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An Evaluation of DGPS-based Continuously Operating Vehicle Monitoring Systems to Determine Site-specific Event Severity Factors

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Foreword

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) under Project CS-1102, "Improved Units of Measure for Training and Testing Area Carrying Capacity Estimation." The technical monitor was Dr. Robert Holst, Compliance and Conservation Program Manager, SERDP. Mr. Bradley P. Smith is Executive Director, SERDP.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Mr. Alan B. Anderson. Part of this work was done by Dr. Paul Ayers, Mr. Michael Vance, and Ms. Liv Haugen of Colorado State University, Fort Collins, CO. The technical editor was Gloria J. Wienke, Information Technology Laboratory. Mr. Steve Hodapp is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director was Dr. William D. Severinghaus, CEERD-TD. The Acting Director of CERL is Dr. William D. Goran.

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1 Introduction

Background

ATTACC methodology

The Department of Defense (DoD) is responsible for administering more than 25 million acres of Federally owned land in the United States (Public Land Law Review Commission 1970), making it the fifth largest Federal land managing agency. In addition, DoD military branches have agreements with states and other Federal land-managing agencies to allow training use of 15 million acres (Council on Environmental Quality 1989).

The Integrated Training Area Management (ITAM) Program (Army Regulation [AR] 350-4 1998) is the Army's program for managing training land. A major objective of the ITAM program has been to develop a method for estimating training land carrying capacity. Training land carrying capacity is defined by the Office the of Deputy Chief of Staff for Operations and Plans (ODCSOPS) as the amount of training that a given parcel of land can accommodate in a sustainable manner, based on a balance of use, condition, and maintenance practices. The Army Training and Testing Area Carrying Capacity (ATTACC) methodology is an initiative sponsored by ODCSPOS to estimate training land carrying capacity (Anderson et al. 1996). ATTACC is based on a system of calculating maneuver impact miles (MIM) based upon predetermined Training Impact Factors (TIF) multiplied by the miles the vehicle traveled.

ATTACC-related Army user requirements

Documentation of the Army's environmental technology requirements has been an iterative process that began with a series of meetings in 1993 and the Office of the Directorate of Environmental Programs' (ODEP) publication *U.S. Army Environmental Requirements and Needs*. The Army's environmental technology requirements describe the critical Research, Development, Test, and Evaluation (RDT&E) needs for accomplishing the Army's mission with the least impact or threat to the environment. "Land Capacity and Characterization" is the third priority conservation user requirement. This user requirement defines the Army's need to estimate training land carrying capacity. It describes the

ATTACC methodology as designed to provide scientifically based information to the land managers to support sound decisionmaking. However, this user requirement defines the current version of ATTACC as limited in its ability to provide the most accurate information. This limitation is due to the accuracy of input data and a simplistic characterization of the three components of the model. The user requirement identifies required research and development to improve the accuracy of the ATTACC methodology.

Twenty-eight exit criteria were identified in the "Land Capacity and Characterization" user requirement. Each exit criteria defines a specific product required to address a specific aspect of the overall requirement. One of these exit criteria defines the need to develop a protocol, tool(s), and/or factor(s) for installation-level use that improve the objectivity of Event Severity Factors (ESF) in ATTACC.

ATTACC sensitivity analysis

A sensitivity analysis is an evaluation of the magnitude of changes in a model's output as a function of changes in the input parameter values. Moreover, a sensitivity analysis of a model's responses to variations in input values can be used to determine the relative importance of individual input values. Results of a sensitivity analysis are used to prioritize data acquisition and model development efforts.

A sensitivity analysis of the ATTACC methodology has been completed (Anderson 1999). The ATTACC methodology is sensitive to changes in training load inputs. All Training Impact Factors have an effect on model output due to the form of the training load equation. The sensitivity analysis indicated that improvements to the ESF could improve the overall accuracy of the ATTACC methodology. Global Positioning Systems (GPS) and existing GPS data potentially can be used to determine dynamic properties of vehicles and to predict the adverse effects of training events.

DGPS systems

GPS provide a means of determining a vehicle's position at a point in time. GPS equipment (units) are fielded as part of some Army weapon systems. When GPS units are used with all vehicles in a training exercise, the resulting positional data provides a "footprint" of the event. Real-time Differentially corrected Global Positioning Systems (DGPS) and post-processing DGPS provide the opportunity to obtain more accurate ESF. Army managers currently do not have accurate ESF. The effectiveness of using DGPS depends on the static, bearing, dynamic position, and velocity accuracy of derived positional data. If the real-time DGPS and post-processing DGPS units prove capable of determining the position and movement of vehicles, this technology can then be applied to develop an accurate system for monitoring soil disturbance and environmental impact. The current system for environmental impact monitoring could be updated to account for the velocity, turning, and sudden stopping of vehicles if GPS can accurately track those vehicles. The GPS data could be used to more accurately define a vehicle's movement during a specific training exercise, and thus provide for a more accurate determination of the impact of that training exercise. The impact areas of the training exercise could be monitored using a GPS and mapped using a Geographical Information System (GIS).

Objectives

The overall objective of this study was to evaluate the feasibility of using real-time DGPS and post-processing DGPS to monitor site-specific vehicle impacts and more accurately estimate ATTACC ESF. Specific objectives include:

1. Static Accuracy: Compare static accuracy of real-time DGPS to post-processing DGPS.
2. Dynamic Accuracy: Determine the dynamic accuracy of a real-time DGPS and post-processing DGPS.
3. Velocity Test: Determine if the velocity of a vehicle can be accurately calculated with GPS position data from real-time DGPS and a post-processing DGPS.
4. Stopping Test: Determine if real-time DGPS and post-processing DGPS can accurately determine sudden changes in velocity.
5. Turning Radius Test: Determine if position data from real-time DGPS and post-processing DGPS can be used to accurately calculate the turning radius of the vehicle. Multi-hertz (10 Hz) real-time DGPS will also be explored to help determine the vehicle turning radius.
6. Army Systems Evaluation: Evaluate the utility of existing military vehicle GPS units.
7. ESF Design Evaluation: Develop a GPS-based continuously operating vehicle impact monitoring system (COVIMS) and determine what models and procedures are necessary for GIS integration of impact severity factors from acquired GPS position data.

Approach

The effectiveness of using DGPS to improve ATTACC ESF depends on the accuracy of the static and dynamic vehicle positions, and the accuracy of the vehicle velocity and turning radius calculated from the data recorded with the units. Static accuracy tests were used to determine if the real-time DGPS and post-processing DGPS could give the accurate position of a benchmark, and the time it takes to determine that position. The real-time DGPS and post-processing DGPS units were then tested to determine if they could accurately locate the position of a vehicle while it was moving, and whether there was a time delay associated with the locating process. Velocity tests were then performed to determine if accurate velocities could be obtained from the real-time DGPS and post-processing DGPS units, and how fast the units responded to changes in velocity. Turning radius tests were then performed to determine if the real-time DGPS and post-processing DGPS units could be used to accurately determine the turning radius of a vehicle from the change in the vehicle's position.

Comparisons of various procedures for data analysis were conducted to determine the most effective procedure for calculating velocity, change in velocity, and turning radius from position data. Evaluations were conducted on the static, dynamic, velocity, stopping, and turning radius test data using the most effective procedures. Evaluations of the data acquired from the static test were performed to determine the average position error, average altitude error, dilution of precision (DOP), circular error probable (CEP), and two-distance root mean square (2DRMS). Evaluations of the dynamic test data were performed to determine the average error of GPS position at the time the vehicle crossed the benchmark and the time lag between when the benchmark was crossed and when the GPS sensed the benchmark position. Evaluations of the velocity test data were completed to compare the GPS position-determined velocity to the distance-over-time measured velocity and to the radar speed sensor velocity. Evaluations of the stopping test data were performed to determine the time for each GPS unit to respond to a change in velocity. Evaluations were performed on the turning radius data (based on the average calculated turning radius from GPS data points) as compared to the actual radius.

If the real-time DGPS and post-processing DGPS units proved capable of determining the position and movement of vehicles, then this technology could be applied to improve the current system for monitoring soil disturbance and environmental impact of training exercises. Vehicles were driven through predefined courses that required varying vehicle velocities and turning radii. Vehicle damage to the course was recorded. Statistical models were developed to quantify the relationship between vehicle dynamic properties and site damage.

Based on the information obtained from each of the studies, a determination was made of the potential to use DGPS systems and data sources to monitor and predict site damage within the ATTACC model.

Scope

The information provided in this report refers to the ATTACC model as described in the *ATTACC Handbook* (U.S. Army Environmental Center [USAEC] 1999). The evaluation of DGPS systems for estimating ATTACC ESF is part of a larger effort to provide a consistent methodology for estimating ATTACC Vehicle Severity Factors (VSF) and Local Condition Factors (LCF) (Sullivan and Anderson 2000), Vehicle Conversion Factors (VCF), and ESF. Results of the larger effort will be documented in subsequent reports.

Models presented in this report that predict site damage from vehicle dynamic properties are site specific. Application of these models to other sites is not appropriate.

Mode of Technology Transfer

The information in this report will be provided directly to Army personnel responsible for ATTACC implementation. The information will also be provided to organizations responsible for developing and refining the ATTACC methodology.

2 GPS Unit Selection

The Trimble AgGPS 132* (12-channel) real-time DGPS unit and the Magellan ProMark X** (10-channel) post-processing DGPS unit were used to evaluate DGPS-based continuously operating vehicle impact monitoring systems. These single-frequency, C/A code (course/acquisition code) units represent some of the most common, robust, and accurate GPS units available. These units were chosen because differential correction is the most accurate way to track off-road vehicle movement. The two types of differential correction (real-time and post-processing) were chosen because they represent two common and easy methods of correction. The real-time differential correction unit records a corrected position immediately (by use of a satellite correction signal). The post-processing differential correction unit uses a method of correction that is conducted after the position data has been collected and stored. The Trimble AgGPS 132 and Magellan ProMark X GPS units were chosen for the project because if these units can be used for accurate vehicle monitoring, then it is possible that other less accurate GPS units can also be used. Also, if the units could not be used to accurately monitor vehicles, then less accurate GPS units would also not be capable of accurately monitoring vehicles in the training field.

* Product of Trimble Navigation, 645 North Mary Ave., Sunnyvale, CA 94086; www.trimble.com.

** Product of Magellan Software, 8717 Research Dr., Irvine, CA 92618; www.magellan.com.

3 Static Accuracy Test

Procedure

The two GPS units were tested on 30 August 1999 from 17:01 Universal Time Coordinate (UTC) to 17:28 UTC, 1 September 1999 from 17:36 UTC to 18:05 UTC, and 2 September 1999 from 21:01 UTC to 22:02 UTC. The GPS units were placed on a benchmark and recorded position data; the resulting data were analyzed to determine the average of position error, average altitude error, DOP, CEP, and 2DRMS. The DOP is the uncertainty of a position fix due to satellite geometry; a higher DOP indicates a higher uncertainty. The CEP is the radius that encloses 50 percent of the two-dimensional position points. The 2DRMS is the radius in which plus or minus two standard deviations of the two-dimensional position points are enclosed. The GPS units were tested at a different time on each day because the satellite geometry used to locate a position changes as the satellites orbit the earth. The use of different satellite geometries for each test provides a more accurate overall representation of the static accuracy to be expected during normal operation of the GPS units.

Methods of Analysis

Both GPS units were placed on a benchmark and were set to log position data, UTC time, Horizontal Dilution Of Precision (HDOP), and altitude data every half hour. The data were transferred from the log files to spreadsheet files for data analysis.

The static position data were collected and recorded using latitude and longitude coordinates. The position data were then converted to the Universal Transverse Mercator (UTM) coordinate system for analysis. The average position for the points was determined by finding the average of the Northing and Easting coordinates. The position error for each point was calculated using the following equation, where the actual known benchmark position is denoted as the B position. The average of the position errors was determined and recorded.

$$ERROR\_A = \sqrt{(A_N - B_N)^2 + (A_E - B_E)^2)}$$

The position error data were sorted in ascending order. The CEP is the distance of GPS error that encloses 50 percent of the data points. The CEP was determined from the sorted position error data by determining the error distance that includes 50 percent of the position error distances. The 2DRMS is the distance of GPS error that encloses 95 percent of the data points' two standard deviations. The 2DRMS distance was determined from the sorted position error data by finding the distance that includes 95 percent of the position error distances.

The HDOP factor was an important factor to consider describing the clarity of which the GPS position can be determined. HDOP factors typically range from 0.9 to greater than 9. A high HDOP indicates a higher uncertainty of position. The average HDOP was calculated for each data set from the recorded HDOP data. The average altitude was also determined for each data set and the average error for altitude was calculated.

Results

Both GPS units were tested to determine if they could accurately determine static position at different times during the day. Figure 1 shows the difference in GPS position and the benchmark position. The CEP is plotted with the GPS position data and contains 50 percent of the GPS position points. Tables 1 and 2 present the results of the three separate static tests.

The Trimble AgGPS 132 unit demonstrated an average position error of 1.07 meters (Table 2), which was 0.46 meters smaller than the average position error of 1.53 meters recorded by the Magellan ProMark X unit. Both errors are small enough that the units can be considered to accurately record a static position.

Two other methods of analyzing static position data for accuracy were also used: the CEP is the distance of GPS error that encloses 50 percent of the data points, and the 2DRMS is the distance of GPS error that encloses 95 percent of the data points. The average CEP and 2DRMS for the Trimble AgGPS 132 static position data were 1.11 meters and 1.59 meters, respectively (Table 2). The average CEP and 2DRMS for the Magellan Pro-Mark X static position data were 1.46 meters and 2.52 meters, respectively (Table 2). The CEP and 2DRMS data show that the Magellan ProMark X can be used to record a static position accurate to 2.5 meters 95 percent of the time, while the Trimble AgGPS unit can be used to record a static position accurate to within 1.6 meters 95 percent of the time.

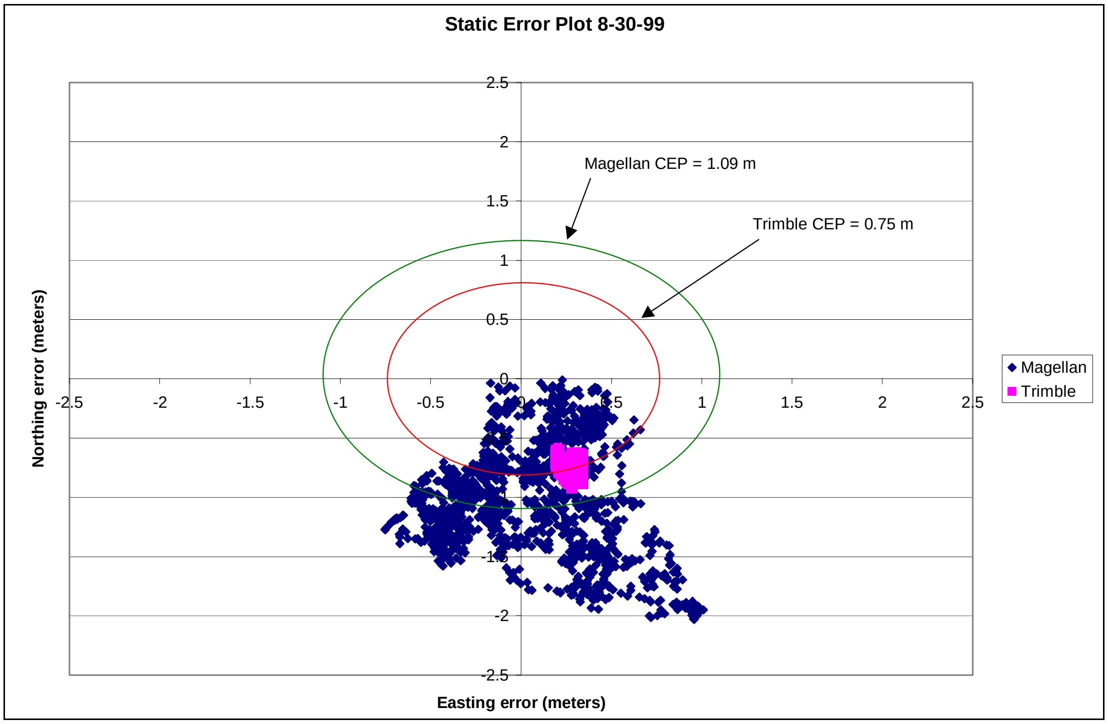

Figure 1. Plot of the difference in position from the GPS position data, recorded on 30 August 1999, to the position of the benchmark.

Table 1. Average HDOP for Trimble AgGPS 132 and Magellan ProMark X units.[1,2]

GPS Receiver	Date	UTC Time	Average HDOP
Magellan ProMark X	30 Aug 1999	17:01:30 - 17:28:40	1.39
Trimble AgGPS 132	30 Aug 1999	17:01:30 - 17:28:40	1.00
Magellan ProMark X	1 Sep 1999	17:36:01 - 18:05:31	1.53
Trimble AgGPS 132	1 Sep 1999	17:36:01 - 18:05:31	1.09
Magellan ProMark X	2 Sep 1999	21:01:30 - 20:22:02	1.61
Trimble AgGPS 132	2 Sep 1999	21:01:30 - 20:22:02	1.61

1. Benchmark Northing, Easting, and altitude are 488275.64, 4493692, 1550.05 m, respectively.
2. Position data recorded for 30 minutes on each of three different days.

Table 2. Average Easting, Northing, Position Error, CEP, and 2DRMS for Trimble AgGPS 132 and Magellan ProMark X units.[1,2]

GPS Receiver	Date	UTC Time	Average Position		Average Position Error	CEP	2DRMS
			Easting (meters)	Northing (meters)	(meters)	(meters)	(meters)
Magellan ProMark X	30 Aug 1999	17:01:30 - 17:28:40	488275.67	4493690.98	1.09	1.09	1.85
Trimble AgGPS 132	30 Aug 1999	17:01:30 - 17:28:40	488275.91	4493691.27	0.77	0.75	0.95
Magellan ProMark X	1 Sep 1999	17:36:01 - 18:05:31	488274.45	4493689.63	2.72	2.47	4.53
Trimble AgGPS 132	1 Sep 1999	17:36:01 - 18:05:31	488276.08	4493692.23	0.52	0.54	0.62
Magellan ProMark X	2 Sep 1999	21:01:30 - 20:22:02	488275.30	4493692.60	0.78	0.81	1.19
Trimble AgGPS 132	2 Sep 1999	21:01:30 - 20:22:02	488275.83	4493690.08	1.92	2.05	3.20

1. Benchmark Northing, Easting, and altitude are 488275.64, 4493692, 1550.05 m, respectively.
2. Position data recorded for 30 minutes on each of three different days.

4 Dynamic Accuracy Test

Procedure

The GPS units were mounted on a John Deere 2020 tractor that was driven at three different speeds across a benchmark of known GPS position. A third GPS unit was used to record the UTC time at which the tractor crossed the benchmark. The position recorded by the GPS units at the UTC time the tractor crossed the benchmark was compared to the actual position of the benchmark. The time was verified with a Video Mapping System (VMS). This test determined if the GPS units could accurately locate the position of the tractor as it was moving.

Methods of Analysis

The position of the vehicle during the dynamic tests was recorded in latitude and longitude coordinates at the 1-Hz frequency. The position data were converted to the UTM coordinate system for data analysis. The vehicle was driven over a benchmark of known GPS position, and the UTC time when the vehicle passed over the benchmark was recorded using a separate GPS unit. The position of the vehicle recorded by the GPS units at the UTC time that the vehicle passed over the benchmark was compared to the position of the benchmark. The comparison of the GPS recorded position to the actual benchmark position consisted of determining the average distance from the benchmark position to the GPS recorded position for each vehicle speed. The distance from the benchmark position to the GPS recorded position was calculated as follows:

Distance in meters from Benchmark Position A to GPS Recorded Position Point B (on the Northing [N] versus Easting [E] axis).

$$\text{Distance}_{A-B} = \sqrt{(A_N - B_N)^2 + (A_E - B_E)^2}$$

The time lag is determined with the velocity the vehicle is moving and the distance from the benchmark to the position point.

$$\text{Time Lag} = \frac{\text{Distance Error (m)}}{\text{Velocity (m/s)}}$$

Results

The position recorded with the GPS units at the time the tractor passed over a benchmark was compared to the known position of the benchmark. Figure 2 shows the position of the benchmark and the positions recorded with GPS at the time the tractor drove over the benchmark. There are points on either side of the benchmark (north and south) because the tractor was driven three times in the north direction and four times in the south direction. Table 3 shows the average distance errors, time lags, and the average velocity of each of the three speeds. The average distance errors of the position data recorded with the Trimble AgGPS 132 were 3.76 meters, 6.59 meters, and 9.95 meters for the slow, medium, and fast speeds, respectively. The average distance errors of the position data recorded by the Magellan ProMark X were 3.58 meters, 6.67 meters, and 10.9 meters for the slow, medium, and fast speeds, respectively. When the distance errors are divided by the velocity at which the position data were recorded, the dynamic time lags were found to be between 1.5 and 1.6 seconds for all three speeds. The Trimble AgGPS 132 and the Magellan ProMark X GPS units thus record an accurate dynamic position with a delay of approximately 1.6 seconds.

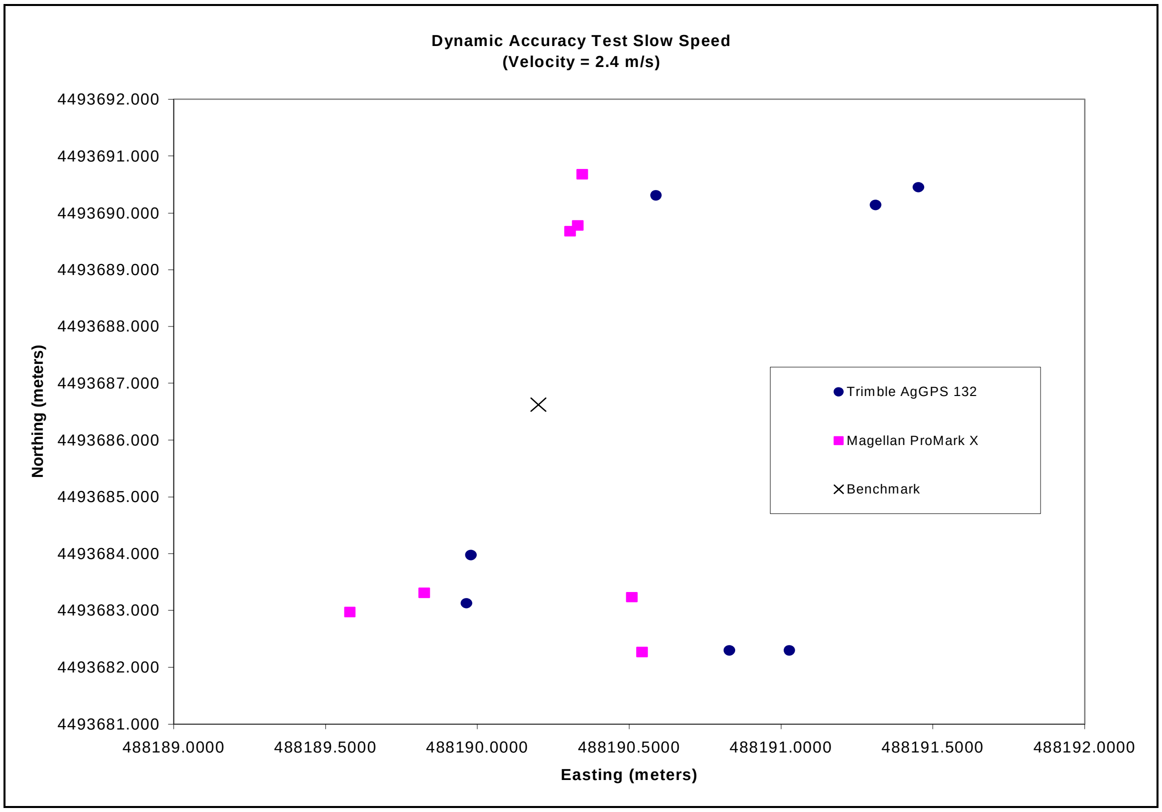

Figure 2. The GPS recorded position at the time the vehicle crossed the benchmark is plotted with the benchmark for comparison.

Table 3. The average dynamic position errors and average time lags were determined from position data recorded with the Trimble AgGPS 132 and Magellan ProMark X GPS units at three different speeds.

Receiver	Slow Speed	Medium Speed	Fast Speed
	Average Distance Error (meters)		
Trimble AgGPS 132	3.76	6.59	9.95
Magellan ProMark X	3.58	6.67	10.9
	Average Time Lag (seconds)		
Trimble AgGPS 132	1.6	1.5	1.5
Magellan ProMark X	1.5	1.5	1.6
Radar Velocity	2.38 m/s	4.55 m/s	6.76 m/s

5 Velocity Test

Procedure

The units were mounted on a John Deere 2020 tractor that was driven at three different but constant velocities along a track of known GPS coordinates. The velocity of the tractor was determined by timing the tractor over a predetermined distance and by using a radar speed sensor. The velocity was also calculated from GPS data by determining the change in position data of the tractor each second. The two velocity measurements were then compared to determine if the GPS position data could be used to accurately monitor a vehicle's velocity.

Methods of Analysis

The position of the vehicle during the velocity tests was recorded in latitude and longitude coordinates; the data were then converted to UTM coordinates to calculate the velocity of the vehicle as a function of its change in position over time. The velocity data were trimmed to include data points only in a 30.5 m long path. The velocity of the vehicle over this path was recorded with a stopwatch (the tractor gearing is such that the vehicle was at a constant velocity for the tests). The velocity of the vehicle as a function of the position change over time was calculated by determining the distance from one position point to the next position point, and dividing that value by the length of time the position change occurred over. The GPS position data for these tests were recorded at the 1-Hz frequency, so the position point data were recorded at 1-second intervals; therefore, the distance between the position points is equal to the velocity of the vehicle. The equations used to determine the velocity of the vehicle are shown below:

Distance in meters from Position Point A to Position Point B (on Northing versus Easting axis) is:

$$\text{Distance}_{A-B} = \sqrt{(A_N - B_N)^2 + (A_E - B_E)^2}$$

Velocity in meters from Position Point A to Position Point B (on Northing versus Easting axis) is:

$$\text{Velocity} = \frac{\text{Distance}_{A-B}}{\text{Time}_{A-B}}$$

The time from Position Point A to Position Point B is 1 second since the data was recorded at the 1-Hz frequency. Thus velocity is calculated as:

$$\text{Velocity} = \frac{\text{Distance}_{A-B}}{1\,\text{Second}}$$

The average velocity calculated from GPS position data for each speed was compared by determining the difference between this velocity, the velocity determined by timing the tractor with a stopwatch over a known distance, and the velocity from the radar speed sensor.

Results

The GPS units were tested to determine the accuracy to which velocity could be calculated from the position data output. Position data were used to calculate the vehicle velocity within 0.05 meters per second (m/s) of the actual velocity for the slow speed, 0.1 m/s for the medium speed, and 0.25 m/s for the fast speed. The actual velocity was determined using a radar speed sensor that was verified by timing the vehicle over a predefined distance. The accuracy of the calculated velocity from position data decreases with increasing velocity, but the error is small compared to the actual velocity. Table 4 lists the average calculated velocity from position data for the GPS units, the calculated velocity from timing the vehicle over a distance of 100 feet (30.48 m) with a stopwatch, and the average measured radar speed sensor data.

Table 4. The average calculated velocities.

Velocity	Magellan ProMark X	Trimble AgGPS	Stopwatch	Radar Speed Sensor
Slow Speed Average Velocity	2.35*	2.33	2.35	2.38
Medium Speed Average Velocity	4.49	4.45	4.64	4.55
Fast Speed Average Velocity	6.52	6.61	6.84	6.76

* The velocity values for the Magellan ProMark X, Trimble AgGPS, and the stopwatch are average calculated values in m/s. The velocity values for the radar speed sensor are average measured values in m/s.

6 Stopping Test

Procedure

The reaction of the GPS units to abrupt change in velocity of a vehicle was measured by mounting the units to a John Deere 2020 tractor and recording GPS position data while the tractor was brought to a sudden stop. The beginning of the stop (time 0) was recorded and used to determine the length of time the GPS units recorded movement of the vehicle after the stop began. The time the GPS units recorded for the stop was then compared to the actual time it took the vehicle to stop.

Methods of Analysis

The vehicle's position during the stopping test was recorded in latitude and longitude coordinates. The position data were converted to UTM coordinates for the data analysis. The tractor was driven at two different velocities and was brought to a sudden stop (i.e., the velocity changed from the initial velocity to 0 in 1 second or less). The UTC time of the stop was recorded. The UTC time was used to determine how long the GPS units recorded movement of the vehicle after the vehicle actually stopped. This analysis was performed by finding the velocity and position of the vehicle at the recorded UTC time of stop. The subsequent velocities were examined to determine at what time the GPS data points indicated that the vehicle was stopped.

Results

Stopping tests were performed using a John Deere 2020 tractor with the GPS units mounted to it. Each tractor was driven at two constant speeds for the test. The speeds were the same as those used for the dynamic test at approximately 2.35 m/s and 4.64 m/s for the slow and medium speeds, respectively. To conduct the test, the tractor was driven at a constant speed toward the benchmark. The operator attempted to stop the tractor directly over the benchmark while an observer recorded the UTC at which the tractor came to a stop. The data were analyzed to determine the time that passed from when the tractor was stopped to when the GPS units indicated that the tractor was at approximately 0 velocity. Figure 3 shows the decrease in position change as time from the stop increased. Notice that the position change decreased as time from the stop increased. Table 5 presents the stop data. The average time to stop as measured by the Trimble AgGPS 132 was between 2 and 2.33 seconds for the slow and medium speeds, respectively. The average time to stop as measured by the Magellan ProMark X was between 2.66 and 3.66 seconds for the slow and the medium speeds, respectively.

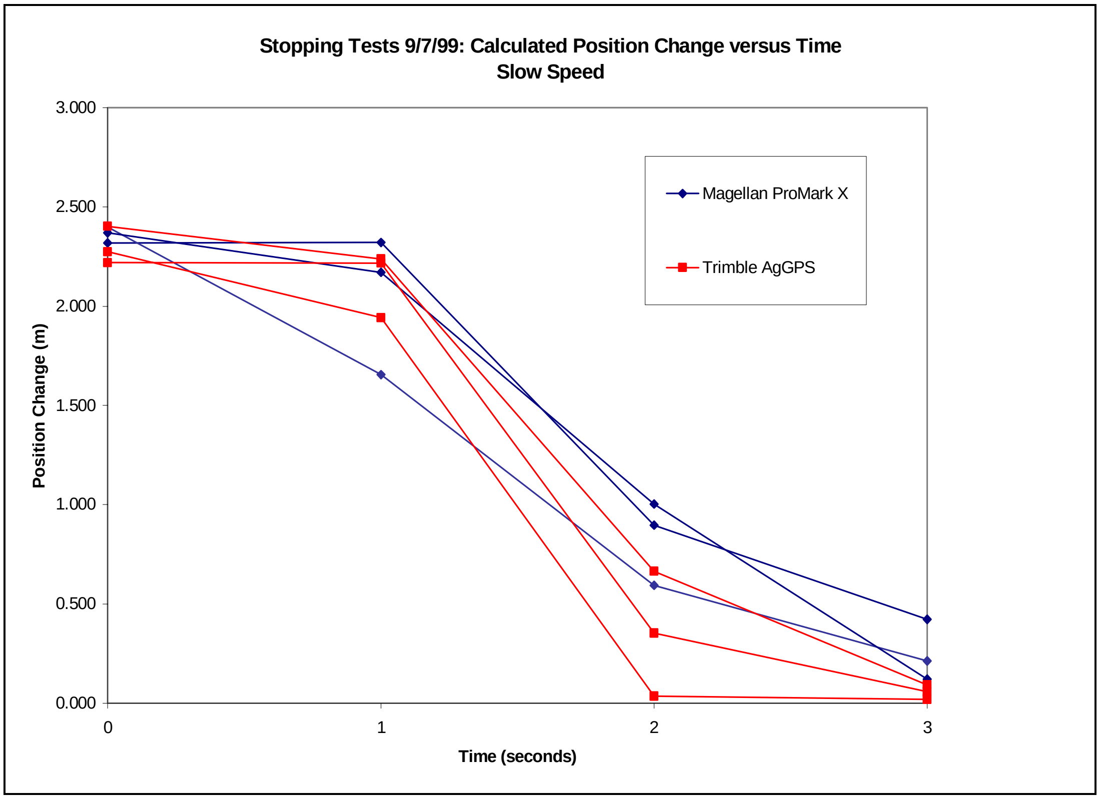

Figure 3. The GPS recorded position change (velocity) for up to 3 seconds after the vehicle had stopped.

Table 5. The average stop data.

Speed	Stop Number	GPS Unit	Time to Stop (sec.)
Slow	First	Trimble AgGPS 132	2
2.35 m/s	First	Magellan ProMark X	3
	Second	Trimble AgGPS 132	2
	Second	Magellan ProMark X	2
	Third	Trimble AgGPS 132	2
	Third	Magellan ProMark X	3
Medium	First	Trimble AgGPS 132	2
4.64 m/s	First	Magellan ProMark X	3
	Second	Trimble AgGPS 132	2
	Second	Magellan ProMark X	4
	Third	Trimble AgGPS 132	3
	Third	Magellan ProMark X	4

7 Turning Radius Test

Procedure

The GPS units were mounted on a John Deere 2020 tractor that was driven around six constant radius tracks and along a straight path. The GPS units were also mounted to a backpack that was used while walking three of the constant radius paths along which the tractor was previously driven. The constant radii for the first two parts of the test were maintained by following a spray-painted path created using a tape measure and a center pivot. The backpack with GPS units mounted on it was also used while walking three constant radius paths on a level surface. The constant radii for the final turning radius test were maintained by holding a tape measure that was mounted to a pole and then walking around the pole. The distance from the center pivot to each of the paths was used as the actual radius and was compared to the radius calculated from the position data provided by the units.

Methods of Analysis

The position of the vehicle during the turning radius tests was recorded in latitude and longitude coordinates. The position points were converted to the UTM coordinate system for turning radius calculations. The turning radius was calculated from five consecutive position data points (Five-Point Method [5PM]). Perpendicular bisects to lines connecting the first to the third and the third to the fifth data points were calculated from the coordinates of those points. The intersection of those perpendicular bisects was determined by solving two equations with two unknowns, and the distance between the intercept and the third point was the turning radius at the third point. This method of using five data points rather than two or three was more consistent and accurate because one outlying point does not affect the calculated turning radius values in a dramatic manner.

A turning radius value of 100m was assigned for a straight drive (vehicle not turning at all), thus all calculated values for the turning radius greater than 100m were set equal to 100m. The turning radii calculated from the position data points were analyzed by determining the average calculated turning radius and standard deviation for each radius, then comparing the average calculated turning radius to the actual turning radius. The equations used to calculate the turning radius are shown below for the points illustrated in Figure 4.

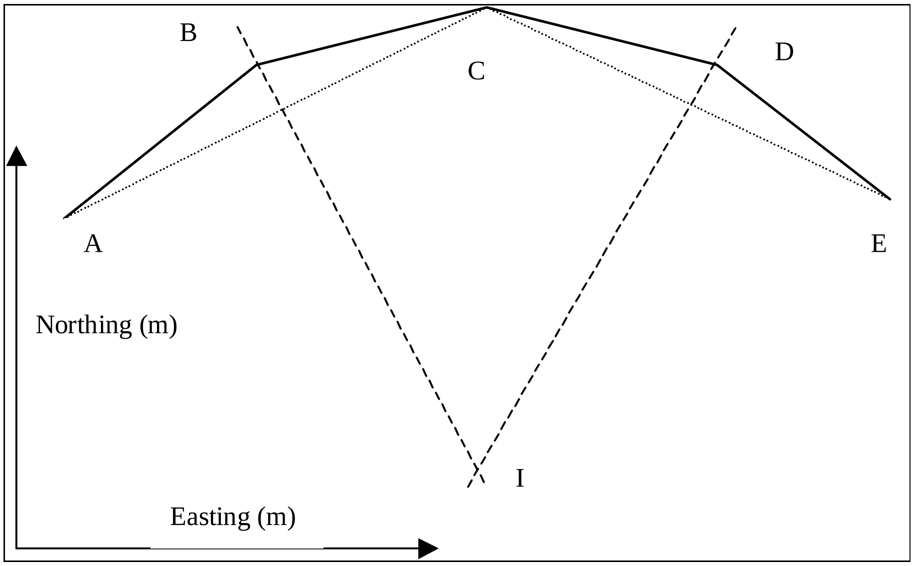

Figure 4. Turning radius measurement points.

The slope of the line from position A to position C is:

$$m_{A-C} = \frac{C_N - A_N}{C_E - A_E}$$

The slope of the line from position C to position E is:

$$m_{C-E} = \frac{E_N - C_N}{E_E - C_N}$$

The slope of the perpendicular bisect to line A-C at position B is:

$$m_{B-I} = \frac{-1}{m_{A-C}}$$

The slope of the perpendicular bisect to line C-E at position D is:

$$m_{D-I} = \frac{-1}{m_{C-E}}$$

Equations to determine the intercepts of the perpendicular bisects are:

$$b_{B-I} = B_N - m_{B-I} B_E$$
$$b_{D-I} = D_N - m_{D-I} D_E$$

Equations to determine the positions of the intersection I of the two bisects are:

$$I_N = m_{B-I} I_E + b_{B-I}$$
$$I_N = m_{D-I} I_E + b_{D-I}$$

The equation to determine distance from point C to intersection I is:

$$\text{Turning Radius (m)} = \sqrt{(I_N - C_N)^2 + (I_E - C_E)^2}$$

A method for calculating the turning radius from bearing (Course Over Ground, COG) and velocity (Speed Over Ground, SOG) was evaluated and determined ineffective. The COG reading varies dramatically, and thus the turning radius calculated from the COG and SOG also varied dramatically. Multi-hertz (10 Hz) GPS data recording was also determined unnecessary for turning radius calculations, as 1 Hz can effectively represent a turn. Multi-hertz recording was also determined inessential because of data storage concerns.

Results

Three tests were performed to determine the accuracy of calculated turning radius from dynamic vehicle position data. The first test consisted of walking on a level surface with backpack-mounted GPS units. The second test consisted of walking constant radius paths over uneven field conditions. The third test consisted of driving a tractor around constant radius paths in a field with an uneven surface.

Turning radius test 1: walking constant radius paths on flat surface

The level surface prevented angular movement of the GPS unit due to roll (resulting from an uneven surface) while walking around the constant radius paths. A tape measure mounted to a pole in the center was used to maintain the constant radius. Figure 5 shows the paths walked for this test. Walking constant radius paths on a level surface was a test of the method of calculation of turning radius from dynamic vehicle position data. Table 6 shows the numerical results.

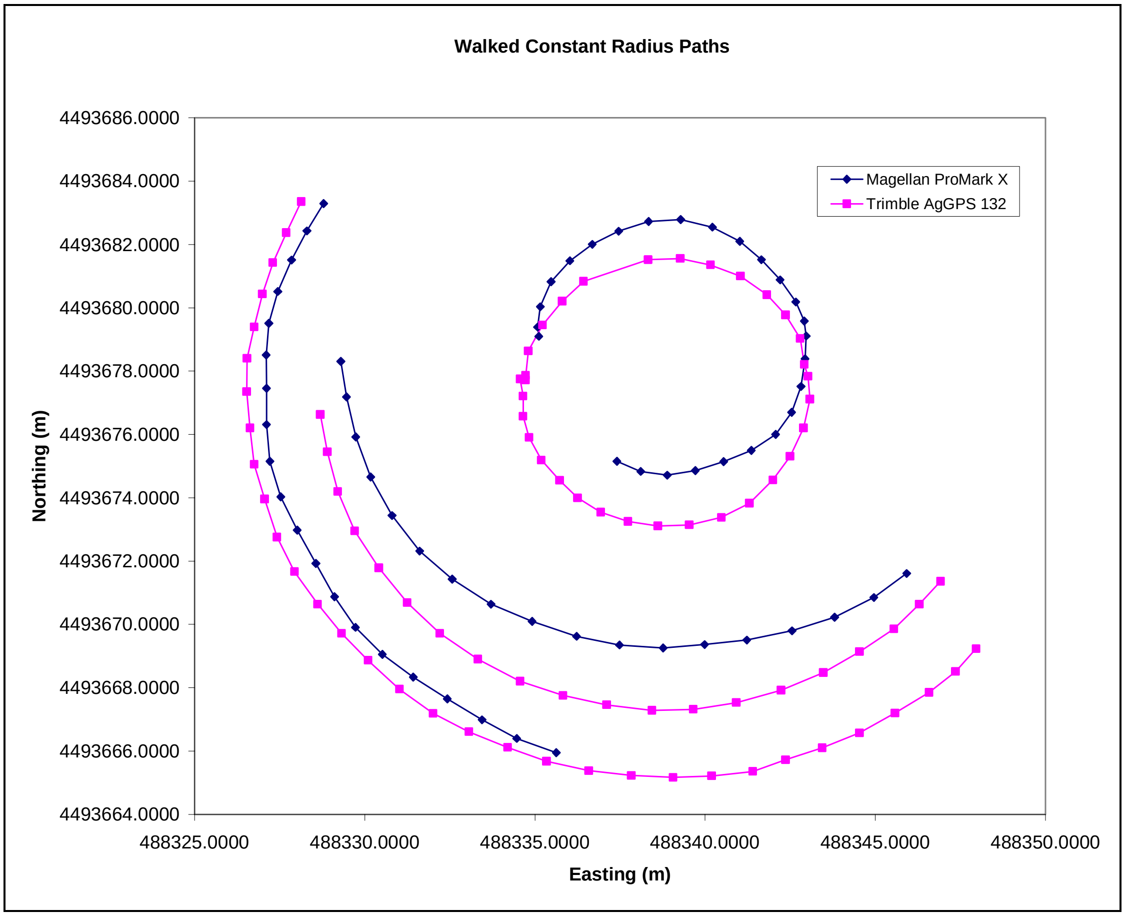

Figure 5. The recorded GPS positions for the calculated turning radius evaluation of paths walked on the level surface.

Table 6. The turning radius calculated from position data compared to the actual turning radius of the paths walked on a level surface with backpack-mounted GPS units.

GPS Unit	Actual Radius (m)	Average Radius (m)	Standard Deviation (m)	Points Used for Calculation
Trimble AgGPS 132	5/small	4.3	0.8	29
	10/medium	10.3	0.9	16
	13/large	13.0	2.7	28
Magellan ProMark X	5/small	4.2	1.2	22
	10/medium	10.5	2.2	14
	13/large	15.5	8.6	16

The average turning radius calculated from Trimble AgGPS dynamic position data was within 0.7 meters of the small turning radius of 5 meters, within 0.3 meters of the medium turning radius of 10 meters, and within 1.0 meter of the large turning radius of 13 meters. The standard deviations of the calculated turning radii from position point data were 0.8 meters for the small turning radius, 0.9 meters for the medium turning radius, and 2.7 meters for the large turning radius.

The turning radius calculated from Magellan ProMark X dynamic position data was within 0.6 meters of the small turning radius of 5 meters, within 0.5 meters of the medium turning radius of 10 meters, and within 2.5 meters of the large turning radius of 13 meters. The standard deviations of the turning radii calculated from position point data were 1.2 meters for the small turning radius, 2.2 meters for the medium turning radius, and 8.6 meters for the large turning radius.

The difference between the Magellan ProMark X results and the Trimble AgGPS results may lie in the differential correction methods used by the units. The Trimble AgGPS unit used real time differential correction from the Omnistar satellite, while the Magellan ProMark X is differentially corrected after the data acquisition using pseudorange data from the Continuously Operating Reference Stations (CORS) website. For the turning radius data sets, the CORS site used was the Platteville Colorado site, which lies approximately 30 miles (48.27 km) from the site of data acquisition. Though turning radii calculated from Magellan ProMark X position data are not quite as accurate as turning radii calculated from the Trimble AgGPS position data, both units show an accuracy acceptable for the application of determining impact of a training vehicle from its turning radius.

Turning radius test 2: driving constant radius paths on uneven surface

The second test of accuracy of calculated turning radius from position data was conducted on a predetermined path of six different turning radii and one straight path. The straight path is considered to have a turning radius of 100 meters because a turning radius that large is nearly a straight path. Figure 6 shows the paths driven for this test of calculated turning radius evaluation on an uneven surface. The difference between the calculated turning radii from position data acquired from the Trimble AgGPS and Magellan ProMark X units and the actual turning radii are similar for both units. Table 7 lists the results for the test of calculation of turning radius from GPS position data acquired while a tractor was driven around constant radius paths.

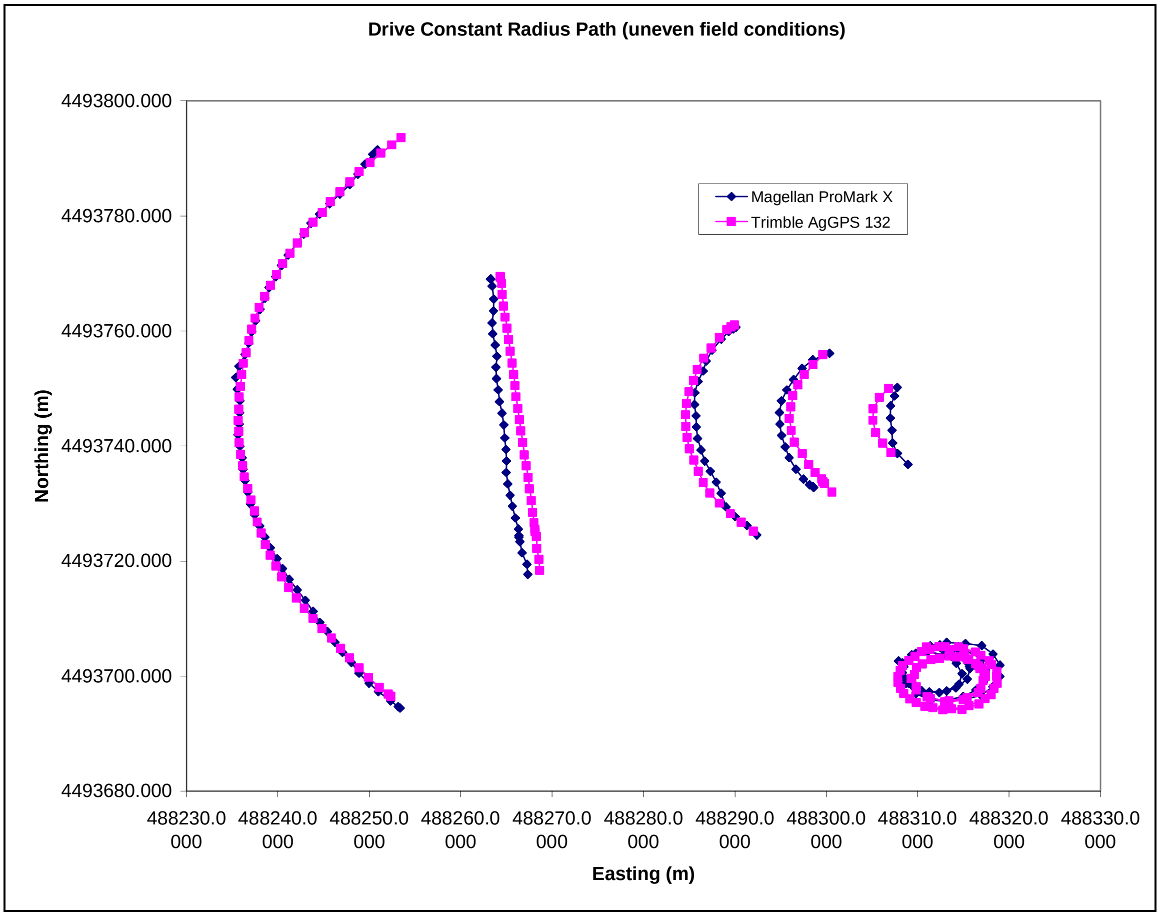

Figure 6. The recorded GPS positions for the calculated turning radius evaluation of paths driven on uneven field conditions.

Table 7. Actual and calculated turning radii data.

GPS Unit	Actual Radius (m)	Average Radius (m)	Standard Deviation (m)	Points Used for Calculation
Trimble AgGPS 132	9.5	9.4	1.2	3
	18.9	18.5	10.8	13
	28.7	30.1	12.3	18
	Straight (100)	87.2	25.3	27
	79.2	74.6	22.1	52
	4.6	5.5	0.4	31
	3.1	3.9	0.3	26
Magellan ProMark X	9.5	22.1	11.5	4
	18.9	16.5	7.3	13
	28.7	39.0	31.6	18
	Straight (100)	66.2	32.4	26
	79.2	64.2	27.9	51
	4.6	5.2	0.8	26
	3.1	3.9	2.0	24

The smaller the actual turning radius, the closer the average calculated turning radii are to the actual turning radius. The increased accuracy at the smaller turning radii is important because the most impact and largest disturbed width occurs at the smaller turning radii, when the vehicle's tracks dig into the soil deeper and slide out over more soil surface area.

The increased difference between the calculated turning radii and the actual turning radii at the large turning radii can be attributed to angular movement of the GPS unit due to vehicle roll on an uneven surface. The error is large at larger turning radii because the angular shift of the GPS unit is more noticeable at larger turning radii when the vehicle itself is not experiencing a large shift in angular position.

Turning radius test 3: walking constant radius paths on uneven surface

To verify that the angular shift of the GPS unit due to rough terrain caused the error of calculated turning radius, the same paths driven with the tractor were walked with backpack-mounted GPS units. Figure 7 shows the paths walked for this test of calculated turning radius evaluation on an uneven surface. The GPS unit experienced much less angular movement from roll when mounted on a backpack than on a vehicle. Table 8 lists the calculated turning radii from GPS position data, the actual turning radii, and the standard deviations.

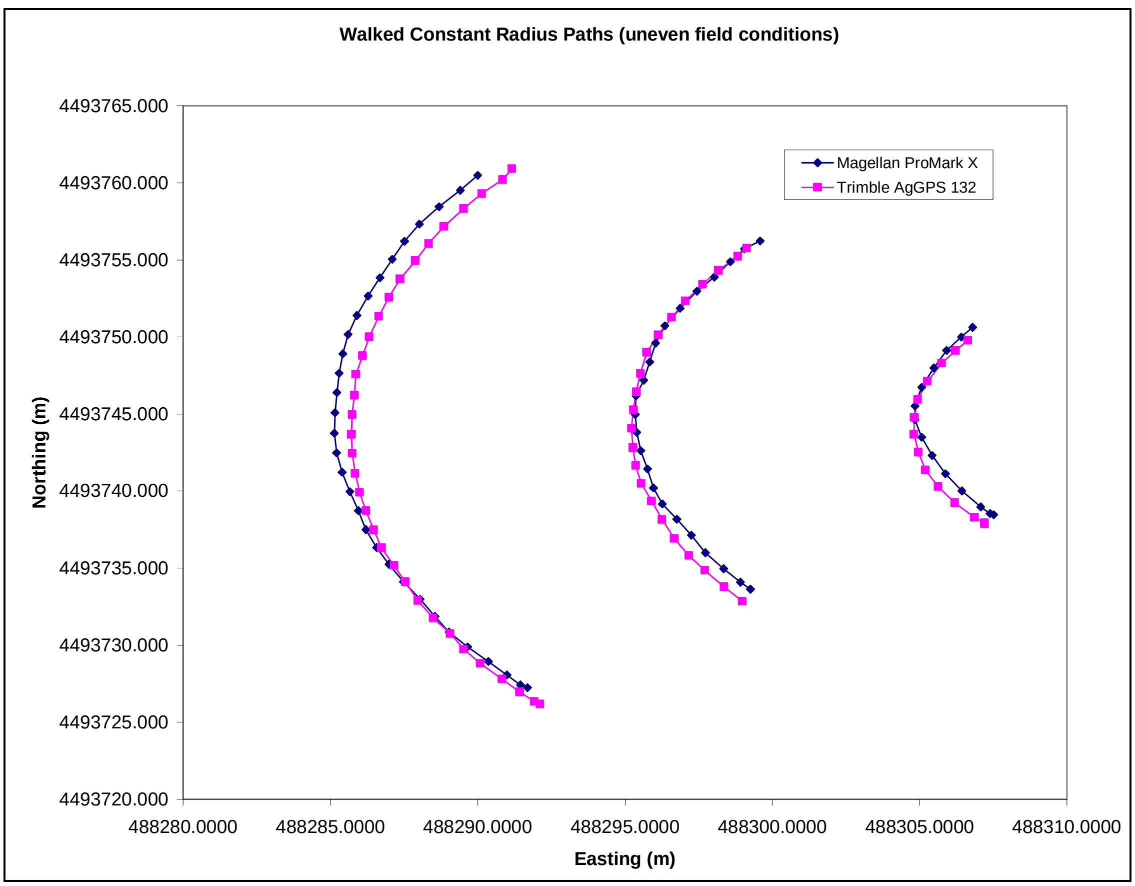

Figure 7. The recorded GPS positions for the calculated turning radius evaluation of paths walked on uneven field conditions.

Table 8. Data from three constant radius paths walked with backpack-mounted GPS units.

GPS Unit	Actual Radius (m)	Average Radius (m)	Standard Deviation (m)	Points Used for Calculation
Trimble AgGPS 132	9.5	9.9	1.0	10
	18.9	21.2	6.8	18
	28.7	34.6	21.0	29
Magellan ProMark X	9.5	11.2	3.6	10
	18.9	34.5	32.8	19
	28.7	38.0	22.7	27

8 Evaluation of Existing Military Vehicle GPS Units

Procedure

Evaluating existing military vehicle GPS units consisted of two tasks. The first was an evaluation of the suitability of using existing military GPS receivers to determine site-specific event severity factors. The factors are obtained by determining vehicle impact (specifically calculating velocity and turning radius from GPS position). The second task was to explore the availability and format of existing GPS-related vehicle position data at military sites. This existing data may be useful in measuring site-specific event severity factors.

Methods of Analysis

The methodology of accomplishing these two tasks consisted of discussions with military (and military-related) personnel and exploring GPS receiver capabilities from specification sheets and evaluation reports.

Results

Existing GPS receivers

The most common vehicle-mounted and other available GPS receiver used by the military is the Rockwell PLGR (Precision Lightweight GPS Receiver) or a recent variation (i.e., PLGR+, PLGR II). The unit can determine satellite pseudo range measurement (necessary for position determination) using both C/A code and P code (precise code) transmissions. The P-code capability requires the encryption option. Re-ported GPS CEP accuracies are as follows:

P-code: < 12 meters (non-differential).

SDGPS: < 2 meters (requires satellite differential correction).

C/A code: < 100 meters SEP (spherical error probable). Probably reported with SA on; usually better accuracies are reported.

C/A code (with SA off): < 20 meters expected.

The Rockwell PLGR is a real-time GPS receiver (NMEA 0183 format) and is not capable of post processing differential correction. The NMEA GPS data strings include $GPGGA and $GPRMC, which would be useful for turning radius, velocity, and position determinations. The communication capability is RS-232 or RS-422. The GPS output rate for these receivers is usually 1 Hz. Differential correction input is possible in RTCM-SC104 format. Radio interfaces are available for transmission of position data. Internal data storage is limited to 999 waypoints, which can be used to store 1-second GPS position.

A recently announced U.S. Army contract to Comtech Mobile Datacom Corporation to create a movement tracking system (MTS) uses the Motorola Oncore GPS chipsets. These chipsets (assumed to be the new M12 version) are similar to the Rockwell PLGR except they are not P-code compatible. The contract calls for placement of these chipsets in 39,000 vehicles with a project completion date of 24 June 2007.

As discussed in the next section Magnavox/Leica GPS receivers are used at three training sites. These are 1989 receivers, incapable of using P-code, but set up for differential correction. The receivers are integrated into an existing vehicle monitoring system, which sends the data, usually every 5 seconds, to a central storage site.

Evaluation of existing military site GPS data collection and storage

Three military training sites were identified as using a similar GPS integrated into a system to monitor vehicle position and operating characteristics: Fort Irwin, CA; Fort Polk, LA; and Hohenfels, Germany. The availability and utility of data from these installations to determine site-specific event severity factors were explored. At the Fort Irwin National Training Center, GPS is utilized for “real-time” monitoring of vehicle position. The data are transferred by radio to the observation center by radio in 5-second “bursts.” The output rate of the vehicle-mounted system is variable and can be adjusted to a 1-second output rate. The data in the burst includes GPS position as well as other vehicle operating characteristics related to military engagement. This information is stored periodically in the form of “snapshots.” Fort Irwin is not required to store GPS datasets, although some datasets are available. Fort Irwin National Training Center has 1500 systems available for vehicle mounting and simultaneous operation.

Both Fort Polk and Hohenfels training sites use similar systems, with 5-second default output rates. The applicability of using 5-second vehicle positional data to determine site-specific vehicle impact needs further exploration.

9 Design of a DGPS-based Continuous Operating Vehicle Impact Monitoring System (COVIMS)

Procedure

Evaluations were performed on the GPS data in terms of improving the vehicle impact severity factors in the current ATTACC methodology. The GPS data were used to create an example of a GIS-based spatial analysis of the environmental impact of a vehicle in the training field. A GPS-based continuous vehicle monitoring system was developed using the most effective procedure. That procedure was applied to the acquisition of field data. Field data were collected using an M109 Self-Propelled Howitzer tracked vehicle with a GPS unit mounted to it while performing predetermined maneuvers in an untracked field environment.

A field data acquisition system was developed. An appropriate GPS unit was selected along with a data recording device so that position data could be acquired for extended periods of time with minimal hardware and unit interface requirements. This field data acquisition system was developed to be employed for the application of the COVIMS.

Methods of Analysis

Impact severity and disturbed width models

The impact severity is the percentage of soil and vegetation that was damaged or removed from a “disturbed width” by the track on the vehicle. The disturbed width is a measurement of the width of soil and vegetation impacted by the vehicle track. When a tracked vehicle is moving fast and turning at a small radius, the vehicle’s track removes more vegetation and soil over a larger area than when the vehicle is moving slowly and is not turning. Figure 8 shows the effect on the soil and ground cover for a tight turning radius. Figure 9 shows the effect on the soil and ground cover when the vehicle is not turning.

Figure 8. The impact on the soil and ground cover by a tracked vehicle with a velocity of 3.7 m/s and a turning radius of 12 meters.

Figure 9. The impact on the soil and ground cover by a tracked vehicle with a speed of 3.3 m/s and a turning radius of 100 meters.

Both impact severity and disturbed width increase with increasing velocity, but decrease with increasing turning radius. Simple models to demonstrate the impact severity as a function of turning radius and velocity, and disturbed width as a function of turning radius and velocity were developed. Images of the soil and ground cover were evaluated for the impact severity and disturbed width. The values for disturbed width and impact severity were evaluated with the turning radius and velocity to develop power functions using a linear least squares regression analysis. The disturbed width was considered the dependent variable; the turning radius and velocity were the independent variables. The impact severity was also considered the dependent variable while the turning radius and velocity were the independent variables. The turning radius and velocity were also considered independent of each other. The method for developing the models for impact severity and disturbed width are shown below.

The impact severity can be written as a generic power function of the Turning Radius and Velocity.

$$\text{Impact Severity[IS]} = a \cdot (\text{Turning Radius[TR]})^{b} \cdot (\text{Velocity[V]})^{c}$$

Taking the Natural Log of both sides of the equation yields a linear equation.

$$\ln(IS) = a + b \cdot \ln(TR) + c \cdot \ln(V)$$

The linear equation with coefficients a, b, and c can be solved using a linear least squares regression to find the values of a, b, and c that best fit the data. Those values were determined to be :

$a = 5.57$ $\exp(a) = 261$

$b = -0.75$

$c = 0.62$

Those coefficients can be put back into the original power equation to create a model for impact severity as a function of turning radius and velocity.

$$\text{Impact Severity (\%)} = 261 \cdot [\text{Turning Radius (m)}]^{-0.75} \cdot [\text{Velocity (m/s)}]^{0.62}$$

$R^2 = 0.76$

The same procedure was used to determine coefficients for the model for disturbed width as a function of turning radius and velocity.

$$\text{Disturbed Width (m)} = 1.0 \cdot [\text{Turning Radius (m)}]^{-0.27} \cdot [\text{Velocity (m/s)}]^{0.034}$$

$R^2 = 0.63$

The negative exponents on the turning radius make sense because as the turning radius increases, both the impact severity and the disturbed width decrease. The positive exponents on the velocity make sense because as the velocity increases, the impact severity and disturbed width also increase. These models were developed holding the soil moisture conditions and vehicle properties constant, thus they are applicable only for the M109 Self-Propelled Howitzer tracked vehicle on a day with moist soil conditions. The models used for actual environmental impact analysis should contain factors for soil conditions and vehicle properties.

Requirements for field data collection equipment

The requirements for the equipment necessary to record field data were evaluated based on the tests that were performed and the parameters for the COVIMS system. The field data collection equipment must meet the criterion established through the testing procedures. The criterion requires the dynamic properties of the vehicle to be accurately determined from the collected GPS position data. The selected equipment should have the ability to collect data that can be used to accurately determine the parameters for impact severity and disturbed width. To determine impact severity and disturbed width, valid turning radius and velocity calculations are necessary. The correct field data collection equipment is necessary to get accurate representations of vehicle impact on training areas.

The equipment must be able to withstand the harsh environment of training exercises and require minimal operator input. The appropriate system would operate as a start-up or turn-key system. The system would begin logging GPS position immediately when the vehicle is started and continue until the vehicle is shut off or the system is manually shut down. A data storage card would be required so the data can be removed from the system periodically and evaluated. The card could be replaced with a new card when the vehicle is not operating and continuous monitoring of the vehicle from one training exercise to the next can take place without any delay.

Results

Impact severity and disturbed width models: GIS-based spatial analysis of environmental impact

The models for impact severity as a function of turning radius and velocity, and disturbed width as a function of turning radius and velocity were used to determine a percentage impact severity and a disturbed width for each turning radius and velocity value associated with a GPS position for the test vehicle in the training field. The test vehicle was an M109 Self-Propelled Howitzer. GPS position data was recorded each second for the duration of the test. The test consisted of driving the tracked vehicle in six spiral patterns, three at a slow velocity, two at a medium velocity, and one at a fast velocity. The objective was to demonstrate the environmental impact of the tracked vehicle over a wide range of velocities and turning radii. The models used to determine the impact severity and the disturbed width as a function of turning radius and velocity are sample functions that do not take into account the vehicle properties, soil moisture content, and the ground cover.

Figure 10 shows the effect of turning radius and velocity on the impact severity, the smaller the turning radius of the vehicle, the more severe the impact; and the faster the vehicle was moving the more severe the impact. Figure 11 shows the effect of turning radius on the disturbed width. The smaller the turning radius, the wider the area of soil and ground cover that was affected by the tracked vehicle. Also, the faster the velocity, the larger the area affected by the vehicle's tracks.

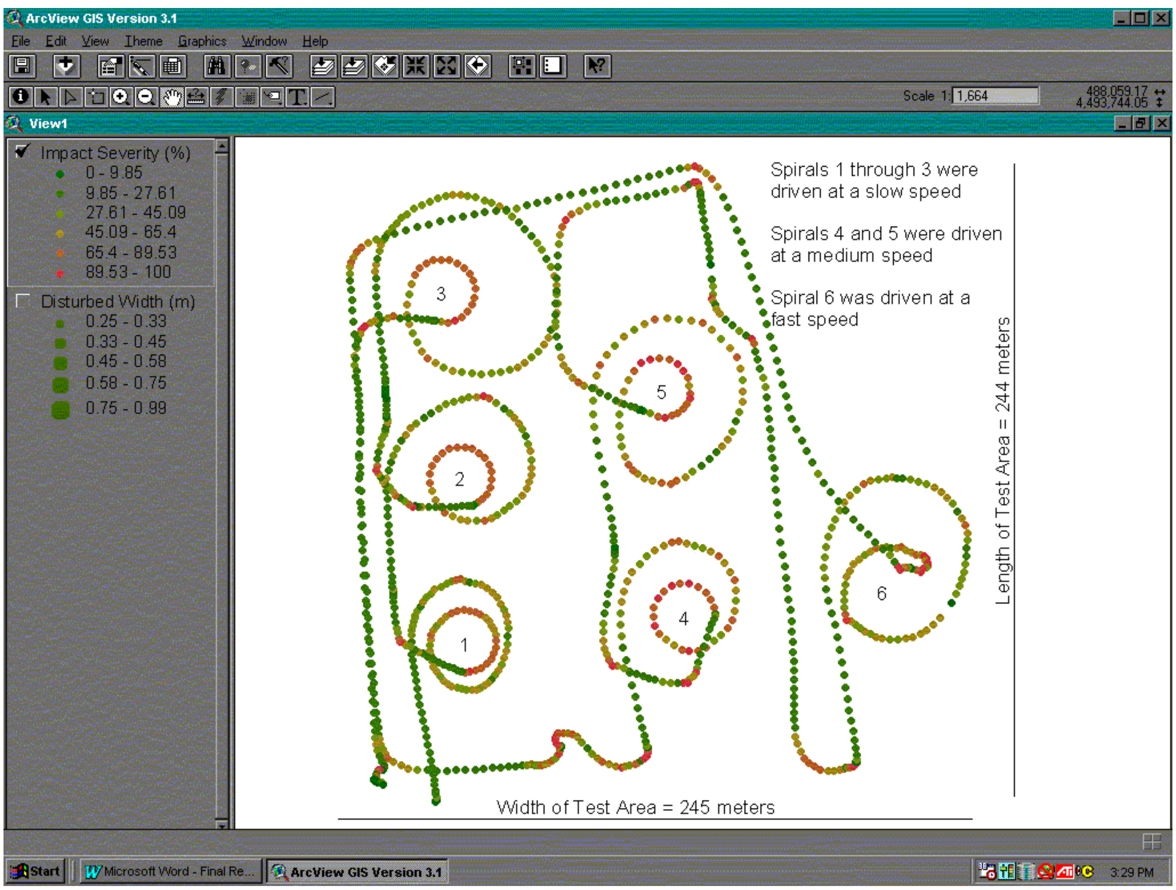

Figure 10. The impact severity of the tracked vehicle on the soil and ground cover is plotted versus the tracked vehicle position in the tracked vehicle field.

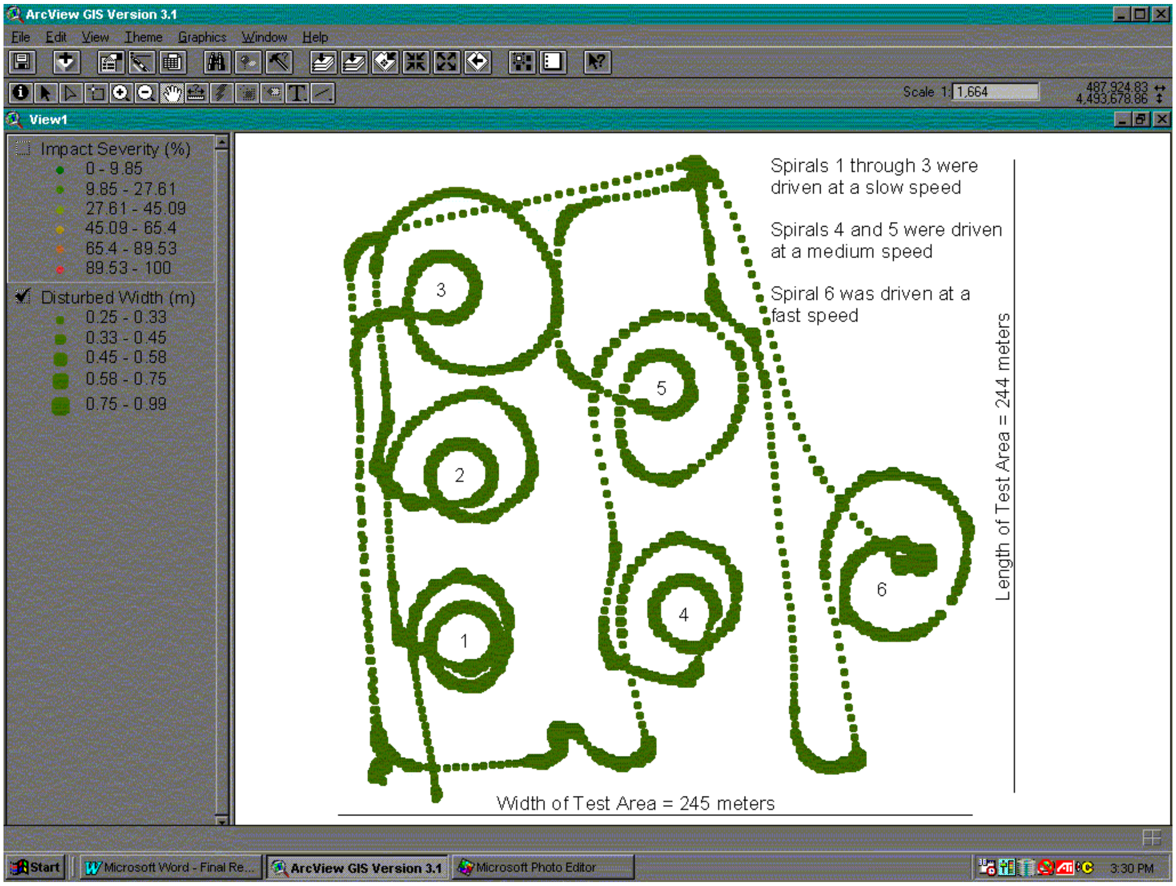

Figure 11. The disturbed width of soil and ground cover is plotted versus the position of the tracked vehicle.

Correct models for the impact severity and disturbed width from a training vehicle would include factors for the vehicle properties such as track width and length for tracked vehicles, tire width and number of tires for wheeled vehicles, weight and width of the vehicle. The models should also take into consideration the soil and vegetation conditions before the training was conducted, the soil moisture conditions, and if the impacted area was driven over once, or several times.

Field data collection equipment requirements

To gather accurate data describing dynamic vehicle properties, the appropriate field data collection equipment is necessary. The equipment must have the ability to accurately determine the vehicle's dynamics and position at any time. The equipment must also require minimal maintenance. The GPS logging equipment must be able to log data from when the vehicle first starts an exercise to when the exercise is complete without requiring the operator to spend too much time with its operation.

Requirements for the field data collection equipment have been determined from the test results. It was determined that both post-processing and real-time DGPS units could accurately determine the vehicle's dynamic properties for use in the COVIMS system. The post-processing and real-time DGPS units both log GPS position at a rate of 1 Hz. It was determined that both modes of differential correction provided an accurate representation of the vehicle's dynamics at 1 Hz, however the dynamic accuracy and turning radius calculations at lower frequencies need further investigation. With current knowledge, the GPS unit used by the COVIMS system should be able to log GPS position at 1 Hz.

For the field data collection system to obtain data that is comparable to what was collected with the Trimble AgGPS 132 and the Magellan ProMark X units it must be able to match the results of tasks 1 through 6 as listed in the Objectives section of Chapter 1. The static accuracy must have an average CEP of approximately 2 meters. The GPS latency should be approximately 1.5 seconds. The average time for the GPS unit to record a stop must be less than 3 seconds. The accuracy of the calculated turning radii must be comparable to the data collected by the tractor-mounted field data collected by the Trimble AgGPS 132.

A data storage device is necessary for data to be collected in the field. The data storage must have the capacity to store GPS position data for hours at a time while the vehicle is performing training exercises. The ideal data storage device would store the data on a removable disk or PCMCIA card in order for the data to be accessed easily at a later time.

A number of currently available GPS units can satisfy these criteria. The DL Series receivers made by Novatel provide the required functionality. The DL Series receiver is composed of an autonomous GPS receiver with a built-in data storage device that uses a PCMCIA card for storage. The receiver and data logging device are incorporated in a single compact, weather-resistant casing, which make them durable and easy to install. An LED display lets the operator know that GPS data are being collected; an on/off switch is provided. The DL Series receiver can be used with a compact, lightweight antenna that is suited for mobile applications. The DL Series receiver can log GPS position at a rate of 1 Hz or 10 Hz. GPS data can be logged in a RINEX (Receiver Independent Exchange) format directly to the PCMCIA card. RINEX is a format that is used to store pseudorange data. Data in RINEX format can be easily used for post-processing applications. The procedure for processing data from this receiver would be similar to that used for the Magellan ProMark X.

10 Conclusions

Army training often includes the use of tracked vehicles capable of inducing significant damage to the soil and vegetation of the training area. The impact caused by tracked vehicles is more severe and spread over a larger area when the vehicles are turning at a small radius and while moving at high velocity. The current system used for monitoring the environmental condition and carrying capacity of the training installations does not accurately account for the impact inflicted on the soil and vegetation by the vehicles. The current model would be improved with validation of the event severity factors for each training exercise with field test impact data. The current system would also be improved with the addition of a Continuously Operating Vehicle Impact Monitoring System (COVIMS) consisting of vehicle position linked with dynamic vehicle properties and impact. The monitoring system could also benefit from the addition of spatial analysis including a vehicle location plot with impact severity and area disturbed.

The use of a Global Positioning System (GPS) for monitoring training vehicles provides not only dynamic vehicle information, but also links the information to a global position. This study has determined that GPS can accurately monitor a vehicle's position and dynamic properties including velocity, turning radius, and change in vehicle velocity. The evaluation of the GPS was based on five tests: GPS static accuracy test, GPS dynamic accuracy test, GPS velocity test, GPS turning radius test, and GPS stopping test.

The GPS systems tested were the Trimble AgGPS 132, a real-time, differentially corrected GPS unit, and the Magellan ProMark X, a post-processing, differentially corrected GPS unit. The results from the GPS tests demonstrate that both the real-time corrected and the post-processing corrected units are capable of recording an accurate GPS position while still (static) and mounted to a moving vehicle (dynamic). The GPS tests also demonstrate that the GPS position data can be used to accurately calculate dynamic vehicle properties including velocity, turning radius, and change in velocity.

The development of a COVIMS system relied on two different components: the equipment required for data acquisition, and the analysis procedures for the data recorded. The equipment required for a COVIMS system was evaluated on the rate of GPS position acquisition and storage capabilities. The procedures for field data analysis were based on using dynamic vehicle information to determine the impact severity and disturbed width at each GPS position of the vehicle. It was determined that the impact severity and disturbed width are dependent on the dynamic properties of the vehicle as well as the physical properties of the vehicle.

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Glossary

Average Position Error is the average of the errors between the static GPS recorded positions and the surveyed position.

C/A Code is the standard (Coarse/Acquisition) GPS code. A sequence of 1023 pseudo-random, binary, biphase modulations on the GPS carrier at a chip rate of 1.023 MHz. Also known as the "civilian code."

Circular Error Probable (CEP) is the radius measured from the surveyed position that encloses 50 percent of the two-dimensional position points.

Course Over Ground (COG) is the true direction of travel achieved, referenced to North and measured as degrees clockwise from North.

Real-Time Differential Correction is correction of a GPS signal by immediately sending the differential correction information to the mobile receiver on-the-go.

Differential Corrected Global Positioning Systems (DGPS) is a technique to improve GPS accuracy using pseudorange corrections measured at a known location to adjust the pseudorange measurements made by other GPS receivers.

Differential Positioning is the accurate measurement of the relative positions of two receivers tracking the same GPS signals.

Dilution of Precision (DOP) is the uncertainty of a position fix due to satellite geometry, where a higher DOP indicates a higher uncertainty. DOP is the multiplicative factor that modifies ranging error. It is caused solely by the geometry between the user and satellite positions.

Dynamic Accuracy is a measurement of the difference between the GPS recorded position and the surveyed position at the exact time the moving GPS is located at the surveyed position. Dynamic accuracy is affected by GPS latency or time delay.

Global Positioning Systems (GPS) is a network of satellites and control stations administered by the U.S. Department of Defense, which transmit signals that permit the accurate determination of a receiver's position.

Horizontal Dilution of Precision (HDOP) is a measure of the contribution of satellite geometry to the two-dimensional (horizontal) uncertainty in a position fix. Values usually range from 1 to 10 with the lower values representing higher quality satellite geometry.

P-code is the precise code. A very long sequence of pseudo random binary biphase modulations on the GPS carrier at a chip rate of 10.23 MHz, which repeats about every 267 days. Each 1-week segment of this code is unique to one GPS satellite and is reset each week.

Post Processing Differential Correction is differential correction of GPS data after it has been collected in the field and stored.

Speed Over Ground (SOG) is the actual ground speed measured as instantaneous speed.

Spherical Error Probable (SEP) is the radius of a sphere measured from the surveyed position enclosing 50 percent of the GPS position points.

Standard Positioning Service (SPS) is the normal civilian positioning accuracy obtained by using the single frequency C/A code.

Static Accuracy is a measurement of the difference between the stationary GPS recorded position and the surveyed position.

Two-Distance Root Mean Square (2DRMS) is the radius measured from the surveyed position that encloses plus or minus two standard deviations (95 percent) of the two-dimensional GPS position points.

Video Mapping System is a spatial multimedia mapping system that includes hardware that embeds GPS data on videotape, and software that links images from the video taped data to GPS positions.

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14. ABSTRACT

The Army Training and Testing Area Carrying Capacity (ATTACC) methodology was developed to estimate the carrying capacity of training and testing land. ATTACC is part of the Army's Integrated Training Area Management (ITAM) Program. The ATTACC methodology quantifies the training load in terms of Maneuver Impact Miles, which are based on training impact factors. Training impact factors represent the difference in impact between various vehicles and events. ATTACC uses Event Severity Factors to account for different types of training exercises.

This report evaluates the potential to use data from differentially corrected global positioning systems (DGPS) in real time and post-processing to monitor site-specific vehicle impacts and more accurately estimate ATTACC Event Severity Factors.

The results show that the two global positioning systems tested can accurately monitor a vehicle's position and dynamic properties including velocity, turning radius, and change in velocity. This data can then be used to determine the Event Severity Factors.

15. SUBJECT TERMS
military training, land use planning, environmental impact analysis, Army Training and Testing Area Carrying Capacity (ATTACC), vehicle training, event severity factors (ESF), carrying capacity

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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