Ferry Systems Data, Scheduling, and Billing

Automated Vehicle Toll Collection

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Washington State Department of Transportation
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FERRY SYSTEMS DATA, SCHEDULING AND BILLING FINAL REPORT ON AUTOMATED VEHICLE TOLL COLLECTION

by

Scott Rutherford
Director

Mark E. Hallenbeck
Research Engineer

Washington State Transportation Center (TRAC)
University of Washington, JE-10
The Corbet Building, Suite 204
4507 University Way N.E.
Seattle, Washington 98105

Washington State Department of Transportation
Technical Monitor
Don Nutter
Director of Planning

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16. ABSTRACT

This report examines the feasibility of implementing an automated vehicle toll collection system for the Washington State Ferry System. The study concluded that such a system would pay for itself in four to five years. Implementation of such a system is not recommended at this time, but it should be considered after similar projects, ongoing in other states, demonstrate that the AVI technology has achieved the accuracy and reliability requirements of a toll collection system.

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SUMMARY

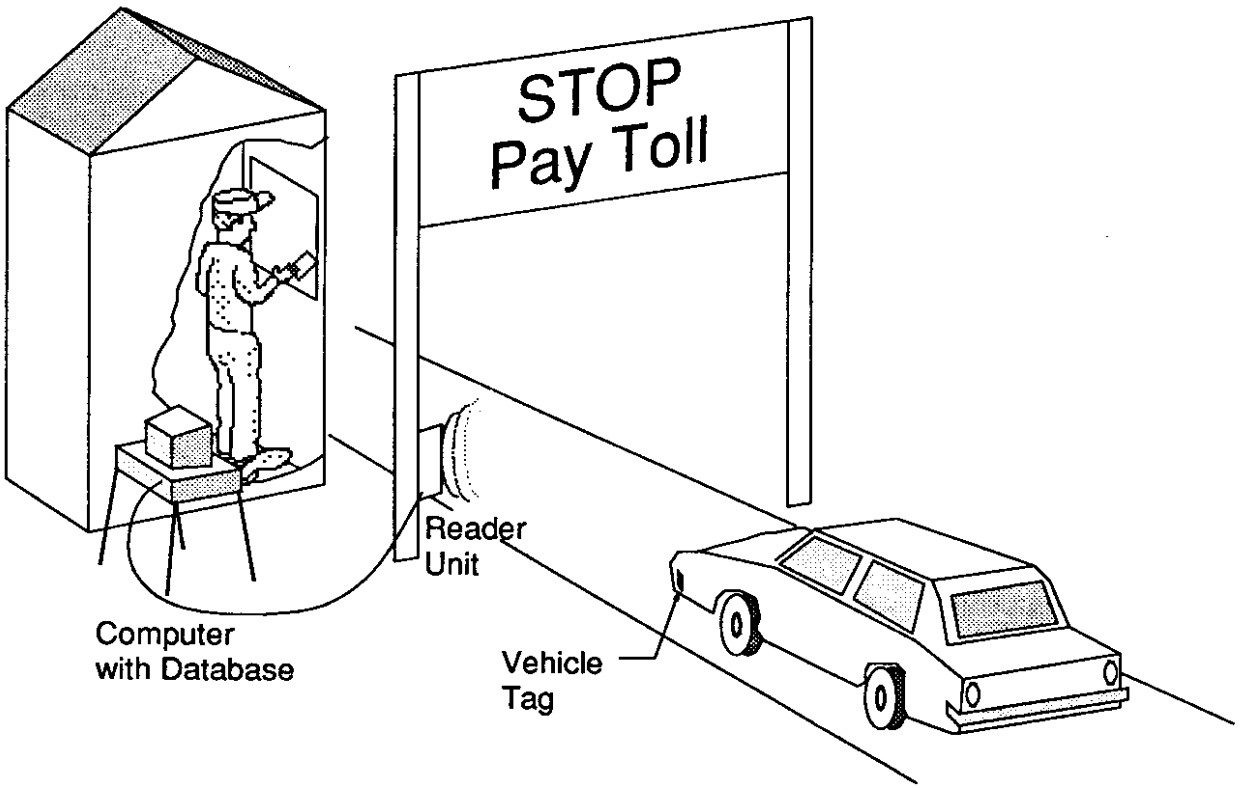
This report examines the feasibility of implementing an automated vehicle toll collection system for the Washington State Ferry System (WSF). Such a system would use the automatic vehicle identification (AVI) technology that is currently being examined for use within the Heavy Vehicle Electronic License Plate (HELP) project in which WSDOT is participating. An automated system would speed toll taking and improve revenue control for the WSF.

This study initially examined the use of AVI-based toll collection for commercial vehicles using the ferries. The scope was expanded to include all vehicles types when it became obvious that use of the AVI system would not be beneficial if it was restricted to commercial vehicles.

When the AVI technology is used as a toll collection system, its application is reasonably simple. Each vehicle participating in the AVI system is fitted with a unique "tag." An electronic unit located at the toll booth reads the tag automatically each time the vehicle passes that point. A computer then uses the tag's identification number to identify the owner of that vehicle and enter that trip into a database/billing system (see Exhibit 1).

The literature review performed for this effort revealed that while the technology required for an AVI toll collection system exists and interest in such a system is high in many parts of the country, no functioning AVI toll collection system is currently operating in the United States. Systems currently under development and testing all exhibit weaknesses that must be corrected before the systems can become operational. While these changes will undoubtedly be forthcoming, the project team believes that the WSF should wait for other

EXHIBIT 1
AUTOMATED TOLL COLLECTION SYSTEM COMPONENTS



transportation agencies to complete the "debugging" of these systems before committing resources to purchase and implement such a system.

The tests done by various transportation agencies indicate that AVI systems do have significant cost reduction potential. Cost reductions will come from two major areas:

- reduction in staffing required to collect tolls, and
- increases in revenue control, through a reduction in money handling at toll facilities.

AVI systems also provide faster processing rates than conventional toll taking procedures. CALTRANS measured improvements of from 100 to 400 percent in toll transaction processing rates when testing an AVI system. This reduces the land area required for toll facilities and increases the productivity of the facilities that are built.

At WSF, the above benefits could be obtained if a large number of vehicles (both cars and commercial vehicles) were equipped with AVI tags. If a sufficiently large number of vehicles used the AVI system,

- the personnel required for selling vehicle tickets could be decreased,
- the operating characteristics at several terminals could be significantly improved, and
- improvements in revenue control could be achieved.

A simplistic evaluation produced an estimate that an AVI system would cost at least $1,200,000 to install and $180,000 per year to maintain. Savings in reduced staffing requirements would be about $406,000 per year. These assumptions indicate that (provided it is heavily used) the AVI system would pay for itself in five and one half years.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The conclusions of this feasibility study of automating vehicle fare collection within the WSF are summarized below.

- The automation of many of the vehicle fare collection transactions currently performed by the WSF could be successfully accomplished now.
- Automating only the collection of commercial vehicle tolls would not be cost effective and would provide very few benefits in comparison to WSF's existing system.
- The automation of the transaction process in and by itself would not result in increased revenue or increased traffic by vehicles on WSF vessels.
- A preliminary cost analysis of existing systems based on figures from a CALTRANS AVI toll facility research report indicates that an

automated system would cost the WSF roughly $1,200,000 to install and $180,000 per year to maintain.

- An preliminary examination of benefits and costs shows a payback period of roughly five and one half years.
- The automated system offers potential for providing increased vehicle processing speed without significant construction or land acquisition costs at many terminals.

Recommendations

The following actions are recommended for the ferry system.

- The ferry system should not attempt to purchase and install an automatic vehicle toll collection system for at least three years while other transportation agencies install, test and debug early AVI systems.
- WSF should not put itself in the position of developing an AVI system but should purchase an existing system that has been proven under similar conditions.
- Further detailed study should be performed to more closely measure expected benefits after the technology has been installed and is functioning at other operating authorities across the nation.

INTRODUCTION

The concept behind automatic vehicle identification (AVI) is to provide vehicles with an electronic tag, license plate, or other identifying device that can be automatically read or activated. The device that reads the tag feeds the identifying information into a computer system, which searches a database that associates specific tags to specific vehicles and/or vehicle tag owners. This information is used to charge that customer for the use of the facility.

In the case of the Washington State Ferries (WSF), the computer system would determine the owner of the vehicle, the vehicle's characteristics (length, weight, number of axles), and enter that information into an accounting system that would either bill the customer for that ferry trip or charge that customer's debit account.

Until recently, the cost and size of the electronic components required to perform the identification and data processing portions of the AVI system were too great to be considered for use by most operating authorities. However, the increasing power and decreasing size and cost of electronic devices has resulted in the rapid development of several technologies that may make AVI cost effective. Another significant impact of the ongoing electronics revolution is the improved reliability of electronic components. This aspect of system performance is critical to the operation of an automated toll collection system.

Types of AVI Technologies

There are six basic AVI technologies described in available literature (Ref. 1, 2 and 3):

- radio frequency modulation (RF),
- optical scanning,
- microwave,
- acoustic,
- magnetic, and
- radioactive.

The differences between a number of these categories is a bit blurred. Most of them read information transferred via some kind of electromagnetic wave, but the electromagnetic waves are at sufficiently different frequency ranges that the various systems have very different operating characteristics.

Within each of these technologies is a variety of different equipment configurations. New combinations of the basic technologies are also being tested,

and new systems may have been developed by the time this report has been completed. For the most part, ongoing research is concentrating on RF, optical and microwave technologies. Exhibit 2 summarizes these three technologies. The technologies available today are briefly described below.

EXHIBIT 2
AVI TECHNOLOGY COMPARISON

	RF	Microwave	Optical
Operating frequency	50-250 kHz	0.5-10 GHz	NA
Interrogate/receive antenna	Large	Small	Small
Sensitive volume	Adequate	Adequate	Adequate
Immunity to dirt, ice, snow	Excellent	Fair	Poor
Bits of data transmitted	Adequate	More than adequate	Adequate
Interrogate power	High	High	Low
Tag transmit power	Low	Low	NA
Operate at highway speed	May need large interrogate/ receive antenna	Yes	Yes
Tag size	Medium	Medium	Small
Variable data input	Yes	Yes	No
Immunity to electromagnetic interference	Fair	Excellent	Excellent
Line-of-sight limited	No	Yes	Yes
Obstruction by intervening metal	Good performance	Good performance	Good performance

Radio Frequency Systems

Like most AVI systems, radio frequency (RF) systems consist of a tag attached to the vehicle, a reader located in the pavement, and an activation signal that initiates the transfer of information. Usually, an inductive loop imbedded in the pavement provides a continuous beacon that activates a passing vehicle tag. The tag then emits an RF signal, which is read and interpreted by a second inductive loop, also buried in the pavement. RF systems are similar to garage door opening systems commonly sold in hardware stores. Many garage door openers use RF technology but require the vehicle operator to activate the tag by pushing a button instead of a sensor in the garage detecting the car.

Radio frequency systems can employ either an active, battery powered transmitter (vehicle tag) or a passive transmitter that is powered by absorbing energy from the actuation signal. Battery powered tags can contain greater amounts of information and can be read over longer distances than passive tags, but they cost more, weigh more, and require charging and maintenance of their power supply.

When compared to other AVI technologies, RF systems are relatively inexpensive and are not constrained by the harsh environmental conditions inherent in highway applications. They are not constrained by line-of-site considerations (i.e., whether a second vehicle is between the reader and the vehicle whose tag is being read), but they can be susceptible to some forms of electromagnetic interference, such as CB radio transmissions.

Currently, RF systems are being widely tested by a number of manufacturers and several operating authorities both within the United States and internationally. The Oregon HELP testing described later in this report includes several RF-based systems.

Microwave Systems

Microwave systems are similar to RF systems but operate at a much higher signal frequency (0.5 to 1.0 GHz versus 50-250 kHz). Like RF systems, the vehicle

transponder or tag consists of a small device that is activated by a burst of energy from the interrogator or reader. Microwave energy passes through the transponder tag and reflects back a unique identifying code. The microwave system's requirements for clear line of sight and transponder cleanliness are substantially lower than those of optical systems but higher than those of most RF systems. Microwave systems do appear to offer better opportunities for reliable, accurate systems than some RF and most optical systems. Among the microwave system's drawbacks are that early systems required relatively large amounts of power and in some cases, required FCC licensing. Manufacturers are attempting to overcome these limitations.

Surface Acoustic Wave (SAW) technology is a combination of the microwave technologies described above and the acoustic technology described below. It is a relatively new technology that has been successfully demonstrated in San Diego, California, for highway toll collection.

In SAW systems, a low power microwave interrogator signal emitted by a device at the toll collection location passes through a metallically etched crystal attached to the vehicle (the tag). The crystal reflects an altered signal, which uniquely identifies the transponder tag. This signal is received by the same device that emits the initial signal.

The SAW system appears to work well in low speed operations, and does not appear to be affected by the environment or external electronic noise. However, it has problems when line of sight is impeded.

Optical Systems

A number of optical systems are currently being tested and marketed. Optical systems can be divided into two categories, those that read existing license plates and those that require special vehicle tags (such as bar codes). Optical systems in general tend to require lighter weight vehicle tags than RF or microwave systems, but they are more susceptible to environmental conditions (rain, snow,

mud, etc.). They usually have lower power requirements than RF and microwave systems but require a good line of site to operate effectively.

License plate scanning uses a complex image processor to obtain and analyze the license plate number of a vehicle. The major advantage of such a system is that it does not require vehicles to be equipped with a special tag. The disadvantages are that optical systems require both the license plate and scanning equipment to be clean, and they also require vehicles to maintain a particular position within a lane (strong vehicle lane discipline) to function accurately. In practice, both of these objectives are hard to maintain.

More common than license plate scanners are optical scanners that consist of a reflective "strip" containing a sequence of bars of various colors or widths that are scanned and interpreted by an optical interrogator. (The railroad industry used this type of technology for several years, and the retail trade industry is using similar systems to speed checkout and manage inventory.) As with other optical systems, the advantage of the system is the relatively low cost of the transponder (i.e., the bar code). The disadvantage is that existing systems lose reliability over time because of environmental and maintenance problems (i.e., dirt obscures the bar codes). The state of Arkansas is currently experimenting with a bar code reading system for interstate trucking regulation.

Infrared scanning also employs an optical scanner, except that this system uses a vehicle mounted transponder in place of a barcode strip. It is similar in function to the SAW and microwave systems described above. Infrared systems also require consistent vehicle alignment, appropriate depth of field, and cleanliness of the surface of the transponder, although to a lesser extent than license plate and bar code style systems.

Magnetic Systems

Magnetic systems use a transponder comprising a set of permanent magnets that are arranged so that each tag produces a unique pattern of voltage in a coil

imbedded in the pavement. The voltage pattern is then interpreted by a set of electronics to identify the vehicle. Magnetic systems are simple, passive (they require little power and respond only when interrogated) and are theoretically reliable. However, preliminary tests show that the use of magnets as an AVI system is constrained by stringent alignment requirements, and little ongoing work is being done in this area.

Radioactive Systems

Radioactive systems consist of a radioactive transponder mounted on a vehicle and associated sensors located in the roadway. When a vehicle passes over the sensor, the coded sequence in the transponder is generated in the sensor. This technology requires strong vehicle lane discipline. It has also generated concerns about driver and pedestrian safety because of the radiation emitted by the tags.

Acoustic Systems

Acoustic systems include a signal transmitter, a tag that modulates and reflects the acoustic signal, and an interpreter that receives the modulated signal. The reflected signal is interpreted by the interrogator to identify the vehicle. Problems associated with early acoustical systems include alignment and environmental conditions. The only ongoing work with acoustic systems is in the SAW technology described earlier.

REVIEW OF PREVIOUS RESEARCH

A variety of related research projects that are ongoing or have been recently completed have had (or are having) a substantial impact on the AVI industry and the availability of an AVI system for the WSF. Projects of interest include

- the Heavy Vehicle Electronic License Plate project (HELP),
- the CALTRANS, San Diego-Coronado Bay Bridge AVI tests,
- the MARAD Cooperative Container Handling project,
- the state of Arkansas barcode tests,

- Texas Turnpike Authority, Automatic Toll System, Dallas, Texas,
- Triborough Bridge and Tunnel Authority, Vehicle Identification Tests in New York City,
- New Jersey Highway Authority, Vehicle Identification Tests, Asbury Park, New Jersey, and
- the Dulles Toll Road, Automatic Toll Collection Project, in Reston, Virginia.

WSDOT is closely involved with the HELP project and is closely monitoring the CALTRANS work as part of the HELP project. Less information is currently available from the other projects, as they are still underway and do not include direct participation or oversight by the Department.

HELP Demonstration Project, AVI Testing

The HELP project has performed several tests of AVI equipment. An initial laboratory phase, conducted in Arizona, tested 12 separate AVI systems for inclusion in later field testing. The top three systems that employed single direction communication (from tag to reader) and one system that used two direction communication were selected for further evaluation in field tests.

Field testing took place in Oregon to determine the equipment's performance under actual traffic conditions. All of the tested systems were preproduction models, and considerable refinement of the equipment will be required before any of the systems will be ready for actual production and use. The four systems tested in Oregon all used an RF technique for reading tags. The systems tested were

- EMX SVD 20 System (made by EMX, Incorporated of Upland, California),
- EID Systems (made by Electric Identification Systems, Ltd. of Edmonton Canada),

- Phillips VETAG System (supplied by Vapor Corporation of Chicago, Illinois), and
- Phillips VECOM System (also supplied by Vapor Corporation of Chicago).

None of the systems tested functioned accurately enough for routine use by the WSF. However, several of the systems, the EID device in particular, showed sufficient promise that with planned improvements, they should be accurate enough for use by WSF. Further system testing is currently being planned. The results of this final stage of system testing should be an AVI system that functions with the accuracy necessary for use by WSF.

The tests may also result in an AVI system that may be used by commercial vehicles operating in the state. If this does happen, the WSF could use this technology for its AVI system. This would reduce the effort needed to convince commercial vehicle owners to use the AVI system, since many would already have AVI equipped vehicles.

CALTRANS Electronic Toll Collection Demonstration Program for the San Diego-Coronado Bay Bridge

The California Department of Transportation (CALTRANS) tested a SAW-based toll collection system separate from, but in conjunction with, the HELP project described above. The system CALTRANS tested for toll collection did not meet the HELP project's speed requirement (vehicles operating above 50 miles per hour) but was adequate at the slower speeds found in a toll collection situation. The CALTRANS work also differed from the basic HELP research in that it examined the specific application of AVI technology to a toll collection system, whereas HELP is examining AVI in general, and with emphasis on interstate truck regulation.

In the CALTRANS project, a SAW-based system was installed and tested on the San Diego-Coronado Bay Bridge toll facility. The study concluded that a complete system

- was feasible,
- would pay for itself in just under one year, and
- would improve the flow of traffic through the existing toll facilities.

The AVI system was examined for implementation on automobiles. The study did not specifically address issues such as carpool discounts, differing toll rates for trucks, or various toll discount programs. Continuing work in these areas by CALTRANS will be of interest to WSF.

The results of the study are summarized below.

- The rates of toll collection with the AVI system were roughly 3 seconds per vehicle, one-half that of collecting prepaid commuter tickets and one-fourth of that of making a credit card transaction.
- The installation cost of the system was estimated as $50,000 per lane, with $7,500 per year per lane in maintenance costs. No cost estimate was made concerning the individual tags.
- The system was determined to be 99.83 percent reliable throughout the testing of the system.
- The reader (interrogator) had a range of 20 feet.
- The system was capable of registering tags on vehicles moving up to 30 miles per hour.
- The system was 100 percent accurate under controlled conditions, 92.2 percent accurate under initial, uncontrolled conditions. Accuracy issues are discussed further below.

The SAW system tested in San Diego used a transponder tag placed in the window of the vehicle. The accuracy of the system was determined to be a function of the placement of the tag, the design of the window (particularly the window slant)

and the tinting of the window glass. When specific problem vehicles were eliminated from the testing procedure and CALTRANS personnel checked the mounting of the remaining tags, the system achieved consistent readings with 100 percent accuracy. Without these controls, (i.e., without the exclusion of problem vehicles and customer placed tags), the system achieved accuracies of 92 percent. No conclusions were reached during the study on how to deal with vehicles whose window tinting and/or configuration partially inhibited the transponder signal. A later phase of the development program will examine this problem in more depth, to see if alternative mountings or positioning in the window could eliminate these problems.

MARAD Cooperative Container Handling Project

The U.S. Department of Transportation, Maritime Administration, in cooperation with the steamship industry is sponsoring research and testing of CMOS (low power requirement) based, microwave systems for automatic identification and tracking of cargo containers. Tests are currently underway in Port Elizabeth, New Jersey, and Oakland, California. Results of these tests are not fully available at this time.

Arkansas Barcode Tests

The state of Arkansas is examining the use of barcodes applied to the sides of heavy trucks as a means of improving regulation of the interstate trucking industry. This project's goals are similar to those of the HELP system, in that the intent is to decrease the time required to process a commercial vehicle's paper work when it crosses the Arkansas border.

The system works like most AVI systems. The barcode identifies a vehicle, and a database contains information on that vehicle. If the appropriate information is in the database, the truck does not have to stop at the port of entry when it crosses the Arkansas border.

Texas Turnpike Authority, Automatic Toll System

This system is intended to collect tolls from vehicles using 58 toll collection lanes throughout the length of the toll facility. It was originally planned for initial system implementation in late 1988. Preliminary work is currently underway.

Triborough Bridge and Tunnel Authority, Vehicle Identification Tests

These tests are being conducted to determine if AVI equipment can be used in conjunction with traditional automatic coin machines to operate barriers on the Verrazano Narrows bridge. Ongoing tests are utilizing non-revenue vehicles.

New Jersey Highway Authority, Vehicle Identification

These tests are similar to those being performed on the Verrazano Narrows Bridge. In the New Jersey test, the AVI tag causes a signal lamp to change from red to green. As with the New York testing, ongoing tests include only non-revenue vehicles at this time.

Dulles Toll Road, Automatic Toll Collection Project

The Virginia Department of Highways and Transportation has recently awarded a contract for the design of automated toll collection facilities on the Dulles Toll Road. Preliminary design, system configuration, and other preliminary work are just beginning.

PROCEDURES

The research plan for this task of this project consisted primarily of an extensive literature review and discussions with WSF personnel, AVI industry personnel and AVI researchers. The information gained from these sources was then synthesized and applied to WSF operations. A list of issues that need to be addressed in order to apply AVI technologies was then developed, and the findings of the project summarized.

This project consisted of only a brief review of the costs, benefits and impacts of AVI systems on the WSF. The project did not detail the specific impacts of such

a project on many functions within the WSF, nor did it perform any actual tests to measure the potential impact of an AVI system on ticket seller performance. Instead, benefits are assumed to be consistent with those found in other studies where testing has been more thorough.

DISCUSSION

The research performed to date in the United States and described earlier in this report indicates that an automated toll collection system for the WSF is technically feasible. At the same time, it is obvious that some development work is still required to make such a system operational. Within five to seven years, the WSF should be able to purchase an "off-the-shelf" AVI toll collection system if it so desires. The project team believes that such a system would be advantageous for the WSF.

The project team does not feel that the benefits to be gained from such a system warrant the costs of developing and installing that system at this point in time. While the cost benefit analysis presented later in this report indicates a four year pay-back (assuming only benefits in reduced seller time), the Benefits/Cost evaluation assumes that the system is installed in functioning order. In other words, it assumes that little or no start up difficulty is encountered.

In practice, new technology systems usually have significant "break-in" difficulties, especially for the first few systems developed. The project team's evaluation is that the Benefits/Cost ratio is not so strong that the WSF should work immediately towards an AVI solution to the detriment of other existing modernization plans. A better solution is to wait until AVI systems are more fully developed and the WSF's information systems are more complete before the WSF adds another system to its development projects.

Further, the WSF must address a number of issues before an AVI system can be implemented. The following issues have been identified by the project team and are examined in the paragraphs below:

- Which vehicles should be able to use the automated toll collection system?
- Can the system be operated automatically without human intervention (i.e., without WSF staff in the seller's both)?
- How should the ferry system account for the different number of passengers that are in vehicles?
- Should electronically equipped vehicles receive a priority treatment for loading?
- Can vehicle tags be moved between vehicles, or should they be permanently attached to a specific vehicle?
- Should all independent vehicles have separate tags, or should one vehicle have one tag (i.e., should a tractor semi-trailer have two tags, one on the cab and one on the trailer)?
- Who pays for the electronic tags that are fitted to each vehicle?
- How would the system handle communications between terminals? Would this need to be different within the San Juan Islands?
- Should the toll collection system be operated on a debit or credit basis?
- What happens when the AVI equipment at a terminal fails?

This list is only a portion of the issues that would need to be decided before specifications for a toll collection system could be developed, but it does cover the major topics that need to be addressed.

The Types Of Vehicles That Should Use The System

This study was initially intended to examine the application of the system to commercial vehicles. While commercial vehicles would benefit from such a system

(provided they took advantage of it and obtained vehicle tags and a WSF account), the system would not make economic sense unless automobiles were allowed to also use it. The volume of commercial vehicles is too small for the WSF to obtain significant savings of any kind through the installation of the toll collection equipment, while the fixed costs of installing the tag readers and computer hardware and software would be reasonably high.

Furthermore, the automated toll system by itself would probably not generate additional commercial vehicle traffic, in that it offers only minor benefits to commercial vehicles over the existing paper pass system. Traffic (and possibly revenue) increasing tactics such as fare decreases, preferential loading or guaranteed loading would be more likely to result in increased system usage and could be instituted without the automated toll collection system.

From the commercial vehicle owner's perspective, the existing paper pass system could be viewed quite competitively with the automated system. With the existing paper system, the operating company has a paper record of ferry trips that it can easily audit. In addition, the firm is not required to maintain an electronic device on each of its vehicles but, instead, has the option of keeping a booklet of paper in the glove compartment of each vehicle or simply handing out a slip to a driver the morning when it is required.

The best argument for expanding the automated toll collection system to frequent automobile users is that it would greatly increase the number of users of the system. Most of the benefits that could be obtained with the automated toll collection system would be achieved through an increase in the volume of transactions per employee and a decrease in the cost of collecting revenue. To obtain increased processing speeds per person sufficient to allow for reductions in seller staff would require that a large number of vehicles use the automated system.

In addition to helping achieve the seller position reductions, the addition of automobile drivers to the AVI system would allow

- the replacement of the existing commuter ticket system (thereby eliminating the need and cost for producing the commuter tickets and operating the commuter ticket program); and
- the expansion of preprocessed transactions (i.e., where no money is exchanged at the time of entry to the terminal) to infrequent users of the system, which in turn would result in 1) (in the case of a debit system) the WSF use of the "float" from its deposits, and 2) improved WSF revenue control through a decreased number of small cash transactions.

Staffed Versus Unstaffed Booths

The need to staff automated toll collection lanes would impact the benefits that could be obtained by using the system. If an operator was not required for toll collection, savings would be made through a reduction in seller staffing required for a given vehicle volume. However, reductions in seller positions might impact the need for increased traffic direction at some terminals.

Even when staffed booths were required, seller positions might still be reduced as a result of increased processing speed. (The seller would not have to make change, only press a key to indicate the number of passengers in the vehicle or the special fare category required.) The CALTRANS study noted increases of 100 to 400 percent in processing speed, and such improvements would be realistic expectations for the WSF. Savings in seller time with staffed booths would be particularly possible during the time periods surrounding peak travel times.

The need for staffed toll collection stations is a function of:

- the need to monitor the number of people in a car (see Accounting for Passenger Fares),
- the space available in the toll booth area for an additional lane or toll booth,

- the number and percentage of vehicles that would use the electronic system, and
- the need for manual input with the toll collection system.

If the WSF maintained the present system of charging for each passenger as well as for each vehicle, it would have to either staff each toll collection location or provide a push button entry system operated by vehicle drivers that would indicate the number of passengers in each vehicle. In the latter case, WSF staff would be required to periodically audit the system to reduce the possibility of fraud. The exception to this would be on the eastbound cross sound routes, which do not currently charge for passengers. In those terminal areas, an unstaffed toll collection lane could function effectively given the constraints listed below.

For staffed booths, the passenger fare could either be deducted from the driver's account or paid for individually by the passengers. A ticket seller could indicate the number of passengers in a vehicle on a keyboard after the system had identified the vehicle. Charging the fare to the driver's account or paying for the passengers separately would be up to the driver.

The issues of space availability and the number of system users will be considered jointly. A staffed toll booth would be necessary at all times the terminals were in operation because some travelers would not have electronic tags and accounts. Consequently, at those locations where available land permitted only one toll collection lane, that lane would have to be staffed at all times. However, in this situation, an electronic system installed in the lane could speed vehicle servicing for that terminal. Similarly, when more than one toll lane was available, that lane could either be used exclusively for AVI toll collection or as a mixed use lane, depending on the mix of traffic.

The greater the number of vehicles using the automated system, the more potential there would be for maintaining an unstaffed lane for the exclusive use of the electronically tagged vehicles. Commercial vehicles or autos towing trailers

would be handled at a designated booth that was staffed. The operator of that booth would also have the duty of overseeing the use of the unstaffed booth and could sell conventional tickets as well.

Accounting For Passenger Fares

The need for collecting passenger fares decreases the number of ticket seller positions that could be saved with the use of an automated toll collection system. As noted above in the section on staffing, the elimination of passenger tolls would increase the ability of the automated system to operate without human supervision. This would reduce the number and cost of ticket sellers to the WSF. It would also reduce the fare revenue collected from passenger tolls. Such toll revenues appear to be considerably greater than the potential savings from reduced ticket sellers.

The alternatives to staff or driver input of the number of passengers per vehicle (which were discussed above) are

- adoption of an honor fare system for passenger fares, and
- elimination of passenger fares.

The adoption of the honor fare system for passenger fares has been briefly examined in a previous WSDOT study, "Self Service Fare Collection -- A Literature Survey." An honor fare system would undoubtedly reduce the need for some ticket sellers, notably those selling walk-on tickets. At the same time, it would increase the potential for an automated vehicle toll collection system to operate without human supervision. An honor fare system would require passenger ticket vending machines on the ferries or in the terminals. In addition, fare inspectors would need to be placed on the vessels and new legislation for enforcing the regulations would be required.

Another problem with the honor fare system is that it would require the printing of tickets for many passengers. (A valid ticket would indicate who had paid the appropriate amount of money.) Unfortunately, tickets cost money to print, collect and clean up.

The idea of having no fare for passengers would be well accepted by the ferry riding public, and as with the honor fare, it would also ease the implementation of the automated toll collection system. It would most likely result in a significant increase in ridership but a major reduction in ferry system revenue. It is unclear if the existing ferry fleet could provide sufficient passenger capacity for such passenger levels, and the loss of revenue probably would not be politically or economically feasible.

Priority Loading

To promote the toll collection system, tagged vehicles could be given priority loading whenever possible. This might entail any of several possible systems:

- a by-pass lane around vehicle queues to reach the toll collection booth (where land availability permitted),
- special toll collection booths for exclusive use by tag equipped vehicles; or
- access to priority lanes on the dock, for preferential loading onto the vessel.

Use of special toll collection lanes probably would be the most attractive of these schemes in those locations where space and road access permitted.

Moving Tags Between Vehicles

The CALTRANS tests used a vehicle tag that could be moved between vehicles. This is probably the correct alternative for the WSF as well. Movable tags would allow commuters to possess only one tag but still use different vehicles on alternate days. This would be desirable. The reduction in the number of tags issued would have several advantages, including the following:

- it would reduce the size of the database that WSF would have to maintain;

- it would reduce the cost of purchasing tags to be used (who would have to purchase the hardware for the tags is discussed later in this section); and
- it would eliminate some of the administrative costs of the system, in that new tags would not have to be issued every time an owner sold or acquired a vehicle.

One disadvantage of movable tags would be some loss of potential data that could be encoded on a tag if it were non-movable. For example, each tag could indicate what type or size of vehicle was passing the toll station (i.e., tag information could indicate the presence of a 30 foot trailer or a subcompact car). If tags were movable, this information would not be reliable without enforcement to ensure its accuracy.

This enforcement could be achieved with the inclusion of some staff monitoring, or the need for enforcement could be eliminated with staffed toll booths and optional entry/override of the of tag's vehicle characteristics by the toll booth staff.

The primary advantage of fixed tags would be the reduction of users' ability to defraud the system by misusing tags. A secondary benefit would be that the WSF would have more control over the location and orientation of the tag on the vehicle. The results of the initial CALTRANS project confirmed the importance of tag positioning for accurate reading by the device. By fixing the tag to a specific vehicle and preventing it from being moved, WSF would reduce the chances that the tag would become misaligned. This would result in improved accuracy in tag reading and a decrease in system problems that would result from misread tags.

The disadvantages of fixed tags would be as follows:

- a larger number of tags would have to be owned by system users (to cover seldom used vehicles);

- the "permanence" of the tag might prevent some riders from acquiring a tag;
- the increased numbers of tags would mean an increase in the cost of purchasing tags and an increase in the size of the database required to hold tag/owner information;
- the complexity of system usage for owners and maintenance for the WSF would be increased (For example, if an owner of a tagged vehicle sold that vehicle and purchased a new vehicle, WSF would need to issue a new tag, invalidate the old tag, and make the appropriate entries in the database.); and
- the complexity of repairing or replacing malfunctioning tags would increase.

For commercial users, the strengths and weaknesses of fixed and movable tags would be magnified. If the cost of tags had to be born by the user, the incentive to use movable tags would be significant. Use of movable tags would not be significantly different than the current pass method, in which a pass is issued by the company at the start of each day or trip. In this case, the company would simply place a tag on a vehicle before it left on a trip that would include a ferry ride. If a tag malfunctioned, it could be removed and returned to WSF for repair.

Fixed tags for commercial users would result in the need to purchase more tags and would restrict the flexibility with which tags could be used. As noted above, however, fixed tags could be used to specifically identify the characteristics of a vehicle or trailer, and this could be advantageous to both the WSF and the company. (For example, a vehicle tracking system could be developed and installed at the company's loading facilities using the tag as a vehicle identifier.)

Issuing Vehicles One Tag Or A Tag For Each Independent Piece

This question is raised by the need to distinguish automobiles alone from automobiles with trailers and to determine the length of commercial vehicles.

Currently, the length of commercial vehicles is indicated by many commercial vehicle drivers on the charge slips they have filled out before arriving at the seller's booth. In cases where the vehicle's length is not previously known, the seller must get out of the booth and physically measure the vehicle. Cars with trailers are charged a flat rate.

If each independent piece of a vehicle was required to have a tag and each tag was assigned to only one vehicle, lengths would no longer need to be measured. Multiple tags on a vehicle would require some improvements over the existing AVI systems. The system would need to differentiate between tags on closely spaced vehicles (the cab and attached trailer) and use software that could add multiple tags together to determine overall vehicle length. Current systems have shown difficulty in separating closely spaced tags.

If only one tag was required per vehicle, the WSF would either have to reduce the number of fare categories it used (not differentiate vehicles by as many length categories) or use a manual entry to log the length of the vehicle. In the case of a car towing a trailer, the manual entry would indicate the presence of the trailer.

In the case of a staffed, automated seller position, the seller could easily enter the appropriate length information at the same time he or she was entering the number of passengers accompanying the vehicle. This would still require the seller to measure some vehicles and would reduce the improvements in processing speed made possible by the electronic system.

Payment For The Electronic Tags

In order to function effectively, the automatic toll collection system would require a large number of vehicle tags. The WSF would need to purchase and initialize the tags. An initialized tag would then be provided to a user.

The WSF could possibly pass the costs of the tags on to the users through increased user fees (i.e., a fee for the tag). Depending on the cost of the individual

tags, the WSF might recoup this cost through the reduction of printing and handling costs for commuter tickets and commercial account passes.

Forcing the users of the tags to pay additional fees to obtain a tag might prevent most users from switching to the device unless other incentives were strong (i.e., preferential loading, a price per trip reduction, etc.). Commercial users, in particular, would be adverse to paying for a system that they essentially are able to use for free now (the pass book/billing system).

If the WSF did not pass the cost of the tags on to the user, the cost of the system implementation and operation would be increased. This cost would affect the benefit/cost ratio of the system. The effects of these costs are explored in the cost/benefit section later in this paper.

The maintenance costs of the tags fall into the same category as initial costs. Most of the tags should not require maintenance, so this cost should be low. However, the WSF should provide a warrantee period for each tag and then charge a small fee to replace any lost, stolen, or damaged tags. Such fees would be more easily accepted by the public after they were using the system (provided it worked) than an initial fee to obtain a tag.

Communications Between Terminals

Each terminal would have to be able to tap into a single WSF database to determine if a specified tag/account had money in it, had been reported stolen, or had some other identifier attached to it. A tag normally used on the Bremerton to Seattle run would also have to work on the Kingston to Edmonds run. In the same vein, a frequent user would not be expected to maintain more than one account with the WSF.

These criteria mean that each of the terminals should be attached to a central facility that maintains the WSF database. This connection could take place in real time, so that the system would act in a manner similar to the automatic teller machines at banks throughout the state, or each terminal could have its own

database that was periodically updated from the central source. For the second of these systems, updates could be done at a number of intervals, with the most likely being once per day. Each of these two systems is discussed below.

One central, real-time database would have the advantage that it would always be up-to-date. This method would minimize the possibility of fare evasion, since the computer being interrogated always would have up-to-date information. The principal difficulty with this method would be that the cost of providing real-time computer interfaces over long distances would be expensive. Providing these communications links, particularly to the islands served by WSF, could add significantly to the cost of the entire system. A second difficulty would be that the need for real-time interaction with the computer could slow the system's processing down. This would be a problem if the designed system outgrew the parameters used when the system was sized.

A time delayed database would allow each automatic toll booth to have access to an on-site database. This database would contain a record of all the WSF's clients' records as of the previous update. The local system would check this database for the validity of an observed tag. It would record transactions for each time period and transmit a copy of those transactions to a central location each update time period (e.g., each day). A central facility would process the transactions from each of the terminals and produce an updated database file, which would be retransmitted to the local toll collection booth databases.

The updates could be done through a variety of techniques, including

- use of the communications system designed for the ECR Phase 2 project,
- use of conventional telephone modems and communications packages, or
- use of diskettes delivered to each terminal.

The selection of an update strategy is a complicated task that would be a significant part of a system's design effort. This paper will not attempt to address these issues in further detail.

Collecting Tolls With a Debit or Credit System

The debit system is a close approximation of the existing commuter book system (i.e., prepaid trips). Such a system reduces the number and likelihood of fare evaders and gives the WSF a "float" of money. The credit system is currently used for commercial patrons. Such a system could be used by WSF, but it would lack the advantages to the WSF of the debit system.

The credit system would be more palatable to commercial vendors than the debit system, and if the goal of the WSF was to encourage commercial account activity, maintaining the credit system probably would be the proper choice. However, the project team feels that the merits to WSF of the debit system would far outweigh the gains to be made from the using the credit system.

A combined system (debit for commuters, credit for commercial accounts) could also be easily implemented through the software that would operate the toll collection system. Such a system would use a code stored in the database that would differentiate between credit (commercial) and debit (commuter) accounts. The database checks made on tag validity would be slightly different, depending on whether the tag read was a "credit" or "debit" tag.

The issue of credit/debit is relatively minor in the scope of working with the automated toll collection system and should not be a major hindrance in the decision if the WSF wishes to pursue such a system.

System Backup

The last issue described in this section is the need for system backup. If the WSF moved towards an automated system, it would have to be able to handle system failures. This could be done through a variety of systems, including

- maintenance of additional hardware at each terminal,
- maintenance of hardware on each vessel capable of reading tags,
- maintenance of paper based systems for billing drivers based on license numbers or some other criteria, or
- free passage to AVI equipped vehicles until the system was repaired.

The methods used to provide system backup might significantly affect the number of spare parts or systems that would have to be purchased by the WSF and would significantly affect the initial cost of the system. It might also be necessary to train terminal agents so that they were capable of repairing the system, or the WSF would need some type of short duration repair guarantee for the vendor of the system.

Benefit/Cost Analysis

Because an automated toll collection system could be designed using any combination of the technologies/issues described in the background section above, the benefit/cost analysis must be scoped to limit the number of factors impacting the estimates of cost and benefit. The system design used to address the issues of cost/benefit is only an attempt to limit those factors, and should not be construed as a recommended system configuration. It should also be noted that different assumptions for the system design might significantly impact the cost/benefit analysis.

Cost estimates for equipment are based on the values used by CALTRANS in its Coronado Bay Bridge study. A functioning automated toll collection system would require at a minimum the following components:

- vehicle tags,
- tag readers at all WSF terminals except Vashon and Tallequah,
- at least one microcomputer at each WSF dock at which the system will function, and
- some form of communications between WSF docks.

The following assumptions about the design, cost and functioning of the system are made:

- 24 reader units (lanes equipped for AVI vehicles) are purchased for use by WSF. These are distributed between terminals as shown in Exhibit 3.
- Each reader unit and associated computer and installation costs $50,000.
- An additional microcomputer at Colman Dock maintains the complete WSF AVI client file, performs the billing function, and maintains the client accounts ($15,000 cost).
- The cost of the billing/accounting software is provided as part of the basic system cost.
- Maintenance costs are assumed to be $7,500 per installed lane per year.
- The cost of vehicle tags are not considered.

EXHIBIT 3
DISTRIBUTION OF AVI EQUIPMENT

Anacortes	2
Bremerton	1
Clinton	2
Edmonds	2
Fauntleroy	1
Keystone	1
Kingston	2
Mukilteo	1
Point Defiance	1
Port Townsend	1
San Juan Islands	4
Seattle	2
Southworth	1
Sydney	1
Winslow	2
Total	24

On the basis of the above assumptions, the initial cost for the system is estimated to be $1,215,000, with an annual maintenance cost of $180,000.

The WSF terminals have been divided into four categories based on the estimated impacts of the AVI system. The terminals that would benefit the most from AVI are those terminals with high traffic levels, that would be the most likely to be able to reduce the number of sellers required to meet existing and expected demand. This group of terminals would include

- Clinton,
- Kingston,
- Winslow,
- Anacortes, and
- Seattle.

The first three terminals serve eastbound, cross-sound traffic. Each could support an AVI exclusive lane, with no ticket seller required. This could potentially decrease required sellers by 8 hours per day at Kingston, 13 hours per day at Clinton, and 12 hours per day at Winslow. While Anacortes and Seattle would both require a seller for all toll lanes (for collecting passenger fares), the speed increase from AVI assistance would probably reduce seller hours by 12 hours per day at Anacortes and 13 hours per day at Seattle.

Terminals that would receive modest benefits from an AVI system are

- Edmonds,
- Fauntleroy,
- Mukilteo,
- Southworth,
- Bremerton,
- Keystone,
- Port Townsend, and
- Point Defiance.

These terminals as a group are estimated to save only 8 hours of seller time, primarily because they currently employ only one seller, or the combination of requirements for selling passenger fares and the number of sellers on duty at one time limits (in the project team's estimation) the seller time that could actually be reduced. The eight hour savings is probably conservative, but being conservative in this area should balance the more optimistic savings from the previous paragraph.

The Sydney, Orcas, Shaw, Lopez and Friday Harbor terminals would require AVI systems, but would gain little advantage from them. The AVI readers at these terminals would mainly be provided to allow use of the AVI system from all locations served by WSF. The Vashon and Tallequah terminals do not require ticketing facilities, and thus would not be impacted by the AVI system.

Total benefits from the reduction in seller time is estimated to be 65 hours per weekday day. Weekend benefits are estimated to be roughly half those of weekday benefits. This translates to $406,000 per year in salary and benefits costs.

With the above assumptions, the system would pay for itself in 5.4 years. This calculation does not account for

- the cost of vehicle tags,
- savings made as a result of better revenue control,
- the cost of billing WSF account holders, or
- increases in seller staff time required to handle growing traffic in future years.

The basic assumption is that the cost of vehicle tags (over the four-year payback period) would be equal to the savings made from not printing and processing commuter tickets, plus the savings in revenue control minus the mailing cost of the billing process.

The benefit/cost analysis also assumes that the current two person staff that performs the WSF commercial billing process would be able to handle the billing process of the AVI system. It is assumed that the increase in accounts (to include

automobiles as well as commercial accounts) would be offset by the automatic entry of the data into the billing system.

IMPLEMENTATION AND APPLICATION

No implementation of an AVI system is currently recommended. While an automated toll collection shows reasonable possibility of success, the current state of the technology and the large amount of system development ongoing at WSF result in the recommendation that the use of AVI be delayed at this time and be reconsidered in three to five years.

If an AVI system was implemented, the WSF should realize that there would be an initial growth period, when the number of AVI tags in service would rapidly increase. This would possibly result in some additional costs as the client database was initially entered.

Finally, reductions in ticket seller requirements at some terminals might not be immediately possible. Reductions in these staffing positions would have to wait until a sufficient number of vehicles carried tags, so that the increases in processing speed of the AVI system could be achieved on a large enough scale to allow changes in staffing to take place.