# TECHNOLOGY EVALUATION FOR IMPLEMENTATION OF VMT BASED REVENUE COLLECTION SYSTEMS

## Final Report

by

David S. Kim, David Porter and Robin Wurl
Department of Industrial and Manufacturing Engineering
Oregon State University
Corvallis, OR 97331-2407

for

The Oregon Department of Transportation
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16. Abstract

The Road User Fee Task Force (RUFTF) was created as part of House Bill 3946 with the purpose of developing a new revenue collection system design for Oregon's roads and highways. The Oregon Department of Transportation (ODOT) is required by House Bill 3946 to begin implementation of pilot alternative revenue collection systems by July 1, 2003. One alternative being considered by the RUFTF is a Vehicles Miles Traveled (VMT) based fee. Currently, ODOT has limited technical information relative to the technologies available that could potentially be used to implement an electronic revenue collection system based on the VMT principle. The research performed in this project focused on obtaining and synthesizing such technical information for ODOT. Technologies explored include, but were not limited to, GPS-based devices, Radio-Frequency Automatic Vehicle Identification devices, and different means of electronic data transfer. This information is then used to assess the feasibility (both technical and economic) of various electronic revenue collection system concepts and to identify technological needs. Based on the results, several conclusions and recommendations are presented.

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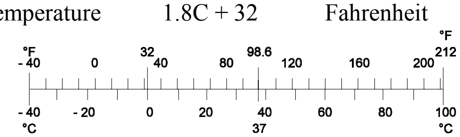
# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| **LENGTH** | | | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| **AREA** | | | | |
| $in^2$ | square inches | 645.2 | millimeters squared | $mm^2$ |
| $ft^2$ | square feet | 0.093 | meters squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ |
| **VOLUME** | | | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | meters cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ |
| NOTE: Volumes greater than 1000 L shall be shown in $m^3$. | | | | |
| **MASS** | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| **TEMPERATURE (exact)** | | | | |
| °F | Fahrenheit temperature | 5(F-32)/9 | Celsius temperature | °C |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| **LENGTH** | | | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| **AREA** | | | | |
| $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | kilometers squared | 0.386 | square miles | $mi^2$ |
| **VOLUME** | | | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| **MASS** | | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams | 1.102 | short tons (2000 lb) | T |
| **TEMPERATURE (exact)** | | | | |
| °C | Celsius temperature | 1.8C + 32 | Fahrenheit | °F |




* SI is the symbol for the International System of Measurement

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Many individuals provided valuable input to this project. The Technical Advisory committee of this project – Jim Whitty from the Road User Fee Task Force, Alan Kirk from the ODOT Research Group, Jack Svadlenak from the ODOT Policy Section, and Victor Dodier from the ODOT Government Relations Section – developed the research issues and provided guidance and valuable feedback during the project. Barnie Jones from the ODOT Research Group, Robert Bertini and Tony Rufolo from Portland State University sat in on project updates and provided valuable feedback. Steve Baumhardt, Scott Doering, Bill Peters, Wayne Laffitte, Jerry Landt, of TransCore, Vince Holbrook of Gilbarco Veder-Root, and Reed Varney (a Gilbarco Veder-Root distributor) provided valuable information and assistance during this project.

# DISCLAIMER

# EXECUTIVE SUMMARY

The Oregon Department of Transportation (ODOT) is required by House Bill 3946 to begin implementation of pilot alternative revenue collection systems by July 1, 2003. These pilot systems are to be designed to test alternatives to the current system of taxing highway use through fuel taxes. The Road User Fee Task Force (RUFTF) was created as part of House Bill 3946 with the purpose of developing a new revenue collection system design for Oregon's roads and highways. One alternative being considered is a Vehicles Miles Traveled (VMT) based fee. Currently, ODOT has limited technical information relative to the technologies available that could potentially be used to implement an *electronic* revenue collection system based on the VMT principle.

The research performed in this project focused on obtaining and synthesizing such technical information for ODOT. This information can then be used to assess the feasibility (both technical and economic) of various electronic revenue collection system concepts and to identify technological needs. Such feasibility analysis should be conducted before any pilot systems are tested. The information collected in this research may also help define criteria to be used in specifying revenue collection system requirements.

In this research, the following steps were used to organize and synthesize the large amount of available technical information:

- Analyze VMT revenue collection scenarios conceptualized by the RUFTF to obtain functional requirements for the technology.
- Identify various technologies that can meet the functional requirements.
- Perform an initial screening of technologies with respect to performance of the functional requirements.
- Perform a first screening of scenarios based on cost and technology integration using the technologies from the prior step. Obtain RUFTF feedback on the preferred scenarios.
- Perform more in-depth analysis of the technologies used in the preferred scenarios.
- Perform more in-depth analysis on the performance of the preferred scenarios as VMT based electronic revenue collection systems.

The major conclusions drawn from this research are as follows:

- Many current Automatic Vehicle Identification and data collection technologies are clearly not appropriate for a VMT based revenue collection system.
- Scenarios involving on-vehicle GPS devices are by far the most costly for total system implementation. Data transfer at fuel dispensers is the most costly method (from a hardware perspective) for obtaining vehicle VMT data.
- Current on-vehicle devices that are envisioned for use in the GPS & RF-AVI, ODO RF-AVI, and Enhanced ODO RF-AVI technology options are not commercially available. If

testing of these scenarios is to commence in July 2003, enough lead time will be needed to perform the required development activities. Three companies have devices with functionality close to that desired for the application at hand. These companies are:

  - ✓ 308 Systems
  - ✓ TransCore
  - ✓ AFX Technology Group International, Inc.

- Privacy issues arise when using the GPS-based technology options in a road segment and congestion pricing system. GPS based systems are not well suited to "real time" congestion pricing unless they are coupled with RF-AVI as in the GPS & RF-AVI technology option.
- Scenarios involving fuel dispensers may have significant control and cost issues with implementation.
- Extensive testing will be required before any system is implemented.
- Monitoring electricity consumption on hybrid vehicles is feasible and technologically straightforward, but devices for doing so are not currently available from the manufacturer or as an aftermarket device.

Based on these conclusions, our recommendations to ODOT are as follows:

- Define specific functional and technical requirements for the preferred scenarios. For example, what is the VMT accuracy required? What is the expected operating life for a device?
- Define technical specifications for the technology options used in the scenarios to meet the functional requirements. Test various technologies when the exact specifications are not known. For example, testing would be required to determine what GPS specifications would be needed to meet the required accuracy and signal availability.
- Consider implementing an electronic VMT-based revenue collection system in phases. The system would have to be designed in such a way that it evolves with technology so that, as new capabilities arise, these could be incorporated without disturbing the existing system.

**TECHNOLOGY EVALUATION FOR IMPLEMENTATION OF VMT BASED REVENUE COLLECTION SYSTEMS**

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# 1.0 INTRODUCTION

## 1.1 PROBLEM STATEMENT

The Oregon Department of Transportation (ODOT) is required by House Bill 3946 to begin implementation of pilot alternative revenue collection systems by July 1, 2003. These pilot systems are to be designed to test alternatives to the current system of taxing highway use through fuel taxes. The Road User Fee Task Force (RUFTF) was created as part of House Bill 3946 with the purpose of developing a new revenue collection system design for Oregon's roads and highways. One alternative being considered is a Vehicles Miles Traveled (VMT) based fee. Currently, ODOT has limited technical information relative to the technologies available that could be used to implement an *electronic* revenue collection system based on the VMT principle.

The research performed in this project focused on obtaining and synthesizing such technical information for ODOT. This information can then be used to assess the feasibility (both technical and economic) of various electronic revenue collection system concepts and to identify technological needs. Such feasibility analysis should be conducted before any pilot systems are tested. The information collected in this research may also help define criteria to be used in specifying revenue collection system requirements.

The eventual design and implementation of an alternative road and highway revenue collection system will affect all Oregon drivers. The information collected in this research will help lead to an economic, feasible, and effective design.

## 1.2 OBJECTIVES OF THE STUDY

As a starting point for this study, six (6) revenue collection scenarios were conceptualized by the RUFTF. In some of these scenarios, the technology concept to be used for specific functions was partially defined. In others, however, a more general concept was developed but the type of technology to be used for a specific function was left open. The OSU research team utilized these scenarios to define functional requirements for the technology as well as to identify a list of technologies to be used (or potentially be used) in the various scenarios.

The objectives of this study were to obtain and synthesize technical information relative to the technologies identified from the scenarios. This includes the following:

1. **VMT Data Collection**. Technologies that could be used to collect and store vehicle-based VMT data.
2. **VMT Data Transfer**. Technologies that could be used to transfer vehicle-based VMT data from a vehicle to a data repository for fee calculation and processing.
3. **VMT System Integration Options**. Technologies evaluated in 1 and 2 were considered in the context of the RUFTF scenarios for an *electronic* revenue collection system based

on VMT. Issues related to the interoperability and cost of the technologies is documented for all feasible system integration options. Additionally, after a review of the technology options for data collection and transfer, other sensible and feasible system concept options may be suggested.

4. **VMT Taxing Options for Electric and Hybrid-Electric Vehicles**. Determine the feasibility and technical components needed for charging electric and hybrid-electric vehicles for electricity consumption. Whereas the first three objectives are all components of a VMT based road tax system, this objective is independent and is addressed separately.

## 1.3 HOW TO READ THIS REPORT

The following sections of this report present the findings of the OSU research team with respect to the individual objectives outlined in the previous section. The main contents of this report are organized into eight sections. The order of the sections was designed to create a logical presentation of the contents of this research but also corresponds roughly to the order in which the project was conducted. Therefore, readers familiar with the study may skip appropriate sections. The eight main chapters of the report are as follows:

1. Introduction.
2. Review of the RUFTF scenarios.
3. Technologies and functional requirements obtained from the scenarios.
4. Initial screening of the technologies and scenarios based on cost and technology interoperability.
5. Technologies for VMT data collection and data transfer.
6. Evaluation of VMT system integration options.
7. VMT taxing options for electric and hybrid vehicles.
8. Conclusions and recommendations

Sections 5 and 6 can be read independently from the other sections, although the background information included in Section 5 will be helpful when reading Section 6. Sections 5 through 8 present content that was added after a mid-project review with the RUFTF and the project's Technical Advisory Committee.

# 2.0 REVIEW OF THE RUFTF SCENARIOS

In this section, the six different scenarios for VMT-based revenue collection systems conceptualized by the RUFTF will be reviewed. The six scenarios correspond to six different general concepts for how VMT-based road user fees will be computed and collected. Within a scenario, multiple options may be available that employ different *technology options* for the on-vehicle devices used for data collection and data transfer. The various technology options will be numbered and will be referred to by number (e.g., Technology Option 1). Four of the six RUFTF scenarios have multiple options.

Text will describe the features of each scenario and a graphical depiction of each scenario will also be presented with an outline of the important features of each scenario. Each scenario is described in the graphic with respect to the technologies/schemes for performing three main functions of an electronic VMT revenue collection system: 1) Collect Oregon VMT on a vehicle; 2) Transmit the VMT data from the vehicle; 3) Calculate and collect the proper VMT fee.

## 2.1 SCENARIO 1 – FEE COLLECTION CENTER SCENARIO

The "Fee Collection Center Scenario" has three different technology options. The common feature among these options is the utilization of a Fee Collection Center (FCCTR). However, they differ in either the mechanism that is used to collect the VMT data or in how VMT information is transferred to the FCCTR. Technology Options 1 and 2 were conceptualized by RUFTF, and the OSU research team developed Technology Option 3 as part of this study.

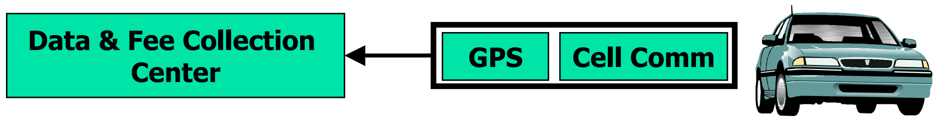
In all these implementation options (at least initially) the fuel tax will remain in place for out-of-state drivers. Oregon drivers will also be paying a fuel tax, so an estimate of fuel tax paid is needed.

### 2.1.1 Fee Collection Center Scenario – Technology Option 1

Figure 2.1 depicts Technology Option 1 for the Fee Collection Center Scenario. In this option, on-vehicle Global Positioning System (GPS) technology is used to collect location points (i.e., longitude and latitude) that can then be used to derive Oregon VMT data. In this option, an on-vehicle GPS-based device will either compute the Oregon VMT as a vehicle travels, or alternatively, it will store GPS location points in memory.

The transfer of GPS data (either VMT or a series of location points and times) will occur via cellular communications to a FCCTR. Once the data is transferred, the VMT tax can be computed and collected by resources at the FCCTR.

**Fee Collection Center Scenario – Technology Option 1**



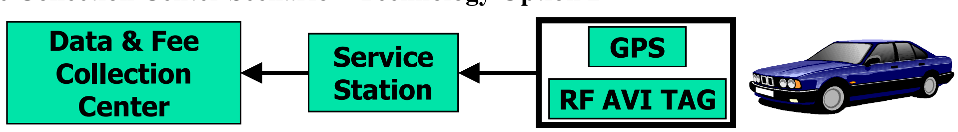

- Oregon VMT Collection
  - Exact Collection from On-Vehicle GPS System
- Transmission of VMT data
  - Cellular direct to Fee Collection Center (FCC)
  - VMT can be calculated off-line using vehicle ID, location and time data, or
  - VMT can be transmitted directly to FCC from vehicle
- Calculation and Collecting Tax
  - Calculated at FCC, owner is billed on a monthly basis

Figure 2.1: Fee Collection Center Scenario – Technology Option 1

### 2.1.2 Fee Collection Center Scenario – Technology Option 2

Technology Option 2 (see Figure 2.2) differs from Option 1 in the mechanism and technology utilized to transmit the data generated by an on-vehicle GPS device to the FCCTR. In this option, the GPS data (VMT or location points) is written to the memory of a Radio Frequency Automatic Vehicle Identification (RF-AVI) tag. Then, RF readers located at the entrances and exits to service stations will automatically read the data stored on the RF-AVI tag as a vehicle enters/exits a service station and relay it to the FCCTR via dedicated phone lines. This information will then be used to compute the tax, which will be collected by FCCTR resources.

**Fee Collection Center Scenario – Technology Option 2**



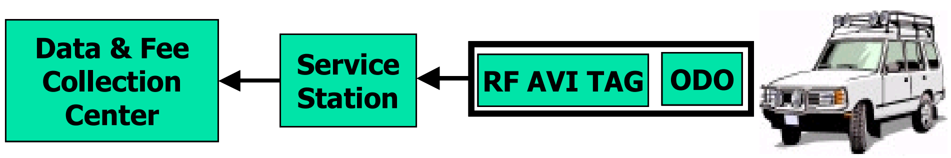

- Oregon VMT Collection
  - Exact Collection from On-Vehicle GPS System
- Transmission of VMT data
  - RF AVI transponder is read at service station
  - VMT can be calculated off-line using vehicle ID, location and time data, or
  - VMT can be read directly off RF AVI transponder
- Calculation and Collecting Tax
  - Calculated at FCC, owner is billed on a monthly basis

Figure 2.2: Fee Collection Center Scenario – Technology Option 2

### 2.1.3 Fee Collection Center Scenario – Technology Option 3

Technology Option 3, depicted in Figure 2.3, was developed by the OSU research team and differs from the prior two options in the on-vehicle technology used to collected VMT data. In this option, a RF-AVI tag that interfaces with the vehicle speed sensor (or an aftermarket mechanical system that can be used to generate odometer readings) is used to collect current vehicle odometer readings. Then, RF readers located at service station entrances/exits and at state border crossings read the vehicle odometer information automatically off the RF-AVI tag as a vehicle passes a reader. These odometer readings are transferred via dedicated phone lines to the FCCTR. Logging of odometer readings taken as a vehicle enters and exits Oregon can be used to calculate Oregon VMT. The data transfer to the FCCTR is similar to Technology Option 2 except that additional readers are needed at state border crossings. The tax will be computed and collected by FCCTR resources.

**Fee Collection Center Scenario – Technology Option 3**




- Oregon VMT Collection
  - RF AVI transponder is linked to an odometer
- Transmission of VMT data
  - RF AVI transponder is read (odometer reading) by RF readers on border crossings & service station entrances and sent to a central server
- Calculation and Collecting Tax
  - OR-VMT calculations & tax matched to EPA MPG based estimate of gas tax and charge/credit mailed or sent with registration

Figure 2.3: Fee Collection Center Scenario – Technology Option 3

## 2.2 SCENARIO 2 – ACTUAL VMT AT PUMP WITH CREDIT SCENARIO AND SCENARIO 3 - ACTUAL VMT AT PUMP WITH SWITCH SCENARIO

These two scenarios are described together since they are identical from a technological perspective. The two scenarios differ in how the VMT tax is collected. For each scenario, the same two technology options for how Oregon VMT is collected (and transferred) are available, creating two options for each scenario. The first technology option employed in these two scenarios is technology Option 2 from the Fee Collection Center Scenario (Scenario #1). The second technology option (which is exclusively used in these two scenarios) is Technology Option 4 – an enhanced RF-AVI device that collects "trip" VMT between fueling operations.

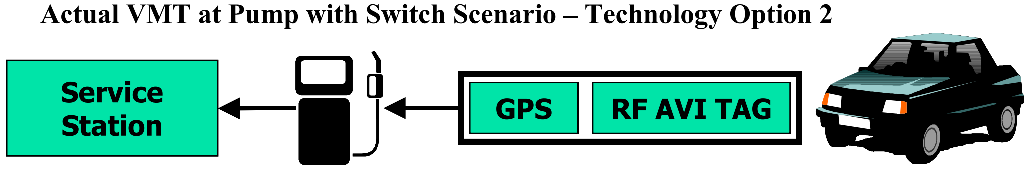
In Scenarios 2 and 3, an on-vehicle device (Technology Option 2 or 4) will calculate exact Oregon-VMT data and then store this information in the memory of a RF AVI tag. Then, RF readers located at service stations fuel dispensers will automatically read the data stored on the RF-AVI tag as a vehicle is fueling. The VMT data from the RF readers will then be used by the point-of-sale system to charge the appropriate VMT tax.

In the Actual VMT at Pump with Credit Scenario, the current fuel tax is maintained. The VMT computed is then used to appropriately increase or decrease the tax. In the Actual VMT at Pump with Switch Scenario, the presence of a valid RF tag will turn off the per-gallon fuel tax and replace it with the proper VMT tax. In both scenarios, out-of-state vehicles fueling in Oregon will be charged a per-gallon fuel tax.

### 2.2.1 Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario – Technology Option 2

In this option, a GPS-based device is used to collect Oregon-VMT data, which is written to the memory of a RF-AVI tag. The VMT data is then read by RF at fuel dispensers and used by the point-of-sale system to compute the VMT-based tax. As part of completing a fuel purchase transaction, the VMT data stored on the RF-AVI tag must be reset to zero miles. Thus, the VMT read by the RF readers is a "trip" Oregon VMT. The Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario using Technology Option 2 are depicted in Figure 2.4.

**Actual VMT at Pump with Credit Scenario and**
**Actual VMT at Pump with Switch Scenario – Technology Option 2**



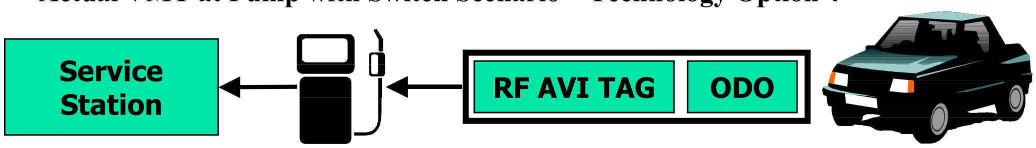

- Oregon VMT Collection
  - Exact Collection from On-Vehicle GPS System
- Transmission of VMT data
  - RF-AVI transponder is read at service station
  - Oregon-VMT data is reset to zero
- Calculation and Collecting Tax
  - Calculated automatically at gas pump
  - Automatic credit for fuel tax or fuel tax turned on/off
  - Net increases or decreases in tax receipts are paid or billed to the Highway Fund or collected tax is forwarded

Figure 2.4: Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario – Technology Option 2

### 2.2.2 Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario – Technology Option 4

In this option, a RF-AVI tag that interfaces with the vehicle speed sensor (or an aftermarket mechanical system that can be used to generate odometer readings) is used to collect Oregon VMT. The odometer data is written to the RF-AVI tag. RF antennae units at border crossings automatically turn the mileage collection off if a properly equipped vehicle travels out of Oregon, and turns the mileage collection on when the same vehicle enters Oregon. Then, RF readers located at service station fuel dispensers read the Oregon VMT as part of a fuel purchase transaction and the point-of-sale system computes the VMT-based tax. As part of completing a fuel purchase transaction, the VMT data stored on the RF-AVI tag must be reset to zero miles. The VMT thus read by the RF readers is a “trip” Oregon VMT. The Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario using Technology Option 4 are depicted in Figure 2.5.

**Actual VMT at Pump with Credit Scenario and**
**Actual VMT at Pump with Switch Scenario – Technology Option 4**



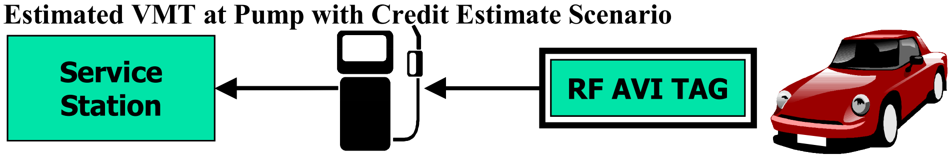

- Oregon VMT Collection
  - Exact Collection from On-Vehicle Odometer and RF-AVI device
- Transmission of VMT data
  - RF-AVI transponder is read at service station
  - Oregon-VMT data is reset to zero
- Calculation and Collecting Tax
  - Calculated automatically at gas pump
  - Automatic credit for fuel tax or fuel tax turned on/off
  - Net increases or decreases in tax receipts are paid or billed to the Highway Fund or collected tax is forwarded

Figure 2.5: Actual VMT at Pump with Credit Scenario and Actual VMT at Pump with Switch Scenario – Technology Option 4

## 2.3 SCENARIO 4 – ESTIMATED VMT AT PUMP WITH CREDIT ESTIMATE SCENARIO

In Scenario 4 (see Figure 2.6), there is no collection of VMT data. Instead, the VMT is estimated based on the amount of fuel purchased and the EPA miles-per-gallon (MPG) estimate for the particular vehicle model. In this scenario, there is no mechanism for estimating Oregon VMT only. The EPA MPG data for a vehicle is to be stored on a RF AVI tag. Then, RF readers located at service station fuel dispensers will automatically read the EPA MPG data stored on the RF-AVI tag as a vehicle is fueling. The data from the RF readers will then be used by the point-of-sale system to charge the appropriate tax (from the estimated VMT). In this scenario the current fuel tax is maintained and the estimated VMT is used to appropriately increase or decrease the tax. Out-of-state vehicles fueling in Oregon will be charged a per-gallon fuel tax.

**Estimated VMT at Pump with Credit Estimate Scenario**




- Oregon VMT Collection
  - Approximated by the use of static ID & EPA data encoded in RF AVI transponder
- Transmission of VMT data
  - Static ID & EPA data is read off RF AVI transponder at service station
- Calculation and Collecting Tax
  - Calculated automatically at gas pump
  - Net increases or decreases in tax receipts are paid or billed to the Highway Fund

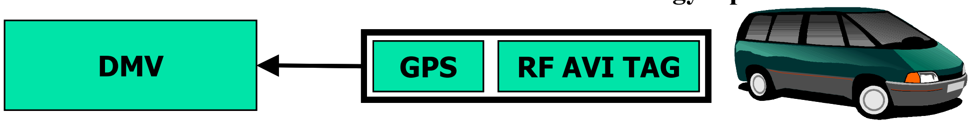
Figure 2.6: Estimated VMT at Pump with Credit Estimate Scenario

## 2.4 SCENARIO 5 – DMV/OTHER PUBLIC COLLECTION CENTER SCENARIO

This scenario is very similar to the Fee Collection Center Scenario except that DMV resources or other public resources will be used to conduct fee collection center tasks. In this scenario, depicted in Figure 2.7, an on-vehicle device is used to collect exact Oregon VMT data. For this scenario, the two technology options under consideration are Technology Option 2 (GPS-based VMT collection) and Technology Option 3 (Odometer based VMT collection).

If a GPS-based device (Technology Option 2) is used, it will either compute the Oregon VMT as a vehicle travels, or store GPS location points in memory. The GPS data (VMT or location points) is written to the memory of a RF-AVI tag. If Technology Option 3 is used, a RF-AVI tag that interfaces with the vehicle speed sensor is used to collect current vehicle odometer readings. RF readers located at state border crossings read the vehicle odometer information automatically off the RF-AVI tag as a vehicle passes a reader. Logging of odometer readings taken as a vehicle enters and exits Oregon can be used to calculate Oregon VMT. Under both technology options, RF readers located at Department of Motor Vehicle (DMV) locations will automatically read the data stored on the RF-AVI tag as a vehicle visits the DMV location for registration or other functions. This information will be used to compute and collect the tax by DMV resources.

**DMV/Other Public Collection Center Scenario – Technology Option 2**



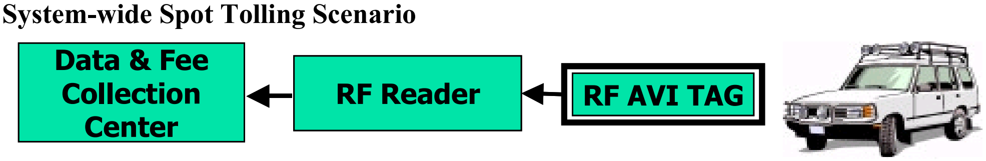

- Oregon VMT Collection
  - Exact Collection from On-Vehicle GPS System
- Transmission of VMT data
  - RF AVI transponder is read at DMV
- Calculation and Collecting Tax
  - Oregon VMT data uploaded at DMV as part of vehicle registration
  - VMT tax computed and paid at DMV

Figure 2.7: DMV/Other Public Collection Center Scenario

## 2.5 SCENARIO 6 – SYSTEM-WIDE SPOT TOLLING SCENARIO

Figure 2.8 depicts the System-wide Spot Tolling Scenario. In this scenario, the Oregon VMT is not directly computed or approximated. Instead, toll charges are used as a surrogate for a VMT tax. Each vehicle will possess a RF-AVI tag similar to those tags used in current electronic toll collection (ETC) applications. RF readers will be placed at locations throughout the state to best capture the bulk of the VMT in Oregon. When vehicles pass a reader, a toll charge will be automatically charged. This charge may be billed directly to a credit card on file or the appropriate amount may be deducted from a pre-paid account that is stored and updated on the tag. These accounts can be pre-paid at designated facilities with the proper equipment. A similar system is currently used in automatic tolling systems found on specific roads in various states.

**System-wide Spot Tolling Scenario**




- Oregon VMT Collection

  Not used directly - Approximated by tolling implemented through the use of static ID encoded in RF AVI transponder
- Transmission of data

  RF AVI transponder is read by RF readers on highways & roads
- Tax/Toll Payment

  Through automatic debit or prepaid charges

Figure 2.8: System-wide Spot Tolling Scenario

## 2.6 NAMING SCHEME FOR SCENARIOS AND TECHNOLOGY OPTIONS

Because of the large number of scenarios and the different technology options considered, a shorthand naming convention will be adopted. The shorthand names for the scenarios and technology options, as well as the technology options applicable to the scenarios, are summarized in Table 2.1.

**Table 2.1: Shorthand naming conventions for Scenarios and Technology Options.**

| Scenario # | Name | Shorthand Name | Technology Option Number and Shorthand Name | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| | | | GPS & Cellular Option | GPS & RF-AVI Option | ODO & RF-AVI Option | Enhanced ODO & RF-AVI Option |
| 1 | Fee Collection Center Scenario | Center Scenario | X | X | X | NA |
| 2 | Actual VMT at Pump with Credit Scenario | Pump with Credit Scenario | NA | X | NA | X |
| 3 | Actual VMT at Pump with Switch Scenario | Pump with Switch Scenario | NA | X | NA | X |
| 4 | Estimated VMT at Pump with Credit Estimate Scenario | Pump with Estimate Scenario | NA | NA | NA | NA |
| 5 | DMV/Other Public Collection Center Scenario | DMV Scenario | X | X | X | NA |
| 6 | System-wide Spot Tolling Scenario | System-wide Tolling Scenario | NA | NA | NA | NA |

# 3.0 TECHNOLOGIES AND FUNCTIONAL REQUIREMENTS OBTAINED FROM THE SCENARIOS

An examination of the RUFTF scenarios reveals basic functional requirements that must be met for any VMT based tax system. These can be identified as follows:

1. Compute or collect data to estimate the Oregon VMT for a vehicle.
2. Transfer this data from the vehicle to a "system" that uses the data for tax assessment.
3. Compute and collect the proper amount of VMT based road tax from the owners of each vehicle.

In some cases, the scenarios specified the technology that would be used to perform the required functions; in other cases the required function was mentioned but the technology used to execute the function was left open. A list of technologies to evaluate, relative to their ability to perform functions within the scenarios, was then derived. These technologies can be separated into three categories:

1. **On-vehicle VMT data collection technologies** - Technologies that are used to either collect Oregon VMT, provide basic data from which Oregon VMT can be calculated, or provide vehicle data from which the VMT is estimated or to which tolls are assessed.
2. **Data transfer technologies** - Technologies used to download data from vehicles. This technology is determined by the type of on-vehicle technology used but differs in how it is employed in each scenario.
3. **Computing and collecting the VMT road tax** – Technologies used to compute and collect the tax once the vehicle data has been obtained. In some scenarios the computing and collecting of the tax is an integral part of the system used to obtain the vehicle data. In other scenarios, the vehicle data is transferred to a centralized facility such as the FCCTR. In these cases, the computing and collecting of taxes is addressed in a separate study (*Bertini, et al. 2002*).

## 3.1 ON-VEHICLE TECHNOLOGIES

The on-vehicle VMT data collection technologies that were investigated for use in the scenarios are as follows:

- Integrated GPS/GIS[1]/RF devices – GPS based devices that can compute Oregon VMT and transfer the data via RF communication.
- GPS-based devices that collect and store location points and transfer this data through RF communication.

[1] GIS stands for Geographic Information System.

- Integrated RF/Vehicle Speed Sensor devices - A RF tag that interfaces with a vehicle's speed sensor and collects "odometer equivalent" mileage data.
- "Read Only" (RO) RF tags containing vehicle identification and EPA MPG data.
- RO RF tags used in electronic toll collection systems.
- Bar codes that encode vehicle identification and EPA MPG data.
- Automatic Vehicle Location (AVL) systems.

The RF technology considered was restricted to devices operating in the 900 MHz frequency range (see Section 3.4.1).

## 3.2 DATA TRANSFER TECHNOLOGIES

The data transfer technologies that were investigated are as follows:

- Stand-alone RF readers and antennae.
- RF readers and antennae integrated into a fuel dispenser.
- Bar code readers integrated into a fuel dispenser.
- Infrared communication systems.
- License plate recognition systems.

Transfer of data via cellular technology was not evaluated (see Section 3.4.7).

## 3.3 COMPUTING AND COLLECTING THE VMT ROAD TAX

Technologies evaluated for computing and collecting the tax are:

- Integrated fuel dispenser, payment, and Point-of-sale (POS) systems.

## 3.4 TECHNOLOGIES EVALUATED AND NOT CONSIDERED FURTHER

### 3.4.1 RF devices operating on frequencies other than 900 MHz

When investigating technology options that use RF as the basis of operation, the OSU research team concentrated on those that employ frequency ranges that have been reserved specifically for industrial, scientific, and medical applications. These are the frequencies classified worldwide as ISM frequency ranges (*Finkenzeller 1999*). For wireless data communication applications, the most common ISM frequency bands are 902-928 MHz, 2.4-2.4835 GHz, and 5.725-5.850 GHz.

The advantages of using RF technologies that operate on one of the ISM frequency bands are as follows:

1. Devices that operate in any of the ISM frequency bands do not require a license from the Federal Communications Commission (FCC).

2. Our research indicated that current intelligent transportation systems (ITS) technology in the State of Oregon uses RF technology (e.g., AVI) that operates in the 902-928 MHz ISM band. Therefore, if the technology deployed to collect VMT data operates in this ISM band, it may also be used for other purposes as well (e.g., electronic toll collection used in real-time congestion pricing).

Thus, RF devices operating outside ISM frequency bands would not be desirable due to licensing requirements. RF devices operating in ISM frequency bands other than the 902-928 MHz frequency would not be desirable candidates for use in a VMT fee collection system, because of the limited availability of existing companies with transportation system related products and development expertise in these frequencies.

### 3.4.2 GPS devices that store location points

On-vehicle GPS based devices that collect and store location and time points were not evaluated in detail due to privacy/perception issues. Of a secondary nature were concerns about data transfer reliability and data processing requirements. In the project coordinated by the Minnesota Department of Transportation (MnDOT) titled *"A New Approach to Assessing Road User Charges,"* privacy/perception issues related to the use of location points were paramount (*Seamone and Forkenbrock 2001; Kuhl 2001*). A major use of on-vehicle GPS devices that store and transfer location points is for the purpose of tracking and monitoring travel (*Advanced Tracking Technologies Inc. 2002*). Even the perceived capability to use location points to track individual travel patterns, whether or not it is actually carried out, has led the team conducting the MnDOT project to develop a system architecture where only data at the minimum level of detail is stored and transferred (*Kuhl 2001; Forkenbrock 2002*).

In addition to the concerns expressed above, the technical issues of data transfer reliability and data processing requirements also indicate that using such devices would be less desirable than using GPS-based devices that can only compute Oregon VMT. In the collection of location points the amount of data to be transferred off a vehicle would be potentially thousands of times more than in the case of just transferring vehicle identification and VMT data. The location data would have to be processed and would require large data processing capabilities if the data were sent to a FCCTR. If the processing were distributed (such as at service stations) then cost, software, and hardware updating and upgrading issues for many decentralized facilities arise.

### 3.4.3 Bar Codes

Although bar code technology is used extensively in manufacturing and retail applications, it typically provides a short-term, lower performance solution for most transportation applications. In the context of the VMT scenarios described in Chapter 2, the utilization of bar codes would compromise the reliability of the overall system due to the following technological limitations:

1. **Line-of-sight requirement**. Barcodes are considered an optical data collection technology. Therefore, bar code readers require a clear line-of-sight in order to be able to acquire and decode the information contained on a bar code. Buildups of grime or snow, poor or excessive lighting conditions, distance between reader and barcode symbol, are only some of the factors that can affect system performance.

2. **Limited data encoding capability**. Unlike RF identification, bar codes can encode only a limited amount of data. In addition, once the symbol is produced, the encoded data cannot be changed unless a new symbol is generated.
3. **Security**. Bar code symbols are very easy to generate. Several off-the-shelf software products exist for personal computers that allow a user to design and print bar codes. In addition, bar code printers and print media are also fairly inexpensive, making forging a very likely occurrence, particularly in tax-oriented applications.

While bar codes initially appear to be a low cost solution, the high cost of maintenance or replacement, plus the unacceptability of increasing failure rates, must be considered in the total life cycle cost (*Doering*).

### 3.4.4 Infrared

Infrared communication is an inexpensive and widely adopted short-range wireless technology that allows devices to "speak" easily to each other. The spectrum of infrared is virtually unlimited, which presents the possibility of achieving extremely high data rates. Also, unlike most of the RF spectrum, the infrared spectrum is unregulated worldwide (*Stallings 2001*).

Despite these advantages over RF-based communication systems, certain features of infrared technology make it unfit for VMT-based revenue collection system applications. First, infrared light does not penetrate opaque objects, therefore forcing the data-carrying device from which data would be collected to be "visible" to the reader. Consequently, the data-carrying device would have to be placed either inside the vehicle (e.g., mounted on windshield or placed over the dashboard) or in an easily accessible area inside one of the vehicle compartments (e.g., engine compartment or trunk), thus creating the possibility of users attempting to tamper with the device.

Secondly, if this type of technology were to be used to collect VMT information in an outdoor environment (e.g., service station or DMV), infrared background radiation from sunlight and artificial lighting sources may affect its performance. It was due to these drawbacks that infrared technology was not further pursued as a technology option for the purpose of this study.

### 3.4.5 Automatic Vehicle Location

Automatic Vehicle Location (AVL) is a state-of-the-art technology for monitoring vehicles through an in-vehicle unit that sends location data to a control center via a communications link such as two-way radio or the cellular network. The most sophisticated type of AVL system relies on GPS navigational data. In GPS/AVL applications, navigational data is sent by the satellites and collected by a vehicle tracking unit (VTU) that contains a GPS receiver. The information is then processed by the GPS receiver in the VTU, which sends location data to a GPS/AVL control center via radio frequencies. Accuracy in these systems is typical of current GPS technology (± 30 meters) (*Broncano 1995*). Figure 3.1 depicts a common architecture of a GPS/AVL system.

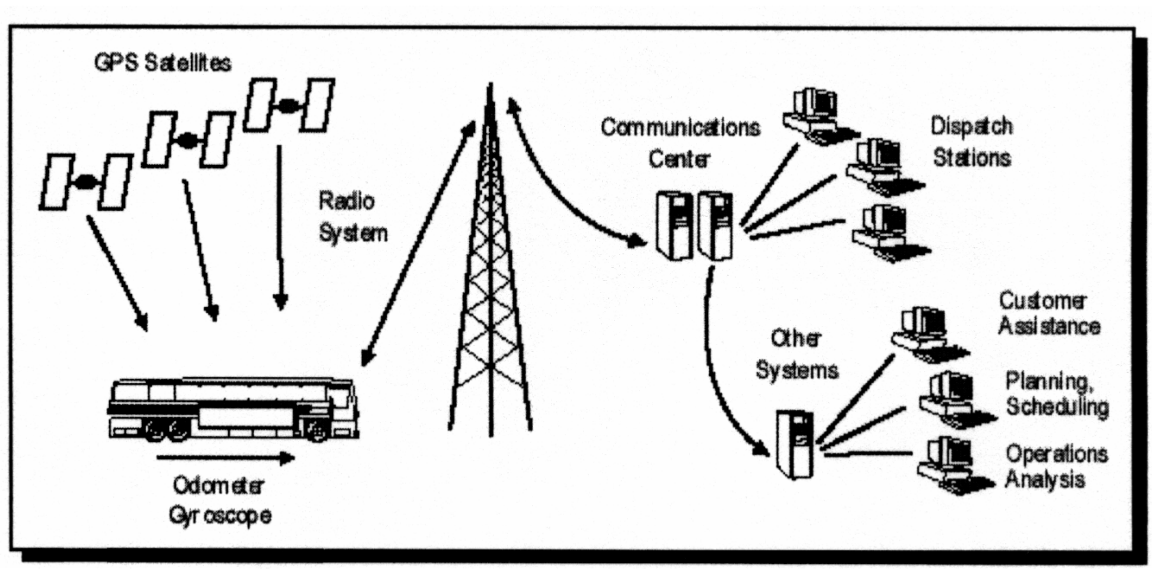



Figure 3.1: Common GPS/AVL system architecture

The key design factors when considering the implementation of a GPS/AVL system include:

- The geographical area that needs to be covered
- Number of antenna towers needed to cover this area
- Ownership of towers (own vs. lease)
- Required speed for data transmission

In addition, a decision on the type of radio network has to be made. There are three types of radio networks available. The first is VHF, operating between 60 and 200 MHz, and the second is UHF, which typically operates in the 450-460 MHz frequency range. In the past several years, 800 MHz systems have been approved and are often used with GPS/AVL technology. Usually, GPS/AVL frequencies are used for data only on dedicated conventional channels.

GPS/AVL technology was not further pursued as a viable solution for VMT applications due mainly to privacy/perception considerations (i.e., user's location can be determined at any point in time). In addition, the radio frequencies used for data communication purposes in these systems require a license from the FCC to ensure that the channels used do not have to be shared with other radio users, which is critical to avoid interference that may disrupt the constant messaging.

### 3.4.6 License Plate Recognition

License Plate Recognition (LPR) is an automatic identification technology that has been primarily used for enforcement functions in tolling and traffic monitoring applications. The technology literally takes pictures of license plates, which must then be interpreted by optical character recognition software. These systems are very expensive and offer little capability beyond what barcode systems provide. The amount of data is limited to what can be interpreted from a picture, and the systems require line-of-sight to the data object.

### 3.4.7 Cellular Communications

Cellular communication of data was not considered in the scope of this project per instruction of ODOT, since a companion research effort by Portland State University included an exploration of this technology.

# 4.0 INITIAL SCREENING OF TECHNOLOGIES AND SCENARIOS BASED ON COST AND TECHNOLOGY INTEROPERABILITY

An initial screening of scenarios and technologies was conducted for the following reasons:

- The initial number of RUFTF scenarios was relatively large with respect to the expected number of final scenarios that could be selected for pilot testing.
- The number of potential technologies that could be used to implement these scenarios was also large.

The purpose of the screening was to eliminate technologies and scenarios that would be clearly infeasible due to cost and technology interoperability reasons. Additionally, technology availability and ease of scenario implementation also had a bearing on the initial screening conclusions.

## 4.1 INITIAL SCREENING COST ESTIMATES – SUMMARY INFORMATION

A summary of cost estimates is presented in Table 4.1. The "Approximate Total Cost" heading in Table 4.1 refers to the approximate total costs if all registered Oregon vehicles were to be outfitted for participation and all data collection devices were installed. These cost estimates were derived from the assumptions listed in Table 4.2, which also shows which scenarios each assumption affects. In Table 4.3, the assumed costs for the devices and the data sources are listed. Some of these costs are not high-volume production cost figures (e.g., the GPS devices) so it is likely that the actual unit costs may be lower in certain cases. Other costs listed are estimates of today's costs for devices that are already produced and sold in high volumes (e.g., "read only" RF tags). Although some costs listed in Table 4.3 are not high-volume production costs, there are cases where the exact technology needed is not available and the cost used is the cost estimate for a unit that is similar to the needed technology. These points are noted in Table 4.3.

**Table 4.1: Cost estimates for total Scenario implementation**

| Aquiring OR-VMT | Scenario(s) | Hardware | Approximate Per Unit Hardware $ | Cost Category | ApproximateTotal Cost | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Aquiring OR-VMT | Getting Data Off Vehicle | Computing Tax | Collecting Tax |
| GPS Based | Center Scenario<br>GPS&RF-AVI Option | Integrated GPS/GIS/RF Unit<br>RF Readers at Service Stations | $500<br>$2,500 | Initial Cost<br>Var. Cost/Yr | $1.5 B<br>New/Repl./Maint. | $9 M<br>Repl./Maint. | Fee Ctr./Network<br>Labor+Network+Lic | Software<br>Labor+Maint+Lic |
| | DMV Scenario<br>GPS&RF-AVI Option | Integrated GPS/GIS/RF Unit<br>RF Readers at DMV Offices | $500<br>$2,500 | Initial Cost<br>Var. Cost/Yr | $1.5 B<br>New/Repl./Maint. | $680 K<br>Repl./Maint. | Hard/soft-ware<br>Labor+Maint+Lic | Software<br>Labor+Maint+Lic |
| | Actual VMT @ Pump<br>with Credit/Switch<br>GPS&RF-AVI Option | Integrated GPS/GIS/RF Unit<br>Dispensers - RF (New/Retrofit)<br>POS system (1/2 need) | $500<br>$7,500<br>$10,000 | Initial Cost<br>Var. Cost/Yr | $1.5 B<br>New/Repl./Maint. | $70 M<br>Repl./Maint. | Software *<br>Maint+Licenses | Software *<br>Maint+Licences |
| Odometer | Center Scenario<br>ODO & RF-AVI Opt. | Integrated RF/Speed Sensor Unit<br>RF Readers @ Service Stations<br>and Border Crossings | $150<br>$2,500 | Initial Cost<br>Var. Cost/Yr | $450 M<br>New/Repl./Maint. | $9 M +<br>Repl./Maint. | Fee Ctr./Network<br>Labor+Network+Lic | Software<br>Labor+Maint+Lic |
| | DMV Scenario<br>ODO & RF-AVI Opt. | Integrated RF/Speed Sensor Unit<br>RF Readers at DMV Offices | $150<br>$2,500 | Initial Cost<br>Var. Cost/Yr | $450 M<br>New/Repl./Maint. | $680 K<br>Repl./Maint. | Hard/soft-ware<br>Labor+Maint+Lic | Software<br>Labor+Maint+Lic |
| | Actual VMT @ Pump<br>with Credit/Switch<br>Enhanced ODO & RF-AVI | Enhanced RF/Speed Sensor Unit<br>Dispensers - RF (New/Retrofit)<br>POS system (1/2 need) | $175<br>$7,500<br>$10,000 | Initial Cost<br>Var. Cost/Yr | $525 M<br>New/Repl./Maint. | $70 M<br>Repl./Maint | Software *<br>Maint+Licenses | Software *<br>Maint+Licences |
| Est. From EPA MPG | Estimated VMT @ Pump<br>with Credit | RO RF Transponders<br>Dispensers - RF (New/Retrofit)<br>POS system (1/2 need) | $5<br>$7,500<br>$10,000 | Initial Cost<br>Var. Cost/Yr | $15 M<br>New/Repl./Maint. | $70 M<br>Repl./Maint | Software *<br>Maint+Licences | Software *<br>Maint+Licences |
| Not Needed | System -Wide<br>Tolling | RO RF Transponders<br>RF Readers on Roads<br>LPR Systems | $5<br>$2,500<br>$25,000 | Initial Cost<br>Var. Cost/Yr | $15 M<br>New/Repl/Maint. | Very Large<br>Labor+maint | Fee Ctr./Network<br>Labor+Network+Lic | Software<br>Labor+maint+Lic |

* Software changes for dispenser radio frequency payment system and point-of–sale system are controlled and implemented by oil companies.

**Table 4.2: Assumptions used in total costs calculations**

| Data Item | Assumed Value | Data Source | Affected Scenarios |
|---|---|---|---|
| Registered OR vehicles | 3 Million | Oregon Blue Book (*2002*) | All |
| Service stations in OR | 1800 | Measurements Department of Oregon Department of Agriculture (*2002*) | 1. Fee Collection Ctr. Scenario (GPS&RF-AVI, ODO&RF-AVI options)<br>2. Pump With Credit/Switch<br>3. Pump With Estimate |
| Fuel dispensers per service station | 4.5 | Gilbarco Veeder-Root Inc. (*2002a*) | 1. Pump With Credit/Switch<br>2. Pump With Estimate |
| DMV field offices | 68 | Oregon Driver and Motor Vehicles Division (*2002*) | DMV Scenario |
| RF readers per DMV location | 4 | Assumed | DMV Scenario |
| RF readers per service station | 2 | Assumed | |

**Table 4.3: Unit device costs used in total cost calculations**

| Data Item | Assumed Cost | Data Source | Affected Scenarios | Additional Information |
|---|---|---|---|---|
| Integrated GPS/GIS/RF Unit | $500 per unit | 308 Systems (*2002*)<br>CSI Wireless (*2002*)<br>Aerodata Inc. (*2002*) | 1. Fee Collection Ctr. Scenario (GPS&RF-AVI Option)<br>2. Pump With Credit/Switch (GPS&RF-AVI Option)<br>3. DMV Scenario (GPS&RF-AVI Option) | No device meets all of the scenario requirements. Unit costs averaged. |
| RF Reader/Antennae Unit | $2,500 per unit | Transcore (*2002*) | 1. Fee Collection Ctr. Scenario (GPS&RF-AVI, ODO&RF-AVI options)<br>2. DMV Scenario<br>3. System-wide Tolling | Many such readers are in use |
| Fuel Dispenser with RF Capability | $7,500 per unit | Gilbarco (*2002a*)<br>Gilbarco (*2002b*) | 1. Pump With Credit/Switch<br>2. Pump with Estimate | $7500 unit cost is an average of the cost of a new dispenser and a dispenser retrofit |
| Point-Of-Sale (POS) System | $10,000 per system | Gilbarco (*2002b*) | 1. Pump With Credit/Switch<br>2. Pump with Estimate | |
| Integrated RF/Speed Sensor Unit | $150 per unit | Transcore (*2002*) | 1. Fee Collection Ctr. Scenario (ODO&RF-AVI option)<br>2. DMV Scenario (ODO&RF-AVI option) | This device may not completely meet requirements |
| Enhanced Integrated RF/Speed Sensor Unit | $175 per unit | Transcore (*2002*) | 1. Pump With Credit/Switch (Enhanced ODO&RF-AVI option) | No device meets all of the scenario requirements |
| Read-Only RF tag | $5 per unit | Transcore (*2002*) | 1. Pump with Estimate<br>2. System-wide Tolling | |
| License Plate Recognition System | $25000 per lane | Transcore (*2002*) | 1. System-wide Tolling | Needed as part of toll enforcement in Scenario 6 |

The purpose of the cost summary is to present "order of magnitude" cost estimates for the scenarios. For example, it is clear that the cost to equip vehicles in scenarios calling for an on-vehicle GPS device will be much more expensive (approximately 10 times more) than scenarios where vehicles are equipped with a read-only RF tag.

There are also costs that were not included in the initial screening for such items as:

- A Fee Collection Center (FCCTR).
- Dedicated phone lines for transfer of data to a FCCTR.
- Installation and debugging of equipment.
- Enforcement equipment for toll systems such as vehicle separation equipment[2].
- Costs for new space (e.g., at DMV locations).
- Costs for signs and hardware such as posts.
- Power consumption costs.

This is not a comprehensive list of costs, but it should cover the majority of costs needed for comparison purposes.

A significant ongoing cost that will affect scenarios involving the use of fuel dispensers (Pump with Credit, Pump with Switch, and Pump with Estimate Scenarios) is the cost of software system changes and upgrades. Point-of-sale (POS)/fuel dispenser system software changes at service stations are controlled by oil companies. If a software change is to be implemented at all its service stations, the change must be executed for all of the different POS/fuel dispenser systems that are being used. Typical time for such software changes is 9 months with an approximate cost of $500K (*Gilbarco 2002a*).

In the System-wide Tolling Scenario, the cost of equipment for getting data off a vehicle is listed as "very large". The exact figure depends on the number of toll reader locations that will be installed. The RF reader and License Plate Recognition system needed per toll location has an estimated cost of $27.5K per lane. This does not include vehicle separation equipment[2], which is needed for toll enforcement. It is clear from these per lane costs that any widespread Oregon based tolling system would be prohibitively costly.

## 4.2 QUALITATIVE EVALUATION OF THE SCENARIOS

Table 4.4 presents a qualitative summary of the RUFTF scenarios. In this table, the costs refer to the total implementation cost for all Oregon drivers. "Pilot Ready" refers to an assessment of whether a required device is likely to be available for pilot testing by July 2003. "Int. Req." refers to the integration requirements with existing systems. For example, all scenarios involving data collection/processing through the fuel dispenser/POS system at service stations require integration with the existing system.

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[2] Equipment used to detect when a vehicle has driven past a certain location

Table 4.4: Qualitative summary of Scenarios

| Aquiring OR-VMT | Scenario | Criteria | On-Vehicle Equipment | Getting Data Off Vehicle | Computing VMT Tax | Collecting VMT Tax |
|---|---|---|---|---|---|---|
| GPS Based | Center Scenario GPS&RF-AVI Option | COST | High | High (@ ser. stations) | Med. (Fee Center) | Med (mail) |
| | | PILOT READY | Likely | Yes | Yes | Yes |
| | | INT. REQ. | Power | None | Software | Software |
| | DMV Scenario GPS&RF-AVI Option | COST | High | Low (at DMV) | Med. (DMV) | Med (mail) |
| | | PILOT READY | Likely | Yes | Yes | Yes |
| | | INT. REQ. | Power | None | Software | Software |
| | Actual VMT @ Pump with Credit/Switch GPS&RF-AVI Option | COST | High | Very High (@ pumps) | Low (@ pump) | Low (@ pump) |
| | | PILOT READY | Likely | No* | No* | No* |
| | | INT. REQ. | Power | W/Pump | W/Pump & POS system | W/Pump & POS system |
| Odometer | Center Scenario ODO & RF-AVI Opt. | COST | Medium | High (@ ser. stations) | Med. (Fee Center) | Med (mail) |
| | | PILOT READY | Likely | Yes | Yes | Yes |
| | | INT. REQ. | Power, Speed Sensor | None | Software | Software |
| | DMV Scenario ODO & RF-AVI Opt. | COST | Medium | Low (at DMV) | Med. (DMV) | Med (mail) |
| | | PILOT READY | Likely | Yes | Yes | Yes |
| | | INT. REQ. | Power, Speed Sensor | None | Software | Software |
| | Actual VMT @ Pump with Credit/Switch Enhanced ODO & RF-AVI | COST | Medium | Very High (@ pumps) | Low (@ pump) | Low (@ pump) |
| | | PILOT READY | Likely | No* | No* | No* |
| | | INT. REQ. | Power, Speed Sensor | W/Pump | W/Pump & POS system | W/Pump & POS system |
| Est. From EPA MPG | Estimated VMT @ Pump with Credit | COST | Low | Very High (@ pumps) | Low (@ pump) | Low (@ pump) |
| | | PILOT READY | Yes | No* | No* | No* |
| | | INT. REQ. | None | W/Pump | W/Pump & POS system | W/Pump & POS system |
| Not Needed | System -Wide Tolling | COST | Low | Very High | Low | Med (cash cards) |
| | | PILOT READY | Yes | Yes | Yes | Yes |
| | | INT. REQ. | None | None | Software | Software |

* Pump (fuel dispenser) systems for getting data & computing/collecting tax are integrated systems: Pilot Ready status is the same for all categories and refers to pilots at actual service stations.

## 4.3 DISCUSSION OF SUMMARY INFORMATION

The cost estimates shown in Table 4.1 indicate that the use of GPS-based on-vehicle devices leads to the largest cost item in any scenario. Part of this cost is due to the fact that GPS-based devices have the potential to provide information above and beyond what is needed for an Oregon VMT based electronic revenue collection system. If future requirements call for separate tax rates for various regions within Oregon, then GPS-based devices should be considered. Other on-vehicle devices such as the Integrated RF/Speed Sensor Unit and RF tags are less expensive but accordingly provide less information and capability. For example, in the Pump with Estimate Scenario (VMT estimated from fuel purchased and EPA MPG data) there is no mechanism to estimate Oregon VMT (only total VMT).

For getting the data off of the vehicles, the largest hardware cost scenarios are those that involve data collection and VMT fee calculation at fuel dispensers (Pump with Credit/Switch Scenarios (both options), and the Pump with Estimate Scenario). The major components of this cost are the purchase or retrofitting of existing fuel dispensers, new POS systems, and making the necessary software changes. The software upgrade cost is one that would continue on a periodic basis if such systems were to be deployed. Another factor that should be considered in these scenarios is the issue of system responsiveness. System changes are currently implemented by oil companies and take approximately 9 months to complete.

## 4.4 TECHNICAL ADVISORY COMMITTEE (TAC) CONCLUSIONS

The results of the initial screening were presented to the TAC on August 19, 2002 and to the RUFTF on September 6, 2002 (approximately the midpoint of this project). The conclusions drawn from the initial screening were that the preferred scenarios included the following:

- Fee Collection Center Scenario – GPS and RF-AVI Option (Technology Option 2), and
- Fee Collection Center Scenario - ODO & RF-AVI Option (Technology Option 3).
- Actual VMT at Pump with Credit/Switch Scenarios – Enhanced ODO & RF-AVI Option (Technology Option 4)

The TAC suggested the last preferred scenario in this list after receiving estimates on Fee Collection Center costs from Bertini et al. (*2002*). Based on these conclusions, the RUFTF and TAC instructed the OSU research team to do the following for the remainder of this project:

- Obtain more in-depth information on the technologies employed in these scenarios:
  - Integrated GPS/GIS/RF devices.
  - Integrated RF/Speed Sensor units.
  - Enhanced Integrated RF/Speed Sensor units.
  - RF-based AVI systems.
- Information about the state-of-the art in fuel dispensers.

This information is presented in the next section.

# 5.0 TECHNOLOGIES FOR VMT DATA COLLECTION AND DATA TRANSFER

In this section more detailed information for the following technologies is presented:

- Integrated GPS/GIS/RF devices
- Integrated RF/Speed Sensor units
- Enhanced RF/Speed Sensor units
- RF-based AVI systems
- Fuel dispenser systems

First, an overview of the technology is presented. This includes the following:

- Basic technology operation overview
- Existing major vendors and current applications
- Technical specifications
- Future developments of the technology

Additional information for fuel dispensers will focus on establishing the state-of-the-art of today's technology. Information on fuel dispensers in Oregon will also be presented.

## 5.1 INTEGRATED GPS/GIS/RF DEVICES

The GPS-based device required in the scenarios is a device that integrates GPS, GIS, and RF technologies. The device must also have the memory and computing power to store GIS data and compute a vehicle's VMT from GPS location points, and the ability to write to memory accessible by a RF-based AVI reader. Additionally the device may also require a backup system in case of signal loss or system malfunction.

For pilot-testing purposes there is no current device marketed that performs all of the functions listed. There are however, GPS-based devices that can compute a vehicle's VMT within predefined geographic zones. Available devices that come close to the having all of the required functionality are discussed.

### 5.1.1 Basic Technology Operation Overview

The fundamental function of a GPS unit relevant to a VMT based revenue collection system is the determination of a vehicle's location and the time that the vehicle is at the determined location (GPS units are also used as clocks). When this type of information is collected over time, many different types of analyses and results can be obtained including calculating a vehicle's VMT. A GPS unit consists of a GPS receiver, antenna, power supply, memory (and associated computational functionality), and user interface. To determine a location, a GPS unit receives signals from multiple GPS satellites (at least three of the 24 GPS satellites) and by calculating the distance to the satellites the unit can then determine the location through a "triangulation" calculation.

There are a wide range of GPS units available that differ in how many satellites they can track (most units now track at least 8-12 satellites), the amount of satellite information provided simultaneously, what types of GPS satellite information they can process, methods they use to increase accuracy, and how they mitigate factors that can cause location errors. GPS units can be generally classified in one of three architectures. The "sequential" and "multiplex" architectures have one or two hardware channels that sequentially provide satellite information, whereas the more accurate and expensive "continuous" architecture will continuously provide information from multiple satellites. Lower priced GPS units interpret what is called "code phase" GPS satellite information. Higher priced units can interpret "carrier phase" GPS satellite information and are more accurate. There many uncontrollable factors that affect the location accuracy obtainable from GPS satellite signals. Effects of the atmosphere on the path of GPS signals, clock errors, and multipath errors (caused by GPS signal deflection) are some but not all of the factors that can cause GPS errors. To increase accuracy there are "Differential GPS" (DGPS) units available that use signals from fixed known ground-based locations to make corrections in GPS satellite signals. There are also navigation units that combine GPS and GLONASS. GLONASS is the Russian equivalent of GPS and also consists of a system of 24 satellites. Units also differ in the algorithms and methods used to mitigate multipath errors. In general, the phrase "you get what you pay for" is true for GPS units. Basic handheld units can be purchased for under $200 whereas centimeter accurate survey units can cost $10,000 or more.

Geographic Information Systems (GIS) are systems that synthesize a variety of types of geographic data for specific purposes. An example of a GIS would be a computer system that on request can display different "views" of specific regions of Oregon. A view may be a population density map, a highway system map, or a vegetation map. At the heart of any GIS is the geographic data. The geographic data and the ability to compute VMT within geographic zones is the GIS component needed in the required device.

A review of RF-based AVI technology will be presented in Section 5.2 and is applicable to the RF portion of this device.

### 5.1.2 Existing Major Vendors and Current Applications

There are many different manufacturers of GPS units. One of the largest companies that manufactures both GPS products as well as components for GPS units is Trimble Navigation Limited (http://www.trimble.com/). For the requirements of the VMT revenue collection scenarios, three vendors marketing devices with functionality closest to the requirements are:

- 308 Systems – Hermosa Beach, California.
- CSI Wireless – Calgary, Canada.
- AeroData - Hillsdale, Michigan.

308 Systems developed a device for the Sacramento Air Quality Management District to be used on trucks, agricultural equipment, and pumps. The device can collect information on the miles

and time traveled within predefined zones (for pumps only operation time is required). The VMT and time data is transferred to a central location via cellular communications. The data is used for air quality management purposes. The cost per unit is $534, not including installation cost. Based on discussions with 308 Systems, their rough estimate of unit costs for a device meeting the scenario requirements is $300 per unit.

CSI Wireless markets and sells devices for vehicle tracking and monitoring. Their devices can be configured with various options but have the capability to compute vehicle VMT within predefined geographic zones and transfer this data via cellular communications. Their devices also have the ability to monitor vehicle speed. CSI Wireless devices have been used by rental car companies and also by university researchers. The cost per unit is $300 or more, not including the installation cost (*CSI Wireless 2002*).

AeroData sells a self-contained "brief case" style unit that has been developed for research purposes. It has the capability to be programmed to compute vehicle VMT within geographic zones and has cellular communication capability. It also has a variety of other capabilities. University researchers have used their units, and the cost per unit is $1,000 or more (*AeroData 2002*).

### 5.1.3 Technical Specifications

The technical specifications will focus on GPS units. GIS are not devices and therefore do not have physical technical specifications. RF-based AVI technical specifications will be presented in Section 5.2. As discussed earlier, GPS units vary widely and increased accuracy and performance usually comes with increased cost. The specifications presented in Table 5.1 are those for a "lower end" GPS unit and represent typical manufacturer specification figures. Different products for various manufacturers will have specifications that differ from what is presented here. Only those specifications that are deemed relevant to VMT revenue collection scenarios are presented. Where necessary the definition of the specification is also given.

The figures in Table 5.1 are typical manufacturers' specifications and are often obtained in ideal environments. To assess performance in practice the only reliable source of data is from testing (*Forkenbrock and Hanley 2001*). There are, however, various published studies of GPS performance that can be called upon to provide some information on real world GPS performance. It is important to note the dates of various published studies since advances in technology have been continuous.

**Table 5.1: Typical lower end GPS unit specifications**

| Specification | Value | Comments |
|---|---|---|
| Position Accuracy | 15 meters | Moving accuracy is better than static accuracy (*Ohio State 2002*). The explanation is that movement reduces the effect of multipath errors, which are errors due to GPS signal reflection. |
| DGPS Position Accuracy | < 2 meters | |
| Signal Acquisition – Cold Start | 1-5 minutes | Signal acquisition with no stored data on the last location (occurs when power is lost or the GPS is moved when turned off). Not likely to occur often in this application. |
| Signal Acquisition – Warm Start | 40 – 60 seconds | Signal acquisition using last position/time information. **The start mode after a vehicle has been parked overnight if the GPS unit is has just been turned off after parking.** |
| Signal Acquisition – Hot Start | 8 – 20 seconds | Signal acquisition when the GPS unit has been off for less than 2 hours. |
| Signal Reacquisition | 0.1 – 3 seconds | The GPS unit is on and loses a signal. |
| Operating Temperature | -50C – 90C | |
| Power Consumption | 150 –300 mA, 9-32 VDC | A fully charged car battery could run a typical GPS unit for approximately 120 hours. |

Sharkey and Johannessen (*1996*) presented a reliability study of GPS receivers. In this study, four GPS units (2 units from two different manufacturers) were installed in fixed locations at an airport. They were installed such that the antennae had no significant low elevation obstruction and the multipath environment was favorable. Positional data was recorded every 15 seconds from each of the units. A total of approximately 7.5 million records were obtained. GPS unit failures were considered to have occurred if there was no location recorded when there should have been, or if the location was off from the unit location by more than 1 kilometer. A total of 20 failures occurred over 31,600 GPS operating hours. In a fully implemented VMT revenue collection system, the number of GPS hours would be far greater on a daily basis. However, errors of the type mentioned here can probably be handled as part of the unit's software since they do not represent a physical failure.

Gilbert (*2002*) showed the results of using a GPS unit (type not specified) at the same location to obtain 200 location points. Under an unobstructed sky, 95% of the location points obtained stayed within a 0.66-meter radius. Under a moderately dense coniferous tree canopy, 95% of the location points stayed within a 4.62-meter radius. One important conclusion from this study is that when turned on and not moving, a GPS can accumulate distance. The data to calculate the rate of accumulated distance was not presented. This is a function of how often the location was determined and the distribution of errors within the total error range. Another statement made in this article is that signal acquisition and reacquisition is more difficult when under a tree canopy and that this is more difficult when moving rapidly. This article further emphasizes that testing in your own environment is the only method to really assess GPS performance.

Lachapelle, et al. (*1994*) conducted tests on the effect of foliage for different code phase GPS units. The tests were conducted while driving and each GPS unit had a roof-mounted antenna. They show that foliage reduces the number of satellites used by the units, which theoretically should affect accuracy. The performance (an accuracy measure was used) of the 10 and 12-channel GPS units did not differ significantly in the presence of foliage, whereas the 6-channel had significantly worse performance.

Melgard et al. (*1994*) conducted tests of GPS signal availability in downtown and residential environments. The residential environment was tree-lined. Three different GPS code phase receivers were tested. The GPS signal availability in downtown was as bad as 16% on some test runs and the best was 70%. Residential signal availability was from 23% - 100%. This data is eight years old but points at the need to conduct Oregon specific tests of any GPS-based device.

### 5.1.4 Future Developments of the Technology

GPS devices have experienced a steady reduction in size, price, and power consumption. This trend will continue as well as the availability of new software developments enabling more applications. Pace and Wilson (*1998*) list vehicle navigation, item tracking, and surveying/mapping as large growth areas for GPS applications and GPS product development.

For the purposes of a VMT based revenue collection system, existing technology has the capabilities to meet system requirements. The main issue is the integration of technology into a cost effective device with the required performance. Testing will be needed to determine the levels (and thus cost) of GPS technology required for such a system.

## 5.2 AUTOMATIC VEHICLE IDENTIFICATION

Automatic Vehicle Identification (AVI) systems are designed to uniquely identify a vehicle at a specific location at a particular time (*Bernstein, et al. 1993*). AVI technology is mature and can be classified under four main categories: laser, infrared, video, and RF (*Rufolo, et al. 2001*). AVI systems whose operation is based on laser technology (i.e., bar codes) or infrared were not further investigated for the reasons expressed in Sections 3.4.3 and 3.4.4, respectively. AVI technology that utilizes video (see Section 3.4.6) was further investigated only as an enforcing mechanism for the different VMT-based tax collection scenarios described in Chapter 2. Therefore, the remainder of this section will focus on describing the characteristics of RF-based AVI technology.

### 5.2.1 Introduction to RF-Based AVI Technology

An RF-based AVI system includes the following four fundamental components:

- RF module
- Reader
- Antenna
- Tag

The RF module generates a continuous-wave RF signal, which in turn, is broadcast into the environment by the antenna. In the presence of this signal from the system, the tag reflects back to the antenna a modified form of the original signal containing the tag's unique, encoded message. The RF module demodulates this signal, preconditions it, and then transmits it to the reader. The reader then processes information and transmits it to the host computer (*TransCore 2002*). A typical RF-based AVI system configuration is depicted in Figure 5.1.

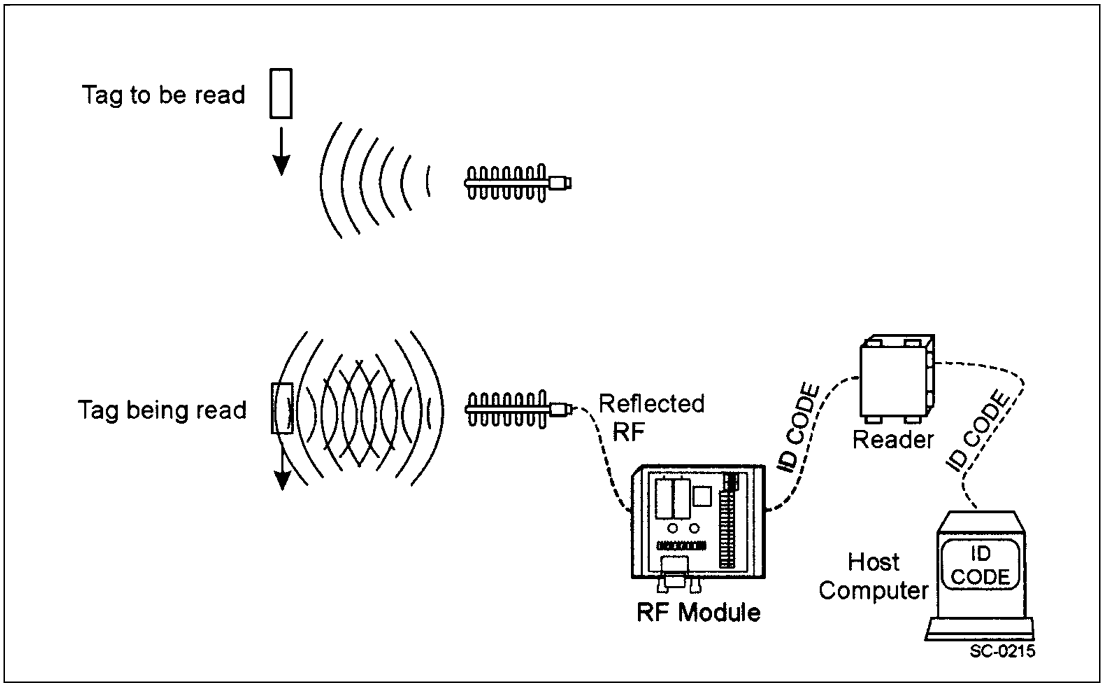


Figure 5.1: Modulated backscatter process

#### *5.2.1.1 RF Module*

The RF module generates a continuous-wave RF signal, which is broadcast by one or two system antennas. The RF module also receives the tag signal from the antenna. The RF module demodulates the signal (deciphers the signal from the modulated RF signal), pre-amplifies the signal, and sends it to the reader for processing. The most common frequencies used in transportation applications in the U.S. are the ISM frequency bands of 902-928 MHz and 2.4-2.4835 GHz (*TransCore 2002*).

#### *5.2.1.2 Antennas*

Antennas are designed to broadcast an RF signal and receive tag-modulated reflections of that signal within a specified optimal area called the *reading range*. In addition, the size and shape of the broadcast field as well as polarization (directional sensitivity of energy emitted from the antenna) are used to further define the reading range to desired specifications. It is important to note that each type of antenna broadcasts RF energy generated by the RF module in a characteristic pattern. Therefore, antenna selection is a very critical design factor, since this can play a big role in determining the reading accuracy of the system.

#### *5.2.1.3 Reader*

The reader provides the operational link between tagged objects and in-house information management systems. The reader receives the demodulated signal from the RF module, decodes the ID code, validates and filters the ID code, and transmits the code along with any appended information to the host computer system. Permanent programming (firmware) in the reader controls reader operation. The firmware accepts commands from the user through the host computer system (or a local terminal), which can customize the reader's operations to the user's needs.

It is important to mention that the firmware that allows the reader to perform the operations described above is very complex. Therefore, it would be very difficult for a person without a strong software engineering background to duplicate it. In addition, the commands issued by the reader to communicate with the tags (and the corresponding protocols) are also system dependent. This provides a high degree of data integrity and security for VMT applications.

#### *5.2.1.4 Tags*

Tags (sometimes also referred to as *transponders*) represent the actual data-carrying device of an RF-based AVI system. They normally consist of a coupling element and an electronic microchip (*Finkenzeller 1999*). A tag is intended for attachment to an item that a user wishes to manage. It is capable of storing a tag ID number and other data regarding the tag or item, and of communicating this information to the reader (*ANSI 1999*). Tags can be classified by operating frequency and power source as follows (*TransCore 2002*):

1. **Operating Frequency**. For applications in the U.S., tags operate in the 915 MHz band (902-928 MHz) as allowed by the FCC. Other countries permit operation of RFID equipment at 2450 MHz or 880 MHz.
2. **Power Source**. Although tags are not RF transmitters, a small amount of power is needed to operate the internal circuitry. Passive tags derive this power directly from the incoming RF signal and are beam-powered. Beam-powered tags have an indefinite life since there is no battery and no moving parts. Other tags use a small lithium battery to drive the internal circuitry. These active tags are battery-powered. Battery-powered tags have a life of eight to fifteen years. These tags can be read farther from the antenna than beam-powered tags.

Passive AVI tags take advantage of a concept known as *modulated backscatter process*. This basically means that passive tags are not radio transmitters and do not radiate signals by themselves. Instead, tags entering an antenna's reading range modify and reflect a portion of the signal received back to the originating antenna. The antenna receives this modified (or *modulated*) signal and transmits it back through the RF module to the system reader. The reader decodes the signal, validates the ID code, appends pertinent information to the code, and transmits the code to a host computer system for further processing. This characteristic of the passive tags adds another level of security to the system, because they only respond to commands issued by the reader and, therefore, are immune to eavesdroppers that may try to intercept the information being transmitted.

## 5.2.2 RF-Based AVI Units

With the exception of the GPS & Cellular Technology Option in the Fee Center Scenario, all scenarios described in Section 2.0 employ RF-based AVI technology. It is important to note, however, that the interaction required between RF-based AVI technology and complementary technologies (e.g., GPS) to achieve the collection of VMT data varies among the scenarios. Three different functionalities are needed:

1. The RF-based AVI device encodes static information (e.g., Vehicle identification data) that would be read by a RF reader at a service station or as a vehicle enters and exits Oregon.
2. The RF-based AVI device interfaces with an on-vehicle GPS device that stores in its memory VMT data (e.g., total mileage).
3. The RF-based AVI device interfaces with the speed sensor of a vehicle and converts a electrical or mechanical signal into an approximate mileage value.

Current RF-based AVI technology offers the functionality described in No. 1 above and is used extensively in multiple U.S. sites for electronic toll collection (ETC) applications. A device that provides the functionality needed to accomplish No. 2 does not currently exist, and new research and development will be needed to develop a device for testing purposes.

Three companies were found that currently manufacture a RF-based AVI device that is integrated with a vehicles speed sensor (generally referred to as an *odometer tag*) that provides functionality similar to that needed to address No. 3. However, the devices would have to be modified to address specific requirements of the application at hand, as detailed in the following sections.

#### *5.2.2.1 Basic technology operation overview – Integrated RF/Speed Sensor Devices*

An integrated RF/speed sensor device uses an automobile's vehicle speed sensor (VSS) for measurement of vehicle mileage. Conversion factors for distance calculation are combined as a scaling factor and stored in the tag. Distance data is then modulated continuously in the tag frame and read by an external reader. Data is encoded (modulated) onto the received radio frequency (RF) carrier and the signal is reflected (backscattered) back to the reader for decoding and processing.

#### *5.2.2.2 Existing major vendors and current applications*

For the requirements of the VMT revenue collection scenarios (Center Scenario and DMV Scenario), three vendors marketing integrated RF/speed sensor devices with functionality closest to the requirements are:

- TransCore – Hummelstown, Pennsylvania – Corporate offices.
- Hi-G-Tek – Or Yehuda, Israel.
- AFX Technology Group International, Inc. – Dallas, TX

##### *5.2.2.2.1 TransCore's AT5770 External Metering Tag*

The device manufactured by TransCore is known as the AT5770 External Metering Tag. The AT5770 is a single-frame dynamic tag designed for use on vehicle exteriors. It is used in asset tracking and counting applications such as odometer tracking, tachometer tracking, event tracking and counting, pulse counting, and on-board sensor monitoring (*TransCore 2002*).

The AT5770 stores up to 128 bits of data providing 10 (6-bit ASCII) alphanumeric characters for the asset identification (ID) and dynamically provides 24 bits of data for counting applications. It also provides two internal user input parameters for the counting value. For example, when used as an odometer meter, the user would input the vehicle's values for the tire revolutions per mile and axle ratio.

The AT5770 uses an automobile's VSS for measurement of vehicle mileage. In order to do this, the tag uses 4 pieces of data. These are:

1. The present odometer reading of the vehicle in increments of 1/10 of a mile.
2. Tire revolutions per mile in increments of 1/10 of a mile.
3. Axle ratio in increments of 1/100 of a mile.
4. Pulses per revolution (# of teeth on the sensor ring) in whole numbers.

Items 1 to 3 above are user programmable whereas item 4 is programmed at the factory. Also, items 2 through 4 are used by the tag to convert pulses from the wheel/axle sensor into tenths of a mile.

Software developed by TransCore will handle tire revolutions/mile between 1 and 999. This means that it should work for virtually any vehicle with a tire circumference of 63.3 inches or greater. A normal car with a 13" wheel, for example, should be at least 68 inches in diameter and be able to be programmed by their tag. The AT5770 is programmed in the factory with a value of 16 teeth/revolution. This 16 teeth/revolution value is converted into pulses, and by using the tire revolutions/mile and axle ratio, these pulses are converted into a pulse/mile value.

Example:

| | |
|---|---|
| (5280 feet/mile) / 68 inch tire circumference = | 932 tire revs/mile |
| (932 tire revs/ mile) * 4.33 axle ratio = | 4034.54 revs/mile (of shaft) |
| 4034.54 revs/mile * 16 teeth/rev = | **64552 teeth/mile = 64552 pulses/mile** |

The tag decodes the pulse data into 24 binary bits that are then computed into miles. The value of the data has a resolution of 0.1 mile. The process is completed by then modulating these distance data continuously in the tag frame so that an external reader can acquire it. The AT5770 operates in the ISM frequency band of 902-928 MHz.

*5.2.2.2.2 Hi-G-Tek's External Metering Tag*

Hi-G-Tek develops and produces active RFID platforms that include sensing (e.g., odometer reading) and communicating the data to readers over low or high frequency channels. Currently, Hi-G-Tek manufactures an active RFID tag that interfaces with the odometer and provides an efficient management and control tool over the vehicle fuel consumption (*Hi-G-Tek 2002*).

In a phone conversation with Hi-G-Tek's engineering division, they indicated that miles traveled information could be collected from each vehicle in a different way: the vehicle computer, automatic transmission, ABS or, in older models, through a special sensor. Depending on the system's needs, the tag can remember the mileage traveled on each month or quarter (to put a real-time clock in the tag).

*5.2.2.2.3 AFX's MinionNet® Technology*

MinionNet® is a two-way intelligent wireless telemetry technology solution, which utilizes very low cost, small package, low power transceivers known as Minions™ (*AFX Technology Group International 2002*). The key features of this solution are as follows:

- It operates under a peer-to-peer network scheme, which allows the transceivers to communicate not only with a central node but also amongst them.
- A Minion™ can receive, process and forward data for itself or any other device, regardless of the application, over a range of up to 300 feet.
- A Minion™ can be configured to "act" as a reader and has the capability of transmitting data via dial-up, Ethernet, or wirelessly (e.g., IEEE 802.11b). This feature can dramatically lower the installation costs when compared to a RFID-based system.
- A Minion™ can interface with a variety of sensors to collect vehicle miles traveled information, including VSS and on-board diagnostic systems (ODB II).
- The board layout of the Minion™ includes a GPS chip. Therefore, expanding the capabilities of the device so that it also collect location points will be straightforward.
- The unlicensed 900 MHz ISM frequency band is used for device-to-device communication.

AFX indicated that the cost of a Minion™ is comparable to an active RFID tag (~$40). Installing the device so that it interfaces with either the VSS or the ODB II would cost approximately $60. Thus, the device plus installation would run at approximately $100/ vehicle. AFX also indicated that they are familiar with fuel pump interfaces due to project work they have done in the past.

#### *5.2.2.3 Technical Specifications*

The technical specifications sheet for TransCore's AT5770 External Metering Tag is included in Appendix A. Hi-G-Tek did not provide a technical specifications sheet, but indicated that they have both a low frequency (<135 kHz) and a high frequency (900 MHz) version of their product. The tags can be written and read multiple times and have a data storage capacity of approximately 2 Kbytes. AFX only provided marketing literature and this is included in Appendix B.

#### *5.2.2.4 Future developments of the technology*

All the companies contacted for this section concur in that additional research and development would be needed to produce a device that meets the needs of a VMT based revenue collection system application.

For example, current devices are typically mounted on the windshield, which allows the reader to capture the information encoded in the tag with relative ease. To minimize the possibility of tampering, a device would have to be installed in the engine compartment, thus requiring either an increase in the output power of the reader (which is tightly regulated by the FCC) or the use of a more expensive battery-powered tag. TransCore also mentioned the possibility of developing a tag that interfaces directly with the odometer rather than with the VSS.

#### *5.2.2.5 Enhanced Integrated RF/Speed Sensor Devices*

As it will be discussed in this section, *Enhanced integrated RF/speed sensor devices* currently do not exist. The concept of an enhanced integrated RF/speed sensor device was developed in response to the initial cost estimates developed in this project, and the cost estimates for running a fee collection center (*Bertini, et al. 2002*). This concept differs from the integrated RF/speed sensor devices presented earlier by providing the capability to collect "trip" VMT. The technology employed is similar to that already discussed for integrated RF/speed sensor devices, but the devices also have the capability to have mileage collection turned off and on (automatically at border crossings), as well as having collected VMT reset to zero. The objective of this concept is to develop a lower cost vehicle-based device that could be used as a technology option for the Actual VMT at Pump scenarios. For these scenarios VMT data (rather than an accumulated Oregon VMT "odometer" reading) is required.

Discussions with TransCore engineers and scientists (*TransCore 2002*) indicate that the conceived device is technologically straightforward to develop using existing and proven technology. TransCore's rough unit cost estimate for such a device is $175 per unit (including cables). This price was based on the unit cost of the TransCore device discussed in Section 5.2.2.2.1. Installation of such a device is estimated to take about 30 minutes. Cost estimates for developing such a device could not be estimated by TransCore without more detailed technical specifications.

## 5.3 FUEL DISPENSER TECHNOLOGY

The Actual VMT at Pump with Credit, Actual VMT at Pump with Switch, and Estimated VMT at Pump with Credit Estimate Scenarios all require the use of fuel dispensers at service stations to obtain data off of a vehicle and use this data to compute and charge the appropriate tax[3]. In this section, the state-of-the-art in current fuel dispenser technology is presented.

The three major manufacturers of gasoline fuel dispensers in the U.S. are:

- Gilbarco Veeder-Root,
- Tokheim Corporation,
- Dresser Wayne.

All three companies produce fuel dispenser (fuel pump/payment system) and point-of-sale (POS) system products. The fuel dispenser pump system is the device that delivers the fuel and measures/controls the volume delivered. The payment system, if present, is the device integrated with the dispenser that a customer may interact with. A common payment system is one that accepts credit cards for "pay at the pump" functionality. The POS system is the system that integrates and stores sales information from the fuel dispensers and convenience store sales (if present at the service station).

For purposes of the three applicable scenarios, all three manufacturers produce a RF payment system that can be integrated with specific fuel dispensers and POS systems. All manufacturers use RF technology developed by Texas Instruments. The most well known current application of such systems is the Mobil "SpeedPass" system. The systems currently available can read information from a vehicle mounted RF transponder (which must be in line-of-sight).

Implementation of functionality as needed in the three scenarios is a matter of software changes (*Texas Instruments 2002*). This assumes the fuel dispenser and POS system can be integrated with the RF system and that the existing RF payment systems requiring a line-of-sight reader and tag meets scenario requirements.

Information from Gilbarco (*2002a*) indicates that implementing a state-wide revenue collection system such as in the three scenarios mentioned will require major software changes whose implementation is controlled by the oil companies. As noted in Section 4, these changes are both costly and time consuming. This again assumes that the fuel dispensers and POS systems are compatible with the RF payment system.

Data from the Measurements Department of the Oregon Department of Agriculture (*2002*) indicates that there are 1,788 service stations in Oregon and 28,163 gas pumps (fuel dispensers may contain more than one pump). Of these "pumps," 10 have RF payment capability. This data indicates that a full implementation of the "Pump Scenarios" would require a large number of fuel dispenser upgrades and retrofits. Estimates of these costs are shown in Table 4.1, where

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[3] A fuel dispenser is a system commonly referred to as a "fuel pump," but as used in this report it includes the fuel pump/volume monitoring system, the payment system, and in some cases, advertising/merchandising systems.

it was assumed that one half of the existing dispensers would need replacement and the other half will require retrofitting.

Information provided by Gilbarco (*2002a*) indicates that the average replacement cycle for a fuel dispenser is 10 to 12 years. Some of these replacements occur in conjunction with other major changes that may be regulatory requirements, such as installing double-lined fuel tanks. Many other fuel dispenser replacements are initiated by major oil companies who want to keep their facilities up-to-date.

# 6.0 EVALUATION OF VMT SYSTEM INTEGRATION OPTIONS

The three preferred scenarios from Section 4.4 (Center Scenario – GPS & RF-AVI Option, Center Scenario – ODO & RF-AVI Option, and Actual VMT at Pump with Credit/Switch – Enhanced ODO & RF-AVI Option) were examined in more detail. The approximate scenario costs were presented in Chapter 4. In this section the focus is on the following criteria:

- Durability,
- Equity (in approximating VMT if applicable),
- Security,
- Privacy,
- Reliability/Accuracy,
- Future expansion to include highway segment-based and congestion-based pricing.

For some criteria (e.g. durability) the evaluation is based on the technological components of the scenarios (Chapter 5). For other criteria, the actual performance is not known, but specific issues relative to Oregon specific applications will be presented.

## 6.1 FEE COLLECTION CENTER SCENARIO – GPS AND RF-AVI OPTION

This section focuses on the GPS technology performance in this scenario. The evaluation of RF-AVI is presented in Section 6.2.

### 6.1.1 Durability

There is very little information on hardware durability for GPS units in on-vehicle applications. This refers to the actual physical failure of the device. Manufacturer specifications for a Trimble GPS-based vehicle tracking device lists the average time between failures at 100,000 operating hours. Current applications of on-vehicle systems such as GM's On-Star and other commercial fleet management applications indicate that the durability of on-vehicle GPS-based is not an issue.

### 6.1.2 Equity

Assuming the GPS-based device computes an accurate VMT and that the system is not tampered with, this system will assess road fees directly proportional to road use.

### 6.1.3 Security

Any electronic device installed on a vehicle can be destroyed if desired. This however would be easily detected since no data would be generated for the vehicle. Of a greater threat to any GPS-based scenario is the ease in which the GPS signal can be blocked. Since GPS signals are weak and do not travel through significant physical obstructions, signal blockage is fairly easy. In particular, metal is an effective signal blocker; a small piece of aluminum foil could serve as a signal blocker. In this case the detection of such blockage would be difficult. To overcome this, redundant odometer systems can be built into the device or roof-top antennas can be used, both of which would add cost. (Although the exact amounts are not known, the added costs should be relatively small compared to other device component costs.) The security of RF data transfer will be discussed in Section 6.2.3.

### 6.1.4 Privacy

In this scenario only vehicle identification and VMT data is to be transferred. This data transfer will occur at various service stations. With this "minimum detail" information vehicles routes cannot be tracked. Additionally, only the central system receiving the VMT data could possibly monitor when vehicles have visited various service stations. This is no more information than is currently available when one uses a credit card for purchases.

### 6.1.5 Reliability/Accuracy

The reliability and accuracy of a GPS-based device to be used in this scenario are similar issues. Reliability is the ability to produce the same results for the same travel pattern. This depends primarily on inherent GPS system accuracy, signal loss and reacquisition, and initial signal acquisition. These are also factors that affect accuracy.

For a State of Oregon system, the specific features of Oregon that may affect reliability/accuracy must be considered. In particular:

- There are many trees present in highly populated areas of Oregon. Approximately 50% of the Portland area is considered wooded or contains tall buildings and other structures.
- Oregon is rainy and cloudy quite often throughout the winter.
- Oregon terrain is hilly/mountainous.

The presence of obstructions may lead to signal loss and increase the time to acquire a signal. Trees and buildings are known to increase the signal acquisition time. Data presented in Chapter 5 shows that a "warm start" (which would be typical when a vehicle is parked overnight) can take a minute in an ideal environment. In the presence of trees and buildings this time may increase such that much of the mileage for short trips is missed. GPS devices cannot capture signals in garages or other structures so that a trip may be underway when the GPS first has access to satellite signals. The stationary accuracy also decreases in the presence of obstructions so that stationary vehicles that are turned on may artificially accumulate mileage (although the quantity may be small). Water and hilly/mountainous terrain are also factors that are known to degrade GPS reliability/accuracy. Many problems may be dealt with by using more sophisticated GPS technology, but this may make the scenario too costly. Another possibility is to use a backup redundant system such as an odometer system if GPS reliability/accuracy does not perform satisfactorily.

### 6.1.6 Future Expansion to Include Highway Segment Based and Congestion Based Pricing

Assuming a GPS-based device provides sufficient reliability/accuracy, it would be technically straightforward to extend the capabilities of the device to monitor and compute miles traveled in specific regions or on specific roads. Computing miles in specific regions, however, would require the addition of information on the region boundaries to the device. Computing miles on specific roads would require controlled access with card readers. This information would then be transferred along with the total Oregon VMT. The computing capability requirements of the device would increase and a method to update information on the device would be needed. For example, there must be a method to tell the device to collect travel data on a new road if congestion on the road becomes problematic.

With increased travel information transferred there is the risk of decreased privacy. In the Minnesota Department of Transportation (MnDOT) study, "A New Approach to Assessing Road User Charges" their conceptualized system computes the road tax within the device and this data instead of VMT data is transferred. This requires updates to the fee schedule stored in the system and is one reason they employ smart card technology. Such a system, however, could not implement "real time" congestion pricing, since the vehicles would not have the latest road fee schedules (*Forkenbrock 2002*).

## 6.2 FEE COLLECTION CENTER SCENARIO – ODO & RF-AVI OPTION

### 6.2.1 Durability

Both the readers and antennae in a RF-based AVI system are highly durable. Once they are installed, there is very little maintenance needed other than software and firmware upgrades for the reader. In most cases, these upgrades can be done remotely via a network interface.

The biggest concern with durability is the RF tag. Current devices are not sturdy enough to be placed, for example, in an engine compartment to minimize the possibility of tampering. Therefore, manufacturers would have to redesign their devices to meet this specification.

### 6.2.2 Equity

Since the RF-based AVI device will interface directly with the VSS, this system is very likely to assess road fees directly proportional to road use. Accuracy figures for the devices investigated are provided in Section 6.2.5 below.

### 6.2.3 Security

As stated in the previous section, any electronic device installed on a vehicle can be destroyed if desired. If visible, RF tags can be either removed or covered with a metallic material to block the signal coming from the reader. However, once the program is fully implemented and every Oregon resident complies with it, detecting the lack of a tag would be really simple, therefore simplifying enforcing. TransCore indicated that they have approximately 12 million tags deployed in the field for ETC applications and that they have never had any issues with tampering or forging.

With regards to the security of RF data transfer, our sources also expressed that the hardware and software that is used for communication purposes between the reader and tag is very complex. Therefore, it is highly unlikely that the common citizen will have the knowledge to intercept a signal and decipher its contents.

### 6.2.4 Privacy

As with the previous scenario, only vehicle identification and VMT data is to be transferred. This data transfer will occur at various service stations and at state borders. With this "minimum detail" information, vehicles routes cannot be tracked. Additionally, only the central system receiving the VMT data could possibly monitor when vehicles visited various service stations. This is no more information than that which is currently available when one uses a credit card for purchases.

### 6.2.5 Reliability/Accuracy

A crucial component in evaluating the functionality of a RF-based AVI system is to quantify how well the system correctly reads tags passing beneath its antennas, a property defined as *reader reliability*. In one of their current EZ Pass implementations, TransCore has 1200 readers deployed in the field and is achieving read rates of approximately 99.9%. Hi-G-Tek provided similar figures for reader reliability.

For this particular scenario, ensuring that the RF tag will be able to obtain an accurate mileage reading from its interface with the VSS is also critical. TransCore reported that in tests they have performed on their AT5770 tag, this device is able to report mileage with a ± 0.5% accuracy, which in some cases, is even more accurate than commercially available odometers. Hi-G-Tek was not able to provide accuracy data for their device.

### 6.2.6 Future Expansion to Include Highway Segment Based and Congestion Based Pricing

Expansion of a RF-based AVI system to include highway segment-based and congestions-based pricing would be straightforward. Dynamic congestion pricing programs are already underway in some U.S. cities (*TransCore 2002*). In these systems, the current price for using a specific limited access facility (calculated based on real-time traffic data) is transmitted from a central location to electronic LED displays located on the side of road via cellular communications. If the user decides to travel on this artery, the price indicated on the LED display will be deducted from the user's account using the information encoded on the RF tag.

## 6.3 ACTUAL VMT AT PUMP WITH CREDIT/SWITCH SCENARIO– ENHANCED ODO & RF-AVI OPTION

### 6.3.1 Durability

Both the readers and antennae in a RF-based AVI system are highly durable. Once they are installed, there is very little maintenance needed other than software and firmware upgrades for the reader. In most cases, these upgrades can be done remotely via a network interface. The same concerns arise concerning the durability of the RF tag as discussed in Section 6.2.1. RF-based payment systems with fuel dispensers have been in use for several years and have proven to be very durable.

### 6.3.2 Equity

Since the RF-based AVI device will interface directly with the VSS, this system is very likely to assess road fees directly proportional to road use. See Section 6.2.2.

### 6.3.3 Security

Any electronic device installed on a vehicle can be destroyed if desired. If visible, RF tags can be either removed or covered with a metallic material to block the signal coming from the reader. In this scenario tampering of the device will be hard to detect within the normal envisioned operation of the system since there is no link to a centralized database of registered Oregon vehicles. It is possible to set up RF readers at various locations that can detect the presence or absence of a device.

With regards to the security of RF data transfer see Section 6.2.3..

### 6.3.4 Privacy

Unlike prior scenarios where data is sent to a central facility, only "trip" VMT data is to be transferred. In this scenario the data transfer will occur at various service stations and is not transferred beyond the service station. Therefore privacy is maintained and information that can be used to track individuals will be very difficult to obtain.

### 6.3.5 Reliability/Accuracy

See Section 6.2.5.

### 6.3.6 Future Expansion to Include Highway Segment Based and Congestion Based Pricing

See Section 6.2..6.

## 6.4 TWO-PHASE IMPLEMENTATION

Both the Center Scenario – GPS & RF-AVI Option, and the Center Scenario – ODO & RF-AVI Option call for the same method of data transfer (RF transfer at service stations) to a Fee Collection Center. They differ in the on-vehicle device employed and the data transferred. In both options only a small quantity of data is transferred. The ODO & RF-AVI Option employs a less costly non GPS-based device and may be considered less risky from a technological perspective since RF-AVI devices have been used in toll and commercial vehicle applications.

It is feasible to have a two-phase implementation that starts with the ODO & RF-AVI Option and migrates to the GPS & RF-AVI Option if needed. The ODO & RF-AVI Option is capable of collecting Oregon VMT for a vehicle, and the RF-AVI component of the system can be used as the on-vehicle device in a real-time congestion pricing system. However, as discussed earlier, it would be difficult to extend the ODO & RF-AVI Option so that VMT is collected by geographic zone within Oregon, as would be required in an area pricing system. The GPS & RF-AVI Option could be phased in if and when an area pricing system were implemented. The RF-AVI component of the system could still be used as in the ODO & RF-AVI Option as part of a real-time congestion pricing system. The infrastructure established for data collection and transfer would not have to change between options.

# 7.0 VMT TAXING OPTIONS FOR ELECTRIC AND HYBRID-ELECTRIC VEHICLES

## 7.1 ELECTRIC VEHICLE

A high capacity battery, usually a Lithium-Ion battery, powers electric vehicles. This limits its usage since the very latest Lithium-Ion battery can only store energy for about 50 miles. Therefore, these vehicles must recharge their batteries every 50 miles. This limitation led to the advent of a new class of vehicle that can stay on the highway for longer range – the "Hybrid Electric Vehicle."

## 7.2 HYBRID ELECTRIC VEHICLE (HEV)

Hybrid Electric Vehicles (HEVs) combine two or more energy conversion technologies (e.g., heat engines, fuel cells, generators, or motors) with one or more energy storage technologies (e.g., fuel, batteries, ultra-capacitors, or flywheels). The combination of conventional and electric propulsion systems offers the possibility of greatly reducing emissions and fuel consumption, while giving consumers both the extended range and convenient refueling they expect from a conventional vehicle. Advanced propulsion technologies are key to the success of HEVs and to the realization of these advantages.

There are a number of competing and complementary technologies, which could potentially be utilized in a commercial HEV propulsion system. All HEVs require a hybrid power unit (HPU), usually an internal combustion (IC) engine. There are two basic HEV configurations: series and parallel (*U.S. Department of Energy 1999*).

### 7.2.1 Series HEV

In a series HEV, a small fuel-burning engine directly drives an alternator to generate electricity. The electricity is then stored in the batteries or sent to the electric motor, which then powers the wheels. The vehicle can operate in zero-emissions mode, and when the batteries are drained to a certain level, the engine turns on and begins to recharge them. Since it is less dependent on the vehicle's changing power demands, the engine can operate within a narrower and more efficient range of speeds. A typical configuration for a series HEV is depicted in Figure 7.1.

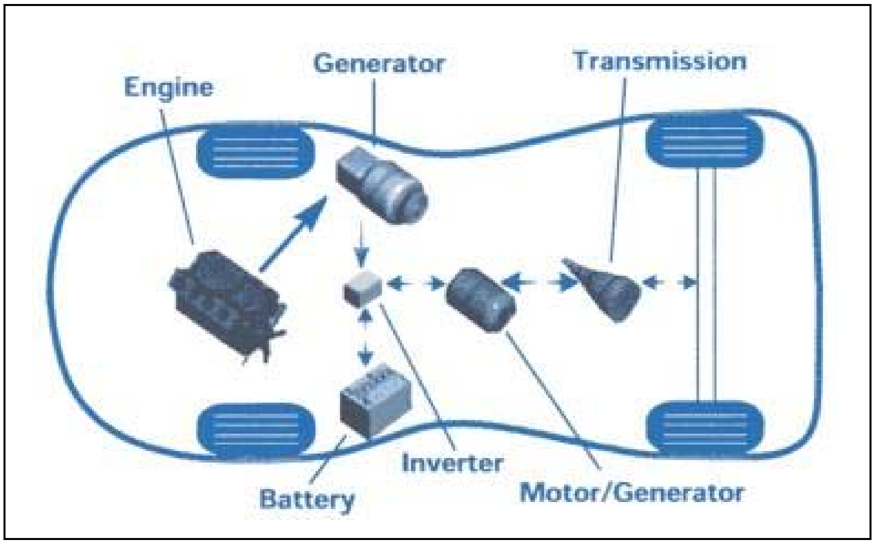


Figure 7.1: Series HEV configuration

### 7.2.2 Parallel HEV

A parallel HEV is configured with two power paths, so that either the HPU engine or the electric propulsion system – or both – can be used to produce the motive power to turn the wheels. In one approach, the electric only mode can be used for short trips. For longer trips, the engine would provide primary power to the vehicle, with the electric motor assisting during hill climbs, fast acceleration, and other periods of high power demand. In such a vehicle, the engine can be downsized in relation to a similar-sized conventional vehicle, reducing weight and providing greater relative fuel economy. A typical configuration for a series HEV is depicted in Figure 7.2.

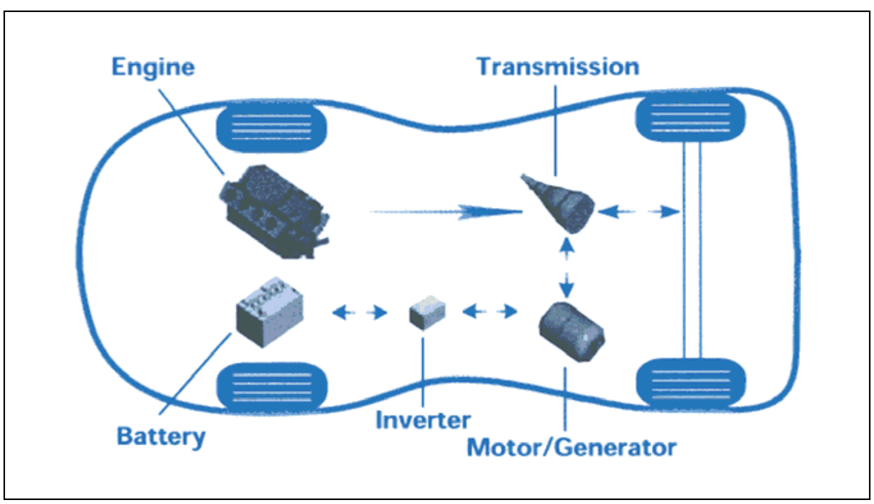


Figure 7.2: Parallel HEV configuration

## 7.3 DEVICES TO COLLECT DATA ON ENERGY CONSUMPTION

The US Department of Energy's Office of Transportation Technologies has conducted electric vehicle tests. In their tests they have collected information about energy use, maintenance requirements, and the effects of accumulated mileage on vehicle ranges. Energy use is collected with on-board devices conductively charged or mounted on dedicated chargers for vehicles that are inductively charged. The energy data is collected in kilowatt-hours (kWh).

There are two different types of Hybrid vehicles: Hybrid A and Hybrid B. Hybrid A vehicles are 50% more fuel-efficient than the traditional gasoline vehicle whereas Hybrid B are 100% more efficient. The cars that we see now fall under the category of Hybrid A. Hybrid A is projected to take 24% of the market in 2010. Projections for 2020 indicate that Hybrid A vehicles will take 21% of the market whereas Hybrid B vehicles will take 19% (*Office of Transportation Technologies 2002*).

In discussions with research engineers from the Department of Energy (DOE), incorporating a device within the existing computers that would track energy consumption in electric and hybrid vehicles should be feasible. Such a device is currently not available, however, and would therefore need to be developed if required under an electric power consumption fee system.

# 8.0 CONCLUSIONS AND FINAL RECOMMENDATIONS

The major conclusions obtained from this research are as follows:

- Many current Automatic Vehicle Identification and data collection technologies are clearly not appropriate for a VMT based revenue collection system.
- Scenarios involving on-vehicle GPS devices are by far the most costly for total system implementation. Data transfer at fuel dispensers is the most costly method (from a hardware perspective) for obtaining vehicle VMT data.
- Current on-vehicle devices for the GPS & RF-AVI, ODO & RF-AVI, and Enhanced ODO & RF-AVI technology options are not commercially available. If testing of these scenarios is to commence in July 2003, enough lead time would be needed to perform the required development activities. Three companies have devices with functionality close to that desired for the application at hand. These companies are:
  - ✓ 308 Systems
  - ✓ TransCore
  - ✓ AFX Technology Group International, Inc.
- Privacy issues arise when using GPS-based systems in a road segment and congestion pricing system. They are not well suited to “real time” congestion pricing.
- Scenarios involving fuel dispensers may have significant control and cost issues with implementation.
- Extensive testing will be required before any system is implemented.
- Monitoring electricity consumption on hybrid vehicles is feasible but devices for doing so are not commercially available.

Based on these conclusions, our recommendations to ODOT are as follows:

- Define specific functional and technical requirements for the preferred scenarios. For example, what is the VMT accuracy required? What is the expected operating life for a device?
- Define technical specifications for the technology used in the scenarios to meet the functional requirements. Test various technologies when the exact specifications are not known. For example, testing would be required to determine what GPS specifications would be needed to meet the required accuracy and signal availability.
- Consider implementing an electronic VMT-based revenue collection system in phases. The system would have to be designed in such a way that it evolves with technology so that, as new capabilities arise, these could be incorporated without disturbing the existing system.

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# APPENDICES

# APPENDIX A

TRANSCORE

PRODUCT PROFILE

# AT5770 External Metering Tag

## FEATURES

- **The external metering tag emulates a full-frame (120 bit) ATA/ISO tag.**
- **Operation not affected by temperature extremes or shock and vibration typical of vehicle environments**
- **Case that provides resistance to chemicals and other agents typically found in transportation environments**
- **Capability to program optional firmware using host software. The programmable parameters are initial odometer reading, scaling factors, and vehicle identification (ID).**
- **Can be reprogrammed in the field or in maintenance facilities using the Amtech AP4270 Programmer/ Tester**


The AT5770 External Metering Tag is a single-frame dynamic tag designed for use on vehicle exteriors. It is used in asset tracking and counting applications such as odometer tracking, tachometer tracking, event tracking and counting, pulse counting, and on-board sensor monitoring.

The external metering tag stores up to 128 bits of data providing 10 (6-bit ASCII) alphanumeric characters for the asset identification (ID) and dynamically provides 24 bits of data for counting applications. The tag provides two internal user input parameters for the counting value. For example, when used as an odometer meter, the user would input the vehicle's values for the tire revolutions per mile and axle ratio.

The AT5770 uses a wire interface for signal inputs. Near real-time signals update the dynamic tag frame data using inputs from external sensors. The tag is contained in a small, exterior-mounted case. An 8-pin connector is provided on the back of the tag case for an external cable assembly providing signal input and tag power.

The AT5770 receives signals from a vehicle speed sensor (VSS) for processing and conversion to a distance measurement for odometer encoding. Conversion factors for distance calculation are combined as a scaling factor and stored in the tag. Distance data is then modulated continuously in the tag frame and read by an external reader.

Data is encoded (modulated) onto the received radio frequency (RF) carrier and the signal is reflected (backscattered) back to the reader for decoding and processing.

SPECIFICATIONS

# AT5770 External Metering Tag

## COMMUNICATIONS

**Frequency Range**
902 to 928 MHz

**Working Range (Typical)**
Up to 21.3 m (70 ft) at 915 MHz
Range depends on system parameters.

**Polarization**
Horizontal, parallel to tag's long axis

## HARDWARE FEATURES

**External Connections**
Eight-pin connector on the tag's back panel

| Pin | Description |
|---|---|
| 1 | Power |
| 2 | Ground |
| 3 | Data/test |
| 4 | Clock |
| 5 | Vpp programming voltage |
| 6 | VSS input signal + |
| 7 | VSS input signal – |
| 8 | Discrete 1 |

## POWER REQUIREMENTS

**Power Source**
External, +12 V DC

## LIFE EXPECTANCY

**Service Life**
10 years minimum

## STANDARDS

**Safety Standards**
AT5770 complies with the requirements of Underwriters Laboratories UL–1950, Standard for Safety of Information Technology Equipment.

## SOFTWARE FEATURES

**Data Memory (128 bits)**

| Bits | Description |
|---|---|
| 0-59 | 10 char asset ID (6-bit ASCII) |
| 60-61 | First checksum |
| 62-63 | First frame marker |
| 64-87 | Dynamic counter value (24-bit binary) |
| 88-105 | NOT USED |
| 106-111 | Security field (6-bit ASCII) |
| 112-117 | Security field (6-bit ASCII) |
| 118-123 | NOT USED |
| 124-125 | Second checksum |
| 126-127 | Second frame marker |

## PHYSICAL ATTRIBUTES

**Dimensions**
**Size:** 11.9 x 6.4 x 3.0 cm
4.7 x 2.5 x 1.2 in

**Weight:** 150 g (5.3 oz)

**Case**
Sealed, polycarbonate alloy, weatherproof, UV stabilized

**Mounting Surface**
Flat metallic, using the tag mounting flanges

**Mounting Method**
Rivets, TIR fasteners, screws, bolts

## ENVIRONMENTAL PARAMETERS

**Operating Temperature**
-40°C to +85°C (-40°F to +185°F)

**Humidity**
95% noncondensing

**Vibration**
1 $G_{rms}$, 15 to 2000 Hz

**Shock Tolerance**
5 G, 1/2 sine pulse, 10 ms duration, 3 axis

## OPTIONS

**Factory Programming**
Operating parameters can be programmed and initialized at the factory to user specifications.

**Custom Labels**
All required identification can be displayed on the tag with an adhesive label. Limited ID information can also be permanently laser-etched into the tag case.

**Custom Colors**
The standard color is red. The AT5770 tag may be custom ordered in a range of colors. Special conditions may apply.

**Custom Cable Interface**
All required definitions of the interface are provided to allow custom cabling. Included are configurations of connectors, cable types, color schemes, wire termination definition, and conductor types. An unwired interface connector is also available.

## ACCESSORIES

Amtech AP4270 Programmer/Tester and PC host software

## DOCUMENTATION

AT5770 External Metering Tag User Guide

AP4270/AT5770 Installation Guide

TRANSCORE

**For more information on Amtech® products, call:** 1.800.923.4824 or 972.733.6600 (outside the U.S.) Fax 972.733.6699

www.transcore.com



411507-003 07/01

# APPENDIX B

# Application Profile

AFX Technology Group International Inc. — Asset Tracking

## AssetManager™

### Introduction

AssetManager is a superior two-way intelligent wireless telemetry solution for tracking containers, trailers, railcars, and other transportation assets using *MinionNet*® technology. *MinionNet* is enabled by intelligent transceivers, known as *Minions*™.
*Minion* advantages include:

- Very low cost
- Small package size
- Extremely low power dissipation
- Ease of installation and maintenance
- Frequency agile for domestic and international application

The local processing capability of *Minion* devices permits exception reporting, such as seal integrity and sensor inputs, without the need to poll every device to identify out-of-spec conditions and other types of alarm situations.

AssetManager *Minion* devices can handle multiple applications and are able to effectively communicate among themselves, sharing and passing data along via the *MinionNet* network, even for applications that are not resident on a particular device. To assure ease of integration into legacy and other client applications, AssetManager technology is easily integrated into existing wired or wireless wide area networks (WANs).

### Asset Management and Load Integrity

The need for an automated system to remotely track and monitor mobile assets within the freight mobility community is obvious from both a financial and security standpoint. To date the main roadblock to implementing a global solution has been the availability of a technology that is robust, secure, cost effective, covers both local and wide area needs, can be easily and quickly deployed, and requires minimal maintenance. The simple need to know an asset location, whether the load integrity has been breached, and when it arrived or departed typically requires a great deal of manpower and manual processing. That is, until now...

**Introducing AssetManager from AFX...**

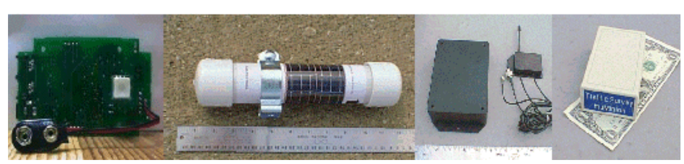
### AssetManager Solution

AssetManager provides the ability to locate, identify, and track the status of freight mobility assets at all times. This is accomplished via automatic status reporting using *MinionNet* technology, which eliminates the need for manual processes, thus saving tremendous amounts of time, manpower and money.

AssetManager has been designed to be extremely flexible, allowing devices and networks to be remotely configured and upgraded without the need to physically touch each *Minion* device. *Minions* can be configured to interface with electronic seals, volumetric sensors, motion detectors, and other inputs to provide asset identification and condition as desired by the user. In addition to uploading status notification, the *MinionNet* network is used to download soft configuration changes to specific devices dynamically.

### Asset Management Architecture

AssetManager *Minion* devices are installed on light poles, buildings, gates, signs, cranes, and other facility locations as desired, in addition to the mobile assets being monitored. The combination of wireless fixed and mobile *Minion* devices form a local network that tracks asset location and status. These devices communicate with each other and pass data along, ultimately providing critical asset information to the *gatewayMinion* inside the terminal, distribution center, container ship, locomotive, or power unit. From the gateway, information is passed on to the Network Operations Center (NOC) via a Wide Area Network (WAN) connection (satellite, cellular, POTS, 802.11 wireless, ethernet, etc.). Authorized personnel can access data via the Internet, or a customer client/server application via your corporate LAN. All data is encrypted for security purposes.



## AssetManager Benefits

*Security:*

- Notification if an asset has arrived or departed, and if the asset condition has changed, such as when a seal is broken or door is opened (as determined by sensor inputs)
- Immediate notification to the proper authorities of a missing or tampered asset
- When used with automatic gates, *Minions* can be used to electronically authorize facility access/egress and log gate transactions

*Productivity:*

- Tracks asset utilization to optimize existing assets and aid in equipment purchase decisions
- Low battery detection and notification
- In addition to assets, can be used to identify and track personnel, and authorize access
- Provides management metrics tool for process improvement, such as tracking equipment moves within a facility
- Installation requires virtually no civil or electrical expense - can be installed temporarily or permanently within a facility
- Mobile devices can be installed in less than a minute (ID only devices, sensor devices may take a little longer)
- No daily physical inventory required to check for "missing" assets

*Location:*

- Locates a desired asset using message hop counts, physical location of fixed devices, signal strength measurements, and/or onboard GPS or RTLS capability

## AssetManager Components

*AssetManager Database:*

- Physical location where asset transaction data is stored
- Generates and maintains reports, inquiries and all other pertinent data in customer defined format
- No special software or hardware needed - a standard web browser and PC can be used to access database
- AssetManager data can be integrated into legacy customer applications, and new applications can be easily developed. Data from the AssetManager database is portable into customer specific applications to provide a seamless system from the user perspective
- Easy to set up and operate.

*Fixed AssetManager Devices:*

- Collect data from mobile assets and forward it to the gateway AssetManager device
- Receive commands from the gateway devices to distribute information and software updates via the *MinionNet* network to any or all *Minion* devices
- Aids in the location of mobile assets
- Installed on gates, light poles, sign posts, buildings, and any other structure using standard commercially available hardware
- Plugs into existing power, or battery/solar powered
- No expensive or permanent civil, electrical, or communications installation required

*Mobile AssetManager Devices:*

- Installed in or on mobile assets
- Installation and set-up time is less than one minute (ID only, sensor interface may take a little longer)
- Generates asset data destined for the AssetManager server database
- Monitors and forwards asset and device activity and status
- Monitors and forwards asset general location in reference to fixed devices

*Gateway AssetManager Devices:*

- Network interface for transferring data to and from the field and the AssetManager database
- Gateway devices are installed at the terminal or distribution center (fixed locations) and/or on the container ship, locomotive, power unit or other mobile platforms with onboard computing and wireless communications capability, as desired to integrate AssetManager *MinionNet* Network data into traditional customer WAN
- Standard PC internet connection provides the WAN connection necessary to transfer data to and from the AssetManager database
- Provides time and date synchronization for the AssetManager System
- Discards unnecessary or duplicate data to maximize storage and network efficiency

## AFX Deliverables

- Provide customer the ability to monitor assets locally and globally
- Provide required fixed, mobile, and gateway AssetManager *Minion* devices, including hand held devices to program *Minions* in the field (if required)
- Provide secured access to AssetManager data via the Internet and/or corporate LAN
- Provide installation instructions and support for fixed, mobile and gateway AssetManager *Minion* devices

AFX Technology Group International Inc.
4407 N. Beltwood Parkway, Suite 108
Dallas, Texas 75244-4215
Phone: 972.858.4215
Fax: 972.858.6163
Visit us at www.afxtech.com
E-mail at afxinfo@afxtech.com
AFXMA02-01

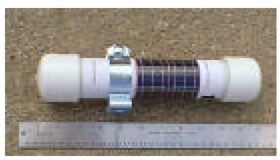
# PRODUCT PROFILE

AFX Technology Group International Inc. Product Profile

# MinionNet® Technology

## INTRODUCTION

*MinionNet®* is a two-way intelligent wireless telemetry technology solution developed by AFX Technology Group International, Inc. (AFX), which utilizes very low cost, small package transceivers with extremely low power dissipation, known as *Minions*™. *Minion*s can handle multiple applications, including monitoring equipment and personnel status, device location, out-of-spec asset conditions and alarms, and many others. Local processing and I/O capability inherent in each *Minion* permits exception reporting without the need to poll every device. As illustrated in Figure 2, *Minions* share and pass data from device to device via the *MinionNet* Network and are easily integrated into legacy and other client applications, interfacing with existing wired and wireless wide area networks (WANs) via *gatewayMinions*.



## MINIONNET HARDWARE DEVICES

Individual *Minion* devices are packaged in a multitude of ways as dictated by the desired application. The I/O interface and microcontroller is configured to collect data from both analog and digital sensors as desired. When *Minion* devices exchange information with each other, they become part of a "community" that shares the workload of conveying messages throughout a defined area. Messages are automatically routed through multiple device-to-device 'hops' to provide robust area coverage, redundancy, noise immunity, dynamic routing, and network self configuration.


## NETWORK COMPARISONS

The *MinionNet* concept is in stark contrast to traditional networks (*see figure 1*), which require the installation of an expensive fixed infrastructure to enable communications. Cellular phones, for example, require that every subscriber phone communicates only with the cellular base station. Even though there may be thousands of actual phones in the area, they are not capable of direct communication with one other.

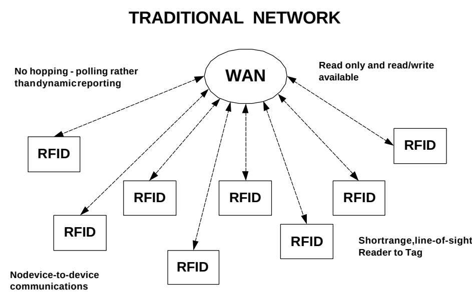



*Figure 1 - Traditional Network Scheme*

Applications such as cellular communications promote the perception that robust real-time connections are a requirement of every wireless network. Real-time connections are very expensive in terms of equipment and air-time. Many wireless data applications have been designed around real-time communications because an existing infrastructure was believed to be available. Unfortunately, many more potential value-added applications have not been implemented because the infrastructure was not available, and the investment required to complete the solution was cost prohibitive. With MinionNet *(see Figure 2*), the requirement for a real-time connection is an artificial constraint, thus enabling the implementation of cost effective wireless telemetry solutions for a broad range of applications, whether "mobile-to-fixed", "mobile-to-mobile" or "fixed-to-fixed", as shown below.

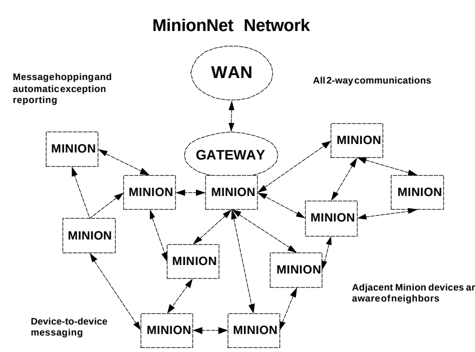



*Figure 2 - MinionNet Network Scheme*

## Asset/Collateral Tracking

- Facility yard management of mobile inventory, vehicles and equipment.
- Collateral location detection and notification
- Telemetry asset condition, usage and service monitoring

## Building and Residence Controls

- Thermostat and condition monitoring and notification
- Personnel access management and control
- Event and device detection, notification and response

## Human Services

- Dependent movement notification
- Emergency condition notification
- Restricted movement and activity monitoring
- Emergency equipment locator

## Intelligent Traffic Management

- Traffic movement time, reporting and response
- Parking, toll and tariff management
- Mass transit information and notification
- Priority vehicle access and signal light preemption
- Low cost and unobtrusive vehicle presence detection

## Material Handling, Freight Mobility and Security

- Container, trailer and railcar condition and security
- Load monitoring and seal integrity
- Cargo tracking
- Hazardous material or environmental event alert

## Utility and Energy Services

- Power load, consumption and management
- Remote condition and outage notification
- Metering and detection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