermetically sealed and can be designed for internal or external vehicle mounting. External mountings are used for motorcycles and vehicles with metallic wind screens.

Power is usually provided through an internal battery which is not user replaceable, although in some cases, replaceable batteries are used when driving display devices which would limit battery life. Power can also be provided by connection to the vehicular power supply, in particular when additional functionality is supported. In the case of "backscatter" technology, batteries are not required. Battery life is an issue which needs to be addressed in the technical specifications and the appropriate use of the OBU.

As well as the familiar rectangular package, OBU's can be packaged as key bob style or a host of different form factors. The backscatter technology and thin film microelectronics also lend to flexible packaging, such as embedding the radio frequency circuits on decal style window stickers. This technology is used by the Free and Secure Trade (FAST) commercial border crossing program. Major vendors, TransCore and SIRIT, provide these physical formats for their eGo and ZIP products respectively. These provide a low cost alternative which can be permanently attached to the vehicle.

2.4.3 OBU User Interfaces

OBU's may have no user interface, they may have indicators using light emitting diodes (LED's) or single line displays. The OBU's may also have more sophisticated interfaces to third party devices. The preferred approach is to minimize the complexity of the OBU and provide interfaces to add-on devices to increase functionality only when required.

Toll applications should provide indications on the OBU, either visible or audible, that a toll charge has been accepted, that an error has occurred and that an OBU fault has been detected as appropriate. These indications require that the OBU be powered which makes the passive backscatter technology less attractive. Readily available OBU's include LED indicators and audible indicators.

2.4.4 SMART Cards

The use of stored value cards, both contact and contact-less smart cards are becoming common for transit and transportation related applications. These stored value cards provide rapid access to mass transit facilities and are also used for small purchases usually at convenience stores and concessions. The classic success story for the use of contact-less smart cards is the Octopus system in Hong Kong. This RFID system allows subscribers to pay for transit fares and purchases from affiliated retail outlets using rechargeable contact-less smart cards. The RFID cards communicate using a proprietary protocol at 13.5 MHz and require close proximity, within a few centimetres, to conduct a transaction. Standards have been developed for smart card communications, however the DSRC standards are different and not applicable to AVI.

Smart cards have been used as a toll payment method in automatic toll lanes. In this case, they provide a more rapid transaction time than debit or credit cards and greater accuracy with less maintenance than cash machines. However, it is still necessary that the vehicle comes to a full stop. Lane capacity is several time less than a free flow lane (say 300-600 vehicle / hour versus 1,800-2,200 vehicle / hour) depending upon the infrastructure design.

In a fully electronic, open road, toll facility, SMART cards could be used for payment, however interfaces through DSRC have a number of concerns regarding transaction security and encryption. SMART cards, both contact and contact-less, utilize highly secure encryption and reliability. These transactions require very secure communications. The required reliability cannot be guaranteed using current DSRC implementations. It is possible to "recharge" stored value OBU's and to pay toll bills through the use of SMART cards.

2.5 Alternative Tolling Methods

Toll collection on the GEB will be performed through a point toll collection system. However, other tolling and road pricing technologies could be relevant in the future. In particular, the use of cordon based tolling and distance based tolling may utilize technology which complements systems proposed for the GEB.

In cordon base road pricing schemes, users who enter a core area during specified time of day are charged a toll. Examples of this are the Singapore road pricing network and the London (England) road pricing network. Although the technologies are different, both concepts rely upon users being charged for entry to the town centre. An alternative approach is to track vehicle usage through global position satellites and charge based upon time of day and distance travelled. In Europe, significant effort has gone into developing architectures for electronic vehicle identification (EVI) which encompasses a wide variety of techniques.

The technology appropriate for these systems which could be relevant is discussed in this section.

2.5.1 DSRC Cordon System

The Singapore road pricing scheme was one of the first road pricing schemes. The electronic system migrated from a manual system where permits were required to travel into the city core. The automated system which replaced the manual system used the same geographical configuration and effectively implemented a DSRC based system. A user crosses through the downtown cordon and is identified through DSRC supported by a license plate recognition and enforcement system.

The technology utilized for a DSRC based cordon system is similar to technology applicable to GEB toll system. However, a cordon based road pricing system depends upon the traffic patterns of users and the road network. In the case of Singapore, the traffic patterns the road pricing system was designed to address were a well defined tidal flow of vehicles entering and leaving the core of city centre during morning and evening rush hours. The geographical core of the city was easily defined and access points controlled.

DSRC based road pricing schemes can be effective under these circumstances. However, if either the traffic patterns are not well defined or there are many alternative routes, then this approach is not very effective, neither technically or as an effective tool for demand management.

2.5.2 Cordon System using License Plate Tracking

As an alternative to DSRC, vehicles entering defined sections of the city can be identified through license plate recognition technology and charged a fee or a fine levied. The operational concepts associated with this technology are discussed in this section, and licence plate recognition technology is discussed in subsequent sections of this report.

The City of London, England, has used this technology successfully as a demand management technique to limit traffic in the city core. A significant fee is charged to drive in the city. The use of many cameras to support the license plate capture system throughout the core area means that even if motorists enter the core through an un-monitored side street, they likely will still be captured on a camera. In order to be successful, the system relies upon the following:

a) Pre-registration is required so un-registered users who are captured are considered violators and fined, not considered video users. This means that lower effective capture rate is necessary than if they needed only pay a video transaction fee.

b) The large number of cameras means that if the license plate capture and number recognition is not successful at one location, it may be successful at another.

For these reasons, the system works even though the effective capture rate has been reported to be 70%.

The operational advantage of this approach over the DSRC cordon is that a larger number of locations can be monitored. In the DSRC approach, both reader and enforcement systems would be required.

2.5.3 Vehicle Tracking Systems

An alternate method to accomplish demand management through tolling is to actually charge users a license fee based on kilometres travelled, when and where. This can be accomplished through global positioning satellites (GPS) and communications with the vehicle.

Vehicle tracking can be accomplished through the use of on-board GPS receivers and associated electronics which keeps a record of travel by time of day and location. Alternatively, radio based tracking schemes can be used through cellular networks or other radio based tracking systems. In either case, on-board equipment is required to enable the vehicle to be tracked.

Communications with the on-board equipment can be accomplished by DSRC or commercial data services, such as the PCS data network, commercial packet switched radio network or other means.

The technology required to accomplish vehicle tracking is readily available. PCS handset manufactures are incorporating GPS receivers into the cell phones. These are being used for fleet management purposes and emergency services.

A system was tested in Europe for commercial vehicles. The idea was to charge commercial vehicles license fees and road use fees based upon distances travelled as opposed to flat rates.

Although technically these systems can work with co-operation of road users and installation of on-board equipment, there are significant privacy issues and public policies issues associated with implementation of any system which tracks vehicles.

2.5.4 Applicability to GEB

Although the technologies associated with license plate recognition and DSRC utilized by these alternatives to tolling is similar to technology proposed on the GEB, the functional requirements are quite different. In addition, the need for these types of applications has not been defined by regional stakeholders. For these reasons, the suitability of the GEB technology to support alternatives to tolling is not considered relevant. The support for distance based tolling should however be considered.

2.6 Comparison of AVI Technology

The report has reviewed automatic vehicle identification technology used in North America. Those which have been discussed are compared in this section. Table 2.1 below provides an overview of the DSRC technologies for AVI and tolling.

Table 2.1 : Comparison of DSRC Supported AVI Technology in North America

Standard	Sponsored By	Supported By	Application	Comments
Public Standards				
Title 21	Caltrans	SIRIT TransCore	Tolling Vehicle Identification	• Primarily read only technology • Narrow detection zone
ASTM v6	ASTM IEEE FHWA	TransCore Raytheon Telematics	CVSIN Tolling	• TDMA technology • Wide area detection • Full read / write
Proprietary Standards				
IAG EZ-Pass	Interagency Group MARK IV	MARK IV	Tolling	• Proprietary transponders with encrypted identification number
ATA	American Trucking Association	Amtech TransCore	Access Control Inventory Tracking	• Limited speeds
eGo	TransCore	TransCore	Tolling FAST Program Access Control	• Passive backscatter technology • Wind screen sticker form factor

Table 2.1 : Comparison of DSRC Supported AVI Technology in North America				
Standard	**Sponsored By**	**Supported By**	**Application**	**Comments**
ZIP	SIRIT	SIRIT	Tolling Access Control	• Passive backscatter technology • Wind screen sticker form factor
SUNPASS E-PASS	Florida DOT	TransCore SIRIT	Tolling Travel Time	• SIRIT has partial access to read identification number
V-TDMA	Amtech / ASTM	TransCore	Tolling	• Wide area with full read / write capability
Multi-Protocol Devices				
ASTM v6 IAG	MARK IV	MARK IV Fusion Tag	CVSIN Tolling	• Used on Highway 407 ETR • Provides inter-operability with IAG
V-TDMA Title 21	TransCore Amtech	TransCore IT Series Tags	Tolling	• Full function OBU

2.7 Identification of Requirements

The project has identified requirements for initial and future applications through the stakeholder workshop and subsequent consultation sessions. The requirements definition is ongoing as stakeholder comments are received and assimilated. The identified requirements by the project team and stakeholders are described below. The objective to obtain inter-operability with existing DSRC users is also described. This analysis also includes requirements derived from TransLink's ITS Strategic Plan and the project team's assessment of which items will utilize or very likely utilize DSRC.

2.7.1 OBU / RSU Requirements

The functional requirements of the DSRC based AVI technology is described below.

a) The AVI technology should be able to support both point based tolling as well as distance based tolling.

b) The AVI technology should support future and planned ITS initiatives which require DSRC. Provisions supporting these requirements need to be made although the precise requirements have not been identified except in general terms.

c) The initial system costs, including costs to users, should be minimized.

d) The system needs to allow for expansion for additional toll facilities and other ITS initiatives through competitive processes.

e) Multiple transponders on vehicles are to be avoided, including commercial vehicles.

Technical requirements, which were not part of the stakeholder workshop, also need to be addressed. These include:

- Very reliable read and write ability at high speed;
- Long life OBU designed to maximize battery life if applicable;
- Open road operation designed to operate with localization equipment for reliable interfacing to license plate recognition systems; and
- Wide area communications zones to support other ITS applications.

2.7.2 Inter-operability with Existing and Proposed DSRC / AVI Systems in the Region

The existing AVI systems which have been identified are for commercial vehicle operations. These are the CVSIN program which supports the weight scale bypass operations and the FAST border pre-screening. The technology used for these two applications is different.

The CVSIN program utilizes the ASTM v6 TDMA open protocol supported by several manufactures. This is a full featured system which provides full wide area read / write capability. The system is widely used by commercial vehicles, however it is not used by all commercial operators.

The FAST program utilizes the eGo decal style OBU. This passive device provides read and limited write capability. It is used to identify pre-registered operators. An important characteristic of the device is the physical mechanism to permanently attach it to the vehicle and tamper resistance. The FAST program currently uses the eGo OBU, however the program is still being expanded and is evolving.

2.8 Recommendations

The use of OBU with DSRC communications to RSU's provides the GEB with a highly accurate and error free method of AVI. It is recognized that all users will not utilize OBU's, however the more users who can be encouraged to utilize OBU's, the higher the overall system capture ratio will be. The use of OBU's which can accommodate future features, such as support for HOT lane and ITS functions, will help reduce the proliferation of types of OBU's. If commercial vehicle traffic can be encouraged or required to utilize OBU's, the requirements of the license recognition system and difficulties tracking down commercial operators will be significantly reduced. Consequently, the following recommendations with regard to the use of OBU's, RSU and DSRC for AVI are made:

a) Frequent users be encouraged to use OBU's as opposed to license plate recognition for payment.

b) The OBU's support open road and preferably wide area communications and provide feedback indication. The final selection should be determined through the competitive bid and evaluation process.

c) The ASTM v6 be supported through dual protocol RSU's to facilitate commercial vehicles with CVSIN OBU's to use the facility without procuring a second OBU.

d) An estimate of the potential volume of OBU equipped commercial vehicles who would utilize the facility initially and when other related infrastructure improvements are made to inter-connecting roadways should be prepared. This traffic estimate could be used to determine when the dual protocol RSU's recommended above could be justified.

3. AVC TECHNOLOGY DATA COLLECTION AND REVIEW

The purpose of the Automatic Vehicle Classification (AVC) system for tolling is to assign the correct vehicle class to each vehicle as the vehicle passes through the toll booth or under a toll gantry in order to apply the correct toll rate. The idea of AVC is to assess tolls in an equitable manner. Equity can be considered in terms of road occupancy (i.e., vehicle size) or axle loading which defines the wear and tear on the infrastructure.

The GEB toll philosophy has established four toll classes as described below.

e) Cars – Cars include most passenger vehicles, vans, sport utility vehicles, pick-up trucks and taxis.

f) Small Trucks – Small trucks are defined to consist of “cars” towing a trailer, light duty commercial vehicles with less than five axles (with or without a trailer), school buses, intercity buses and non-exempt transit buses.

g) Large Trucks – Large trucks consist of all other vehicles (typically with five or more axles) with or without a trailer.

h) Motorcycles – Motorcycles are defined to consist of mechanized, licensed two-wheel vehicles. Note that this category does not include bicycles.

3.1 Overview of Current AVC Technology

Vehicle classification has been a part of toll roads since the earliest toll roads went into operation. Initially, the classes were simple and all classification activities were manually performed by the toll collector. Subsequently, systems were developed to provide a means for automatically determining the class of a vehicle. The earliest systems consisted of a treadle and a loop, the purpose of which was to detect the number of axles associated with a vehicle. Since that time, significant progress has been made in the development of classification technology. Systems around the world use a variety of measurements to create fare schedules. In America, the number of axles has been a significant factor in most fare schedules. Some schedules have been based upon the weight of the vehicle. In Europe, emphasis has been placed on the physical size of the vehicle.

The number of classes which an AVC is capable of determining and the nature of these classes is determined by the amount of information being collected and processed, and the ability of the system to make maximum use of that information. The better and more complete this information is, the greater the accuracy of the classification.

The accuracy of the classification is also dependent upon the accuracy, precision and freedom from errors of the data collected. The categories of vehicles need to be clearly differentiable using the available data, processing capabilities with an awareness of potential sensor inaccuracies, failures and errors.

Recent advances in classification capabilities have allowed agencies to increase the number and types of classification categories. These include such categories as buses, vans, motorcycles, each with or without accompanying trailers. In order to classify these vehicles, the following information about the vehicle is generally required:

- Length of the vehicle;
- Height profile of the vehicle;
- Number of axles and their locations; and
- Existence of a hitch (trailer) and its location.

In order to define each of them accurately, the system must be able to accurately track the position of the vehicle during the time that it is in the detection zone.

3.1.1 Profiling Classification

In order to identify the classifications required for the GEB, a profile of the vehicle in question is required. The profile will measure vehicle height and in some cases width, as the vehicle passes through the classification system.

The accuracy of the distance measurements should be better than 30 cm and the height profile should reflect the height of the vehicle at small increments along the entire length of the vehicle. In order to be able to generate an accurate and useful profile, the system must be able to determine where the vehicle is located at all times.

3.1.2 Axle Counts and Location

The GEB classifications also require that the number and relative locations of the axles be determined along the length of the vehicle.

The combination of vehicle profile, axle number and location will be required to uniquely identify vehicles in the GEB classifications.

The next portion on this section discusses relevant technologies which are suitable for vehicle classification.

3.2 Vehicle Height Profile

The height of the vehicle can be measured by overhead detectors or roadside mounted detectors. The detector technologies discussed include ranging radar, ultrasonic and light based.

Overhead mounted detectors can either measure point height at frequent intervals as the vehicle passes under the detector or develop a width profile of the vehicle. Side mounted detectors are suitable for lane based applications where access to both sides of the vehicle is possible. In all cases, these detectors are non-intrusive and do not require equipment installed in or under the roadway.

3.2.1 Ultrasonic Detectors

Early height measuring designs utilized ultrasonic detectors. Sound waves were broadcast from an overhead transmitter and the time measured until an echo was received. Without a vehicle under the transmitter, the signal was reflected by the ground and an echo was received at a delta time based upon the speed of sound and the distance above the ground. When a vehicle was located under the unit, the echo time was reduced by the distance of the vehicle above the ground, thereby giving an indication of height. However, since the overall system did not determine the position of the vehicle at all times, the only useful height information gathered was the maximum height of the vehicle. The sensor suffered from several other limitations, namely the beam width of the antenna and the time required per sample due to the slow speed of sound wave propagation through the air medium. As a result, this sensor has been used on several occasions to separate vehicles for classification by axle count, but it cannot be used to provide height information from which a profile might be generated.

3.2.2 Ranging Radar

Similar to ultrasonic detectors, ranging radar detectors can be used to measure vehicle height without the delay constraints of ultrasonic detectors. As well, radar detection provides weather and temperature independent operation. The beam width varies based upon the design. However, as is the case with ultrasonic detector, it measures basic spot height as the vehicle moves and relies upon side mounted or below ground presence detectors to complete the profile by determining the vehicle speed and length.

3.2.3 Light Curtains

Light curtains were initially used in the industry as vehicle separators. A vertical series of very narrow beams provided an excellent method for determining the beginning and ending of a vehicle. If periodically samples as the vehicle passes, and also provides good lateral profile information from which a height profile can be constructed and from which axles and hitches can be detected. Unlike the ultrasonic curtain, the light curtain could be scanned in less than 5 milliseconds and can provide excellent data on both stop and go traffic and high speed targets. Since these devices need equipment on both sides of a lane, their use is restricted to lane based operations.

3.2.4 Overhead Laser Detectors

An overhead laser can be used to measure the height of a vehicle based upon the reflected light ray. If the laser is reflected by a scanning mirror, then the width of the vehicle can also be measured. As the vehicle moves, a profile of the vehicle including width can be generated. This profile can be mapped to various vehicle classifications. In order to determine the length of the vehicle and calibrate the profile, the length or speed of the vehicle must be determined. This can be accomplished if required by a doppler radar or by an integrated dual beam laser system.

The overhead laser detector, due to its rapid scan rate, provides a good trigger to video recognition systems or the roadside unit communicating with OBU's.

The scanning laser detector technology is well proven and provides excellent performance. One vendor claims that 13 different standard vehicle profiles can be generated. A detector needs to be mounted over each travelled lane.

3.3 Axle Detection

In order to classify vehicles based upon the number of axles, or a combination of axles and profile, axle detectors are required. All types of axle detectors rely upon devices in the travelled road surface. These devices are either mechanical sensors, electronic sensors or electro-magnetic sensors.

3.3.1 Mechanical Treadles

The traditional method of detecting axles is through the use of mechanical treadles installed in the roadway. The treadle consists of a series of mechanical fingers, which when compressed by the wheel make an electrical contact. The treadle then detects the passage of a wheel. They must be installed in the portion of the lane where the vehicles wheel must pass. They can estimate the width of the tire to assist in identifying commercial vehicles. If the treadle is installed at an angle off perpendicular to the edge of pavement, then multi-tired vehicles can be identified.

The treadle technology requires that vehicle tire crosses the treadle, therefore they are only suitable if lane discipline can be enforced or for single lanes of traffic passing through a toll plaza. Motorcycles will usually not be detected by treadle.

Although the technology is very mature and toll operators claim very high reliability, they are still mechanical devices subject to mechanical problems and weather conditions. In addition, care is required during installation to ensure that they are flush with surrounding pavement. The surrounding pavement must be carefully maintained to prevent cracking, frost heaving and tire wear.

The advantages of treadles are that they provide reliable detection of wheels thereby axles and a very simple and proven technology. The disadvantages however are maintenance requirements due to mechanical design and road surface constraints. They are not suitable for open road unless lane discipline can be enforced and require intrusive installation into the pavement surface. For these reasons, treadles are not recommended for GEB.

3.3.2 Piezo-Electric Treadles

Piezo-electric sensors are mounted in a groove that is cut into the roadway surface within the traffic lane. The sensors gather data by converting mechanical energy into electrical energy. Mechanical deformation of the piezo-electric material causes a change in the surface charge density of the material so that a change in voltage appears between the electrodes. The amplitude and frequency of the signal is directly proportional to the degree of deformation. When the force of the vehicle axle is removed, the output voltage is of opposite polarity. The change in polarity results in an alternating output voltage. This change in voltage can be used to detect and record vehicle count and classification, weight in motion and speed.

Key characteristics include:

- Long term stability;
- Measures very accurately at both walking and freeway speeds;
- Insensitive to temperature changes;
- Frost-resistant and protective against ingress of water;
- Analogue output can be calibrated for load thresholds; and
- The sensor is installed below the road surface which can be reground for limited roadway resurfacing.

These sensors also have some drawbacks which are:

- They require an intrusive installation in the roadway, a 50 mm saw cut across the travelled lane.
- In order for the sensors to operate properly, the vehicle must be moving through the detection zone.
- In an open road configuration, multiple sensors will be required, likely one per lane plus a mid lane installation unless lane discipline can be enforced.

3.3.3 Fibre Optic Treadles

Fibre optic treadles provide similar functionality to piezo-electric treadles. However, they are based upon the characteristics of optical fibres. Fibre optics used in telecommunication systems provides high speed, interference free communications. These systems rely upon the fibre optical characteristic of low attenuation and immunity to electro-magnetic and radio frequency interference. However, the characteristic of low attenuation only occurs when the optical fibre does not undergo physical stress. If the optical fibre is tightly bent or compressed, the attenuation sharply increases. Fibre optic treadles take advantage of this characteristic to identify the compression caused by a vehicle's wheel.

Fibre optic treadles are mounted in a similar fashion to piezo-electric treadles, however the mounting requirements are less stringent. For example, temporary installations can be mounted on the road surface and even in gravel roads. The immunity to electro-magnetic interference is another advantage.

Key characteristics include:

- Long term stability;
- Detects vehicles at all speeds, including highway speeds;
- Insensitive to temperature changes;
- Immunity to interference and lightning;
- Frost-resistant and protective against ingress of water; and
- The sensor is installed below the road surface which can be reground for limited roadway resurfacing.

These sensors have similar drawbacks to piezo-electric sensors, namely:

- Permanent installations require an intrusive installation in the roadway, a 50 mm saw cut across the travelled lane.
- In an open road configuration, multiple sensors will be required, likely one per lane plus a mid lane installation unless lane discipline can be enforced.

The flexibility of fibre-optic treadles makes them a good alternative for the GEB to count vehicular axles.

3.4 Inductive Loop Detectors

Inductive loop detectors have been utilized in ITS systems for a wide variety of purposes for many years. The technology has evolved and improved with improvements in electronics and availability of microprocessors which can interact with the detector electronic. The fundamental technology has not changed. Essentially, the inductive field of a coil of wire embedded in the pavement is affected by the presence of the metal structure of a vehicle located above the loop. The metallic structure changes the inductance of the loop which is detected by the detector electronics. This change in inductance can be used to detect the presence of the vehicle or to determine a rough profile.

3.4.1 Presence Detection

The developments of inductive loop technology over many years were to develop electronics which could accurately determine whether a vehicle was over the loop or not. The developments were associated with making this binary determination regardless of the construction and shape of the loop and the length of the loop lead in wires (distance from the electronics and the loop).

Current digital loop and loop electronics have reached the stage where loop detectors can accurately detect the presence of vehicles, count and measure speed of all sizes of vehicles with a wide range of loop shapes and sizes.

In the toll application, loop technology can be used with other axle detection technology to classify vehicles in terms of presence and length. Height will not be considered in that classification.

The advantages of utilizing loops for profile determination are their low cost, accuracy, proven and well understood technology. The disadvantages are the need to cut into the roadway and the maintenance problems when the road surface deteriorates. On elevated structures, particular care needs to be taken to avoid metallic rebar which will degrade performance of the loop. The rebar needs to be protected from damage during loop installation to avoid future maintenance issues of the structure.

3.4.2 Analogue Profiles

As noted above, a great deal of effort has been placed in developing a technology which would allow a binary decision based upon the varying analogue signals developed when a vehicle passes over a loop. However, the actual analogue signal can be processed in a different manner to generate recognizable pattern when a vehicle crosses the loop.

The analogue pattern can be used to identify the front and rear of the vehicle and a variety of vehicle classifications. The recognizable patterns have been used in the development of incident detection schemes and to categorize vehicles into classes.

This is being done by the IDIS system from PEEK and the IVIS system from UCS. IVIS utilizes a variety of loops of different sizes, shapes and locations to obtain different inductive profiles. As each vehicle crosses the series of loops, a group of inductive profiles are generated. These groups of profiles are then compared with groups of profiles in a database and the closest match determined. When a match is determined, a confidence factor is also generated determined by how closely the group of inductive profiles matches the one in the database. The system also has the ability to be “trained” to develop new profiles and store them in the database. The vendors claim that using this method, a wide variety of vehicle classes can be determined and in fact the number of axles can be included in the classification.

IVIS has been installed in toll facilities in California and the results are positive. The advantage of this technology is that there is no need for multiple types of sensor inputs to determine classifications which include profile and number of axles. Also overhead mounting of detectors is not required. The disadvantages are once again the need to cut into pavement and the relatively few current installations for evaluation. On a structure, the number of loops required and their locations make avoiding close proximity to rebar more difficult than for digital detectors discussed above.

3.5 Weight in Motion

The vehicle weight and axle loading can be considered the most important component to quantify the damage, or wear and tear of the roadway caused by a specific vehicle. The weight of each axle of a vehicle can be measured to a rough level of accuracy through weight in motion systems. These can consist of mechanical scales, which are suitable for low speed measurements only, bending plate sensors and electronic sensors.

The electronic sensors utilize piezo-electric sensors which are embedded in the road perpendicular to the traffic flow. The force of the tire caused by the weight of the vehicle compresses the sensor. The sensors gather data by converting mechanical energy into electrical energy. Mechanical deformation of the piezo-electric material causes a change in the surface charge density of the material so that a change in voltage appears between the electrodes. The change in sensor characteristics is mapped to an axle weight in combination with vehicle speed.

The accuracy of the measurement can vary. For reasonably accurate and consistent readings, the approach to the scale needs to be very level and smooth.

Weight in motion scales are used extensively for commercial vehicle mainline bypass of commercial vehicle inspection stations. In these applications, the weight in motion sensors are installed in shoulder lane of the highway, in advance of the main inspection station. Vehicles which are overweight are signalled into the main inspection station.

International Road Dynamics (Saskatoon) is one of the main suppliers of weight in motions systems in the world.

Weight in motion has not been used extensively for tolling applications since charging by vehicle weights would require variable toll rates based on weight and the difficulty confirming the accuracy once the billing has occurred.

The GEB is also not considering the use of weight as a classification method. However, this type of sensors could be used as axle counters as discussed under piezo-electric treadles above. In the case of open road tolling, such as for GEB, separate sensors would be required for each lane and another technique for vehicles which are straddling lanes would be required.

3.6 Comparison of AVC Technology

The technology applicable for automatic vehicle classification for toll application described in the previous sections is evaluated for its suitability for the GEB in Table 3.1.

Table 3.1 : Comparison of AVC Technology

Type	Measures	Intrusive	Open Road	Comments
Profiles Classification				
Ultrasonic	Height @ sample time	No	Yes	• Multiple detectors mounted on gantry to cover all lane, length requires speed
Ranging Radar	Height @ sample time	No	Yes	• Detector per lane, straddling lane problems
Light Curtains	Height / Length	No	No	• Requires speed for length • Equipment required on both sides of lane
Overhead Laser	Height / Length / Width	No	Yes	• Provides accurate profile
Inductive loop	Length / Speed / Presence	Yes	Yes	• Digital output when vehicle detected, speed requires multiple loops
Axle Detection				
Mechanical Treadles	Tire / Axles	Very	Difficult	• Maintenance of roadway and units required
Piezo-Electric Treadles (Note 1)	Axles (by tire pressure)	Yes	Yes	• Requires movement of vehicle • Can provide weight indication
Fibre Optic Treadles	Axles	Yes	Yes	• Any speed, less intrusive
Inductive Loop	Profile	Yes	Yes	• Depends upon multiple loops to create and match profile which may include axle characteristics

Note 1: Weight in motion not included since weight is not a classification requirement.

3.7 Recommendations

Recommendations of suitable AVC technology required to provide the required vehicle classifications in an open road environment are provided in this section. In addition, suggestions for consideration to simplify the classifications are made.

In general, it is desirable to minimize the installation of equipment in the roadway and sensors which place additional maintenance requirements on the road conditions are discouraged.

3.7.1 Relative to GEB Requirements

The GEB classifications require that a combination of vehicle profile and axle counting be provided in an integrated AVC. It is common for vehicles in North America to be classified in this manner as this provides an equitable relationship between maximum weight (axles) and road usage (length).

It is recommended that the configuration of AVC be left to the design-build-operate Contractor to propose for an evaluation based upon technical and price considerations. However, certain technology is considered unsuitable and should be precluded. Technology which is recommended not to be permitted are listed below:

- Side mounted light curtains due to need for median between lanes and maintenance requirements; and
- Mechanical treadles due to ongoing road maintenance and intrusive requirements.

The favoured configurations for technical reasons are noted below:

- Fibre optic treadles in combination with digital loops or scanning laser detector would provide accurate axle count with vehicle lengths. In the case of digital loops, care will be required to differentiate between closely following vehicles and vehicles with trailers.
- Analogue loop technology is attractive in that a single technology is utilized from a single vendor which minimizes integration issues. However, the maturity of the technology needs to be demonstrated by the proponent.

3.7.2 Considerations

The classifications proposed for GEB require both axle count and vehicle profile. If simplified classifications utilizing either axle count or vehicle profile were utilized, then the technology requirements would be reduced. Two alternatives are presented below for discussion.

a) Simple axle counting would still require treadles and loops but the determination of vehicles with and without trailers could be eliminated. It would be necessary to decide how to address buses and two axle commercial vehicles. However, this could be accomplished by a simple length measurement. Above a certain size, the vehicle is considered commercial and charged per additional axle.

b) If the requirement for classification by axle was eliminated, then a vehicle classification system based upon profile could be utilized. A single overheard detector could generate length and width profiles which could be compared against the toll fee schedule.

c) The requirement for all commercial vehicles to utilize OBU and DSRC communications would also ease requirements of the AVC. In this case, the AVC only needs to confirm that the embedded classification on the OBU is consistent with the detected classification.

It is recommended that if legal enforcement capabilities are available, consideration be given to a simplified vehicle classification system and that all commercial vehicles be required to have OBU's to use the toll facility.

4. LICENSE PLATE RECOGNITION TECHNOLOGY ASSESSMENT

License Plate Recognition (LPR) is utilized in toll system to capture an image of the license plate of selected roadway users and, using a combination of automatic Optical Character Recognition (OCR) and manual methods, extract the license plate number. Using the license plate number, the registered vehicle owner is identified. The process of identifying the owner of the vehicle can be through the local vehicle registration authority, toll agencies database or clearinghouse and interagency sharing agreements. The identification of the registered owner of the vehicle is a backend office function which is discussed in more details in the next section of this report.

In this section of the report, an overview of how LPR systems work and the interaction between the various toll subsystems is presented. As well, important issues associated with LPR and impacts on the operational performance are discussed.

The capabilities of LPR technology and how it can meet the requirements of the GEB toll systems are discussed.

4.1 Overview of LPR Systems

The license plate recognition systems include the image capture subsystem components and the optical character recognition subsystem, which consist of the following major components:

- Camera, including lens, image sensor and housing assembly;
- Light source;
- Frame capture electronics in the camera or processing hardware;
- Image processing hardware and software;
- Pole or gantry for mounting camera and light source; and
- Inter-connections to AVC, AVI and back office subsystems.

4.1.1 Camera

There are different types of camera used for LPR system application, including colour, monochrome and infra-red cameras.

Most LPR suppliers recommend monochrome CCD camera with high infra-red sensitivity. The sensor / lens combination will define the image resolution and useable field of view. In the case of the GEB, the precise choice of camera will be left to the Contractor. However, the design specifications need to be aware of the technological capabilities and limitations. The characteristics of the camera which are of particular performance are discussed.

4.1.1.1 Resolution

The resolution of the camera is measured in pixels, or the smallest element that can be differentiated. The terminology of TV lines, dating back to pre-digital cameras, refers to the number of lines when the imager is scanned. The cost of the cameras is dependent upon the resolution. However, if the resolution of a single camera is not adequate, the scene can be split over several cameras to increase the effective resolution. The resulting image is then merged. The capability of merging images is a useful feature as it can be used to capture images at the edge of the lanes or vehicles straddling lanes.

4.1.1.2 Field of View

The field of view is determined by the lens, image size and location. The lens, resolution and camera mounting must be co-ordinated such that the field of view includes all possible license plate locations. If a single camera is used for a lane, this would be an entire lane width. If multiple cameras are used, then the individual field of view would be adjusted accordingly.

4.1.1.3 Dynamic Range and Spectral Sensitivity

The dynamic range of the camera is a measure of the range of ambient light levels which a camera can operate with and generate a useable image. To successfully and consistently capture license plates, the ambient light level is controlled. For this reason, dynamic range is not important in viewing the license plate. However, related to this is the effect of blooming and over-saturation caused by head lights and tail lights which can wash out the other portion of the image, including license plate. These are well known affects and have been dealt with by experienced vendors.

The light spectrum at which the camera is sensitive will also help to determine how effectively the license plate can be read. Retro-reflective license plates, common in North America but not common in Europe, have created obstacles in LPR since the reflected images cannot be easily read. Sensors which are sensitive in the infra-red range perform better.

It is important that the specifications for the LPR recognize the different license plate technologies employed and develop a performance specification to mitigate these issues.

Camera sensors can have increased sensitivity in the infra-red band which improves the performance of the camera in the infra-red range. However, since the total energy in the infra-red spectrum is limited, true infra-red camera requires the use of infra-red illuminators.

Infra-red cameras are equipped with filters which attenuate the non-infra red signals. This results in a darkened image. However, when flooded with infra-red light, retro-reflective license plates are clearly visible. Infra-red cameras offer superior performance on retro-reflective plates, however the remainder of the image is poor. If an image of the rear of the vehicle is required, then a second camera needs to be used to supplement the image from the infra-red camera.

The infra-red filters eliminate the difficulties associated with blooming and over-saturation which results in a useable license plate image with shadowy vehicle image.

4.1.2 Illumination

In most cases, external illumination is used to provide the necessary light levels to support the image collection. The illumination can be continuous or strobed and can be halogen lighting or infra-red illumination.

In lane based toll systems with manual toll collection, the ambient lighting of the toll plaza provides the necessary illumination for the camera sensors.

Open road toll systems mount high intensity halogen lights on gantries over the travelled lanes, focused on the license plate area of the roadway. Strobe lights are used for enforcement systems (speed enforcement and red light violation) where a lower duty cycle is required.

The high intensity halogen lights provide consistent contrast and luminance levels for optimum LPR and OCR. These bright lights can be focussed on the rear of the vehicle. However, they are too bright to be focused on the front of the vehicle since they will disturb the motorist's visibility.

Infra-red illuminators can be strobed or continuous and will not obstruct the visibility of the driver. They are therefore suitable for illuminating either front or rear license plates.

4.1.3 Image Processing

The images from the camera are captured either by the camera or a "frame grapper" and processed to locate the license plate on the video image. In order to capture the image, a trigger is required.

4.1.3.1 Camera Triggering

The precise location of the vehicle is essential for LPR operation because the distance between the camera and the license plate must be carefully controlled for the recognition process.

In the case of a front camera, the trigger is generated when a vehicle enters the capture zone defined by the sensor. In the case of a rear camera, the trigger is generated when the vehicle has exited the capture zone. This integrated mechanism provides an extremely accurate trigger for both cameras.

In many toll systems, the image capture is "triggered" by some external device, such as a loop, laser or light curtain. In other cases, an internal trigger is generated solely from the video image itself.

The advantage of using an external triggering mechanism is that the vehicle location is very precisely known and camera triggering is consequentially accurate. The disadvantage is the external detectors and associated integration required.

Software triggering methods detect the grey level change in the image to identify an incoming vehicle and then trigger the camera. The advantage of this internal triggering method is that no extra vehicle detector is needed and integration responsibilities are reduced. However, additional errors may be generated by the vehicle imaging triggering mechanism.

4.1.3.2 Optical Characteristic Recognition

The captured image is processed to isolate the location of the license plate and the characters are processed. The OCR process can interpret the characters through a variety of heuristic methods and neural network processes.

The success of OCR technologies is very dependent upon the quality of the image and the characteristics of the license plates. Clearly, the use of graphic images and so called "vanity plates" has made the requirements of OCR much more difficult. Fortunately, the technology to decipher characters and decode license plates has improved considerably, and if a decent image of the plate can be provided to the OCR processor, a reasonable result be achieved.

The OCR processor should provide a quantitative confidence indicator for decoding of the overall license plate, each individual character and possible alternatives.

OCR technologies cannot overcome inherent limitations in the optical image. In particular, partial blockages of the plate caused by trailer hitches and bicycle racks cannot be decoded.

Using images capture of both front and rear plates, the system is likely capable of capturing at least 1 readable image on almost all vehicles. The OCR processes both images on a character by character basis and assigns a probability number to each character. The final license plate number is determined by using the higher probability character from each capture.

4.1.4 Camera Mounting

Camera mounting is a compromise between the optimal angle to capture a perfect image of the license plate, normal to the camera and preventing occlusion of the plate by other vehicles. The camera mounting angle is one of the most significant factors which impact the capture ratio for valid plates. Published figures much above 95% are likely to have only been achieved in situations where the cameras are mounted at strictly managed facilities, such as border crossings, control access facilities and manual toll facilities. In an open road toll application and real life situation with bumper to bumper traffic, much poorer performance is to be expected.

In order to minimize occlusion, the camera angle should be as steep as possible. This of course reduces the potential resolution of the plate image. Manufacturers indicate that maximum camera offset from normal can be between 20 and 40 degrees. The actual performance, relative to specific project examples and product cut sheets, will depend on a variety of factors, including camera mounting.

The use of front and rear cameras will provide a significant improvement in the OCR process and thus reduce the amount of manpower required to process the violations.

4.1.5 Inter-connections

The LPR system has interfaces to the AVI system, AVC and the backend office. The interface with the AVI is required to ascertain if vehicles detected are registered as valid OBU users. The AVC interface can provide the trigger to the LPR capture process as discussed above. The backend office interface will provide digital images for manual license plate recognition and transaction information.

4.2 Key Issues Associated with LPR Technology

The technology associated with LPR is well known and produced by a wide variety of companies. It is important to select a well qualified supplier with a proven track record. The specifications need to have measurable real life performance measures. However, there are practical and physical constraints which limit the performance of even the best quality LPR system.

4.2.1 Plate Location

Private motor vehicles, other than motorcycles, have both front and rear plates. However, other adjacent jurisdictions only have rear plates. This requires that rear license plate numbers be read if it is necessary to collect from these users. This may be required simply for perceived fairness. Commercial vehicles may have different front and rear plates. The front plate identifies the registered hauler whereas the rear plate identifies the owner of the trailer. If it is necessary to identify the hauler and an OBU is not required, then front LPR would be required.

4.2.2 Occlusion and Camera Mounting Angle

In order to capture a suitable image, a clear line of site is required for the camera. In closely spaced traffic, for rear license plate capture, the following vehicle may block the view of the license plate of the vehicle in front. The case is particularly acute when a large vehicle, such as a bus with a vertical front, follows a small vehicle. In order to compensate for this, the camera is mounted at an angle. In the open road configuration, this would be above the lane. The steeper the angle off of normal (parallel to the road), the closer vehicles can be spaced without occlusion occurring. Unfortunately, as the mounting angle increases, the number of pixels visible to the camera to differentiate decreases and the quality of the image decreases. If the rear of the plate is mounted facing slightly upward, which is the case of many vehicles, the effective angle is reduced and performance improved. Unfortunately, in the case of other vehicles, such as some sedans and trucks, the plate is mounted vertically and the bumper may slightly protrude resulting in poorer performance. Driving a pickup truck with the tailgate down is an extreme example of this.

Plates on the front of the vehicle tend to be mounted at a lower height and mounted perpendicularly, so the improvement resulting from the plate angle is lost. In addition, the rear of many vehicles, such as vans, sport utility vehicles and commercial vehicles is square, resulting in increased occlusion relative to the sloped hood of the front of most small cars.

Vendors claim very high performance capturing and decoding license plates with mounting angles up to 20° off of normal. However, as the angle increases to 40°, performance guarantees are less forthcoming.

In order to determine the possible effects of occlusion and minimum vehicle spacing, the physical characteristics of the vehicles, mix of vehicles and traffic conditions need to be considered. For comparison purposes, the relationship between camera angle and minimum vehicle spacing is illustrated in Figure 4.1 for assumed vehicle heights and license plate location.

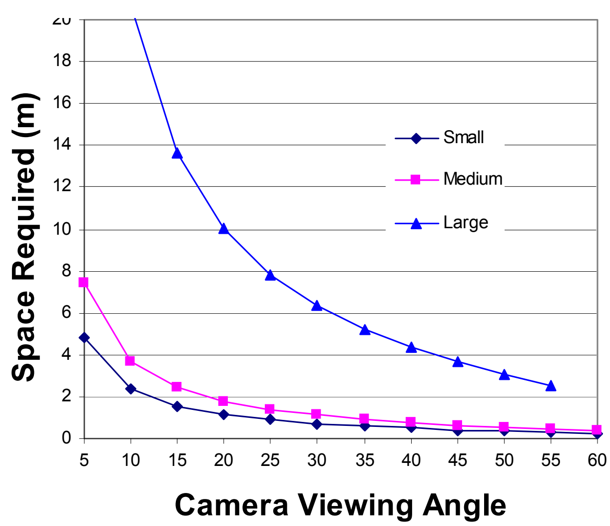

Figure 4.1 : Camera Viewing Angle vs Vehicle Spacing

4.2.3 License Plate Obstructions

It is illegal to obstruct the license plate. However, many forms of partial obstruction for which a police officer would not charge a motorist can result in a plate which is unreadable or requires manual intervention.

Examples are trailer hitches, bicycle racks, items on the roof rack (canoes, ocean kayak, building material, etc.), dirt, rust and so forth. The system evaluated can demonstrate remarkable partial reads in many situations, especially using infra-red cameras. However, there are a wide variety of plates which are simply not readable at the angles necessary to avoid occlusion.

License plate screens and spray on reflective products also are designed specifically to prevent the automatic reading of license plates. The screens are effectively polarized lenses which prevent reading of the plate at an angle due to the reflections from the flash or illuminator. The spray-on products are designed to reflect the light as well, resulting in over-exposure of the image. The effectiveness of these products varies by technology. The spray-on products are not effective when infra-red cameras are used.

It is recommended that the legal remedies available in British Columbia regarding the obstruction of licenses plates be reviewed. Wording in some jurisdictions requires plates to be legible and machine readable.

4.2.4 Traffic Conditions

It is often believed that high speed traffic presents a challenge to LPR systems. The advent of high speed cameras with rapid shutters and triggers has overcome any practical speed restrictions. The larger problem is stop and go traffic.

In stop and go traffic, vehicles tend to tailgate which results in occlusion of the plates as discussed above. This condition usually arises when a high speed facility joins a slow speed facility, either in the urban road network or a congested freeway. A classic example would be a free flowing toll facility with a ramp onto a very congested public highway. Queues build up on exit ramp and plates are not captured due to non-intentional occlusion.

In order to minimize this effect, the location of the toll gantries should be selected where traffic is most likely to be free flowing.

Front end license plate recognition presents an additional problem with intentional occlusion. In a rear plate reading LPR, it is unlikely a driver would tailgate the vehicle in front so that the driver in front would not need to pay a toll. However, in front plate reading LPR, a driver could intentional tailgate the vehicle in front, and may be choose a larger commercial vehicle to avoid being charged a toll. This type of driving behaviour is very difficult to control through enforcement.

4.2.5 Weather Conditions

Clearly weather conditions will affect the visibility of license plates and the success rate of LPR. Vendors claim that their systems work in most weather conditions, however this is very difficult to quantify. The worse case situations are:

- Heavy snow, not only is the view obstructed but the plate itself becomes covered in snow;
- Driving rain which obstructs the view; and
- Heavy fog.

In Vancouver, the snow should not be a significant concern and even driving rain is not that common. However, fog may be an issue. Local conditions of frequent fog should be considered when locating the tolling point. As well, this should be considered when the overall system performance calculations are prepared.

4.3 GEB Requirements and Recommendations for LPR

The GEB requires the use of LPR as a payment option for casual users who do not have OBU's and is also considering deploying a LPR only system in the initial phase. These two scenarios are considered in developing our recommendations. The GEB is also a point based tolling system utilizing an open road configuration.

The discussion of LPR technology shows that although vendors may claim very high successful capture rates, there are a wide variety of factors which will result in worse performance under real situations. Unfortunately, the impact of these effects on the real life LPR performance is very difficult to quantify.

The performance can be affected by traffic conditions, weather conditions, mix of vehicle types (not only commercial and private, but type of private vehicle), and even driver behaviour. In order to try and quantify the potential range of performance, experiences in other jurisdictions can be considered. For example, in a lane based scenario with slow moving vehicles and controlled access, such as a border crossing or manual plaza, performance in the high 90's can be expected. In a free flow open road toll scenario with fast moving traffic, the mid 90's are reasonable. However, in an open environment with requirement for a cordon type toll system, performance at 70% is acceptable. The GEB design should be between these two numbers, much better than the 70's but less than 90%. If the performance achieved is between 80% and 90%, significant revenue will still be lost.

In the event that GEB continues with its plan to utilize OBU's with DRSC to collect tolls from regular users and tractor trailer operators, then it is recommended that rear only LPR be used. The reasons for this recommendation are provided below.

a) Reduced problems with occlusion since there is less mismatch between vehicle heights, that is the front of vehicles are usually smaller than the rear.

b) Tailgating does not result in the tailgater not paying a toll.

c) The option of infra-red or regular cameras can be used which provides more options of suppliers.

In the event that it is decided to implement a video only system or it is determined that the use of OBU's by truckers cannot be mandated, then it is recommended that both rear and front license plate recognition systems be installed. The front facing needs to be an infra-red and the rear should, although not necessarily, be a monochrome unit. In addition, provision should be made for the integration with OBU based systems in the future. The reasons for these recommendations are noted below.

a) The losses discussed above will be reduced since although one plate may be obscured or partly obscured, it is unlikely both are.

b) Front and rear LPR's are required to capture all vehicle types, in particular tractor trailer cabs.

c) Rear LPR also discourages tailgating to avoid toll payment.

d) Interfaces to future systems should be provided to reduce eventual backend office costs when adjacent roadways are improved and volume increases.

There are other considerations if it is determined to change to an LPR only toll system. There is a greater uncertainty in the eventual performance of an LPR only toll facility. The collectable tolls for the OBU based portion of the users will approach 100%. Although it is only a portion, in the event of difficulties with LPR performance, incentives can be provided to switch to become OBU. There will be an increase in backend office costs since more manual evaluation will be required. Furthermore, the cost of backend office operations will rise as usage increases. In the hybrid (OBU plus LPR) arrangement, frequent users would use OBU's and only casual users would use LPR, resulting in limited growth in the backend office requirements. Finally, the use of OBU's allows for easier vehicle classification and makes it easier to accommodate HOT lanes, congestion based pricing and more complex toll strategies.

In the event a LPR only system is developed, it will be necessary to make provisions to add DRSC options in the future. The future cost of adding the systems will be much higher due to both technological and commercial reasons.

5. BACKEND TECHNOLOGY EVALUATION AND REQUIREMENTS

5.1 Payment Options

Toll road authorities can require that users register in advance of using the facility and maintain a positive account balance in order not to be considered a "violator" or the agency can issue invoices and collect balances from users through a variety of options.

The pre-registration has advantages in that all users must provide registration information which reduces reliance upon the motorist registry and ICBC to provide information on normal users. It is also attractive in that the agency maintains a positive cash flow which is important for toll authorities financed through bond issues. On the other hand, requiring pre-registration and pre-payment may reduce the number of roadway users and convert potential customers into violators (unhappy customers).

This section of the report discusses the various issues associated with the payment options.

5.1.1 Pre-Paid Account Issues

Pre-paid AVI accounts afford the highest assurance of the timely funding of toll transaction payments. The structure of pre-paid accounts mirrors the structure of bank "checking" accounts. Funds are present in advance of posting toll transaction debits to the AVI account. When accounts lack adequate funding to cover the toll transaction, information is passed to the lanes disallowing the transponder for payment such that violation images are captured of the passing vehicle and a violation transaction is created. Customers holding pre-paid accounts receive periodic statements, showing all transaction credits and debits to the AVI account. Delivery of statements is discussed in subsequent sections of this report.

Toll agency policies regarding notification to account holders of a low balance for check and cash replenishment methods, expiring credit cards, failed AVI transactions, and/or deactivation of account status must be clear with due consideration of customer service and constituent issues. Further, these policies must also balance those customer and constituent issues against the potential to grow negative account balance liabilities, and the cost of issuing the notices and related correspondence. Consideration should also be given to agency policies regarding collection of negative account balances and a write-off policy for aged uncollectible accounts. It is likely that a pre-paid account system is the least costly to operate and will result in the highest yield in tolls properly collected.

5.1.2 Post-Paid Account Issues

Post-paid AVI accounts afford the greatest ease-of-use for the occasional toll road customer and very likely, the greatest uncollectible balance liability. In a post-paid environment, toll transaction costs accumulate to an AVI account. Periodic billing is then delivered to the account holder and subsequent payment is received to clear the outstanding debt. Image identification of each toll transaction would be required to protect against the potential for lost and stolen transponders or uncollectible account balances. In any post-paid account structure, the credit worthiness of the applicant must be assessed and monitored throughout the life of the account.

Further, legislative action should be considered to ensure that uncollected balances could be converted to pursuable violations. Losses attributable to the unusable violation-image rate should also be considered when contemplating a post-paid account structure. The implications of a floating receivable balance against the fiscal plan need to be explored, as well as the high propensity of growing sizable negative uncollected account balances. As with pre-paid accounts, agency polices regarding customer and constituent notification must be explored. It is likely that a post-paid account system will be somewhat more costly to operate than a pre-paid system. It is also anticipated that the post-paid system will result in a lower collection rate when compared to a pre-paid system.

5.1.3 Anonymous Accounts

Accurate and prompt identification of the account holder is an essential element to any post-paid account structure, but less important in a pre-paid environment. Since the credit worthiness of the account holder is not in question in a pre-paid structure, the existence of anonymous accounts is possible. Anonymous account replenishments would be possible through multiple venues, much like any other pre-paid instrument. However, an automatic replenishment would be very unlikely for anonymous accounts. Tight polices guarding against the potential of any negative balance condition must be in place. As such, real time lane interfaces and an image capture protocol should be considered for all anonymous accounts.

In place of anonymous accounts, some may consider issuing stored value OBU's. The security leakage potential of stored value OBU's must be evaluated. However, "breakage" (lost, broken, or otherwise unused OBU's) may be an offset to the leakage potential of the stored value OBU. A study should be undertaken to evaluate and estimate the loss potential against breakage. Consideration should also be given to the distribution network desired to issue store value OBU's.

5.2 Functions of the Backend Office

Toll functions require a variety of systems to support effective and efficient toll collection operations. The functions that will be covered by this section of the report include:

- Toll-posting;
- Transaction auditing;
- Recurring payment / billing and payment processing;

- Statements and account notices;
- Demographics and annotations;
- Imaging, violations posting;
- DMV interfaces;
- OBU tracking and fulfillment;
- Inter-operable interfaces;
- Reporting;
- Internet hosting;
- Marketing interfaces;
- Communications interfaces and telephony; and
- Front end user interface and others.

5.2.1 Toll-Posting

The primary role of any backend toll processing system is to maintain an accurate posting of all AVI and image based toll transactions. The unique record of every toll transaction should be associated with the appropriate account for purposes of completing the financial transfer / billing of the transaction. The successful transfer of the transaction should then interface with the host systems in a manner to complete the reconciliation of the transaction, indicating the closure of the financial record in the host. The transactional record should also be linked to the debt / credit system established to maintain the AVI account holder data. The linkage of toll posting to daily, weekly and monthly reports is an essential part of any sound reconciliation and audit process.

There are many toll posting systems available in the industry. These systems range from customized proprietary hardware and software solutions to more modern open architecture systems operating on off-the-shelf hardware using Internet protocols. When evaluating toll posting systems, considerations of scale, expandability, ease-of-use and maintainability are important for both costs and access issues.

5.2.2 Transaction Auditing

The lane and host systems are the essential creators of the transaction record and must be independently audited if the tolling system integrity is to be guaranteed. Counters in the lanes tick off transactional data to the host. An independent automated periodic audit count of those transactions should be undertaken to ensue that all transactions are accurately posted to the host and lane systems. This process is vital to system integrity and the ability to detect and address potential attacks and fraud against the system revenues. To achieve this audit responsibility, systems ranging from manual observation, to on-site monitoring, to remote automated monitoring are available.

5.2.3 Recurring Payment / Billing and Payment Processing

As part of closing the AVI financial transaction, funds must transfer between the customer and GVTA. These funds may either be available in a pre-paid account or through a post-paid mechanism. Pre-paid accounts may be funded through a variety of methods that include credit cards, debit cards, electronic checks, gift certificates, other prepaid instruments (i.e., stored value cards), cash and check deposits, or third party transfers (clearinghouse and inter-operable systems). Post-paid methods could also include the aforementioned list, but would most likely come in the form of a check processing via a remittance.

As part of the backend system, automated interfaces with credit card processors, banking processors, and other payment processors would be needed. Systems are also available that assist in check processing, such that more automation of that function reduces error potential and labour cost. Recurring billing that is consistent with the end result of the gap analysis regarding post-paid and pre-paid business rules is paramount to the daily financial viability of the tolling system. As such, backend systems must include a sophisticated multi-dimensional recurring billing module.

5.2.4 Statements and Account Notices

Billings and statements are also a major component of a backend system. Statements are associated with pre-paid toll systems and provide the account holder with a record of toll system use and beginning and period ending account balances. Billings are associated with post-paid tolling systems and reflect the actual toll usage and any other charges that may be incurred against an account, such as a monthly OBU rental fee. In either case, these must be generated on a periodic basis for account holders. These should include a reconciliation of all account activity during the given billing / statement period. Other important information should also be included on these communications (e.g., balance information, reference numbers, etc.). A list of more than 30 other types of customer communications must be routinely generated.

Backend system modules must handle these communications and other forms of customer contacts, annotate / log their creation and interface with whatever means is chosen to generate and distribute those communications. Traditional postal, e-delivery, fax and over the counter hand delivery methods must be considered in the system design. As such, both printed and file delivery modules should be addressed.

5.2.5 Demographics and Annotations

The front end system is dependent on tables maintained in the backend to search and identify specific transactional activity associated with particular toll transactions, accounts and account holders. To differentiate between individual accounts or account holders, specific unique identifying demographic information must be maintained, stored and queried. These data includes such items as names, addresses, telephone numbers, e-mail addresses, account numbers, vehicles, OBU’s, account types (individual, commercial, non-revenue, etc.), payment sources, PIN’s, toll system use history, etc.

Moreover, annotations in accounts must also exist as part of the historical account record. The historical account record must be accessible to queries and viewable from the front end. Annotations can include such items as statement and notice delivery dates, replenishment histories, historical changes to account information, customer contact notes, etc. The front end and backend systems must account for these demographic and annotation needs.

5.2.6 Imaging

As back up to the OBU and to protect revenue leakage, a state-of-the-art on-road imaging system is essential. The basic field components of this system as discussed in Section 4 of this report include multiple high speed, high resolution image capture units per lane (e.g., infra red, OCR, etc.) and image processing systems. Image processing, image based transaction storage and retrieval systems are also required at the operations centre. These systems must integrate with the backend system as well as the host and lane systems.

5.2.7 Video User and Violation Posting

The role of the backend violation posting system is to accurately post all violation transactions to violation accounts consistent with established business rules. The unique record of video transactions should be associated with the appropriate account for purposes of completing the financial transfer of responsibility to the appropriate party, as allowed within the local laws and/or jurisdictions. The successful transfer of the transaction should then interface with the host systems to complete the reconciliation of the transaction, indicating the closure of the financial record in the host and the opening of the financial record in the violation posting system. The transactional record should also be linked to the debt / credit system established to maintain the violation account holder data. The linkage of violation toll posting to daily, weekly and monthly reports is an essential part of any sound reconciliation and audit process.

The video user and violation posting system should be a module to the backend system, as the likelihood of shared data between the violation and customer database is high.

In the context of the GEB, violators can be considered as video or OBU users who prevent the proper operation of the toll equipment or have lengthy outstanding uncollectible balances.

5.2.8 DMV Interfaces

To identify, process and secure enforceable video transactions, interfaces must be established between the GVTA and the government vehicle registration systems (ICBC). The ability to query the vehicle registry database and read / write to and from that database is an essential key to the success of a violation enforcement program. Registered owner information, vehicle registration information, vehicle make, model, year and other important information are key elements to the establishment of a violation enforcement program.

5.2.9 OBU Tracking and Fulfillment

The backend system is also responsible for tracking inventory levels of OBU's and their assignment statuses, linking individual OBU's with accounts and account holders. This also includes interfacing to the field and host systems for the purpose of expressing those statuses in a near real time environment. Backend systems must also handle the return and issuance of the OBU's. Interfaces to report modules must enable routine and periodic queries such that ordering levels, auditing and other important OBU tracking and fulfillment functions are accomplished. These backend systems must also track and maintain logs and statuses of warranty activity showing the location of OBU's at all times in the warranty process and the statuses of returned OBU's and shipping / receiving information.

5.2.10 Inter-operable Interfaces

As AVI grows within the geographic region, the ability to accept foreign OBU's as payment on the GVTA system becomes more important. The backend system must be capable of identifying, validating, accepting and reporting transactions for both home-agency and away-agency OBU's. Further, the backend system must be able to separately identify, validate, accept and report image based transactions for inter-operable accounts. Lastly, the backend system must reconcile the aforementioned toll and image based transactions on a routine periodic basis, and create billing and settlement files. Reconciliation of these files is key to the integrity of any inter-operable process that GVTA may establish.

The backend system must be capable of providing interface to the new DSRC / WAVE RSU as they are adopted in the future.

5.2.11 Reporting

The backend system must have a sophisticated reporting module that provides both identified routine reports and enables specialized non-standard queries of the database. Report categories include audit reports, exception reports, financial reports, inventory and warranty reports, inter-operable reports, management reports, marketing reports, operational reports, system maintenance reports and transactional reports. The system should enable the production of these reports in multiple formats and from multiple locations. More modern systems also enable the production of these reports remotely from desktops and provide the ability to transfer the data to modern desktop applications, such as Microsoft Excel or Access.

5.2.12 Internet Hosting

The backend systems should include a front end module that provides account holders (OBU and LPR) and violators the ability to review basic information and make payments or otherwise receive customer service through their home / office computer. This requires the establishment of secure and non-secure websites hosted on behalf of

GVTA and the connection of the secure portion of those sites to the backend database. To reduce ongoing labour cost associated with customer service requests, manual updates / processing, the website should read / write directly to the backend database in a secure environment.

5.2.13 Marketing Interfaces

The backend system must allow for the identification of specific characteristics to accounts and account holders. This includes enrolments in special programs, the application of special promotions affecting either the financial aspects of the account (i.e., transactional discount promotions, incentive credits, time-of-day or location-based discounts), and/or informational enrolments (i.e., newsletters, partnership alliances, affinity groups). The ability to evaluate the performance of specific promotions and marketing programs is key to gauging specific successes / failures. As such, the backend system must enable routine measurement of these programs and the application of the promotion / program to the account base.

5.2.14 Communications Interfaces and Telephony

The backend system will require a detailed communication and telephony plan that includes accommodations for multiple remote accesses to the system, call centre functions with call routing, interactive voice response, predictive dialler ability, call monitoring, establishment of multiple call banks and other operational functions. This system should provide monitoring and performance reports.

5.2.15 Front End User Interface

The front end should provide ease of use with a search engine that allows for searches based on demographic information, such as names, addresses, telephone numbers, AVI / violation account numbers, OBU numbers, violation / transaction numbers, license plates, replenishment methods and e-mail addresses. The front end should have security features that require a username and password to log into the system. The front end should enable new enrolments. It should also have the ability to see account annotations and demographic, financial history, transactional history, communication history, statement history and more for existing accounts. The front end should allow for updates, modifications and payments to be applied to accounts.

6. COMMUNICATION REQUIREMENTS

A communication link is required between the field equipment and the backend office. This link needs to be adequate to transmit the images for storing and manual processing. It is also needed to provide a data path for transactions between the roadside equipment and the backend office equipment.

The communications can be provided by a simple dedicated connection using Internet Protocol (IP). A high speed fibre optic link should be installed between the field equipment and the equipment room or wiring closet at the bridge control and electrical rooms.

A secondary link, likely a secure leased link, will need to be provided by the operator between that room and the operations centre. The operations centre and call centre will require high speed Internet access and suitable telephone service to handle peak customer service requirements.

The communications associated with a single point based toll system as proposed for the GEB can be provided at a low cost with virtually no risk. However, the responsibilities and demarcation points between the facilities constructor and the toll system supplier need to be clearly defined in the respective contract documents.

7. CONCLUSIONS AND RECOMMENDATIONS

The previous sections of this report have presented a review of applicable technology and analyzed the aspects relevant to the GEB. Each section of the report provides recommendations and conclusions relevant to the specific technology. This section of the report provides overall conclusions and recommendations. In particular, the technology aspects which are relevant to tolling policy decisions are highlighted herein.

Relevant toll policy questions are presented below.

a) Should the toll system use license plate recognition only or enable on-board units (OBU's) to be used and a discounted toll paid?

   The current tolling policy framework is based upon a dual fare system where a customer either utilizes an on-board unit (OBU) for vehicle identification and billing, or license plate recognition technology and vehicle registration information is used to issue invoices. An option which has been suggested is to utilize only licence plate recognition and not to implement a hybrid, OBU plus LPR system. The advantages and disadvantages are discussed and a recommendation made to utilize the hybrid approach.

b) Is it appropriate to revisit the proposed vehicle classifications to simplify the technology?

   Currently, four vehicular classifications have been proposed. In order to differentiate between vehicular classes, it will be necessary to count axles and evaluate vehicle profiles (shapes). Alternatives which simplify the technology have been proposed for consideration. An important consideration is the impact on the structure of installation in the deck surface.

c) Can commercial vehicles be mandated to use an OBU?

   Mandatory use of OBU's by commercial vehicles, in particular tractor trailers, will reduce the number of "out of province" commercial truckers who avoid payment of tolls. Even if the total revenue lost is not very significant, if trucks registered "out of province" can avoid paying tolls whereas "local" truckers need to pay, there could be a perception of unfairness. Even though the current legislature does not support mandatory use of OBU's, the differential toll rate for LPR commercial users could be increased significantly to reflect the increased collection costs.

d) What payment options should be available to users?

Toll payments can be through pre-paid accounts, post-payment invoicing and the use of smart cards or stored value devices. These options were reviewed and recommendations made.

The toll technology addressed by this report includes:

- Automatic Vehicle Identification (AVI) through the use of dedicated short range communications (DSRC);
- Automatic Vehicle Classification (AVC) systems;
- License Plate Recognition (LPR) and Optical Character Recognition (OCR) systems; and
- Back Office systems.

Specific recommendations are made to address each of these technologies.

7.1 License Plate Recognition Systems vs Hybrid Technology

The performance in terms of billable tolls versus uncollectible tolls for toll collection using OBU's and DSRC is significantly better and more consistent than when LPR is used for billing purposes. Billable tolls using DSRC are in the 99.9x% range whereas when LPR is used in the proposed configuration, it is anticipated that the rate could well be less than 90% depending upon local conditions. The lack of certainty is also a concern due to the dependence upon local conditions. In the hybrid system, since LPR patrons are considered clients and not violators, the overall performance will be a blend depending upon the mix of DSRC versus LPR patrons.

The advantages of the hybrid versus the LPR only approach are:

- Improved revenue capture ratio with less uncertainty;
- Ability to easily offer toll incentives for high occupancy vehicles, low emission vehicles, emergency / public service vehicle, etc.;
- Commercial vehicles can be separated into an infinite number of classifications based upon data in the OBU;
- Fleet of OBU equipped vehicles on the roadway suitable for a variety of other ITS requirements;
- As the number of users increases, the backend office costs for LPR should remain constant since frequent users would be encouraged to use OBU's;
- It is much less expensive to adopt the hybrid approach during the initial procurement as opposed to retrofitting at a future date as other toll facilities come on line; and
- Commercial vehicles can be encouraged to use OBU's so issues associated with different license plates on the cab and the trailers can be addressed. If an OBU is used, the account holder is immediately known.

On the other hand, the LPR only system also has advantages, these are:

- All users are dealt with the same even though the toll required may be higher;
- Issues associated with DSRC standardization, future expansion and DSRC needs of other applications need not be dealt with until more global policy decisions are made in the future; and
- Legislation or other means to require commercial vehicles to utilize DSRC is no longer relevant.

It is recommended that a hybrid approach be adopted since it is estimated that the revenue lost through unpaid tolls will be significantly reduced, and the administrative cost of identifying users, resolving conflicts and collection will also be reduced.

7.2 Licence Plate Recognition Technology

The LPR technology needs to be designed to take maximum advantage of OCR technology since the ongoing operational costs will be a major and increasing concern for all manual functions.

The technology must address the requirement to detect both reflective and non-reflective plates and deal with vanity plates and graphical images which are common in North America but not in other parts of the world.

An important criteria to be specified is the maximum angle for which the LPR can reliably capture plate images which are suitable for OCR. The steeper the angle, the closer the vehicles can drive in stop and go traffic. However, this results in poorer images and requirements for more sophisticated OCR software.

Since the enabling toll legislation does not permit the GVTA to mandate the use of OBU's for commercial vehicles or trucks, it is necessary to utilize both front and rear license plate capture. The front capture is required for tractor trailers, and the rear capture to support out of province drivers with rear plates only and to remove the incentive for motorist to tail gate to avoid paying tolls.

7.3 Vehicle Classification Systems

Four vehicle classifications have been defined.

a) Cars – Cars include most passenger vehicles, vans, sport utility vehicles, pick-up trucks and taxis.

b) Small Trucks – Small trucks are defined to consist of "cars" towing a trailer, light duty commercial vehicles with less than five axles (with or without a trailer), school buses, intercity buses and non-exempt transit buses.

c) Large Trucks – Large trucks consist of all other vehicles (typically with five or more axles) with or without a trailer.

d) Motorcycles – Motorcycles are defined to consist of mechanized, licensed two-wheel vehicles. Note that this category does not include bicycles.

The classifications suggest that the number of axles plus the profile of the vehicle be considered to determine the toll classification. In the event that the number of axles need to be counted in order to definitively determine the vehicle class, then sensors in the pavement will be required. It is possible to identify vehicles within these four classes using a combination of axle counters and profilers or through sophisticated analogue inductive loop detectors.

However, it is recommended that the toll classifications be reviewed to ensure that the vehicles can be classified strictly either through axle counting or vehicle profiles. The use of non-intrusive above ground detectors is preferred to minimize road maintenance activities.

Technology appropriate for AVC includes both intrusive and non-intrusive technology. It is recommended that the AVC be permitted to utilize intrusive technology, such as inductive loops, piezo-electric detectors and fibre optic detectors. However, the use of mechanical devices, such as treadles, should be precluded.

7.4 Toll Payment Options

The operator would prefer to receive all toll payments in advance from registered toll users. This provides the operator with a list of potential clients, independent of the motor vehicle registry, and allows operation with a positive cash position. However, the reality is that if users must register and pay in advance, they are less likely to utilize the facility resulting in lost revenue.

Therefore, it is recommended that the facility allows for both pre-paid and post-paid accounts and develop a methodology to address infrequent users.

The use of pre-paid accounts with cash balances stored in OBU's or smart card is also technically possible, however offers few advantages. The cash value stored on the OBU's or smart card is a liability, and there are more secure and less expensive mechanisms to manage pre-paid accounts. Hence, it is not recommended that the GEB adopt an OBU or smart card based payment scheme until more robust security can be ensured. This will occur as part of the 5.9 GHz standard development.

7.5 DSRC Technology

The selected DSRC technology will set the stage and provide a de-facto or actual standard for tolling and for other ITS applications in the lower BC mainland. A variety of options have been analyzed in the report, however it is recommended that a specific standard not be mandated. The specification should address the requirements of future toll facilities and other ITS applications. This will require that the functionality of the OBU's and DSRC be specified to allow for future applications, such as read / write capability and wide area operation. As well, the contractual terms need to address the requirement associated with use by others, such as battery life and allocation of memory. There is an existing family of commercial vehicles who utilize DSRC for commercial vehicle operations. Specifically, the CSVIN program for commercial vehicle licensing and weight scale bypass use an open DSRC standard, ASTM v6, which is also suitable for tolling. The trucking industry desires to utilize a single OBU on commercial vehicles, for this reason the toll plazas should support the use of ASTM v6 to accommodate commercial vehicles without the requirement for a separate transponder or OBU. However, prior to committing to support dual DSRC standards, a review of the potential number of ASTM v6 equipment vehicles which may utilize the GEB should be conducted relative to the incremental infrastructure cost. A decision will then need to be taken considering the use of LPR only for GEB tolling, the strong desire from the trucking association for a single OBU, and the precedent being set for future toll and ITS applications in the region.

7.6 Recommendations

The recommendations can be summarized as follows:

a) The tolling system should allow motorists to utilize OBU and DSRC communications to identify the account holder. In addition, video users should be permitted, albeit at the higher toll rate.

b) The DSRC technology should support existing CVSIN applications if used by a significant number of commercial users. The technology selected should provide for future ITS and tolling applications, but a specific standard need not be adopted. A migration path to IEEE 802.11p needs to be considered for the future and incorporated into the procurement process.

c) The vehicle classifications should be developed to allow simple and reliable vehicle classification systems. Specifically, the requirement to both count axles and profile vehicles should be avoided. Non-intrusive technologies are preferred and mechanical systems should be precluded.

d) The back office systems should allow for both pre-paid accounts and post-paid invoicing. Provisions for smart cards and cash value on OBU's need not be provided. The back office systems should support OBU's, video transactions and violations.

e) Specifications for the supply, installation and operation of the toll system should be based upon performance specifications which are as much as possible technology and supplier independent.