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RoadLIFE GPS – Software Application for Processing GPS Data

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16. Abstract

Public-private partnerships as an alternative means of delivering goods and services are receiving increased attention as state departments of transportation consider ways to maximize limited resources. In 1998 the New Mexico Department of Transportation (formerly New Mexico State Highway and Transportation Department) entered into an innovative partnership with a private consultant to design and manage the reconstruction of a major highway, and the numerous innovations of the agreement included a first-of-its-kind long term performance warranty. The innovations used on this project, primarily regarding features of the public-private partnership between the parties, make this project one of national interest and significance.

RoadLIFE is the name given to a broad research effort to examine various aspects of the benefits expected from innovations used on the US550 Project as required by agreements between the New Mexico Department of Transportation and the federal government. This paper provides an examination into one aspect of the US550 Project as part of the *RoadLIFE* effort: the occurrence of unexpected pavement distresses and erosion along the corridor, and efforts to identify trends in these distresses through logging and mapping their location. While determining the cause of unexpected performance along the corridor is central to evaluation of the effectiveness of the features of the public-private partnership used on this project, the scope of this paper is confined to describing the development of a software application to correlate milepoints along the corridor with field GPS coordinates, and preliminary efforts to identify trends in this data.

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RoadLIFE GPS – Software Application

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INTRODUCTION

US Highway 550 (formerly NM 44) in northern New Mexico was reconstructed between 1998 and 2001, and the project incorporates a number of innovative features including:

- Innovative GARVEE bonding to finance reconstruction
- Contractor-provided design and construction management
- Limited state oversight of design and construction
- Abbreviated schedule of 3.5 years to complete 118 miles of major reconstruction
- First-of-its-kind long term pavement and structures performance warranties

Two separate performance warranties were negotiated for this project. The first is a 20 year pavement warranty purchased for an upfront cost of $60 Million, and the second is a 10 year structures warranty purchased for $2 Million. These warranties will expire based on the following factors:

1. Time - 20 years for the Pavement Warranty; 10 years for the Structures Warranty
2. Money - Approximately $110 Million for pavement; $4 Million for structures
3. ESALs* - 4 Million for pavement; 2 Million for structures

*Equivalent Single Axle Loads (ESALs) are defined by FHWA as:

"*The damage per pass to a pavement caused by a specific axle load relative to the damage per pass of a standard 18,000 pound axle load moving on the same pavement*".

The pavement and structures warranties are performance-based warranties that provide threshold values for the acceptable limits of distresses in various categories. These categories include:

Pavement	*Bridges*	*Drainage*
Smoothness (IRI)	Deformation	Erosion
Cracking	Settlement	Damage from Water Leaks
Bleeding	Spalling	Spalling, Rusting, Cracking
Raveling	Fatigue Cracking	Sediment Deposition
Delamination	Delamination	Ponding
Potholes	Damage from Water Leaks	Damage to Ditch Linings
Depressions and Shoving	Ponding	

Allowable distress thresholds increase incrementally in periods of five years. Accordingly, the warranties are divided into four five-year periods which carry different distress criteria. For example, the allowable smoothness, as measured through the International Roughness Index (IRI) in inches per mile, is <1.25, <1,70, <2.10, <2.50, for each of the four Periods respectively. Annual inspections are conducted by the warranty provider as required by contract to measure these distresses, and the warranty provider is required to perform corrective action as necessary for any areas that fall below minimum criteria. The warranty provider has the option of performing these inspections manually, or through the use of automated equipment in conformance with industry standards, and may perform corrective work as required and preventive work as it deems appropriate. NMDOT reserves the right to perform supplemental inspections at any time, and to order repairs for those areas that are non-compliant with distress criteria. NMDOT also reserves the right to perform emergency repair work in accordance with its statutory obligations.

The warranty provides limitations on the warranty provider's liability on damages, including exclusions for damage caused by destruction, disasters, civil strife and military mobilization, as well as limits to its financial liability. The warranty also provides a limit on the liability of the warranty provider for third party claims.

BACKGROUND

New Mexico Highway 44, re-designated as US550 in January, 2000, consistently ranked among the most dangerous roads in the country. According to the NMDOT Traffic Safety Bureau, 36 people died and 264 were seriously injured in traffic crashes on NM 44 during the period from 1992 through 1996. Prior to reconstruction, the Four Corners area, which includes the City of Farmington and San Juan County, had the 4^{th} highest population, while having the 9^{th} highest unemployment rate in New Mexico. Driven by concerns about public safety and the desire to provide economic development opportunities to the area, then Governor of New Mexico Gary Johnson directed that reconstruction of the 118 mile, four lane road be a high priority during his administration.

Traditional road design and construction methods used by the New Mexico Department of Transportation (NMDOT), formerly known as the New Mexico State Highway and Transportation Department (NMSHTD), included the practice of bidding projects in roughly 4 to 5 mile increments. This approach would have taken as long as 27 years to upgrade the entire corridor. To satisfy the Governor's directive, a new approach to road construction was required.

Project Description

In July 1998, the NMDOT entered into a lump sum performance based contract with Mesa Project Development Corporation (PDC), a limited liability company owned by Koch Materials of Wichita, Kansas to design, manage construction and warrant NM 44 from San Ysidro to Bloomfield. Total cost of the project was $323.82 Million, which included $46.82 Million for project design and construction management, $215.0 Million for construction, and $62.0 Million for performance warranties. Maintenance costs over twenty years, in present value terms, were estimated by NMDOT officials to be $151 Million. The warranty, using this cost projection, was estimated to save $89 Million in repair and maintenance.

The project involved reconstructing and widening 118 miles of roadway, rehabilitation or replacement of seven bridges and replacement or extension of 393 culverts. PDC contracted with CH_2M Hill (Denver, Colorado) as the primary design firm and with Flatiron Structures (Longmont, Colorado) for construction management and quality assurance (CM/QA)

The project was divided into four bid segments with NMDOT awarding each construction segment in accordance with state procurement regulations. The initial construction phase of the project was substantially completed in November, 2001, less than 3.5 years after the PDC contract was executed.

Professional Services and Performance Warranties

The Design Professional Services portion of the contract obligated PDC to design the project in accordance with NMDOT and American Association of State Highway and Transportation Officials (AASHTO) guidelines as the minimum required design standards. It also required PDC to perform geotechnical subsurface testing to ensure the roadbed and structures foundations met acceptable design standards. Although NMDOT reviewed the design provided by PDC, contract terms provided that NMDOT review would not relieve PDC from full responsibility for the performance of the professional services in accordance with the standards, terms and conditions of the agreement.

Additionally, PDC warranted for three years from substantial completion, that if design or construction management failed to meet standards, it would perform any necessary corrective design and would be liable for the cost of repairs or replacement directly attributable to the failure. The contract specified that PDC's liability on the professional services warranty would be limited to $25 million.

NMDOT paid $60 million for the 20-year pavement warranty and $2 million for the 10-year structures (bridge, drainage and erosion) warranty. The duration of the warranty agreement is limited to time, number of Equivalent Single Axle Loads (ESALs), or total expenditures, whichever occurs first. The pavement warranty is limited to 20 years of service life, 4,000,000 ESALs, or $110 Million of total PDC expenditures. Therefore, beyond the $60 million payments from the State, PDC is at risk for an additional $50 million in pavement expenditures, if necessary to meet the terms of the warranty. The structures warranty is limited to 10 years of service life, 2,000,000 ESALs, or $4 million of total PDC expenditures. PDC is at risk for an additional $2 million in structure expenditures, if necessary to meet the terms of the warranty. The pavement and structures warranties are therefore treated as two separate and distinct contracts and are secured by a $114 million surety bond.

The warranties are divided into four segments (same as the construction segments), each of which is subject to expiration depending on the Equivalent Single Axle Load (ESAL) count for that segment. PDC submits the Annual ESAL Calculation Report that summarizes the cumulative amount of ESALs calculated from data obtained from three weigh-in-motion (WIM) stations located at the beginning, middle and end of the project. NMDOT is responsible for WIM station maintenance and data, and PDC is responsible for processing WIM data and calculating ESALs.

The pavement and structures warranty portions of the contract state that PDC will repair or replace any portions of the project that fail to meet specific objective performance measurement criteria. The pavement performance criteria establishes minimum acceptable criteria for various road conditions including smoothness, rutting, cracking, bleeding, raveling, delamination, potholes and depressions. The structures performance criteria establish minimum acceptable criteria for various bridge, drainage and erosion conditions.

Pavement and structures are inspected annually by PDC sub-consultants to locate and identify areas that do not meet the performance criteria. An *Annual Maintenance Plan* is then prepared by PDC summarizing the findings of the inspections and outlining a plan for maintenance and repairs for the next construction season. Deficiencies identified during the annual inspections are then repaired, bringing the problem areas back into compliance with the performance criteria.

The NMDOT is responsible for non-pavement maintenance along the roadway, such as mowing, metal barrier repairs, snow removal, striping and signage.

Warranty Maintenance and Repair Work

Under the warranty, PDC is required to initiate, prepare and submit bid packages to NMDOT for maintenance and repair contracts. In addition, PDC serves as authorized agent for the NMDOT in construction management, quality assurance, payment certification, and oversight of the contracts.

Contract provisions require that repair and maintenance work under the warranty be performed by contractors in accordance with standard state procurement rules. Maintenance contracts are therefore executed directly between NMDOT and the contractors, with PDC serving as authorized agent of the state. Progress payments for warranty work are made to the contractor by NMDOT, and these costs are reimbursed back to the state by PDC.

The project reached substantial completion in 2001, and in 2002 NMDOT personnel observed unexpected distresses in the form of pavement heaving, cracking, erosion and settlement, particularly in the southern portion of the project. The nature, magnitude, frequency and location of these distresses suggested a pattern of unexpected performance on the project, possibly arising from design or construction issues. The need for a systematic means of plotting the locations of these distresses for following investigation was identified, and this paper discusses the effort by NMDOT to establish an effective and reliable means for processing and mapping location information as collected from GPS equipment.

EARLY IDENTIFICATION OF DISTRESSES

The US550 project reached *Substantial Completion* on November 21, 2001, at which time the pavement and structures warranties became active. In 2002, NMDOT established a US550 Warranty Engineer position to oversee administration of the warranties, and during 2002 NMDOT identified the onset of various unexpected distresses. These early distresses manifested primarily in the form of pavement cracking, settlement at culverts, erosion at drainage features and pavement heaving. Rapid onset of these conditions was of considerable concern to NMDOT, especially in consideration of the apparently widespread, systemic nature of the distresses. Also noted were isolated areas of deep sinkholes in the project right-of-way, longitudinal cracking in the driving lanes, and voids or loosely compacted subgrade in the driving lanes.

Following are representative photographs of the distress categories identified during Period One of the warranty.

Figure 1 – Typical Erosion at Rundowns

Figure 2 – Pavement Heaves

Figure 3 – Settlement Cracks in Shoulder

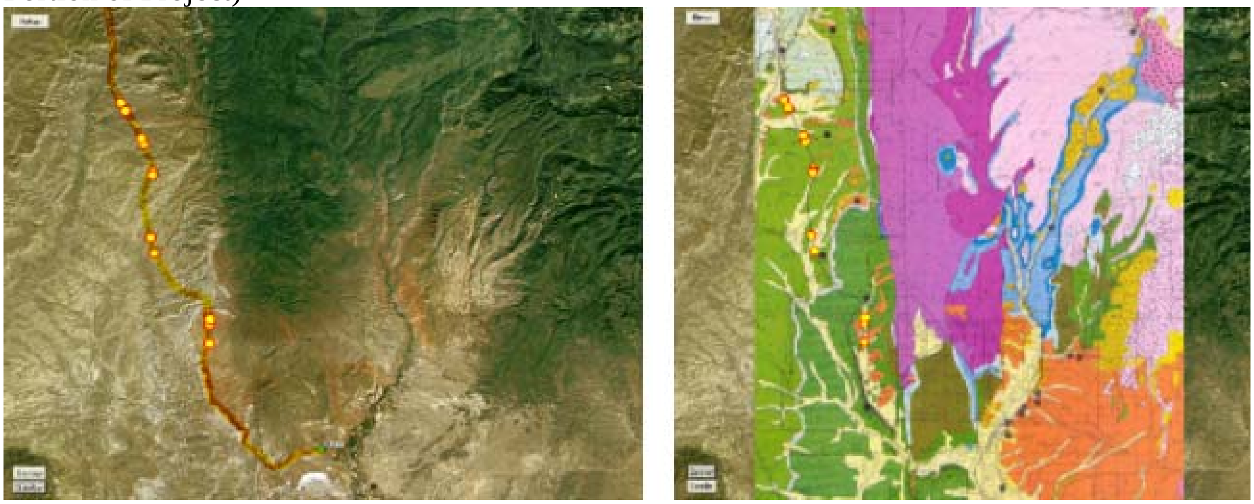
Figure 4 - Settlement at Culverts, Slope Failure

Figure 5 – Erosion at Bridge and Embankment

During Period One, the most prevalent distresses manifested in the form of settlement at culverts, sulfate heaves, pavement cracking, and erosion. In response to these unexpected failures, NMDOT retained the services of an independent geotechnical engineering firm to determine the cause of these distresses and to provide recommendations for remedial countermeasures. While a full description of the findings of the geotechnical analysis is beyond the scope of this paper, in brief it was found that erosion and settlement was attributable to a combination of highly erodible soils and poor compaction techniques, while pavement heaving was due to the use of lime soil stabilant with gypsum bearing soils. The introduction of moisture to this combination of compounds initiated a chemical reaction which produced rapid expansion of the soil. During Period One, pavement cracking was primarily associated with these conditions, along with improperly compacted pavement subgrade. Most of these distressed areas were satisfactorily repaired after discovery, and paid through the professional services and performance warranties negotiated as part of the contract.

Initial efforts by NMDOT personnel to identify trends in these distresses included logging their locations with GPS equipment, and plotting this data on various maps. Following is a plot of pavement heaves on a satellite map in comparison with a superimposed geological map.

Figure 6 – Comparison of Satellite and Geological Maps (Heaved Areas Plotted, Southern Portion of Project)



On examination of the satellite map, it was evident that the heave phenomenon was associated with local geological features. When a geological map was superimposed over the satellite map, the association between pavement heaving and known gypsum deposits along the corridor was readily apparent. NMDOT engineers therefore speculated that the observed heaves were sulfate heaves resulting from the chemical interation between moisture, gypsum-bearing soils and the lime used to stabilize those soils. Later geotechnical analysis on core samples from the area confirmed this suspicion.

REFINING THE GPS DATA

While collection of location information from GPS equipment is convenient and reasonably accurate, in practice the location of features along the corridor is performed through reference to milepoints. When inspections are conducted and repairs are performed, for example, these are referenced by milepoint. Similarly, when the contractor is requested to address conditions along the project, he is directed to the milepoint. Given the transitory nature of the observed distresses and the volume of their locations, however, it was considered unnecessarily time-consuming and hazardous to collect data on these locations by referencing milepoints. What was needed was the means to observe various categories of distresses and to log their locations while traveling at highway speeds. Keeping track of milepoints and estimating tenth points through observation of the vehicle odometer is distracting to the driver and potentially hazardous. It was therefore necessary to develop the means to log the locations of various features through the use of GPS equipment while traveling at highway speeds, and to convert the coordinates of these locations from latitude and longitude to milepoints through an office based custom software application.

EQUIPMENT SELECTION

The first step in this process was to identify appropriate equipment. In recent years, the use of consumer grade GPS equipment has increased significantly, and there are a wide variety of specialized devices on the market to fill specific needs. These include:

- In-Car Navigation Systems

- PDA-based Systems
- Laptop-based Systems
- Full Survey-Grade Systems
- Consumer-Grade Handheld Units

Some of the variations of these systems are cross-platform. For example, *Trimble™* markets a PDA system with integrated GPS features, and some handheld units offer street navigation software and mounting equipment for in-vehicle use. Other manufacturers produce compact flash (CF) based GPS antennas and software as an aftermarket device for consumer Personal Digital Assistants (PDAs). More recently, the variety and availability of in-car navigation systems, in combination with technology improvements and dramatically lowered costs for these units, has led to a significant increase in the use of this technology among the motoring public. Each of these systems is designed for a specific use, and each has its own advantages and disadvantages, which are briefly described below.

- In-car navigation systems are typically consumer-grade devices which may be portable or hard-wired into the vehicle. These systems are designed to assist motorists in navigating through unfamiliar road networks, and are generally not practical for off-road applications. Because they are powered through the vehicle's electrical system, battery life is generally not an issue.

- PDA-based systems are older technology, and involve the use of after-market compact flash based GPS antennas which are inserted into the PDA's CF card slot. These are generally provided with proprietary mapping software and may be used on or off road. These units suffer from heavy power consumption demands on the PDA battery, which is sometimes limited to a few hours of continual use before recharging becomes necessary. These systems take advantage of the wide array of software applications available for PDAs, and are useful in field data collection activities.

- Laptop-based systems use an external antenna that uses the computer's USB port to transfer information. These systems take full advantage of the processing power and software availability of office computers, and may display an enormous amount of satellite, topographical and road network information on an easy-to-use screen.

- Full survey grade systems are typically more costly and bulky, and offer a higher degree of precision through the use of land-based differential correction technology. These units are advantageous, for example, when logging the precise location of fixed assets is required.

- Handheld units offer the portability necessary for off-road activities such as hiking, camping and biking. Some units offer the feature of topographic mapping, road navigation and in-vehicle mounting hardware, however the screen size is typically smaller and harder to read than other devices. These units offer the advantage of the ability to quickly mark "waypoints", which are points of interest associated with latitude, longitude and elevation, and battery life is extended as compared to other portable devices. Some units offer the feature of tracking, which provides a detailed log of the path traversed by the user, and the ability to download log files to a computer for further processing. While many of these units are severely limited by the capacity of on-board memory, some newer models offer additional memory through the use of external microSD memory cards.

Several factors were considered in the choice of appropriate equipment. The greatest needs were the ability to quickly and safely mark points of interest while traveling at highway speeds, the ability to save this data as a log file, and the ability to download and process this data in the office. This immediately eliminated PDA based systems which require the user to view the screen and use a stylus to enter information. Similarly, laptop based systems were impractical due to the need to use a mouse and to divert attention away from driving. In-car navigation systems were impractical due to the inability to efficiently mark and process data, and full navigation systems were found to be cost-prohibitive. By elimination, therefore, the handheld unit was the only remaining viable alternative.

Of immediate concern was the accuracy and reliability of the data collected by these units while traveling in excess of 60 mph. As a means to test this accuracy, the engineers procured a test handheld unit to compare data collected through this unit with the milepoint coordinate information collected previously on US550 with survey grade equipment. The engineers conducted a test run using the *Magellan SportTrak™* GPS model, which is a generic consumer grade device, to log coordinates at each milepoint location along the corridor while traveling at an average speed of 65 mph.

These coordinates were downloaded to a computer in the office, plotted on *ArcView GIS™* and compared with the coordinates collected previously. On review of the data, it was determined that locations were accurate, on average, to less than +/- 50 feet, or 1/100th mile. While this error might be unsuitable for survey applications or locating fixed assets, it was deemed to be acceptable for logging the temporary and transitory distresses encountered along US550. Further, the driver reported that he was easily able to safely mark these locations using the device while operating the vehicle. Accordingly, a market survey was conducted to identify the most appropriate equipment for this purpose in the handheld GPS category.

Following exhaustive market research, the engineers selected the *Garmin GPSMAP CSx™* handheld GPS model, in conjunction with mapping software and in-vehicle mounting hardware. This unit was selected because of its long and reliable service in both consumer and military applications, its wide range of features including compass and altimeter, road navigation features and one-handed operation for logging points of interest. The later model features an advanced SiRF antenna and external memory for storing a large volume of data.

DATA COLLECTION AND PROCESSING

The US550 Warranty Engineer has the need to quickly and safely collect coordinate information on distresses and points of interest along the US550 corridor. Much of this information is ultimately conveyed to the warranty provider, contractor or NMDOT management, and it is therefore necessary to effectively translate latitude and longitude coordinates as logged by the equipment into equivalent milepoints. It is also necessary to translate location information expressed as milepoints into latitude and longitude for the purpose of plotting this data to satellite, topographic and road-network maps. Following is a sample log file downloaded from the GPS equipment.

Figure 7 – Sample Unprocessed GPS Log File

Waypoint	001	09-APR-08	9:04:50AM	User	Waypoint	N35	33.360	W106	47.762	5502 ft
Waypoint	002	09-APR-08	9:14:48AM	User	Waypoint	N35	33.218	W106	48.810	5510 ft
Waypoint	003	09-APR-08	9:17:11AM	User	Waypoint	N35	32.718	W106	50.679	5561 ft
Waypoint	004	09-APR-08	9:17:48AM	User	Waypoint	N35	33.094	W106	51.070	5562 ft
Waypoint	005	09-APR-08	9:18:25AM	User	Waypoint	N35	33.324	W106	51.354	5587 ft
Waypoint	006	09-APR-08	9:19:29AM	User	Waypoint	N35	34.052	W106	51.628	5627 ft
Waypoint	007	09-APR-08	9:24:41AM	User	Waypoint	N35	35.360	W106	53.178	5734 ft
Waypoint	008	09-APR-08	9:26:19AM	User	Waypoint	N35	36.677	W106	53.544	5841 ft
Waypoint	009	09-APR-08	9:26:46AM	User	Waypoint	N35	37.065	W106	53.649	5864 ft
Waypoint	010	09-APR-08	9:27:11AM	User	Waypoint	N35	37.435	W106	53.680	5914 ft

This file contains descriptive information ("Waypoint 001"), date and time, data type, latitude, longitude and elevation as logged by the GPS unit. In this example, the US550 Warranty Engineer logged each of nearly 250 guardrail locations, of which only a fraction are shown. The following file is the result of processing this data.

Figure 8 – Sample Processed File

35.556,	-106.796,	024.5,	Waypoint	001
35.554,	-106.814,	025.6,	Waypoint	002
35.545,	-106.845,	027.7,	Waypoint	003
35.552,	-106.851,	028.3,	Waypoint	004
35.555,	-106.856,	028.6,	Waypoint	005
35.568,	-106.860,	029.6,	Waypoint	006
35.589,	-106.886,	031.7,	Waypoint	007
35.611,	-106.892,	033.3,	Waypoint	008
35.618,	-106.894,	033.8,	Waypoint	009
35.624,	-106.895,	034.2,	Waypoint	010

This file presents the latitude and longitude in decimal format, and corresponding milepoint along US550, which may be plotted on many commercial mapping programs, as follows.

Figure 8 – Plot of Logged Data (Plotted on *Microsoft Streets and Trips*™)

Processing the Data

There are two primary components in processing the data. The first is converting the logged coordinates from degrees/minutes into decimal degrees, and the second is calculating the corresponding milepoint. Conversion of data into decimal degrees is a matter of parsing the text file to extract the degrees and minutes, and performing the following simple mathematical operation.

$$Degrees_{decimal} = Degrees + Minutes/60$$

To correlate latitude and longitude to milepoints, the engineers first logged milepoints along US550 at each tenth mile, for a total of 1,161 data points. This information was entered into a database which serves as the control file by which to compare collected field coordinate data. When the data log is downloaded and processed by the software application, each set of coordinates is compared with coordinates in the database, and the milepoint which is closest those coordinates is selected. This is a simple algebraic operation, as illustrated below.

If Lat_1 = Latitude of logged data point
Lon_1 = Longitude of logged data point

And

Lat_A = Latitude of milepoint in database
Lon_A = Longitude of milepoint in database

The distance between these points is given by

$$\text{Distance} = \sqrt{(Lat_1 - Lat_A)^2 + (Lon_1 - Lon_A)^2}$$

This operation is performed on each set of coordinates in the database, and the milepoint that corresponds to the shortest distance between the two points is selected.

To illustrate these operations, refer to Waypoint 001 in Figure 7. Latitude and longitude are converted to decimal values by

$$\text{Latitude} = 35 + \frac{33.360}{60} = 35.556$$

$$\text{Longitude} = 106 + \frac{47.762}{60} = 106.796$$

From the milepoint database, the coordinates for milepoints 24.4, 24.5 and 24.6 are (35.5563,106.7937), (35.5560,106.7954), and (35.5558,106.7971) respectively. The distance between the logged data point (Waypoint 001) and milepoint 24.4 is calculated as

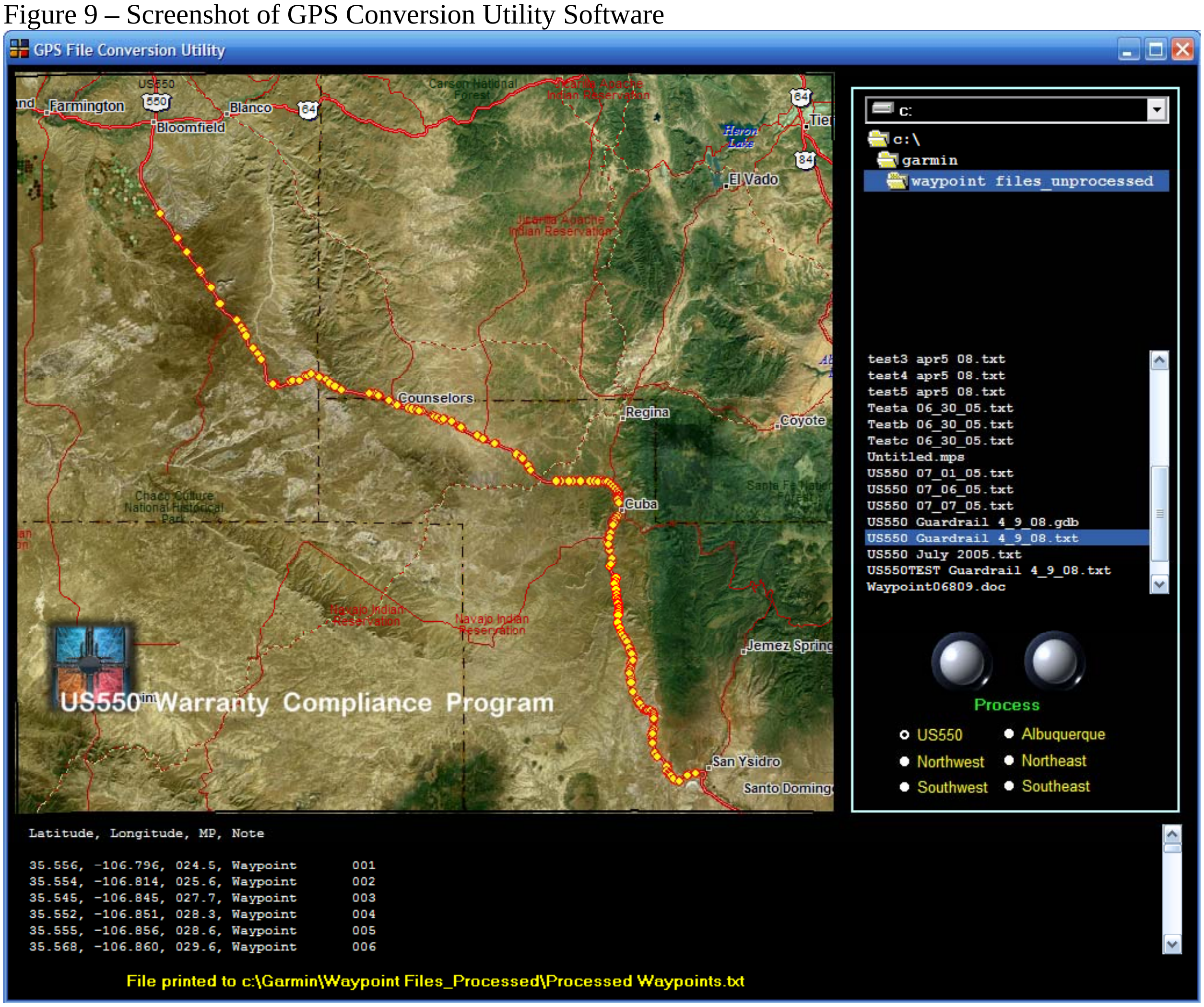
$$\text{Distance} = \sqrt{(35.556 - 35.5563)^2 + (106.796 - 106.7937)^2} = 2.319 \times 10^{-3}$$

Similarly, distances between Waypoint 001 and milepoints 24.5 and 24.6 are $6\text{x}10^{-4}$ and $1.118\text{x}10^{-3}$ respectively. (Results are in units of degrees). Because the shortest distance is $6\text{x}10^{-4}$, the closest milepoint to the logged location is milepoint 24.5. In this way, milepoints are determined for each point in the log file*. In a similar manner, milepoints may be converted to latitude and longitude, which is necessary when location data expressed in units of milepoints need to be plotted to a map.

**Due to the curvature of the Earth, the absolute length of a degree will be different for units of latitude and longitude. For this application, however, the relative distance between points is the determining factor, and the error is negligible. In this example, the distance between the logged point and the calculated milepoint is approximately 180 feet, or 0.34 tenths of a mile. This is well within acceptable tolerance for field work.*

Following is a screenshot taken from the software application.

Figure 9 – Screenshot of GPS Conversion Utility Software



SUMMARY

US550 in northwestern New Mexico was constructed between 1998 and 2001 using numerous innovations, which make this public-private partnership one of national interest and significance. In recognition of the significance of this project and its implications for other states that might be contemplating a similar public-private partnership, NMDOT initiated the RoadLIFE research effort which seeks to evaluate the effectiveness of the numerous innovations used on the project.

Early into the warranty phase of the project, NMDOT engineers observed a pattern of unexpected distresses along the southern portion of the project. These distresses manifested in the form of pavement heaving, cracking, settlement, slope and embankment failures, and erosion at drainage features. The location, volume and magnitude of these distresses suggested a systematic pattern, and engineers identified a need for an efficient means of logging the locations of the distresses for later evaluation.

This paper addresses the efforts by NMDOT to deploy appropriate GPS equipment to log the locations of distresses in various categories, and to develop the software necessary to process the log files generated through this equipment.