TECHNOLOGY DEVELOPMENT AND SYSTEM INTEGRATION FOR A VEHICLE MILES TRAVELED BASED REVENUE COLLECTION SYSTEM PROTOTYPE

Test Results

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1.0 INTRODUCTION

This document presents the test results from the evaluation of the performance of the prototype GPS-based and Odometer-based technology configurations developed by Oregon State University (OSU). These prototype technology configurations were developed for the project *Technology Development and System Integration for a Vehicle Miles Traveled Based Revenue Collection System Prototype*, sponsored by the Oregon Department of Transportation (ODOT) and the Federal Highway Administration (FHWA). An overview of the prototype technology configurations and a detailed description of the tests and assessments conducted are presented in the *Test Plan* V1.0 (referred to as *Test Plan*), which accompanies this document. The *Test Plan* was developed to assess the performance of the technology configurations relative to key performance areas defined by the Road User Fee Task Force and this project's technical advisory committee.

2.0 DATA COLLECTION AND ANALYSIS

Before presenting test results, a review of the rationale and methods for data collection and analysis is presented. This material is taken from *Test Plan* document and is presented here for completeness.

2.1 TEST REPLICATIONS AND STATISTICAL ANALYSIS

2.1.1 Test Replications

The performance tests documented in the test plan were repeated multiple times. The number of replications was dictated by two considerations:

1. The time to execute a test, and
2. The number of replications required to make statistically significant conclusions with a pre-specified level of precision.

When the time to execute a test imposed a practical limit on the number of tests that could be executed, then the maximum possible number of test replications was performed. Where time was not a limiting factor, the minimum number of test replications to satisfy consideration 2 was executed.

2.1.2 Statistical Analysis

The physical tests in this test plan are of two basic types. The first type of test is an assessment of a probability where the test outcomes are binary. For example, the reliability test is based on the success or the failure (i.e., 1 or 0) of an outcome of some system function. The second type of test is a comparison of differences in mileage between the figure reported by the vehicle's odometer and the mileage collected with the various on-vehicle devices developed in this project.

For the first type of test, a total of *n* test replications were used. The number of successful outcomes out of the total *n* replications was represented as *x*. The desired level of confidence for an estimate of the true reliability level (*p*) is a confidence level of 98%. Given a total of *n* replications and *x* successful outcomes, the upper (p_U) and lower (p_L) limits of the confidence interval for *p* were calculated as follows.

$$p_U = \left(1 + \frac{n-x}{(x+1)F_{2(x+1),2(n-x),\alpha/2}}\right)^{-1} \qquad \text{Equation 1}$$

$$p_L = \left(1 + \frac{n-x+1}{xF_{2x,2(n-x+1),1-\alpha/2}}\right)^{-1} \qquad \text{Equation 2}$$

In the above equations, the term $F_{i,j,\beta}$ denotes the inverse of an F-distribution with *i* and *j* degrees of freedom such that the cumulative probability of the F-distribution equals β .

For the mileage collection comparison tests, the outcomes were the percent difference in mileage collection between the vehicle's odometer and the on-vehicle device. Let d_i represent the percent difference in mileage collection for the *i*th replication of a mileage comparison test, calculated as:

$$d_i = \frac{vd_i - O_i}{O_i} \qquad \text{Equation 3}$$

where vd_i is the mileage collected from the on-vehicle device on the *i*th test replication and O_i is the mileage collection from the vehicle's odometer on the *i*th test replication.

Given a total of *n* replications $vd_i, i = 1,2,\ldots,n,$ a confidence interval (i.e., a standard "t confidence interval") was constructed. The desired level of precision was set at $\pm 1\%$ (although this level of precision required an unpractical number of test replications).

2.2 ASSUMPTION REGARDING ON-VEHICLE DEVICES

Prior to conducting the performance tests, an evaluation was conducted to ensure that mileage collection by all devices was the same. To do so, mileage was collected with each device and compared to the odometer readings. There was less than a 5% difference in mileage collection among units. Based on this determination, units were considered equal and were chosen at random for use in the performance tests.

3.0 TEST RESULTS FOR THE GPS-BASED TECHNOLOGY CONFIGURATION

For a detailed explanation of each test, please refer to the *Test Plan*. Also note that the number for each heading below corresponds to the same heading in the *Test Plan*.

3.1 RELIABILITY TESTS

3.1.1 Basic Reliability Test

The *Basic Reliability Test* assesses the reliability of a prototype technology configuration with respect to successfully completing simulated fuel purchase transactions requiring the incorporation of a VMT fee based on the mileage collected by a vehicle (using the on-vehicle device). To successfully complete such a fuel purchase transaction, the functions of reading VMT data from a vehicle's on-vehicle device, processing the correct VMT fee, and adding this fee to the fuel price (and not applying the per gallon fuel tax) must all be completed successfully. This requires successful interactions among the system components, such as the OSU Software, POS system and fuel dispenser simulator, RF host computer, and central DB.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The transaction was applied to the correct pump number.
- The database record matched the manually recorded data for each transaction.

An error message or incorrect data for either of these measures constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 1 shows the results for the basic reliability test. Table 1 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 1. Results for Basic Reliability Test

Number of Transactions	Number of Successful Transactions	Number of Unsuccessful Transactions	98% Confidence Interval for Probability of Success	
			Upper	Lower
15	13	2	0.990	0.547

The 98% confidence interval with a lower limit of 0.547 and upper limit of 0.99 is fairly large and is limited by the time to execute the tests. Precision on the order of $\pm 1\%$ will require a very large number of transactions. For future work, alternative methods will be explored for this analysis.

The two transaction failures occurred when no VMT information could be retrieved from the on-vehicle device.

3.1.2 Discontinued Fueling Transaction Test

The objective of this test was to ensure that the Central DB was not updated with on-vehicle device data when a fueling transaction was cancelled before completion.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The Central DB record for the vehicle was the same before and after the cancelled transaction.

An error message or incorrect data for this measure constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 2 shows the results for the discontinued fueling transaction test. Table 2 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 2. Results for Discontinued Fueling Transaction Test

Number of Transactions	Number of Successful Transactions	98% Confidence Interval for Probability of Success	
		Upper	Lower
5	5	1.000	0.398

Again, the upper and lower limits of the confidence interval define a large range, which is due to the time required to execute the tests. The reason for the large range is that with 5 transactions, a large range of “true” values for the probability of success are likely to result in 5 successful transactions.

3.1.3 No On-Vehicle Device Test

The objective of this test was to ensure that the fuel tax was applied to the correct pump at the POS system for vehicles without an on-vehicle device.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The fuel tax was included for this transaction.

An error message or incorrect data for this measure constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 3 shows the results for the no on-vehicle device test. Table 3 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 3. Results for No On-Vehicle Device Test

Number of Transactions	Number of Successful Transactions	98% Confidence Interval for Probability of Success	
		Upper	Lower
5	5	1.000	0.398

Again, the upper and lower limits of the confidence interval define a large range due to the time required to execute the tests.

3.1.4 Multiple On-Vehicle Devices Test

The objective of this test was to determine whether successful transactions between the system components could be achieved when multiple on-vehicle devices were present. This test examined the reliability of the system under likely working conditions when there are multiple on-vehicle devices and Fixed Minions.

Three configurations of two test vehicles were used to conduct this test. The location of the on-vehicle devices on the test vehicles was fixed but the relative orientation of the test vehicles was changed to simulate scenarios that may occur at a real fueling station.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The transaction was applied to the correct pump number.
- The database record matched the manually recorded data for each transaction.

An error message or incorrect data for either of these measures constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Results presented in the following subsections compare the reliability of the test units and are presented based on the following configurations.

3.1.4.1 Configuration 1

Configuration 1 was designed to test reliability when two on-vehicle devices are close together and the test Fixed Minion is close to the on-vehicle device being considered for the transaction.

Table 4 shows the results for configuration 1. Table 4 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 4. Results for the Multiple On-Vehicle Devices Test for Configuration 1

Number of Transactions	Number of Successful Transactions	98% Confidence Interval for Probability of Success	
		Upper	Lower
5	5	1.000	0.398

3.1.4.2 Configuration 2

Configuration 2 was designed to test reliability when two on-vehicle devices are far apart and the test Fixed Minion is close to the on-vehicle device from which VMT information will be requested.

Table 5 shows the results for configuration 2. Table 5 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 5. Results for the Multiple On-Vehicle Devices Test for Configuration 2

Number of Transactions	Number of Successful Transactions	Number of Unsuccessful Transactions	98% Confidence Interval for Probability of Success	
			Upper	Lower
5	4	1	0.998	0.222

The single failure occurred when the on-vehicle device could not be found by the Fixed Minion once the transaction was started from the dispenser.

3.1.4.3 Configuration 3

Configuration 3 was designed to test reliability when two on-vehicle devices are far away from each other and the test Fixed Minion was far away from the on-vehicle device which VMT information was to be read off.

Table 6 shows the results for configuration 3. Table 6 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 6. Results for Multiple On-Vehicle Devices (Configuration 3) Test

Number of Transactions	Number of Successful Transactions	Number of Unsuccessful Transactions	98% Confidence Interval for Probability of Success	
			Upper	Lower
5	2	3	0.894	0.033

The results suggest that more development is required to increase system performance in Configuration 3. Since additional development may also affect the other configurations, the prior tests (i.e., configuration 1 and 2) will have to be repeated.

The three failures occurred when the on-vehicle device could not be found by the Fixed Minion once the transaction was started from the fuel dispenser.

3.2 ACCURACY TESTS

3.2.1 Accuracy Test

To compare mileage collection accuracy across the three types of on-vehicle units (GPS, Hybrid GPS/ODO, and Odometer), the Accuracy Test results for all three types of on-vehicle devices are discussed here together.

The Accuracy Test assessed whether the mileage collected with the GPS, Hybrid, and Odometer-only on-vehicle devices was statistically different from that obtained from the test vehicles' odometer. The accuracy of the test vehicles' odometers was verified by comparing odometer mileage collection with measured mile posts.

For all units, a randomized block design was used to test the influence of the following factors on mileage collection:

- Weather
  - Clear Sky
  - Rain
- Geography
  - Urban[1]
  - Forest
  - Corvallis test route

Data collected in this test was analyzed by conducting multifactor ANOVA. The following subsections compare the accuracy of the different on-vehicle units based on the test route.

[1] Due to time constraints, the Odometer-only units were **not** tested on the Urban test route.

3.2.1.1 Corvallis Test Route

The Corvallis test route was designed to test driving conditions typically found in Oregon towns and small cities. Based on the results shown in Table 7, , there were no differences in mileage collection for the Corvallis test route based on:

- Type of unit (GPS, Hybrid GPS/ODO, Odometer-only), or
- Weather (clear sky, rain)

Table 7. Mean (Percent Miles Collected by Unit Compared to Miles Collected by Vehicle Odometer) and 95% Confidence Interval under Rainy and Clear Skies for "n" Trials.

Unit	Weather	n	Mean (%)	95% CI
GPS	Rainy	3	100.2	91.3-109.1
GPS	Clear sky	4	99.0	91.3-106.6
Hybrid	Rainy	3	100.2	91.3-109.1
Hybrid	Clear sky	5	94.2	87.4-101.1
ODO	Rainy	3	99.3	90.4-108.1
ODO	Clear sky	3	100.1	91.3-109.0

With the exception of the Hybrid units tested during clear skies, all units collected mileage within 2% of that recorded by the vehicle odometer. Note that that data collection for the Hybrid units included one outlier, which decreased the accuracy of mileage collection to an average of 94.2% of that collected by the vehicle odometer. With the elimination of the outlier, the Hybrid units collected mileage as accurately (within 2%) as the GPS-only or Odometer units.

Therefore, these results suggest that all the units collect miles with a high degree of accuracy under driving conditions found in the majority of Oregon.

3.2.1.2 Forest Test Route

The Forest test route was designed to test the following conditions/concerns:

1. Sinuosity and how well the on-vehicle devices deal with curves when accumulating distance.
2. Hilly terrain and how well the GPS fixes its vertical position (z-axis) for the calculation of distance.
3. The impact of a heavily forested environment on GPS signal loss, and the magnitude of "multipath" errors on mileage collection.

The results for this test are shown in Table 8. For the Forest test route, there were statistically significant differences in mileage collection based on the type of unit. Mean mileage collection by the Odometer units (102.6%) was significantly different than

mileage collection by the GPS units (75.8%) and Hybrid units (71.8%) which did not differ significantly from each other.

Table 8. Mean (Percent Miles Collected by Unit Compared to Miles Collected by Vehicle Odometer) and 95% Confidence Interval under Rainy and Clear Skies for "n" Trials.

Unit	Weather	n	Mean (%)	95% CI
GPS	Rainy	3	71.5	51.9-91.0
GPS	Clear sky	4	80.1	63.2-96.9
Hybrid	Rainy	3	54.9	35.4-74.4
Hybrid	Clear sky	3	88.1	68.6-107.6
ODO	Rainy	3	105.0	85.5-124.5
ODO	Clear sky	4	100.3	83.4-117.2

Although weather did not have a statistically significant effect on mileage collection at the 95% level, the decline in mean mileage collection under rainy skies for the GPS and Hybrid units suggests that inclement weather can impact mileage collection accuracy.

Note that although the Hybrid units use the VSS to collect miles, the placement of the miles into the proper zone is based on location and time information gathered via GPS. Without a GPS signal, the Hybrid units discard the incomplete mileage information instead of accruing the miles. This suggests that future modifications must be made to the Hybrid device to send mileage to a "default" mileage accumulator when a GPS signal is lost. With this added feature, there will be no difference in total mileage collection between the Hybrid and Odometer-only on-vehicle devices.

Additionally, for GPS-only on-vehicle devices, the loss of mileage collection when a GPS signal is lost also depends on "recovery" methods used when a GPS signal is reacquired. Information on the recovery methods used on the on-vehicle devices and how these methods compare to those used on commercial GPS units was not available.

3.2.2 Start Test

The Start Test assessed whether the mileage collected with the GPS-only on-vehicle device and a Hybrid on-vehicle device with warm and cold starts was statistically different from that obtained from the calibrated odometer. The test also compared whether there was a significant difference in signal acquisition time for warm and cold starts. For testing purposes, warm and cold starts were considered as follows:

- Warm starts were defined as an on-vehicle device sitting unused for 1 day (24 hrs. +/- 4 hrs.)
- Cold starts were defined as an on-vehicle device sitting unused for 3 days (72 hrs. +/- 6 hrs.)

The mileage collected in the Start Test was compared to that collected during the Accuracy Test (on the Corvallis test route). The mileage collection was statistically

different. During the Accuracy Tests, the on-vehicle units acquired a GPS signal before the mileage collection started.

The results for the Start Test are presented in Tables 9 and 10. Table 9 presents the mean signal acquisition times (in seconds), whereas Table 10 shows the mean percent miles collected by unit compared to miles collected by vehicle odometer.

Table 9. Mean signal acquisition times (in seconds) and 95% confidence interval for cold and warm starts for n trials.

Start	Unit	n	Mean (sec)	95% CI
Cold	GPS	5	157	74-239
Cold	Hybrid	5	247	63.2-96.9
Warm	GPS	5	133	51-216
Warm	Hybrid	5	155	72-238

Table 10. Mean (percent miles collected by unit compared to miles collected by vehicle odometer) and 95% confidence interval for cold, warm, and hot starts for n trials.

Start	Unit	n	Mean (%)	95% CI
Cold	GPS	5	93.0	85.2-100.9
Cold	Hybrid	5	89.8	82.0-97.7
Warm	GPS	5	96.2	88.3-104.0
Warm	Hybrid	5	95.5	87.6-103.4
Hot	GPS	4	99.0	85.2-100.9
Hot	Hybrid	5	94.2	86.4-102.1

According to the results shown in Table 9, it took units an average of 202 seconds (3.36 min) to acquire a GPS signal after 3 days of non-use (cold start) and an average of 144 seconds (2.40 min) to acquire a GPS signal after 1 day of non-use (warm start). Cold and warm starts had significantly longer acquisition times than hot starts but were not significantly different from each other. There were no significant differences based on type of unit.

During signal acquisition, no miles are collected by the on-vehicle devices. The number of miles “lost” or unrecorded during signal acquisition is dependent on driving conditions. The test route for the Start Test began at a parking lot exit, which often required the vehicle to wait until it was clear to pull out onto the road, minimizing the mileage “lost” during signal acquisition. The test results reflect the choice of the test route. No significant differences in mileage collection based on start condition or type of unit was found.

Note that, although not statistically significant, on average it took longer to acquire a signal (and thus less miles were collected) under a cold start. We anticipate that the longer a vehicle sits between uses (that is, the “colder” the start), the longer it will take the on-vehicle device to acquire a signal and begin collecting miles.

3.3 EVASION POTENTIAL TESTS

The objective of the *Evasion Potential Tests* was to determine whether a user could prevent the system from working properly *without* affecting the physical integrity of the on-vehicle device, Fixed Minions, Gateway Minions, and POS system.

3.3.1 Mileage Collection Evasion Test

For the *Mileage Collection Evasion Test*, the system was tested under the following evasive modifications:

- Blocking the GPS antenna of the on-vehicle device—The antenna was wrapped in aluminum foil.
- Using magnets to try to alter readings—Magnets were attached to the on-vehicle device GPS antenna.
-

After performing the evasive modification, the procedure outlined in the ***Error! Reference source not found.*** was completed and the difference between miles per zone collected by on-vehicle device to miles per zone recorded by the odometer was recorded.

3.3.1.1 Antenna blocking with aluminum foil

This test with terminated after six 10-mile runs with a total of 0.004 miles collected. Based on the results, the following conclusions were drawn:

1. For both the GPS-only and Hybrid GPS/ODO units, no miles were collected when the antenna was blocked with aluminum foil.
2. Zero miles were also reported when the antennas of Hybrid GPS/ODO units were covered with aluminum foil. Recall that in the Hybrid units, the VSS is used to collect the mileage and the GPS is used only to determine location for assigning miles to the correct zone. In this situation, the inability to acquire a GPS signal resulted in the unit having insufficient information to allocate VSS-acquired miles in the proper zone, and thus. *This situation can be modified in future development so that total mileage collection of the Hybrid units should not be affected by this evasion method.*

Based on the tests (formal and informal), anytime the GPS antenna was covered, the units could not acquire a satellite signal to properly collect miles.

3.3.1.2 Magnets attached to GPS antenna

Mileage collection accuracy tests were conducted with one and two magnets positioned near the GPS antenna affixed to the vehicle roof. The use of magnets had no impact on mileage collection rates.

3.3.2 Data Transmission Evasion Test

For the *Data Transmission Evasion Test*, the system was tested under the following evasive modification:

- Blocking the RF antenna of the Fixed Minion device—The antenna and the body of the Fixed Minion were wrapped in aluminum foil.

After performing the evasive modification, the procedure outlined in the *Basic Reliability Test* was completed and a trial was considered a success if the following information was recorded correctly without any error messages:

- The transaction was applied to the correct pump number.
- The database record matched the manually recorded data for each transaction.

An error message or incorrect data for either of these measures constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 11 shows the results for the data transmission evasion test. Table 11 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 11. Results for Data Transmission Evasion Test

Number of Transactions	**Number of Successful Transactions**	**98% Confidence Interval for Probability of Success**	
		Upper	**Lower**
5	0	0.581	0.000

In all cases, the Gateway Minion did not successfully establish any communication with the Fixed Minion resulting in no possible communication with the on-vehicle device.

4.0 RESULTS FOR ODOMETER-BASED TECHNOLOGY CONFIGURATIONS

4.1 RELIABILITY TESTS

4.1.1 Basic Reliability Test

The Basic Reliability Test assesses the reliability of the odometer-based prototype technology configuration with respect to successfully completing simulated fuel purchase transactions requiring the incorporation of a VMT fee based on the mileage collected by a vehicle (using the odometer-only on-vehicle device). To successfully complete a such a fuel purchase transaction, the functions of reading VMT data from a vehicle's on-vehicle device, processing the correct VMT fee, adding this fee to the fuel price (and not applying the per gallon fuel tax), and updating the mileage accumulators on the on-vehicle device must all be completed successfully. This requires successful interactions among the system components, such as the OSU Software (odometer-based technology configuration version), POS system and fuel dispenser simulator, RF host computer, and local DB.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The transaction was applied to the correct pump number.
- The database record matched the manually recorded data for each transaction.

An error message or incorrect data for either of these measures constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 12 shows the results for the basic reliability test. Table 12 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 12. Results for Basic Reliability Test

Number of Transactions	Number of Successful Transactions	Number of Unsuccessful Transactions	98% Confidence Interval for Probability of Success	
			Upper	Lower
15	13	2	0.990	0.547

The two failures occurred when no VMT information could be retrieved from the on-vehicle device.

4.1.2 Discontinued Fueling Transaction Test

The objectives of this test were to ensure that:

1. The mileage "buckets" stored in the non-volatile memory of the odometer-based on-vehicle device were not updated, and
2. The Local DB was not updated

when a fueling transaction was cancelled before completion.

Therefore, a trial was considered a success if the following information was recorded correctly without any error messages:

- The VMT information on the on-vehicle device was not updated.
- Local DB did not record the cancelled transaction.

An error message or incorrect data for this measure constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 13 shows the results for the basic reliability test. Table 13 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 13. Results for Discontinued Fueling Transaction Test

Number of Transactions	Number of Successful Transactions	98% Confidence Interval for Probability of Success	
		Upper	Lower
5	5	1.000	0.398

4.1.3 No On-Vehicle Device Test

The objective of this test was to ensure that the fuel tax was applied to the correct pump at the POS system for vehicles without an on-vehicle device.

A trial was considered a success if the following information was recorded correctly without any error messages:

- The fuel tax was included for this transaction.

An error message or incorrect data for this measure constituted a failure of the system. The analysis described for tests with binary outcomes was followed.

Table 14 shows the results for the basic reliability test. Table 14 includes the number of transactions attempted, the number of successes, as well as the upper and lower limits for the 98% confidence interval for the probability of success.

Table 14. Results for No On-Vehicle Device Test

Number of Transactions	Number of Successful Transactions	98% Confidence Interval for Probability of Success	
		Upper	Lower
5	5	1.000	0.398

4.1.4 Speed Test

The speed test was not performed on the Odometer-based prototype technology configuration due to development issues related to the Fixed Minions that were to act as the "border crossing beacons". Nevertheless, a test procedure was developed and is included in the *Test Plan* document in case ODOT decides to pursue an Odometer-based VMT system.

4.2 ACCURACY TESTS

4.2.1 Accuracy Test

For a discussion of the results for the Accuracy Test of the Odometer-only on-vehicle devices, see Section 3.2.1. Accuracy Test results for all three types of on-vehicle devices (GPS, Hybrid GPS/ODO, Odometer-only) are discussed together in this section.

4.3 EVASION POTENTIAL TESTS

4.3.1 Mileage Collection Evasion Test

See results from the GPS-based technology configuration in Section 3.

4.3.2 Data Transmission Evasion Test

See results from the GPS-based technology configuration in Section 3.

5.0 SYSTEM ASSESSMENTS

5.1 INTEROPERABILITY ASSESSMENT

The objective of the *Interoperability Assessment* was to evaluate the features of the technology configurations that may impact its ability (or the ability of its components) to interoperate with other systems and applications.

As currently developed, the wireless data collection system developed by AFX Technology Group International, Inc. will likely be unable to interoperate with similar systems since it uses its own operating system and its capabilities are dependent on the source code and the functionality programmed into it. AFX's system operates in the 914 MHz ISM band; most other systems operate at 2.45 GHz or employ cellular technology for data communications.

In the *Data Transmission Test* the system was tested in the presence of other devices that operate in the 902-928 MHz ISM frequency band. Systems operating at other frequencies should not experience interference from our system and should be able to coexist without negative results. Likewise, because the Minions communicate using frequency hopping spread spectrum, the wireless network cannot be jammed, and the network tracks the quality of transmission on all the frequencies used. Frequencies experiencing noise are automatically isolated, and retested and reconfigured when they improve.

5.2 SECURITY ASSESSMENT

The objective of the *Security Assessment* was to evaluate the ability of the VMT-based fee collection systems to prevent eavesdropping. Based on the prototype technology configurations, the collected mileage data are transmitted:

- Between an on-vehicle device and a service station Fixed Minion via wireless network.
- Between the service station Fixed Minion and other system components via wired networks.

For the wireless network, the collected mileage data are transmitted on a 914 MHz ISM frequency band using time division multiple access (TDMA) and frequency hopping spread spectrum. The Minions use 72 frequencies over a 20MHz band. The wireless system can send up to 1200 packets per minute, and frequency selection between any two Minions passing data is negotiated between them and randomly keyed from a random number extracted from the receiver. Packets are only reassembled into the original message at the receiving Minion. These techniques make eavesdropping impractical and very difficult. For additional protection, a proprietary (AFX) 64-bit encryption is used as well to encode messages.

For the wired network, the system's susceptibility is dependent on the configuration.

5.3 PRIVACY ASSESSMENT

The objective of the *Privacy Assessment* was to demonstrate that the on-vehicle devices used in the technology configurations do not store any location information permanently.

Based on the XML messages exchanged between the AFX Minion devices, POS system, and OSU software, it is concluded that each of the on-vehicle devices collect and transmit only mileage information; no location information is required to calculate VMT-base fees. See Appendix A for sample XML-based communications between these parts of the system.

To verify the above independently, the test team can also send a request for location information by time instead of the VMT data and assess "success" or "failure". Note also that the Central DB does not receive any location information, nor is it designed to store any.

The VMT-based revenue collection system does not require more personal information than existing systems.

5.4 DURABILITY / TAMPER RESISTANCE ASSESSMENT

The objective of the *Durability / Tamper Resistance Assessment* was to estimate the expected life of the on-vehicle device when exposed to a variety of operational conditions, (e.g. high/low temperatures, humidity, vibration, dust and particles) given a tightly sealed final product.

This assessment will need to be conducted on production models of the devices, as the devices used in these tests are designed for installation in the passenger compartment only. Briefly, the proposed design specification of a production model on-vehicle device is as follows:

- Approximately 5" long, 2.5" wide, and 1.5" in height (12.7 x 6.4 x 3.8 cm).
- Housed in a NEMA4X[2] compliant enclosure, made out of ABS material (ABS is a strong, lightweight plastic that resists stains and chemicals.) The lid and the base will be equipped with a tongue and groove sealing system with a neoprene gasket. The mounting holes and the lid fastening screws are outside the seal, which prevents moisture and dust from entering the enclosure. Internal guide slots allow the vertical mounting of PCB assemblies. The

[2] NEMA4X: Constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, windblown dust, splashing water, hose-directed water, and corrosion; and that will be undamaged by the external formation of ice on the enclosure (www.nema.org).

bosses on the internal base allow the horizontal attachment of PCBs, connectors, etc.
- Constructed for either indoor or outdoor use.

5.5 SYSTEM EVASION POTENTIAL ASSESSMENT

The objective of the *Evasion Potential Assessment* was to determine the different actions that can be performed to avoid paying the VMT-based fee.

Several possible methods to evade paying the VMT-based fee are:

- Block antenna
  For the GPS-only units, blocking the GPS antenna with aluminum foil or other material results in signal loss and loss of miles collected.
- Disconnect VSS
  For the Odometer-only and Hybrid GPS/ODO units, disconnecting the VSS would decrease the number of miles a driver is charged a VMT fee for. Catching these system evaders would involve identifying low-mileage vehicles in the local or central DB, or educating gas attendants to understand that a vehicle with an on-vehicle device should not have a VMT fee of zero. To avoid a VMT fee of zero, this type of system evader would have to disconnect and reconnect the VSS so that some miles accumulated between each fueling.
- Change size of tires on vehicle with an on-vehicle device that uses the VSS
  To decrease the amount of VMT fee paid, a driver could increase tire size (holding wheel size the same) after the VSS is calibrated for the on-vehicle device. For example, a 1” increase from 27” to 28” in overall wheel/tire size diameter is equivalent to a 3.7% loss in mileage collected.

5.6 EASE OF ENFORCEMENT / AUDITABILITY ASSESSMENT

The objective of the *Ease of Enforcement/Auditability Assessment* was to demonstrate that the VMT-based fee collection systems evaluated in this project easily present adequate reports that will aid in ensuring that the user compliance.

To meet this requirement, for the GPS technology configuration, stored procedures were created in SQL that display the required reporting information. The contents of these views are detailed in the *Central Database Documentation* report. For the Odometer technology configuration, several reports were created in Access. The contents of these are detailed in the *Local Database Documentation* report. Each of these reports accompanies this document.

5.7 EASE OF USE ASSESSMENT

The objective of the *Ease of Use Assessment* was to demonstrate that users will have no interaction with the on-vehicle device, other than initial installation and eventual maintenance.

A second objective of this assessment was to show the extra steps that must be performed by gas station attendants on the POS side of the VMT-based fee collection systems.

This assessment is based on the present design of the technology configurations. Future changes may change the results presented.

To meet these objectives, interviews and observations were conducted at three gas stations located in Corvallis, OR (Chevron, ARCO, and 76). During a fueling transaction, the following additional steps have been identified as necessary if the VMT-based system is implemented:

For gas station attendants: Four additional steps were identified.

After starting the transaction at the pump and greeting the customer, the attendant must:

1. Wait for POS system to calculate VMT fee.
2. Read VMT fee from the fuel dispenser display.
3. Inform customer of fee and ask if customer accepts it.
4. If customer declines fee, cancel transaction.
   If customer accepts fee, continue with standard fueling transaction. No further additional steps are required.

For customers: One additional step will be required. Customers must tell the attendant whether they accept or reject the VMT-fee. If rejected, a customer cannot fuel up a vehicle.

The additional steps required to process the VMT-based fee are highlighted in the flow chart depicted in Figure 1.

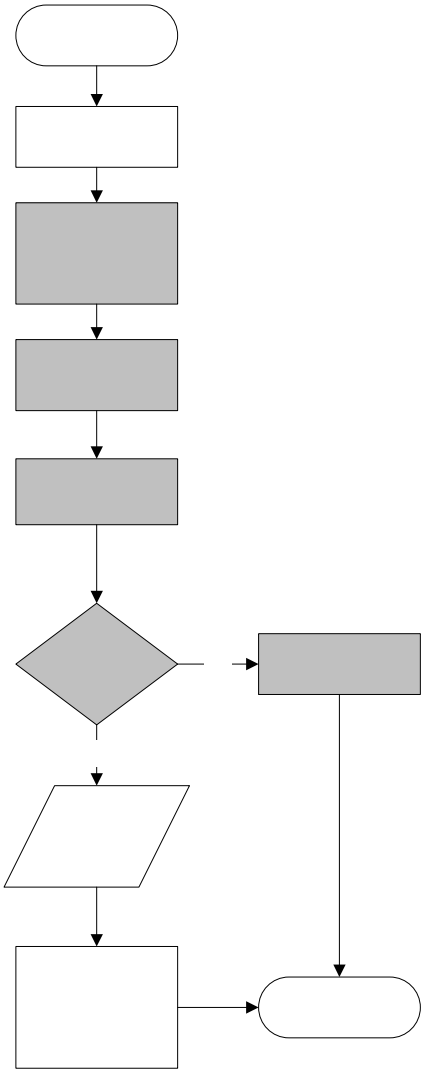

Figure 1. Additional Steps Required to Process the VMT-based Fee

6.0 APPENDIX B

Sample XML code used in data transfers.

6.1 TRANSACTION EXAMPLE 1

The following is a sample of XML data that the OSU software interface might send to the *MinionNet* Server (scenario: a car just pulled up to pump #6, and at the same time a car has completed a transaction and is ready to drive away at pump # 3):

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE MinionNet_Xaction_List SYSTEM
"minionnet_in_oregon_dot.dtd">
<MinionNet_Xaction_List>
  <MinionNet_Xaction>
    <Xaction_Type> <VMT_Data_Request /> </Xaction_Type>
    <Pump_Num> 6 </Pump_Num>
    <Timestamp> 2003-07-27 14:25:03 </Timestamp>
  </MinionNet_Xaction>

  <MinionNet_Xaction>
    <Xaction_Type> <Xaction_Complete /> </Xaction_Type>
    <Pump_Num> 3 </Pump_Num>
    <Timestamp> 2003-07-27 14:25:04 </Timestamp>
  </MinionNet_Xaction>
</MinionNet_Xaction_List>
```

Action	Purpose
<!DOCTYPE xxxxx> SYSTEM “xxxx”>	Per HTML and XHTML standards, a DOCTYPE (short for “document type declaration”) informs the validator which version of (X)HTML is being used, and must appear at the very top of every web page. DOCTYPEs are a key component of compliant web pages: your markup and CSS will not validate without them.
<MinionNet_Xaction_List>	Transaction List Start Statement
<MinionNet_Xaction>	Transaction Start Statement.
<Xaction_Type> <VMT_Data_Request /> </Xaction_Type>	This initiates the type of transaction, specifically a data request. End statement.
<Pump_Num> 6 </Pump_Num>	This will associate the transaction to a specific pump. Pump 6 for this scenario.
<Timestamp> 2003-07-27 14:25:03 </Timestamp>	This can assign a date/time stamp to the transaction.
</MinionNet_Xaction>	Transaction End Statement
<MinionNet_Xaction>	Transaction Start Statement
<Xaction_Type> <Xaction_Complete /> </Xaction_Type>	Type of Action. Statement for transaction complete. End Statement.
<Pump_Num> 3 </Pump_Num>	This will associate the next transaction to Pump 3. End Statement.
<Timestamp> 2003-07-27 14:25:04 </Timestamp>	This can assign a date/time stamp to the transaction.
</MinionNet_Xaction>	Transaction End Statement
</MinionNet_Xaction_List>	Transaction List End Statement

6.2 TRANSACTION EXAMPLE 2

The following is a sample of XML data that the *MinionNet* Server might send to the OSU software interface (scenario: the car at pump #6 is responding with odometer/AVI-based Vehicle Miles Traveled data):

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE MinionNet_Xaction_List SYSTEM
"minionnet_in_oregon_dot.dtd">
<MinionNet_Xaction_List>
  <MinionNet_Xaction>
    <Xaction_Type> <VMT_Data_Response /> </Xaction_Type>
    <Pump_Num> 6 </Pump_Num>
    <VIN_Data> WDB C A 45 E X K A 478654 </VIN_Data>
    <VMT_Data_List>
      <ODOM_Data_List>
        <non_Oregon_Miles> 273 </non_Oregon_Miles>
        <Oregon_Miles> 527 </Oregon_Miles>
        <Oregon_Miles_Paid> 0 </Oregon_Miles_Paid>
      </ODOM_Data_List>
    </VMT_Data_List>
  </MinionNet_Xaction>
</MinionNet_Xaction_List>
```

Action	**Purpose**
<!DOCTYPE xxxxx> SYSTEM “xxxx”>	Per HTML and XHTML standards, a DOCTYPE (short for “document type declaration”) informs the validator which version of (X)HTML is being, and must appear at the very top of every web page. DOCTYPEs are a key component of compliant web pages: your markup and CSS will not validate without them.
<MinionNet_Xaction_List>	Transaction List Start Statement
<MinionNet_Xaction>	Transaction Start Statement
<Xaction_Type> <VMT_Data_Response /> </Xaction_Type>	This initiates the type of transaction, specifically a data response. End statement.
<Pump_Num> 6 </Pump_Num>	This will associate the transaction to a specific pump. Pump 6 for this scenario.
<VIN_Data> WDB C A 45 E X K A 478654 </VIN_Data>	This will associate the transaction with a specific vehicle’s VIN.
<VMT_Data_List>	VMT Data List Start Statement
<ODOM_Data_List>	Odometer Data List Start Statement
<non_Oregon_Miles> 273 </non_Oregon_Miles>	Open statement, data and close statement. This example indicates 273 non-Oregon miles traveled since collection started.
<Oregon_Miles> 527 </Oregon_Miles>	Open statement, data and close statement. This example indicates 527 Oregon miles traveled since collection started.
<Oregon_Miles_Paid> 0 </Oregon_Miles_Paid>	Open statement, data and close statement. This example indicates 0 Oregon miles paid for since collection started.
</ODOM_Data_List>	Odometer Data List Close Statement
</VMT_Data_List>	VMT Data List Close Statement
</MinionNet_Xaction>	Transaction End Statement

Action	Purpose
</MinionNet_Xaction_List>	Transaction List End Statement

6.3 TRANSACTION EXAMPLE 3

The following sample of XML data that the *MinionNet* Server might send to the OSU software (Scenario: Vehicle at Pump #4 is responding with GPS/AVI-based vehicle miles traveled data and optional accumulated zone mileage per time slot data.)

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE MinionNet_Xaction_List SYSTEM "minionnet_in_oregon_dot.dtd">
<MinionNet_Xaction_List>
  <MinionNet_Xaction>
    <Xaction_Type> <VMT_Data_Response /> </Xaction_Type>
    <Pump_Num> 4 </Pump_Num>
    <VIN_Data> 7A8DH2G0702413059 </VIN_Data>
    <VMT_Data_List>
      <GPS_Data_List>
        <Zone_Miles id="1"> 60 </Zone_Miles>
        <Zone_Miles id="3"> 38 </Zone_Miles>
        <Zone_Miles id="4"> 76 </Zone_Miles>
      </GPS_Data_List>
      <Zone_Time_List>
        <Zone_Time_Record>
          <Start_TimeSpec> 00:00 </Start_TimeSpec>
          <Stop_TimeSpec> 09:00 </Stop_TimeSpec>
          <Zone_Time_Miles id="1"> 23 </Zone_Time_Miles>
          <Zone_Time_Miles id="3"> 0 </Zone_Time_Miles>
          <Zone_Time_Miles id="4"> 0 </Zone_Time_Miles>
        </Zone_Time_Record>
        <Zone_Time_Record>
          <Start_TimeSpec> 09:00 </Start_TimeSpec>
          <Stop_TimeSpec> 17:00 </Stop_TimeSpec>
          <Zone_Time_Miles id="1"> 7 </Zone_Time_Miles>
          <Zone_Time_Miles id="3"> 19 </Zone_Time_Miles>
          <Zone_Time_Miles id="4"> 70 </Zone_Time_Miles>
        </Zone_Time_Record>
        <Zone_Time_Record>
          <Start_TimeSpec> 17:00 </Start_TimeSpec>
          <Stop_TimeSpec> 00:00 </Stop_TimeSpec>
          <Zone_Time_Miles id="1"> 30 </Zone_Time_Miles>
          <Zone_Time_Miles id="3"> 19 </Zone_Time_Miles>
          <Zone_Time_Miles id="4"> 6 </Zone_Time_Miles>
        </Zone_Time_Record>
      </Zone_Time_List>
    </VMT_Data_List>
  </MinionNet_Xaction>
</MinionNet_Xaction_List>
```

Action	Purpose
<!DOCTYPE xxxxx> SYSTEM “xxxx”>	Per HTML and XHTML standards, a DOCTYPE (short for “document type declaration”) informs the validator which version of (X)HTML is

Action	Purpose
	being used, and must appear at the very top of every web page. DOCTYPEs are a key component of compliant web pages: your markup and CSS will not validate without them.
<MinionNet_Xaction_List>	Transaction List Start Statement
</MinionNet_Xaction>	Transaction Start Statement
<Xaction_Type> <VMT_Data_Response /> </Xaction_Type>	This initiates the type of transaction, specifically a data response. End statement.
<Pump_Num> 4 </Pump_Num >	This will associate the transaction to a specific pump. Pump 4 for this scenario.
<VIN_Data> 7A8DH2G0702413059 </VIN_Data>	This will associate the transaction with a specific vehicle.
<VMT_Data_List>	VMT Data List Start Statement
<GPS_Data_List>	GPS Data List Start Statement
<Zone_Miles id="1"> 60 </Zone_Miles>	Open statement, data and close statement. This example indicates 60 miles traveled in Zone 1.
<Zone_Miles id="3"> 38 </Zone_Miles>	Open statement, data and close statement. This example indicates 38 miles traveled in Zone 3.
<Zone_Miles id="4"> 76 </Zone_Miles>	Open statement, data and close statement. This example indicates 76 miles traveled in Zone 4.
</GPS_Data_List>	GPS Data List End statement
<Zone_Time_List>	Zone List Time List Start Statement
<Zone_Time_Record>	Zone Time Record Start Statement
<Start_TimeSpec> 00:00 </Start_TimeSpec>	Open statement, data and close statement. This example indicates Time Slot starts at midnight.
<Stop_TimeSpec> 09:00 </Stop_TimeSpec>	Open statement, data and close statement. This example indicates time Slot stops at 0900.
<Zone_Time_Miles id="1"> 7 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 23 miles traveled in Zone 1.
<Zone_Time_Miles id="3"> 19 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 0 miles traveled in Zone 3.
<Zone_Time_Miles id="4"> 70 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 0 miles traveled in Zone 4.
</Zone_Miles_Record >	Zone Time Record End statement.
<Zone_Time_Record>	Zone Time Record Start Statement
<Start_TimeSpec> 09:00 </Start_TimeSpec>	Open statement, data and close statement. This example indicates Time Slot starts at 0900.
<Stop_TimeSpec> 17:00 </Stop_TimeSpec>	Open statement, data and close statement. This example indicates time Slot stops at 1700.
<Zone_Time_Miles id="1"> 30 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 30 miles traveled in Zone 1.
<Zone_Time_Miles id="3"> 19 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 19 miles traveled in Zone 3.
<Zone_Time_Miles id="4"> 6 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 6 miles traveled in Zone 4.
</ Zone_Time_Record >	Zone Time Record End statement.
<Zone_Time_Record>	Zone Time Record Start Statement

Action	Purpose
<Start_TimeSpec> `17:00` </Start_TimeSpec>	Open statement, data and close statement. This example indicates Time Slot starts at 1700.
<Stop_TimeSpec> `00:00` </Stop_TimeSpec>	Open statement, data and close statement. This example indicates time Slot stops at Midnight.
<Zone_Time_Miles id="1"> 30 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 30 miles traveled in Zone 1.
<Zone_Time_Miles id="3"> 19 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 19 miles traveled in Zone 3.
<Zone_Time_Miles id="4"> 6 </Zone_Time_Miles>	Open statement, data and close statement. This example indicates 6 miles traveled in Zone 4.
</Zone_Time_Record>	Zone Time End Statement
</Zone_Time_List>	Zone Time List End Statement
</VMT_Data_List>	VMT Data List End Statement
</MinionNet_Xaction>	Transaction End Statement
</MinionNet_Xaction_List>	Transaction List End Statement.