September 2009

Environmental Technology Verification Report

AVANTE INTERNATIONAL TECHNOLOGY, INC.
PANASEC MOBILE PERSONNEL AND ASSET VISIBILITY SYSTEM

Prepared by
Battelle

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EPA U.S. Environmental Protection Agency

ETV ETV ETV

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ETV Advanced Monitoring Systems Center

AVANTE INTERNATIONAL TECHNOLOGY, INC.
PANASEC MOBILE PERSONNEL AND ASSET VISIBILITY SYSTEM

by
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Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, funded and managed, or partially funded and collaborated in, the research described herein. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the author (s) and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and groundwater; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

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List of Abbreviations

AMS	Advanced Monitoring Systems
AVANTE	AVANTE International Technology, Inc
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification
GPS	Global positioning system
GPRS	General packet radio service
GHz	Gigahertz
HAZMAT	Hazardous materials
LRB	Laboratory record book
MHz	Megahertz
mph	Miles per hour
MX	Mexico
NMBA	New Mexico Border Authority
NMDPS	New Mexico Department of Public Safety
NRMRL	National Risk Management Research Laboratory
PAVS	PanaSec Mobile Personnel and Asset Visibility System
poly	Polyethylene
POE	Port of Entry
QA	Quality assurance
QMP	Quality Management Plan
RFID	Radio-frequency identification
RT	Round Trip
SATCOM	Satellite communication
SD	Standard deviation
STIL	Servicio de Transporte Internacional y Local
TQAP	Test Quality Assurance Plan
U.S.	United States
VDC	volts direct current

Chapter 1
Background

The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Risk Management Research Laboratory (NRMRL) and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. ETV AMS Center verifies the performance of technologies for monitoring, sampling, and characterizing contaminants and natural species in a variety of matrices including air, water, and soil. The AMS Center evaluated the performance of the PanaSec Mobile Personnel and Asset Visibility System by AVANTE International Technology, Inc. (AVANTE), a web-based real-time locating and reporting system, in tracking hazardous materials (HAZMAT) being returned to the U.S. from Mexico under terms of the La Paz Agreement. Under this agreement, all HAZMAT waste generated by raw materials shipped into Mexico for use in foreign-owned factories (called maquilas) must be shipped back to their country of origin. Mexico does not classify the returned material as hazardous, but as a returned product, and therefore does not submit a Notice of Intent to the United States for the export of such HAZMAT waste. The current process makes it difficult to develop an accurate accounting of HAZMAT waste entering the United States from the maquilas and does not provide for timely identification of shipments that do not reach their designated receiving facilities. The lack of tracking of these wastes creates the possibility for waste to be illegally abandoned. An enhanced tracking system that provides accurate, timely data to regulatory officials would be beneficial in preventing this from occurring. This verification test evaluated the performance of such tracking technologies.

Chapter 2
Technology Description

This verification report provides results for the verification testing of AVANTE's PanaSec Mobile Personnel and Asset Visibility System (hereafter referred to as PAVS). Following is a description of two configurations of AVANTE's PAVS that were used during this verification test based on information provided by the vendor.

PAVS is a web-based real-time locating and reporting system that provides real-time tracking of HAZMAT in transit or in storage as well as the whereabouts of the responsible personnel. This HAZMAT transportation tracking system and solution incorporates patented radio-frequency identification (RFID) technologies coupled with global positioning system (GPS)-general packet radio service (GPRS) cellular data communications to assist in HAZMAT transportation security. The AVANTE data center server stores all transit and condition data to facilitate real-time tracking of the HAZMAT.

Each container of HAZMAT is individually tagged with an active ZONER™ tag. Figure 2-1 shows these active RFID tags that get attached to containers with pressure-sensitive adhesive or other mechanical fasteners. The identity of each container is linked to the active tag identification. During verification testing, AVANTE's PAVS used two different methods for RFID tag reading and communication: (1) external roadside readers and (2) an uplinked system using a vehicle mounted and powered RELAYER™.

Figure 2-1. AVANTE's RFID Tags

External Readers. The roadside reading configuration of the PAVS consisted of pole-mounted antennae coupled with an external tag data storage device. These are shown in Figure 2-2 and are referred to in this report as external readers. The external readers are located in a fixed position (e.g., on the side of a road or at the entrance to a facility); this location is referred to as a read location. As the RFID tags come within range of the external readers (e.g., as the truck drives past), the external readers collect the information transmitted by the RFID tags and records this information onto a secure digital memory card loaded into the external reader. The information collected by the external reader is collected by removing the memory card and downloading the information to a computer.

Figure 2-2. AVANTE's External Readers

Uplinked System. The ZONER™-RELAYER™ configuration (referred to as "Uplinked System") is capable of collecting information from RFID tags while the shipment is either stationary or in transit. It functions by equipping each carrier with a monitoring reader/transponder unit called the RELAYER™-CTCR (Relayer) (shown in Figure 2-3) that communicates with all of the active RFID tags inside the container or trailer. Each Relayer is equipped with GPS and GPRS and/or SATCOM capabilities. The Relayer transmits all transit and condition data to the AVANTE data center servers. This information may then be viewed using a world-wide web application providing near real-time viewing. The uplinked system also allows for the use of personnel badges that identify him/her along with their proximity to the Relayer and the "panic button" feature.

Prior to the start of the verification test, AVANTE was responsible for setting up the PAVS technology using both the external readers and the uplinked system according to their recommended configuration for optimal performance. This included configuring the system to ensure that read events occur at each of the testing route read points. Both the external readers and Relayer are powered by 12 VDC and backup battery. The Relayer system was configured to download the RFID data to the AVANTE data center server via cellular telephone communication link.

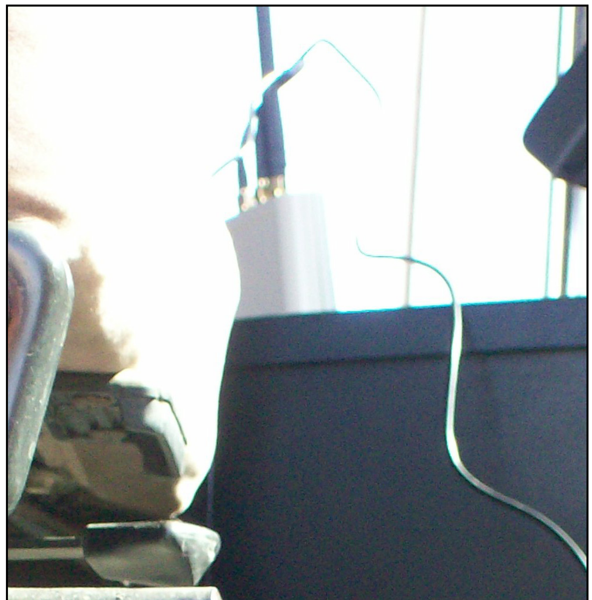

Figure 2-3. AVANTE's Uplinked System (Relayer)

Chapter 3
Test Design and Procedures

3.1 Test Overview

This verification test was conducted according to procedures specified in the *Test/QA Plan for Verification of Radio Frequency Identification (RFID) for Tracking Hazardous Waste Shipments across International Borders*[1] (TQAP) and adhered to the quality system defined in the ETV AMS Center Quality Management Plan (QMP).[2] Battelle conducted this verification test with support from the New Mexico Border Authority (NMBA), New Mexico Department of Public Safety (NMDPS), Texas Transportation Institute, U.S. EPA Region 6 El Paso Border Office, U.S. EPA Office of Enforcement and Compliance Assurance, BorderWriting (a New Mexico company that coordinated participation of the local collaborators prior to the ETV test), and Servicio de Transporte Internacional y Local (STIL).

This verification test simulated shipments of HAZMAT waste contained in polyethylene (poly) drums, metal drums, and corrugated boxes through routine land transportation routes and across international ports of entry in the El Paso/Ciudad Juárez trade area. Originally, this ETV test was planned with the expectation that all of the trucking routes would include border crossings. However, due to concern of local authorities related to the violence in Ciudad Juarez during the test, there were some difficulties in obtaining permission to cross the border into Mexico (MX), so two of the trucking routes did not cross into MX and two routes included crossing the border into MX. RFID tags were attached to various containers and loaded onto a truck at the U.S. loading dock at the NMBA facility using a standard 53-foot semi-truck and trailer provided by STIL, a local trucking company. Throughout the testing, the containers were arranged in the trailer in either a tight-packed or loose-packed orientation. The PAVS included the RFID tags (attached to HAZMAT waste containers) and readers (roadside external or an in-truck reader (referred to as the Relayer) that resided in the cab of the truck and uplinked data to a central server in near real-time. The truck then left the NMBA loading dock, drove a prescribed route either solely in the U.S. or across the U.S. – MX Border. RFID tag reads were recorded electronically throughout each truck route.

This verification test was conducted from March 24-26, 2009 at the NMBA Santa Teresa facility and other field locations throughout the El Paso/Ciudad Juárez trade area. The PAVS was verified by evaluating the following parameters:

- Accuracy – proper identification of the tagged containers at various locations, at various truck speeds, on corrugated boxes or steel and poly 55-gallon drums, and in tightly packed and loosely packed loading orientations. Specifically, proper identification is defined as the retrieval of all information available about the tagged item according to the vendor's standard procedures.

- Precision – standard deviation (SD) of percent accuracy RFID tag read results.
- Interference of other RFID signals (collision test) – ability to discriminate the tags on the HAZMAT waste containers from other commercially-available RFID tags.
- Influence of confounding factors – container type, packing configuration and placement of tags/containers, environmental conditions, and internal trailer conditions.
- Operational factors – ease of use, technology cost, user-friendliness of vendor software, troubleshooting/downtime, etc.

3.2 Experimental Design

3.2.1 RFID Tags and HAZMAT Waste Containers

At the beginning of each day of testing, verification staff verified the function of 12 AVANTE RFID tags to be used as part of this verfication testing by measuring the frequency and the effective radiated power of the tag using a Rhode and Schwartz FSH6 spectrum analyzer with a 435 Megahertz (MHz) antenna. This was done by placing all the RFID tags involved in the test into the trunk of an automobile thereby isolating the signals emitted by each RFID tag from the spectrum analyzer. Next, a single RFID tag was removed from the trunk, the trunk was again closed, and the RFID tag was taken into the NMBA office building where the frequency and the effective radiated power was measured using the spectrum analyzer. This process was repeated for all 12 AVANTE RFID tags and the four RFID tags used for the collision test.

According to current shipping data, most of the HAZMAT entering MX from the U.S. are contained in either poly or steel 55-gallon drums, and much of the HAZMAT waste returning from the maquilas and entering the U.S. is solid and packaged in one-cubic yard corrugated boxes or as drummed liquids. Therefore, when the functioning of the RFID tags had been confirmed, four RFID tags were secured to poly 55-gallon drums, four were secured to the steel 55-gallon drums, and four were affixed to corrugated boxes for a total of twelve individual containers. One tag was affixed to each individual container. Figure 3-1 is a photo of an AVANTE RFID tag affixed to a poly drum. In the interest of safety, no actual HAZMAT waste was transported during the verification test. Each poly and metal 55-gallon drum used in the verification testing was filled with tap water and each corrugated box was filled with loosely folded cardboard. RFID tags were secured to the top of each poly and metal drum and to the side of each corrugated box using Velcro tape.

Figure 3-1. RFID tag affixed to poly drum

3.2.2 Waste Container Configuration in the Semi-Trailer

Each round trip (RT) conducted in the U.S. was performed using a tightly packed configuration of the HAZMAT waste containers. Each RT into MX was performed using a loosely packed configuration.

Each packaging configuration consisted of 12 individual containers. Two metal drums were placed on a pallet and the drums were shrink-wrapped to secure the drums during transport. The process was repeated for the poly drums as well. Therefore, four pallets of drums were created; two pallets of two metal drums each and two pallets of two poly drums each. The corrugated boxes were not affixed to a pallet but placed directly on the floor of the trailer. The corrugated boxes and the pallets of drums were then positioned inside the truck trailer in a tightly-packed configuration. For the loosely-packed configuration, each pallet contained one of each kind of drum. Figures 3-2 and 3-3 show diagrams of tightly packed and loosely packed container configurations.

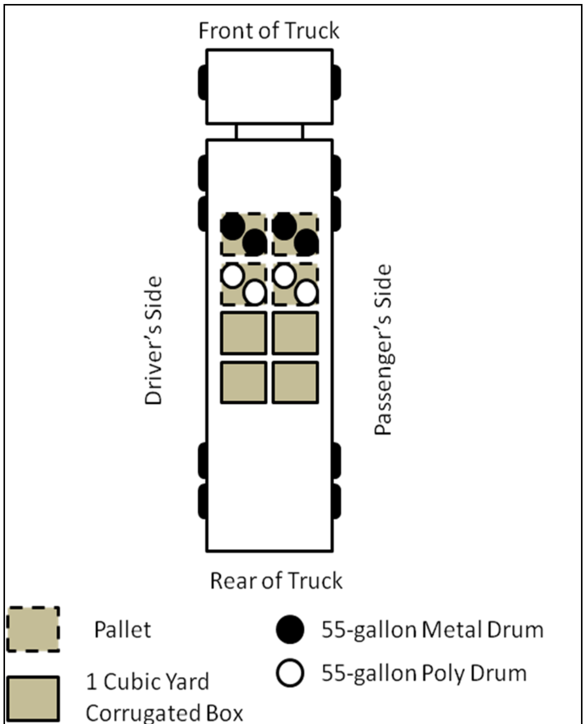

Figure 3-2. Tightly-packed configuration

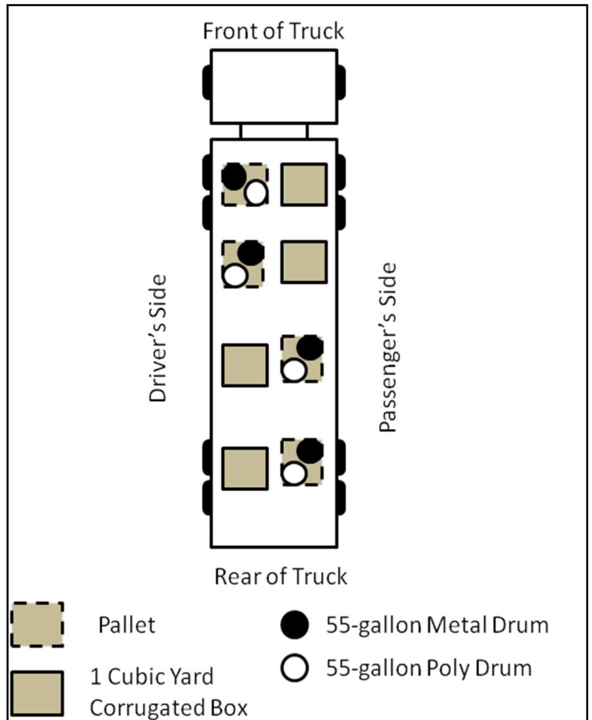

Figure 3-3. Loosely-packed configuration

Regardless of packing configuration, each corrugated box was positioned such that one RFID tag faced each side of the trailer (i.e., one RFID tag faced the driver's side, the passenger's side, the front, and the rear of the trailer).

3.2.3 Meteorological and Shock Data

After the palletized poly and metal 55-gallon drums and the corrugated boxes were loaded into the trailer and positioned in the correct packaging configuration, a Shocklog™ RD 298 system (Shocklog) was installed directly onto the floor of the trailer and a calibrated hot wire anemometer (TSI Incorporated, VelociCalc 9555-P Multi-function Ventilation Meter), capable of measuring temperature, barometric pressure, and relative humidity, was affixed to the passenger's side of the trailer approximately two feet above the floor. At the end of each day of verification testing, the electronic data generated and captured by the Shocklog and the anemometer were transferred from the instrument to a computer by means of a portable drive.

3.2.4 Collision Test

A collision test was performed during each RT to evaluate the ability for the PAVS to discriminate the AVANTE RFID tags from other commercially available active tags. Battelle supplied four commercially available tags for collision testing; the collision tags were 433 MHz, the same frequency at which the PAVS operated, active tags (Wavetrend® TG801). The collision tags were affixed to a wooden block as shown in Figure 3-4. At the beginning of the day of testing, the function of each collision tag was verified separately by measuring the frequency and the effective radiated power of the tags using the spectrum analyzer.

Figure 3-4. Collision Tags

A collision test was performed during each verification test run at the NMDPS truck inspection facility. The truck conducted its first pass of the 25 and 15 mph read locations. The truck then began its second pass of the 25 mph read location. After passing the 25 mph read location the second time, the truck stopped, the trailer was opened, and the collision tags were added to one of the one-cubic yard corrugated boxes. The trailer doors were then closed and the truck proceeded past the 15 mph read location. After passing the 15 mph read location, the truck stopped and the collision tags were removed.

3.2.5 Truck Routes and Descriptions of Round Trips

The TQAP[1] was written with the expectation that the same trucking route would be used throughout the verification test and that the route would include crossing over into MX. However, there was some difficulty in obtaining permission to cross the border into MX, so two of the truck RTs were performed within the U.S. and when the proper permission was obtained, the other two RTs were performed crossing the border into MX. Also, the TQAP was written with the assumption that the technologies to be evaluated would have external readers that would be set up at various read points throughout the trucking route. While this was the case for AVANTE, AVANTE's technology also had a feature that uplinked the RFID data, as well as GPS coordinates, to a server via a cellular telephone communication link at approximately one minute time intervals, reporting the presence and location of each RFID tags at each time interval. Therefore, fixed read locations were used for the AVANTE external readers and the uplinked data were reported every minute to provide additional tag identification and location data throughout the RTs than specified in the TQAP. The two RTs performed in the U.S. and the two RTs including the border crossing into MX are described below.

U.S. Trucking Route. The U.S. routes (RT 1 and 2) were selected to mimic, as much as possible, the read locations presented in the TQAP and to challenge the PAVS under similar test conditions specified in the TQAP.

Figure 3-5. Stationary Tag Read with External Readers

The HAZMAT waste containers were loaded into the trailer and placed in the tightly-packed configuration for both of the U.S. RTs. The truck began all of the RTs (U.S. and MX) at the NMBA facility. Prior to embarking on each RT, an external reader was situated on a stand at 90° with respect to the road with the stand placed four feet from the side of the front bumper. This is shown in Figure 3-5. At that time, RFID tag reads were made at distances of 5, 15, 30, 50, and 70 feet from the front bumper of the stationary truck by moving the external reader straight forward from the initial placement of the reader. The external readers were kept at each distance for approximately one minute. Following the stationary RFID reads, the reader was moved to the exit of the NMBA and the truck embarked on its RT by first driving past the reader for a slow moving read. During only the start of the first U.S. RT, a second reader was placed at 45° with respect to the road, in addition to the reader at each read point that was placed at 90°.

Figure 3-6. U.S. route used during testing (border area enlargement)

Upon exit from the NMBA, the truck travelled to the NMDPS facility. Figure 3-6 shows the path of the truck between the NMBA and the NMDPS facility. The total distance between the two locations was approximately 0.75 miles. External readers were placed at two locations at the facility. The first reader was designated as a 25 mile per hour (mph) read location and the second reader was designated a 15 mph read location. The readers used here were also placed at 90°

with respect to the plane of the truck As the truck approached both the 25 mph and 15 mph read points, the speed at which the truck was travelling was measured using a Stalker Sport™ 24.15 Gigahertz (GHz) Doppler radar gun. The truck then exited the NMDPS facility and doubled back to make a second pass. After passing the 25 mph read location, the truck was stopped, the trailer doors opened, the contents of the trailer inspected for any shifting of the load, and collision tags were added. The truck then passed the 15 mph read location. After passing the 15 mph read location, the truck was stopped, the trailer doors opened, and the collision tags were removed. As was the case with the first pass of the truck through the NMDPS facility, the speed at which the truck was travelling past the 25 mph and 15 mph read location was measured using the radar gun.

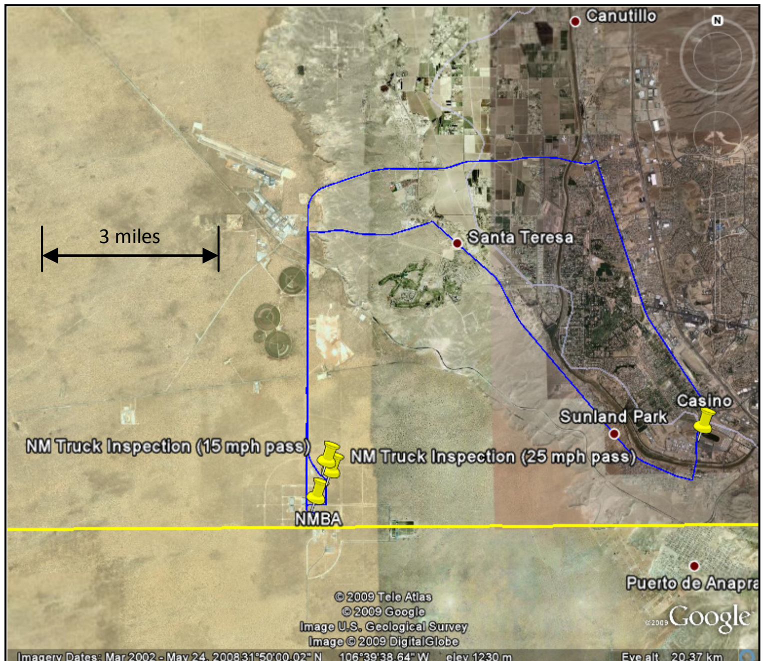

Figure 3-7. U.S. route used during testing

The truck then proceeded to the Sunland Park Racetrack and Casino parking lot (referred to as the casino read location) as is shown in Figure 3-7. This location was selected because the route to the casino (approximately 13 miles) provided highway and city driving and the parking lot at the casino provided adequate space for the external reader to be set up as well as space for the truck to turn around. From the NMDPS facility, the truck travelled northbound on Peter V. Domenici Boulevard, east on Airport Road, southeast on McNutt Road (NM-273) and finally north on Sunland Park Drive to the Sunland Park Racetrack and Casino parking lot. The external reader was placed at the entrance of the parking lot and upon arrival, the truck passed the reader for a slow moving read. Again, the reader was situated at 90° with respect to the road. The speed of the truck passing this read location was not dictated to the driver, but was documented on a data sheet (from a speedometer reading) by a passenger in the truck.

The truck left the Sunland Park Racetrack and Casino parking lot and proceeded northbound on Sunland Park Drive. The truck next travelled northwest on Doniphan Road, west on Aircraft Road and south on Peter V. Domenici Boulevard. During one of the U.S. Route runs, two read locations were placed on Peter V. Domenici Boulevard to allow for tag reads at speeds of 55 mph and 40 mph using external readers. The truck then returned to the NMBA facility.

The final read location of the RT was at the entrance to the NMBA facility. The truck passed the read location for a slow moving read. Following the tag read at the entrance to the NMBA facility, tag reads were made at distances of 5, 15, 30, 50, and 70 feet from the truck and trailer as they had been prior to the RT.

In addition to the external reader data collected during the U.S. RTs, the PAVS uplinked communication system was also verified. The difference between this system and the external readers is that instead of a fixed location that defines the read location (at which the RFID tags are read to confirm their presence), the RFID tags are read and their presence and location (as latitude/longitude coordinates) recorded to a central database approximately every minute, regardless of location. Therefore, additional data were collected in addition to the fixed read points defined by the location of the readers. However, because of a malfunction with that system, these data were not collected during the first U.S. RT. and approximately half of the data were missing from the second U.S. RT.

Mexico Trucking Route. The MX route was slightly different from what was planned in the TQAP[1], but was selected to mimic, as closely as possible, the route in the TQAP and to challenge the PAVS under similar test conditions specified in the TQAP, which included crossing the border to evaluate an considerations regarding the technology in an actual border crossing.

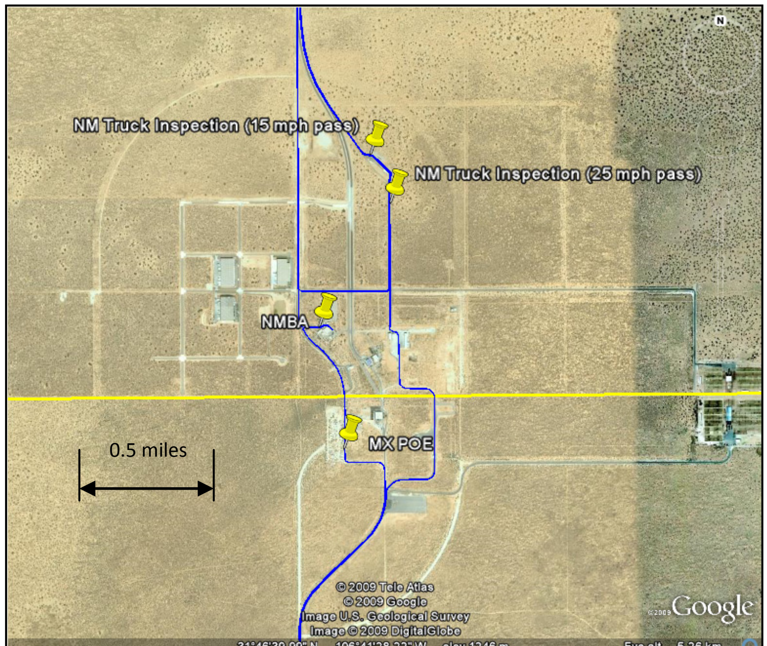

Figure 3-8. Mexico route used during testing (border area enlargement)

The HAZMAT waste containers were loaded into the trailer and placed in the loosely-packed configuration for both of the MX RTs. The external reader locations used during the MX route are identified in Figure 3-8 and Figure 3-9. These were only used during RT3 as AVANTE opted to not use readers and only the uplinked technology during RT4. As for each U.S. and MX RT, the truck began its route at the NMBA facility. Prior to embarking on the first MX RT, tag reads were made at distances of 5, 15, 30, 50, and 70 feet from the truck. Following the stationary RFID tag reads at various distances, the reader was moved to the exit of the NMBA and the truck embarked on RT3 by first driving past the external reader for a slow moving read.

The truck then proceeded south through the Jerónimo, MX POE and into MX. A read location was located at the south end of the Jerónimo POE and the truck passed the read location for a slow moving read. After passing this external reader, the truck proceeded for approximately 12 miles southbound on the Samalayuca-El Oasis Highway (Carratera Samalayuca-El Oasis).

The third read location (referred to as MX Turnaround) on the MX Route was located 0.6 miles north of the intersection of the Samalayuca-El Oasis Highway and MX Highway 2. After passing this read location, the truck performed a U-turn and proceeded northbound on the Samalayuca-El Oasis Highway, passing back into the U.S. through the Santa Teresa POE and through U.S. Customs.

After passing through U.S. Customs, the truck then proceeded to the NMDPS facility and encountered the same read locations that had been included for the U.S RTs. Two read locations were located at the facility. In all, the truck passed a 25 mph read point and a 15 mph read point and then doubled back to pass them again, with the collision tags added before the second pass by the 15 mph read point. As was the case during the U.S. RTs, the speed at which the truck was travelling past the 25 mph and 15 mph read location was measured using a radar gun. The truck then proceeded back to the NMBA read location. The RT was completed after passing an external reader upon re-entry to the NMBA and then a final stationary read at distances between 5 and 70 feet from the front bumper of the truck. Each of the four RTs are summarized in Table 3-1.

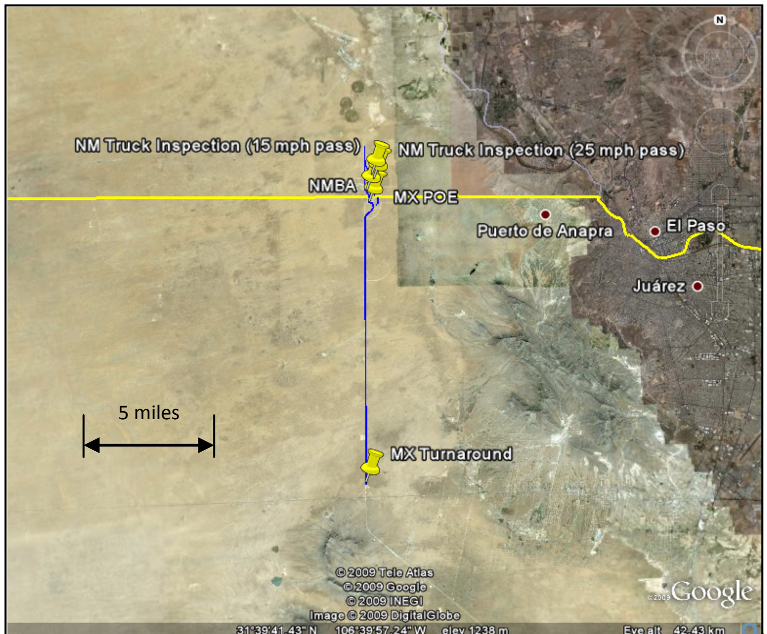

Figure 3-9. Mexico route used during testing

Table 3-1. Summary of Round Trips

Truck Route	Read Locations of Round Trips	Information about RT
RT 1 U.S.	Began at NMBA, NMDPS Facility (25 and 15 mph, collision test), Casino, completed at NMBA	Tightly packed configuration, uplinked data not collected because of system malfunction, stationary tag reads at various distances performed at NMBA before and after RT
RT 2 U.S.	Began at NMBA, NMDPS, Facility (25 and 15 mph, collision test), Casino, 40 mph and 55 mph highway reads, completed at NMBA	Tightly packed configuration,some uplinked data collected, stationary tag reads at various distances performed at NMBA before and after RT
RT 3 MX	Began at NMBA, MX Port of Entry, MX turnaround, NMDPS Facility (25 and 15 mph, collision test), completed at NMBA	Loosely packed configuration, uplinked data collected, stationary tag reads at various distances performed at NMBA before and after RT
RT 4 MX	Began at NMBA, MX Port of Entry, MX turnaround, NMDPS Facility (25 and 15 mph, collision test), completed at NMBA	Loosely packed configuration, external reader data not collected because AVANTE opted not to have them used, uplinked data collected, stationary tag reads at various distances performed at NMBA before and after RT

3.2.6 Route Deviation

The AVANTE uplinked system had an optional feature to provide indication when the RFID tags had traveled outside a pre-programmed route. To test this feature, during RT 4, the truck was diverted by approximately one mile and then directed to return to the planned route. The test evaluated whether or not the proper alert for such a route deviation was made.

3.3 Qualitative Evaluation Parameters

Operational factors such as ease of use, technology cost, user-friendliness of vendor software, and troubleshooting/downtime, etc. documented based on observations by Battelle, Border Writing, and U.S. EPA staff.

Chapter 4
Quality Assurance/Quality Control

QA/QC procedures were performed in accordance with the TQAP for this verification test[1] and the QMP for the AMS Center[2]. As noted throughout Chapter 3, there were some deviations from the TQAP, but the work was performed as described in the previous sections. None of the deviations from the test/QA plan resulted in any adverse impacts on the quality of the data produced by this verification test. All deviations were reviewed with the EPA ETV AMS Center Project Officer and EPA ETV AMS Center Quality Manager. QA/QC procedures and results are described in the following subchapters.

4.1 Audits

Two types of audits were performed during the verification test: a technical systems audit (TSA) of the verification test procedures, and a data quality audit. Because of the nature of RFID measurements, a performance evaluation audit, as is usually performed to confirm the accuracy of the reference method, was not applicable for this verification test. Audit procedures for the TSA and the data quality audit are described further below.

4.1.1 Technical Systems Audit

The Battelle AMS Center Quality Manager performed a TSA during the test to ensure that the verification test was performed in accordance with the TQAP for this verification test[1] and the QMP for the AMS Center[2]. The TSA noted no adverse findings. A TSA report was prepared, and a copy was distributed to the EPA AMS Center Quality Manager. In addition, the EPA AMS Center Quality Manager was present during the majority of the verification test and also performed a separate TSA.

4.1.2 Data Quality Audit

At least 10% of the data acquired during the verification test were audited. The data were traced from the initial acquisition, through reduction and statistical analysis, to final reporting to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

4.2 QA/QC Reporting

Each audit was documented in accordance with Sections 3.3.4 and 3.3.5 of the QMP for the AMS Center.[2] Once the audit reports were prepared, the Battelle Verification Test Coordinator ensured that a response was provided for each adverse finding or potential problem and implemented any necessary follow-up corrective action. The Battelle Quality Manager ensured that follow-up corrective action was taken. The results of the TSA were submitted to the EPA.

4.3 Data Review

Records generated in the verification test received a one-over-one review before these records were used to calculate, evaluate, or report verification results. Data were reviewed by a Battelle technical staff member involved in the verification test. The person performing the review added his/her initials and the date to a hard copy of the record being reviewed.

Chapter 5
Statistical Methods

The statistical methods used to evaluate the quantitative performance factors listed in Section 3.1 are presented in this chapter. Qualitative observations were also used to evaluate verification test data.

5.1 Accuracy

A primary objective for this verification test was to determine the accuracy of PAVS performance with reading tags under critical variables and test conditions. Accuracy is a measure of the agreement between a measured value and the "true" value. For this verification, accuracy was determined as a percentage according to the following formula:

$$A = (1 - E/N) \times 100 \qquad (1)$$

where A is the percent accuracy of the RFID system reader, E is the total number of tags that were not properly recognized by the reader, and N is the total number of tagged HAZMAT containers. The accuracy of the system was determined for each read point and packaging type. The highest percent accuracy possible is 100%.

5.2 Precision

Precision is a measure of agreement among repeated measurements. The precision of tag reads completed the PAVS was determined by calculating the standard deviation of the accuracy at all possible read locations (i.e., from the accuracy at each external read location when external readers were used or the accuracy at each uplinked tag read event when the uplinked data system was used). The standard deviation of the accuracy measurements was calculated using the following formula:

$$S_{N,i} = \frac{1}{n}\sum_{k=1}^{n}\left(A_{k,i} - \overline{A_i}\right)^2$$

where, $S_{N,i}$ is the standard deviation of all accuracy measurements in verification test run i, n is the total number of possible read events in verification test run i, $A_{k,i}$ is the percent accuracy of the RFID system reader for read event k during verification test run i, and $\overline{A}_i$ is the overall arithmetic mean percent accuracy of the RFID system during verification test run i.

5.3 Influence of Possible Confounding Factors

The influence of the different container types on the accuracy of container identification was evaluated by calculating the accuracy in each container during each RT. Then a paired t-test was performed to determine if significant differences existed between the accuracy of the identification of steel drums, poly drums, and cardboard boxes. Other possible confounding factors included meteorological and environmental conditions. These data were reviewed qualitatively in attempt to identify possible correlations where statistical approaches should be considered.

Chapter 6
Test Results

As mentioned previously, this verification test included both quantitative and qualitative evaluations. The quantitative evaluation was conducted to assess the accuracy and precision of PAVS, as well as by testing the influence of confounding factors and its ability to discriminate the HAZMAT waste tags from other commercially-available active tags. The qualitative evaluation was performed to document the operational aspects of PAVS when it was used during verification testing. The following sections provide the results of the quantitative and qualitative evaluations.

6.1 Accuracy

As described in Section 3.1, two configurations of the Mobile PAVS technologies were tested. One configuration included roadside readers that read the RFID tags in the truck at fixed locations and a second configuration that include a reader (referred to as the Relayer) that resided in the cab of the truck and communicated (uplinked) the container identifications each minute to a central database via a cellular phone connection. Both configurations of the PAVS were tested simultaneously and the results are presented separately below.

6.1.1 External Reader Accuracy

Table 6-1 gives the accuracy results for the external reader configuration of the PAVS technology. The left column of the table gives each read location as described throughout Section 3.2 and the top row of the table gives the RT number, what route was followed, and whether the load was packed in a tight or loose configuration. Because the truck contained 12 HAZMAT containers with vendor RFID tags, each read location had the possibility of 12 correct tag identifications. Each tag was identified with a unique eight digit number (e.g., 40000020) that was labeled on the outside of the tag. This number was also the piece of information that was recorded by the RFID reader upon a successful read event. Therefore, the accuracy of each read location is presented as a percentage of correctly read tags based on a total of 12 possible correct tag reads at each read location. AVANTE opted not to include the external readers in the second RT into MX (RT4). As was described in Section 3.2, during the stationary reads at various distances prior to RT 1 and the initial exit from NMBA, the external readers were placed at angles of 90° and 45° with respect to the road. At that time, AVANTE indicated a likely interference between the two readers so use of readers at both angles was discontinued. Upon review of the data, it did not appear that there was any interference between the two readers so the available results for both reader angles are shown. Some of the read locations given in the table were not used during every RT. The casino read location was only used during the U.S. RTs, the MX POE and MX turnaround read location were only used during the MX RTs,

Table 6-1. Accuracy - External Readers

Round Trip (RT) Number Truck Route Packaging Configuration:	RT 1 US Tight	RT 2 US Tight	RT 3 MX Loose
Read Location New Mexico Border Authority (NMBA) Distance/Angle Reads:			
5ft, 90°	100% (12/12)	83% (10/12)	83% (10/12)
5ft, 45°	100% (12/12)	(1)	(1)
15ft, 90°	100% (12/12)	83% (10/12)	92% (11/12)
15ft, 45°	100% (12/12)	(1)	(1)
30ft, 90°	92% (11/12)	83% (10/12)	83% (10/12)
30ft, 45°	92% (11/12)	(1)	(1)
50ft, 90°	92% (11/12)	83% (10/12)	83% (10/12)
50ft, 45°	92% (11/12)	(1)	(1)
70ft, 90°	92% (11/12)	83% (10/12)	92% (11/12)
70ft, 45°	92% (11/12)	(1)	(1)
NMBA Exit, 90°	100% (12/12)	100% (12/12)	100% (12/12)
NMBA Exit, 45°	100% (12/12)	(1)	(1)
Casino	100% (12/12)	100% (12/12)	(2)
MX Port of Entry	(2)	(2)	100% (12/12)
MX Turnaround	(2)	(2)	100% (12/12)
55 mph pass	(3)	100% (12/12)	(2)
40 mph pass	(3)	100% (12/12)	(2)
NMDPS Truck Inspection Facility			
25 mph pass	92% (11/12)	75% (9/12)	17% (2/12)
15 mph pass	92% (11/12)	100% (12/12)	(4)
25 mph pass	100% (12/12)	100% (12/12)	33% (4/12)
15 mph pass (collision test)	100% (12/12)	75% (9/12)	(4)
NMBA Entrance	(3)	100% (12/12)	100% (12/12)
5ft, 90°	100% (12/12)	100% (12/12)	100% (12/12)
15ft, 90°	83% (10/12)	100% (12/12)	100% (12/12)
30ft, 90°	83% (10/12)	100% (12/12)	100% (12/12)
50ft, 90°	83% (10/12)	100% (12/12)	100% (12/12)
70ft, 90°	83% (10/12)	92% (11/12)	100% (12/12)
Overall External Reader Average	94% (248/264)	93% (211/228)	86% (166/192)

(1) 45° Read angle not used following RT 1
(2) Read location not applicable for this RT
(3) Read location not used because readers not in place during RT 1
(4) Data not collected for undetermined reason; reader was in place and seemingly recording, but no data stored.

and the 55 mph and 45 mph read locations were only used during the second U.S. RT. The stationary reads at various distances were performed before and after each RT at the NMBA and there were two read locations (25 and 15 mph) at the NMDPS facility. The truck passed the NMDPS facility twice during each RT.

For all of the RTs, when a container was identified correctly, the identification number of its RFID tag was read and documented by the external reader. If it was not identified, the tag identification number was not read and documented. During RT 1, there were 22 possibilities for the PAVS external reader configuration to make 12 correct reads of the tagged containers. All 12 containers were identified in 10 instances, 11 out of 12 containers were identified in eight instances, and 10 out of 12 containers were identified in four instances. Over the entire RT, 248 out of 264 containers were identified correctly for an overall accuracy of 94%.

During RT 2, there were 19 read locations to make 12 correct reads of the tagged containers. All 12 containers were identified in 11 instances, 11 out of 12 containers were identified in one instance, 10 out of 12 containers were identified in five instances, and 9 out of 12 containers were identified in two instances. Over the entire RT, 211 out of 228 containers were identified correctly for an overall accuracy of 93%. Prior to the RT, the stationary reads at various distances from the truck produced 10 out of 12 correct identifications at each distance, but following the RT, the same test produced 12 out of 12 correct identifications at all but the furthest distance. Also, this was the only RT that included a 40 mph and 55 mph read location and the results for both were 100% accuracy. Two 75% accuracy reads occurred at the NMDPS facility, one at 25 mph and one at 15 mph. There was no discernable reason for the diminished accuracy at these locations given that the read locations immediately before and after these read locations produced 100% accurate results.

During RT 3, there were 16 possibilities to make 12 correct reads of the tagged containers. All 12 containers were identified in 9 instances, 11 out of 12 containers were identified in two instances, and 10 out of 12 containers were identified in three instances, and two instances that generated results that were less than 50%. There were two completely unique read locations during this RT, the Mexican POE and the MX turnaround point. The MX POE read location was located in a place that truck traffic waited in line to enter MX therefore, the external reader was passed at a low rate of speed (~5 mph). The MX turnaround read location was approximately 12 miles south of the MX POE in a location just north of where the truck turned around to return to the U.S. The truck was traveling at 30 mph when it passed the external reader. Both of these read locations produced 100% accurate identifications. Upon the return to the U.S., the truck passed the 25 mph and 15 mph read locations at the NMDPS facility. For a reason that was not able to be determined, no data were collected at the 15 mph read location during this RT. The results for the two 25 mph read locations during this RT were 17% and 33%, respectively, with no discernible reason for the relatively low levels of accuracy given that the rest of the RT had accuracies between 80% and 100%. Over the entire RT, 166 out of 192 containers were identified correctly for an overall accuracy of 86%.

6.1.2 Relayer Uplinked Accuracy

This configuration of the Mobile PAVS technology included an RFID tag reader (referred to as the Relayer) that was located in the cab of the truck. The RELAYER also served as the communication link by uplinking the collected data via cellular to an AVANTE computer server once per minute during each RT. Because the tags were being read every minute, regardless of location, it eliminated the need to pass by an external reader at a single location. However, because the data for both configurations were being collected simultaneously, the results are presented in the same fashion, recording the accuracy of the container identification at the times that the truck was at the various read locations. Performing reads at various distances from the truck, an aspect of testing that included only the external readers, was not conducted for this configuration of the Mobile PAVS technology.

Table 6-2 presents the results for the uplinked data in a similar fashion as in the previous section for the external reader data. The uplinked data were collected for only RT 2, RT 3, and RT 4 as data were not collected for RT 1. According to AVANTE, this gap in data was due to a gap in cell phone service coverage preventing the transmittal and storage of the tag identification and GPS tracking data. In addition to the missing data from RT1, uplinked data were only collected for the first 40 minutes of RT 2. At that point in the RT, there was a gap in cell phone coverage and the PAVS was unable to restart the communication when the truck travelled back in to an area with cell phone service. Data collected for RT2 included the NMBA exit, three of the four read locations at the NMDPS facility (data were not collected for the second 25 mph pass) and part of the way to the casino. The RT lasted from approximately 4:00 p.m. until 5:25 p.m., but data were collected only until 4:45 p.m. Throughout this time period, there were 233 correct identifications of containers out of 348 possibilities for an overall accuracy (while the technology was functional) of 67%.

Table 6-3 gives the data completeness for RT 2-4. Data completeness is defined as the fraction of the total duration of the RT that the continuous data uplink was occurring (less than two minutes between data uplinks). RT 2 had a data completeness of 37%. Most of the missing data occurred during the final 40 minutes of the RT, but there was also 11 minutes of missing data surrounding the second 25 mph read location.

The accuracy of RT 3 ranged from 75% to 100% at the various read locations, but during the time period that data were being collected properly, the overall accuracy was 1,594 correct container identifications out of 1,786 possible identifications for an overall accuracy of 89%. In addition, the data completeness for this RT was much higher than for RT2 as data were uplinked at least once every two minutes for 86% of the RT. According to AVANTE, the missing data were again due to a lack of cell phone coverage, but prior to RT 3, they were able to make a change to the PAVS firmware to accommodate the restart of data transmission when the truck returned into an area with adequate cell phone coverage. This restarting of data transmission was observed following a time period of missing data during RT 3.

The accuracy at the various read locations during RT 4 was 100% with the exception of the second 25 mph pass which did not identify two of the containers within the truck for 83% accuracy at that location. However, during the time period that data were being collected properly, the overall accuracy was 804 correct container identifications out of 850 possible identifications for an overall accuracy of 95%. In addition, the data completeness for this RT was 81% as there were 17 minutes of missing data when the truck was in MX. The time period of missing data included the MX turnaround so there was no data collected for that read location. The reason for the missing data was again a lapse in cell phone service coverage which was apparently regained by the end of RT 4 as data collection resumed.

Table 6-2. Accuracy – In-truck Reader and Uplinked Communication

Round Trip Number Truck Route Packaging Configuration	RT 2 US Tight	RT 3 MX Loose	RT 4 MX Loose
Read Locations			
NMBA exit	75% (9/12)	100% (12/12)	100% (12/12)
MX POE	(1)	100% (12/12)	100% (12/12)
NM Casino	(2)	(1)	(1)
MX Turnaround	(1)	83% (30/36)	(2)
NMDPS Truck Inspection Facility			
25 mph pass	58% (7/12)	83% (10/12)	100% (12/12)
15 mph pass	83% (10/12)	83% (10/12)	100% (12/12)
25 mph pass	(2)	92% (11/12)	83% (10/12)
15 mph pass (collision test)	100% (12/12)	92% (11/12)	100% (12/12)
55 mph pass	(2)	(1)	(1)
40 mph pass	(2)	(1)	(1)
NMBA entrance	(2)	75% (9/12)	100% (12/12)
Overall Road Driving	67% (233/348)	89% (1594/1786)	95% (804/850)[3]

(1) Read location not applicable for this RT
(2) Data not collected for undetermined reason, data collection halted completely after 40 minutes of the RT
(3) 25% of the misidentifications may have been due to a wet RFID tag (see Section 6.4)

Table 6-3. Data Completeness Due to Continuity of Data Uplink

Round Trip Number Route	RT 2 US	RT 3 MX	RT 4 MX
Elapsed Time (min) of route	81	162	91
Duration of continuous data uplinks (min)	30	140	74
Data completeness	37%	86%	81%

6.2 Precision

The precision, or repeatability, of the RFID accuracy data were determined as described in Section 5.2 and is given in Table 6-4 along with the overall accuracy for each RT.

Table 6-4. Overall Accuracy ± Standard Deviation of Each RT

Truck Routes	External Reader ± SD	Uplinked Data ± SD
RT1-US	94% ± 6%	(1)
RT2-US	93% ± 10%	67% ± 32%
RT3-MX	86% ± 25%	89% ± 15%
RT4-MX	(1)	95% ± 7%

(1) Read location not applicable for this RT

For the external readers, the standard deviations were 10% or less for RT 1 and 2. The uplinked data became more precise over the three RTs, with RT 2 generating a SD of 32% and RT 4 generating a SD of 7%.

6.3 Interference of Other RFID Signals

The collision test was performed as described in Section 3.2.4 by placing four RFID tags into the trailer along with the containers that were tagged with the AVANTE RFID tags. Thereafter, the truck passed the second 15 mph read location at the NMDPS facility. The data for that read location are shown in Table 6-5. Overall, three out of the five available data sets resulted in 100% accuracy, one had 92% accuracy, and one had 75% accuracy. While difficult to determine conclusively with this small data set, these results were similar to the non-collision test results presented in Tables 6-1 and 6-2 in that some non-collision test read locations resulted in accuracy percentages of 75%, 92%, and 100%. These similarities, while not a quantitative evaluation, suggest that the presence of the collision tags did not negatively impact the accuracy results.

Table 6-5. Collision Test Results

15 mph pass - Collision Test	RT 1 US	RT 2 US	RT 3 MX	RT 4 MX
External Readers	100% (12/12)	75% (9/12)	(1)	(2)
Uplinked Data	(1)	100% (12/12)	92% (11/12)	100% (12/12)

(1) Data not collected for undetermined reason; reader was in place and seemingly recording, but no data stored.
(2) Read location not applicable for this RT

6.4 Influence of Confounding Factors

Container type and packaging configuration. The RFID tags were placed on three different types of containers during the round trips. The accuracy results are presented in Table 6-6 by container type. The container identification accuracy ranged from 59% to 100% with an average of 85% for the steel drums, 72% to 99% with an average of 89% for the poly drums, and 69% to 100% with an average of 88% for the cardboard boxes. A paired t-test was performed on the results by container type and no significant differences were determined at a 95% confidence interval. As shown in Table 6-2 above, the overall accuracy of the uplinked data during RT 2 was considerably lower than RTs 3 and 4. This is consistent with the container-specific accuracy data shown here as the accuracies for RT 2 are lower for all three RTs. RT 2 was the only RT for which uplinked data were collected when the containers were in a tightly-packed configuration so the lower container identification accuracies could be attributed to packing configuration. However, the uplinking data system stopped functioning 45 minutes into RT 2, and upon review of the raw data, there was an increased number of missed container identifications just before it stopped functioning, suggesting that the problem with the equipment was more likely the contributing cause rather than the packing configuration. In addition, the external readers did not exhibit the same diminished accuracy with the tight configuration.

Table 6-6. Accuracy Results by Container Type (in percent)

Configuration	Round Trip #	Steel Drum	Poly Drum	Cardboard Box
External Readers	RT1	100	93	89
	RT2	96	91	91
	RT3	83	86	91
	RT4	(1)	(1)	(1)
Uplinked	RT1	(1)	(1)	(1)
	RT2	59	72	69
	RT3	85	94	89
	RT4	85	99	100
Average		85	89	88
SD		14	9	10

(1) Read location not applicable for this RT

Meteorological and other environmental conditions. Throughout the two days of testing, the temperature inside the truck never exceeded 25.1 degrees Celsius (°C) and never dropped below 15.8 °C. The relative humidity ranged from 12% to 19%, and the barometric pressure ranged from 25.4 inches of mercury (in Hg) to 26.1 in Hg. Upon a qualitative review of the accuracy data, there was no suggestion that meteorological conditions impacted the results in any way so no statistical analyses were performed. However, high winds caused sandstorm conditions during the testing which caused difficulty in reading the memory cards used for data collection on the external readers. Instead of using the memory card, the data were downloaded using an ethernet port. Similar to the meteorological conditions, there was no suggestion of a correlation between the Shocklog data collected during each RT and the accuracy results so no statistical analyses were performed.

Other factors. Following RT 4, the verification staff noticed that one of the tags was very wet (from water that had splashed out of the drum it was attached to) after the truck returned from the

RT. Review of the tag specific data revealed that of the 46 incorrect container identifications (out of 804 possible identifications) during RT 4, 25 of them had been due to the tag that was found to be wet. Throughout RT 4, that tag had a 65% accuracy. One other tag (with no similar explanation) had 79% accuracy while the others were between 96% and 100%.

6.5 Operational Factors

The verification staff found that AVANTE's PanaSec Mobile PAVS was easy to use. AVANTE staff set up the external readers and assisted with the application of the RFID tags to the HAZMAT waste containers. The Mobile PAVS was setup quickly by powering the system through the dashboard 12v power outlet and positioning two small antennae inside the truck's cab.

As described in Section 6.1, the PAVS technology had a decreased level of data completeness due to blocks of missing data during the verification test. According to AVANTE, the reason for these missing blocks were due to lack of cellular phone coverage. During RTs 1and 2 the loss of cell phone service coverage took place in the U.S., during RT 3 the loss of cell phone service coverage took place on both sides of the border near the MX POE on the way back in to the U.S., and during RT 4 the loss of coverage took place in MX on the way to the turnaround point. During RTs 1 and 2, the transmission of tag identification data did not restart when the truck re-entered an area with adequate cell phone service coverage. Prior to RT 3, AVANTE was able to make a change to the PAVS firmware that allowed for this to take place during RTs 3 and 4. This update did not accommodate simultaneous operation with the external reader configuration so the external readers were not used for RT 4. In addition, following RT 1, AVANTE staff had to repair a faulty GPS receiver within the Relayer.

AVANTE concluded that the RF conditions at the test location in close proximity to the United States – Mexico Border were particularly adverse to the efficiency of communication between the RFID tags and the vehicle-based Relayer component of our equipment. This adverse local RF environment decreased the nominal read distance between Relayer and RFID tags from 500 ft to less than 100 ft. AVANTE believe this RF interference caused diminished tag read accuracy during the verification test. AVANTE has taken steps to resolve these problems such as adding an amplifier to the Relayer to increase read distances, changing the orientation and type of the external antenna, shifting the reception frequency of the antenna, and revising the software to allow PAVS to store the tag identification and GPS tracking data and then transmit it when the truck returns to an area with adequate cell phone coverage.

The software that AVANTE uses to handle the data collected by the uplinked data connection is web-based and offers a number of optional utilities that were used during the verification test. One feature that was tested was the ability for the software to provide an alert when the truck deviated from its planned path by more than one mile. This was performed once during the verification test and the alert was provided in real-time to verification staff that were watching the computer monitor as well as by text message. In addition to the RFID tag identification data, the uplinked data included the GPS coordinates of the Relayer at the time of uplink. Using AVANTE's online software, the coordinates can be mapped in real-time and displayed as is shown in Figure 6-1. The path of green shapes show the route of the truck from the NMBA into MX. In addition to the GPS mapping, another utility was the use of a wallet sized "Driver's Identification card" incorporating a "panic-button" that can be given to the driver of a truck. This can be used as an actual panic button for the driver to alert those monitoring the truck, or those designated in advance to receive alert text messages on their mobile phones or via email, in the event of a dangerous or threatening situation with a discreet one-second squeeze at a certain point on the badge. This card can also be used to send an alert if the driver leaves the truck and then send another report when the driver returns. While not a part of the formal testing, AVANTE successfully demonstrated each of these utilities during the verification test. The user-friendliness of the vendor software was very apparent as the interface was graphical and intuitive. The time needed to train testing staff in the proper use of the system was minimal.

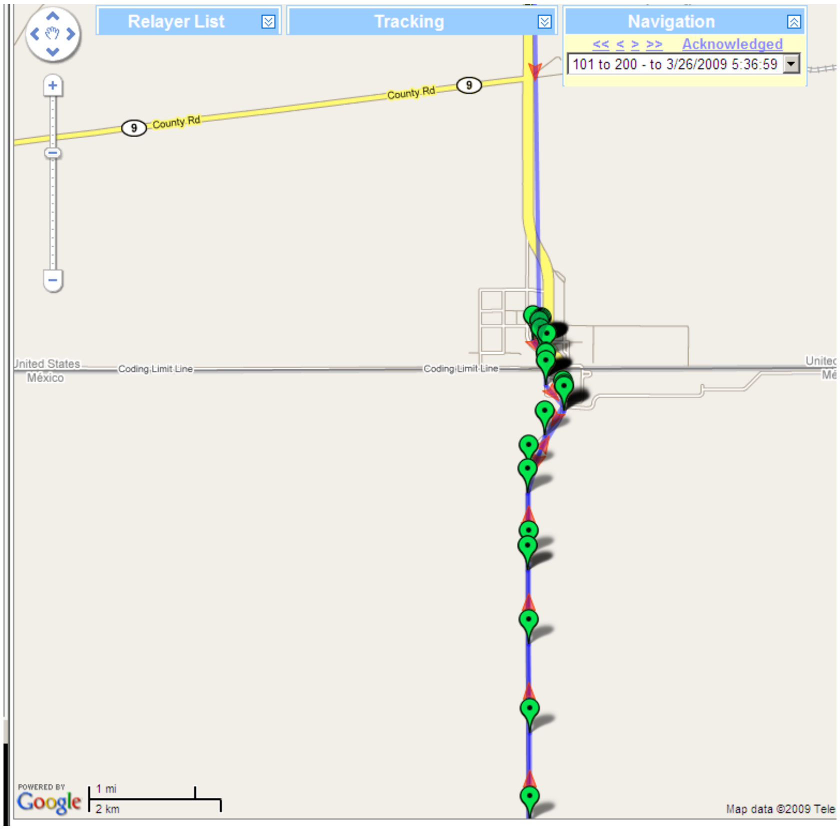

Figure 6-1. Screenshot from AVANTE's Software.

The uplinked configuration of the AVANTE PAVS can be purchased as a service at a current price of $1/day/vehicle which includes the Relayer, one Driver's identification badge with Panic Button, and two RFID tags for cargo or wall mount. The price is based on a two year contract, with a $200 security deposit refundable at lease termination. The price includes the utilities described above (i.e., route deviation, driver location alerts, panic button functionality, text message alerts, etc.). Additional RFID tags are available for purchase at $25 - $32 depending on quantity.

Chapter 7
Performance Summary

Three RTs were performed using the external reader and uplinked configurations of the PAVS system. The external readers were used during the first two RTs that were performed within the U.S. and the first RT into MX. Prior to RT 3, AVANTE performed a firmware update to their software to ensure the uplinked system worked properly. That update did not accommodate simultaneous operation with the external reader configuration. The uplinked system was used for all four RTs but had higher levels of data completeness during RTs 3 and 4. No uplinked data were collected during RT 1 and data from 63% of RT 2 were not collected due to gaps in cell phone coverage required for data transmission. Table 7-1 summarizes the accuracy, precision, and data completeness of the PAVS system.

Table 7-1. Accuracy and Precision Summary for the PAVS

Truck Route	External Reader (Identified Tags/Total Tags)±SD	Uplinked Data (Identified Tags/Total Tags)±SD
RT1-US	94% (248/264) ± 6%	(1)
RT2-US	93% (211/228) ± 10%	67% (233/348) ± 32%
RT3-MX	86% (166/192) ± 25%	89% (1,594/1,786) ± 15%
RT4-MX	(1)	95% (804-850) ± 7%

(1) Read location not applicable for this RT

The external readers generated container identification accuracies that were above 90% and had SDs of 10% or less for RTs 1 and 2. RT 3 resulted in a lower overall accuracy and a higher SD with two read locations as part of RT 3 that resulted in less than 35% accurate results, thus impacting the overall accuracy for that RT. All of the other read locations for that RT had greater than 83% accuracy.

The uplinked configuration for RTs 2, 3, and 4 generated accuracies of 67%, 89%, and 95%, respectively. Data were only collected for the first 40 minutes of RT 2 for data completeness of 37% and the frequency of missed reads increased throughout that time period. The results from RTs 3 and 4 show that data were collected during more than 80% of the time. According to AVANTE, these gaps in data were due to gaps in cell phone service coverage preventing the transmittal and storage of the tag identification and GPS tracking data.

Interference with other RFID signals. The collision test was performed as described in Section 3.2.4 by placing four RFID tags into the trailer along with the containers that were tagged with the AVANTE RFID tags. Three out of the five collision test data sets resulted in 100% accuracy, one had 92% accuracy, and one had 75% accuracy. While difficult to determine conclusively with this small data set, these results were similar to the non-collision test results presented in Tables 6-1 and 6-2 in that some non-collision test read locations resulted in accuracy percentages of 75%, 92%, and 100%. These similarities, while not a quantitative evaluation, suggest that the presence of the collision tags did not negatively impact the accuracy results.

Influence of Confounding Factors. The influence of container type was quantitatively considered as a possible factor in PAVS performance. A paired t-test was performed on the container identification accuracies as a function of container type and no significant differences were determined between the container types. In addition, there was no indication that environmental conditions during the testing significantly impacted any of the results. However, one tag was wetted by water splashed from a container during a RT. This tag was missed at a higher rate compared to other tags. High winds caused sandstorm conditions during the testing which caused difficulty in reading the memory cards used for data collection on the external readers. Instead of using the memory card, the data were downloaded using an ethernet port.

Operational Factors. AVANTE staff set up the external readers and assisted with the application of the RFID tags to the HAZMAT waste containers. The ease of use of the Mobile PAVS was notable as setup could be quickly accomplished by powering the system through the dashboard 12 volt power outlet and positioning of two small antenna inside the truck's cab.

As described in Section 6.1, the PAVS technology had a decreased level of data completeness for the uplinking system due to blocks of missing data during the verification test. The reason for these missing blocks were not fully known for RTs 1 and 2, and for RTs 3 and 4, the gaps in data collection were due to lack of cellular phone coverage. During RTs 1and 2 the loss of cell phone service coverage took place in the U.S., during RT 3 the loss of cell phone service coverage took place on both sides of the border near the MX POE on the way back in to the U.S., and during RT 4 the loss of coverage took place in MX on the way to the turnaround point. During RTs 1 and 2, the transmission of tag identification data did not restart when the truck re-entered and area with adequate cell phone service coverage. Prior to RT 3, AVANTE was able to make a change to the PAVS firmware that allowed for this to take place during RTs 3 and 4. This update did not accommodate simultaneous operation with the external reader configuration so the external readers were not used for RT 4. In addition, following RT 1, AVANTE staff had to repair a faulty GPS receiver within the Relayer.

AVANTE concluded that the RF conditions at the test location in close proximity to the United States – Mexico Border were particularly adverse to the efficiency of communication between the RFID tags and the vehicle-based Relayer component of our equipment. This adverse local RF environment decreased the nominal read distance between Relayer and RFID tags from 500 ft to less than 100 ft. AVANTE believes this RF interference caused diminished tag read accuracy during the verification test. AVANTE has taken steps to resolve these problems such as adding an amplifier to the Relayer to increase read distances, changing the orientation and type of the external antenna, shifting the reception frequency of the antenna, and revising the software to allow PAVS to store the tag identification and GPS tracking data and than transmit it when the truck returns to an area with adequate cell phone coverage.

The uplinked configuration of the AVANT PAVS can be purchased as a service at a current price of $1/day/vehicle which includes the Relayer, one Driver's identification badge with Panic Button, and two RFID tags for cargo or wall mount. The price is based on a two year contract, with a $200 security deposit refundable at lease termination. The price includes the utilities described above (i.e., route deviation, driver location alerts, panic button functionality, text message alerts, etc.). Additional RFID tags are available for purchase at $25 - $32 depending on quantity.

Chapter 8
References

1. *Test/QA Plan for Verification of Radio Frequency Identification (RFID) for Tracking Hazardous Waste Shipments across International Borders,* Battelle, Columbus, Ohio, March 23, 2009.

2. Quality Management Plan for the ETV Advanced Monitoring Systems Center, Version 7.0, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, November, 2008