An Investigation of The Use of Global Positioning System (GPS) Technology and Its Augmentations Within State and Local Transportation Departments

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

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SUMMARY

This report summarizes the results of an investigation conducted by the Federal Highway Administration's (FHWA's) Office of Operations Research and Development at the Turner-Fairbank Highway Research Center (TFHRC). This investigation targets the evolving character of applications utilizing Global Positioning System (GPS) technology and its augmentation for surface transportation, especially highway departments, on the State and local government level.

GPS is a satellite-based radio-beacon navigation system developed, owned, and operated by the U.S. Department of Defense. GPS utilizes a constellation of 24 satellites that transmit time signals continuously. Users equipped with the appropriate receivers can receive signals from the satellites to calculate the user position, time, and velocity. The GPS signal is available free of charge worldwide.

Many transportation applications require better accuracy than can be provided by basic GPS. To achieve such accuracy, an augmentation technique commonly known as Differential GPS (DGPS) is utilized. The DGPS technique is based on the knowledge of a highly accurate geodetically surveyed location of a GPS reference station. The reference station observes GPS signals in real-time and compares their ranging information to the ranges expected to be observed at its fixed location. The difference between observed ranges and predicted ranges are used to compute differential correction, which is then broadcast to GPS users.

In general, GPS augmentation techniques can be categorized as either "real-time" or "post-processing." In real-time correction, the appropriate GPS receiver receives the differential signal at the time of data collection. The process is automatic and is transparent to the user since it is done within the receiver hardware. On the other hand, the post-processing technique is a multi-step process. It starts with collecting GPS data in the field and saving it in electronic format. Then, upon returning to an office or facility equipped with computers and specific software applications, as well as access to the Continuously Operating Reference Stations (CORS) archived GPS data files, the user would begin a procedure to initiate a lengthy computer calculations process. The length of the process varies, depending on the number of GPS data points corrected. It should be noted that centimeter accuracy is achievable using the post-processing technique. Several GPS augmentation systems either have been developed or are under development to enhance the accuracy of GPS.

Numerous State and local transportation departments are already utilizing this technology, while others are in the process of evaluating it for their specific application requirements. There are several incentives for transportation departments to utilize this evolving technology. An example of such an incentive is to improve public safety, e.g., through faster emergency response. Yet another example is to increase efficiency since GPS technology and its augmentations are easy to use and more efficient, e.g., fewer work-hours are required to collect and process locational data.

Each transportation department's use of GPS is based on its particular needs. However, there is a common thread among transportation applications. Each uses GPS technology and its augmentation to improve public and personnel safety, as well as efficiency.

There is a whole gamut of transportation applications utilizing GPS and its augmentation. Such applications include:

- Creation of a geographic database for use in emergency 911 systems.
- Highway inventory (e.g., cantle signs, milepost markers, rights-of-way, guardrails, and bridges).
- Emergency response services (i.e., police, fire, and rescue).
- Automatic Vehicle Location (AVL) for public transit and other fleets.
- Navigation snowplows for low-visibility situations.
- Inventorying of railroad crossings and road centerline.
- Land-use planning.
- Inventorying of highway assets.
- Tracking hazardous materials from origin to destination.
- Mapping pavement condition data, safety data, accident data, and traffic data.

One of the most widely utilized applications within transportation agencies is the integration of GPS/DGPS with a Geographic Information System (GIS). GIS allows the association of data statistics of any kind with a specific geographic location and the display of the data on an interactive map. The role of GPS and DGPS comes in determining a location for each data point. An example is the use of GPS/DGPS to monitor dangerous sections of highways by mapping accident statistics on a GIS map.

To date, 32 State representatives have provided a description of their GPS-related activities and applications. These States include Alabama, Arizona, Arkansas, Colorado, Connecticut, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Maine, Maryland, Michigan, Minnesota, Montana, Nevada, New Hampshire, New York, North Dakota, Oklahoma, Oregon, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, Wisconsin, and Wyoming.

GPS applications are not limited to transportation departments. Hence, several State, local, and federal agencies rely on GPS technology to carry out their missions. Examples of such entities are:

- Park service and wildlife departments.
- Public lands management.
- Planning and surveying departments.
- Environmental agencies.
- Police departments.

Finally, this limited-scope investigation sheds light on numerous applications, especially transportation applications that rely on GPS technology and its augmentations. It is difficult to compile a comprehensive list of GPS-related activities since there are extensive numbers of government entities that are using the technology, conducting operational tests or planing to use it in the future. Consequently, the information provided herein is a “best effort” that has been conducted within the twin constraints of time and budget.

INTRODUCTION

The Federal Highway Administration (FHWA) Office of Operations Research and Development at the Turner-Fairbank Highway Research Center (TFHRC) is conducting an investigation of Global Positioning System (GPS) technology and its augmentation applications for surface transportation. This investigation targets the evolving nature of applications relying on this technology within State and local transportation departments nationwide. State and local transportation agencies rely on GPS and its augmentations to improve public safety, enhance efficiency, and increase productivity.

This report summarizes GPS and its augmentation-related activities within State and local transportation agencies. In general, the following items will be addressed for each State that participated in this investigation and provided FHWA with information about its activities:

- Agency name.
- Description of GPS-related transportation activities.
- Projects.
- Contact person.

It is worth noting that most of the information contained in this report was provided by, and is the perspective of, the staffs of the State and local agencies.

Set forth below is a brief description of several State and local governments' transportation-related activities that are currently using and/or plan to use GPS and its augmentations.

ALABAMA

Contact: Adams, William
Title: PE/Location Engineer
Affiliation: Alabama Department of Transportation
Telephone: (334) 242-6488
Fax: (334) 269-0826
E-mail: adamswi@dot.state.al.us
Reference:

The Alabama Department of Transportation (ALDOT) makes extensive use of GPS in its surface transportation activities. ALDOT first began using GPS in 1988 in an effort to establish a statewide survey network set with GPS methods. This work was completed in 1995 with a total of 3,176 survey sites. The information was "blue booked" and sent to the National Geodetic Survey (NGS) for publication and is now available to the general public.

The Design Bureau currently has one survey crew specializing in GPS surveys for project location. This crew sets survey control for individual projects using static observation methods and the GPS first-order accuracy network previously set. We typically set pairs of GPS points at 3.2-km (2-mi) intervals through a project and then fill in with conventional surveying methods as needed. This crew is also equipped to perform real-time kinematic surveys that are useful in getting 1-cm topographic data quickly. However, in Alabama, its use is often limited due to extensive forest areas blocking the satellite's views.

The Environmental Section of the Design Bureau uses post-processing and real-time DGPS to delineate wetland and archeological sites and also to log site locations for noise receptors. Laser rangefinders are interfaced with GPS systems and are used to collect remote data points in congested or inaccessible areas.

The Bridge Scour Section of the Maintenance Bureau also uses post-processing and real-time DGPS to routinely monitor major water crossings to assist in the bridge inspection program. These surveys create contour maps that are used to monitor degradation as well as lateral migration. In addition, GPS is used to collect field data for various flood analyses, as well as to check for any scour or migration that may have occurred after high-water events.

The Transportation Planning Bureau currently uses one vehicle equipped with real-time DGPS to inventory the State road system. This number will be increased as budgeting allows.

ARIZONA

Contact: Owens, Steve
Title:
Affiliation: Arizona Department of Transportation, Technology Group
Telephone: (602) 285-2264
Fax: (602) 407-3394
E-mail:
Reference:

The Arizona Department of Transportation (ADOT) is currently involved in a variety of research and field deployment projects that involve the use of Global Positioning System (GPS) and Geographic Information System (GIS) technologies. The following projects in the GPS/GIS arena are presently in progress within Arizona:

- Highway Closure and Restrictions System (HCRS) – This system offers statewide real-time access to all planned and emergency road closures and restrictions on the State and Interstate highway system. This system is in place and operational, providing route information to the traveling public through ADOT's Internet website at www.azfms.com. The HCRS involves several agency partners with ADOT, including the Arizona Department of Public Safety, the U.S. Forest Service, and local 911 services. ADOT field offices and other partners input specific project descriptions, referenced by milepost location and time period. This data then posts to a State map on all client workstations, as well as the dial-up service, kiosks, and ADOT's website. Future deployment to counties and cites is planned. Also being developed is a similar Road Closure Restriction System (RCRS) for use within and between contiguous Arizona cities.

- Advanced Traveler Information System (ATIS) – With federal funding support, Arizona is carrying out a field operational test of Intelligent Transportation Systems (ITS) traveler information media along the 483-km (300-mi) northern Arizona I-40 corridor. ADOT, with private partner Castle Rock Consultants, will deploy up to 100 desktop computer-based kiosks in private business locations such as restaurants, hotels, service stations, and tourist attractions. Further media options for this testing include variable message signs; an Internet website; dial-up telephone service; radio and television; in-vehicle units; and freestanding kiosks at rest areas, visitor centers, truckstops, and ports of entry.

- Differential Global Positioning System (DGPS) – Arizona has taken an active role in pursuing funding for the establishment of DGPS stations in the State, in an effort to help accelerate the deployment of this technology from its present coastal/river focus to larger rural market areas. ADOT views the DGPS concept with its 1-m enhanced accuracy as vital for future public and private fleet management, emergency services response and coordination, rural mayday technology, and vehicle navigation systems.

- Vehicle Guidance System – The Intelligent Vehicle Initiative (IVI) promotes a variety of

guidance systems, many of which are based on DGPS or other satellite-based concepts. ADOT has taken a lead role in performing tests and demonstrations of vehicles developed using this technology. Both magnetic guidance courses and test sites (California PATH), as well as a vision-based control system (Carnegie-Mellon University), have been showcased in Arizona. In addition, ADOT is actively participating in a coalition with Caltrans and other DOTs for the testing of prototype snowplow guidance systems, with DGPS support as a possible component for primary or secondary location referencing. Also, ADOT is involved in the ITS America-sponsored national working group on ITS Applications in Road Maintenance.

- Featured Inventory – Arizona has maintained a videolog of roadside features for many years, and a program is underway to key this feature inventory into a database using GPS technology. The ADOT effort employs current civilian GPS technology and levels of accuracy with good results. It is planned to further refine the database with DGPS technology as it becomes available.

- Rural Mayday Technology – ADOT has funded a research project to evaluate current and proposed communications and location technology for emergency service applications in the vast rural areas of the State. It is recognized that many rural highway corridors have very limited cellular service, as well as significant terrain problems for GPS location systems. Arizona's goal is to identify the best possible technology for its geography, at acceptable levels of user cost, to enhance the safety of the traveling public. A field test is planned if the research results so warrant.

ARKANSAS

Contact: Carson, D. Kit
Title: PE, RLS/Division Head–Survey
Affiliation: Arkansas Highway and Transportation Department
Telephone: (501) 569-2341
Fax: (501) 569-2344
E-mail: DKCE035@ahtd.state.ar.us
Reference:

Several divisions within the Arkansas State Highway and Transportation Department (AHTD) utilize GPS technology in various applications. Set forth below is a description of GPS applications:

- Surveys Division

  < GPS

  All GPS control surveys for highway projects are established from first-order (1:100,000) NGS Geodetic Survey control points in the area using GEOID96 adjusted data. The Arkansas High-Accuracy Reference Network (HARN) points are also utilized. Procedures for GPS comply with those set out in *Geometric Geodetic Standards and Specifications for Using GPS Relative Positioning Techniques*, Version 5.0 (reprinted 8/01/89) or later, by the Federal Geodetic Control Committee.

  < DGPS

  The Surveys Division has one crew operating with Static GPS units to set control on construction jobs. These control points consist of pairs of intervisible points. One point is designated as the station monument and one as an azimuth mark. To date, they have set more than 1,100 points. Points set prior to 1997 are currently being updated to the HARN.

  < RTK

  The Surveys Division has two crews operating with real-time kinematic (RTK) GPS units. These two crews collect information for control traverses, including traverse points, benchmarks, and horizontal and vertical points of tangency for photogrammetric jobs.

  The Surveys Division has utilized RTK techniques to perform small roadway and design survey jobs. We anticipate being able to expand this and work more design survey jobs and branch out to do parcel survey jobs, land ties (measurements to reference monuments), right-of-way stakeout, and construction stakeout.

< HARN

In 1996, AHTD had a cooperative agreement with NGS to establish high-precision reference points that are to be part of HARN and the Federal Baseline Network (FBLN). At that time, five points were established at a published precision of 1:1,000,000, with an actual precision of 1:10,000,000.

< CORS

The department has two GPS Continuous Operating Reference Stations (CORS) in operation. One of these stations is located at the AHTD Central Headquarters in Little Rock. The other station is located in Southeast Arkansas at Monticello. The information is posted and accessible from the AHTD website.

The Surveys Division intends to set up three additional CORS in fiscal year 1999-2000 – one in northern Arkansas at Harrison, one in northeast Arkansas at Batesville, and one in southwest Arkansas at Hope.

The goal of the department is to have up to nine CORS sites in operation, based on present needs and requirements.

< AERIAL GPS

The Photogrammetry Section of the Surveys Division intends to implement GPS technology so that for any aerial photograph there would be a latitude and longitude at the center of the photograph.

< GIS

The Surveys Division keeps a database of all horizontal control points and benchmarks set or found around the State. Current projects include using hand-held GPS units to determine a latitude/longitude on all benchmarks around the State. In the near future, the intent is to incorporate this information in the department's GIS.

• Environmental Division

GPS will be used to create locational databases of sites or structures for use with GIS. These GPS databases could then be attached to other databases that contain information or pictures of the sites or structures. The databases could then be incorporated into the GIS system for impact evaluation. GPS locational databases could include:

< Archeological sites.
< Historic structures/sites.

- Wetlands.
- Hazardous waste sites.
- Illegal dumps.
- Underground storage tanks.
- Endangered species.

GPS will be used for the delineation of boundaries for wetlands, archeological/historic sites, hazardous waste sites, or endangered species habitats, along with the calculation of the area of those sites. GPS will also be useful for the accurate location of previously unknown cemeteries/graves, samples taken from cleanup sites, or specific areas within sites in relation to the project area for impact assessment.

• Planning Division

The planning division includes the mapping section and research section. The Mapping Section uses the GPS application to assist in the geo-referencing of our county photographs. This provides AHTD with on-screen revisions for any of our maps. Studies for large areas are provided for using mosaics and the GPS applications offer control.

The research section utilized GPS technology in the following projects:

- TRC-9903, "Life-Cycle Comparison of Stone Versus Asphalt Treated Bases": GPS data has been collected for integration into a GIS system for specific locations of test sites throughout the State.

- TRC-9702, "Highway Infrastructure Management Using GPS and GIS": Research in progress to develop a database in which the department can locate inventory on the roadway and log associated information directly into a database using a GPS receiver and computer software.

- MBTC-9703, "Evaluation of an Existing Imaging System for Pavement Surface Distress Survey": GPS data was used to precisely locate test sections for further evaluation by the contractor using a different roadway analysis vehicle.

- GPS data has been collected on recent New Product Evaluation sites. Two such sites are the GlassGrid site on Highway 7 near Arkadelphia and some Econocrete test sections located around the Little Rock area.

  In addition, GPS data will be collected on all research test sections in the State. The data dictionary is currently under development and staff training is pending for personnel involved in the collection of the data. These sites will include, but are not limited to, New Product Evaluation sites, LTPP/SHRP sites, and TRC/MBTC test sections.

< GPS data will be collected in August 1999 for the "Greene County Bridges GPS/GIS" project. This will involve the collection of GPS positions for all bridges in Greene County (approximately 500). The Greene County Roads Department will use the data for maintenance operations. In addition, the GPS data will be used to assist with 911/emergency dispatch operations.

< GPS data will be utilized to map hiking trails as part of the "Crowley's Ridge Parkway Promotional Plan." This will involve mapping trails at Crowley's Ridge State Park and trails along the Crowley's Ridge Parkway in northeast Arkansas. The extent of the data collection should be determined by the contractor by the end of August 1999, with data collection occurring in September 1999.

< Development of a Billboard Management System through Digital Collection and GIS Management: Working with the Environmental Division to create a billboard database to effectively monitor and control the removal of existing outdoor signs and displays.

AHTD predicts GPS benefits in the following surface transportation areas:

- **S** Accident location/investigation.
- **S** Facilities inventorying/maintenance.
- **S** Materials inventorying/tracking.

< Vehicle tracking/trends.

< Project-specific applications in design and construction.

AHTD sees the need for FHWA involvement in GPS technology through:

- Technology transfer.
- Possibly assisting in the development of standards that States can use as criteria for policy and procedures for the use of GPS based on the precision requirements of a particular task.

COLORADO

Contact: O'Loughlin, Carl B.
Title: Survey Supervisor
Affiliation: Colorado Department of Transportation
Telephone: (303) 757-9856
Fax: (303) 757-9820
E-mail:
Reference:

There are several efforts and initiatives within Colorado that are utilizing GPS, especially applications integrated with GIS technology:

The Colorado Department of Transportation (CDOT) has taken the lead in creating a "B" order, Class 2 (1:500,000 accuracy) densification of the High-Accuracy Reference Network (HARN) throughout Colorado. CDOT has taken an aggressive approach in setting monumentation at a 10-km (6-mi) spacing along State highways to facilitate the use of real-time kinematic (RTK) GPS. These stations have been "blue booked" and sent to the National Geodetic Survey (NGS) for inclusion in the national database. Similar countywide grids using the same density have been developed.

The Transportation Commission of Colorado funded a statewide GPS project so that CDOT personnel could take part in partnering efforts with cities, counties, and other government agencies, and even the private sector. They visualized the long-term savings that CDOT would realize in the future. Now GPS equipment using Rapid Static or RTK methods can be utilized, showing a savings in manpower since these methods require very short occupation time (from a few seconds to 15 min) as opposed to static methods (from 30 min to 2.5 h).

Other than setting control for engineering projects, there has been little done by CDOT as far as using GPS for GIS purposes. CDOT engineering regions have purchased equipment that is capable of doing preliminary surveys for roadway design using GPS almost entirely. This also means that they are capable of performing as-built surveys that could be entered into the transportation layer of CDOT's GIS map.

The CDOT Intelligent Transportation System Branch of Highway Operations has been working with a GPS company in Monument, Colorado to develop their mayday system. This is being developed for use by the Colorado State Patrol and eventually CDOT maintenance for snowplows. The system will be operated through CDOT's radio network and the patrol dispatchers, and will trigger an "officer needs assistance" or "snowplow in trouble" signal. The current plan does not consider upgrading the present roadmap using GPS. Consequently, the mayday system locational accuracy will be limited to 100 m, which is, in some cases, on the other side of the canyon and is unreachable from this side of the road.

The CDOT Division of Transportation Development has purchased some resource-grade Trimble equipment to locate railroad crossings. This is being done through autonomous GPS, but with no post-

processing, hence settling for the 100-m accuracy. The post-processing technique has been explored, but because of the time required to process data, it wasn't an efficient option. It is a matter of a trade-off between better accuracy and higher costs.

Colorado counties have a very good idea of how GPS can make their GIS systems better. The main problem for the counties is their lack of funds to achieve their goals. Some of the counties that have their own county HARN system are starting to drive the road centerlines using GPS/DGPS technology and are locating section corners, utilities, and many other features that will allow them to update their maps.

One county judge ordered that every traffic sign in the county be located and updated on a regular basis using GPS technology. The judge now has the data in a computer system that tells him if the sign was there on a certain date, since in traffic court, a major excuse is "there was no sign when I went through the intersection."

The counties are required to submit a road and bridge report to CDOT for allocation of Highway Users Tax funds for the building and maintenance of county roads. For this purpose, CDOT prepares a county roadmap and distributes them with digital data of the map to each county. One county bought GPS equipment to update their report and it was soon obvious that the CDOT map was not very accurate. By locating the bridges, it was found that these structures were not only nowhere near the road, but also nowhere near the rivers they were supposed to cross.

In the near future, CDOT intends to take advantage of the Federal Aviation Administration (FAA) Area Navigation Array (ANA) project. The project will be putting a HARN station and some secondary survey monuments at selected airports. CDOT's Aeronautics Board voted to furnish the funds to cover those airports not covered under the FAA plan.

CONNECTICUT

Contact: Baron, Robert
Title: PLS / Manager of Survey Operations
Affiliation: Connecticut Department of Transportation
Telephone: (860) 594-2509
Fax: (860) 594-2678
E-mail: robert.baron@po.state.ct.us
Reference:

The Connecticut Department of Transportation (ConnDOT), Office of Central Surveys has instituted the use of GPS for departmental geodetic surveys for more than 5 years. GPS systems have been used and are presently being expanded. The goal is to set up eight new GPS base stations. This new initiative will provide an unprecedented service to towns, other State agencies, surveyors, engineers, and planners on a simultaneous statewide basis. This base station array will also be available for use by neighboring States. It will be a service that will be provided free of charge.

Based on the projects for which ConnDOT relied on GPS to provide survey control, ConnDOT has realized significant savings in both costs and schedules. It is estimated that ConnDOT saved approximately $30,000 to $50,000 per project and was able to provide this control more accurately and more quickly than by conventional total station surveying techniques. The use of GPS technology will allow the completion of a project at least 3 months ahead of schedule and up to $50,000 in cost-savings.

The Right-of-Way units in ConnDOT's districts will be starting a project to establish Connecticut State Plan coordinates on the State's unbound highways. There are hundreds of miles of these roadways that are not monumented. Most cannot be accurately surveyed. The project is designed to establish coordinates on these highway lines so that they can be more easily and yet accurately monumented in the future.

FLORIDA

Contact: Brazet, David
Title:
Affiliation: Florida Department of Transportation, Surveying and Mapping Office, GPS/GIS Applications
Telephone:
Fax:
E-mail: david.brazet@dot.state.fl.us
Reference:

The Florida Department of Transportation (FDOT) is a major user of GPS/GIS in Florida. FDOT uses GPS/GIS for roadway inventory, as well as for locating roads and water resources.

The FDOT Surveying and Mapping Office in Tallahassee is undertaking a few initiatives integrating GPS with GIS:

The first initiative is a multi-year effort to provide GPS capabilities directly to the districts and indirectly to the State consultants to improve survey data-collection efforts in support of FDOT to design, build, and maintain transportation systems in Florida. This year (1998), FDOT is in the process of outfitting each of its districts with a minimum of four survey-grade GPS units. In future years, FDOT plans to locate GPS base stations around the State every 40 km or so. This network of approximately 75 stations should provide total statewide coverage for post-processing capabilities in support of the State's surveying needs. FDOT is researching the possibility of utilizing airborne GPS to produce seamless maps for GIS and determination of orthometric heights using DGPS.

The second initiative is a multi-year effort to develop and maintain a Civil Engineering Data (CED) Base Map. This CED Base Map is built from and will serve as the framework to provide the State with ready access to all of its planning, design, construction, and maintenance data associated with the transportation systems. In the future, the CED Base Map should provide for an accurate base map that could readily be used for Intelligent Transportation Systems (ITS). As a point of reference, the CED Base Map is not a map in the conventional sense. It is the data gathered during the planning, design, construction, and maintenance phases of all transportation projects.

In future years, FDOT hopes that with assistance from other federal, State, and local agencies, it will be able to combine the benefits of the above two efforts into a highly accurate ITS for Florida by converting some of the base stations to broadcast stations.

The Florida State Transportation Planning Office is in the process of using data collected for the Bridge Inventory System to help edit road graphics. The GPS data being collected for bridges can help in the locating of roads and water resources.

HAWAII

Contact: Aona, Wilfred
Title:
Affiliation: Hawaii Department of Transportation
Telephone: (808) 692-7597
Fax: (808) 692-7606
E-mail: wilfred_aona@exec.state.hi.us
Reference:

We are new to GPS. We have just been recently trained in the use of our new GPS equipment. Since we are in the process of setting things up, all we have are preliminary plans. We plan to use our GPS to create and update the control station network on Oahu. Projects for the neighboring islands (Kauai, Maui, and Hawaii) are not in the immediate plans.

Up until now, we were primarily a total station unit (Electronic Distance Measuring (EDM) unit). All surveys were done by total stations using our triangulation stations as controls. We are planning to create an extended network of control stations that would be more usable than the triangulation stations. More and more of the existing triangulation stations are becoming unusable due to construction and lack of maintenance.

Other than setting up the control network, it was suggested that we locate highway signs using GPS. This is not part of the active plans as of now. We are considering the possibility of setting up guidelines and procedures for the setting of control stations. This should be tied in closely with NGS standards. FHWA might also consider setting up minimal tolerances in setting and recording these control settings.

IDAHO

Contact: Short, Dave
Title: PLS / District 3 Land Surveyor
Affiliation: Idaho Transportation Department
Telephone: (208) 334-8918
Fax: (208) 334-8917
E-mail: dshort@itd.state.id.us
Reference:

A summary of some of the applications in which Idaho employs GPS and GIS are outlined below:

- Department of Environmental Quality (DEQ) locates wells for the monitoring of toxic contaminants with GPS and then maps the sites by contaminant and concentration using GIS.
- Idaho Department of Water Resources locates drinking water wells with GPS and catalogs them into their database.
- The Bureau of Land Management (BLM) locates abandoned mines with GPS and then, using GIS, compares ownership and population to determine priority for cleanup.
- BLM uses GPS to map fire boundaries for map preparation.
- Idaho Department of Lands uses GPS to map the location of gypsy moth infestations.
- EPA uses GIS and GPS to map the location of confined animal feeding operations.
- The cities are expanding their 911 services that use GIS or may use GPS if it were available.
- Farmers use GPS and GIS for precision farming practices.
- The Idaho Transportation Department (ITD) uses GPS in conjunction with GIS to locate and log all of its roadway facilities, as well as local roads. ITD uses real-time OmniStar differentially corrected GPS. They also locate all railroad crossings in the same manner. ITD also uses survey-grade GPS to set the location of highway projects on both geodetic and cadastral data. ITD also uses survey-grade GPS to topographically map areas for highway projects.
- Many private firms also use GPS to support GIS functions, mapping, and land surveying.

ILLINOIS

Contact: Rich, Donald R.
Title: PE / Engineer of Aerial Surveys
Affiliation: Illinois Department of Transportation
Telephone: (217) 782-7627
Fax: (217) 524-4149
E-mail: richdr@nt.dot.state.il.us
Reference:

The Illinois Department of Transportation (IDOT) purchased its first GPS receivers in 1987. They were used to perform geodetic-type surveys to establish control at or near highway projects. Since that first purchase, IDOT has purchased receivers for all nine district offices and the Aerial Surveys Section located in the central office. The department now owns 35 geodetic-type receivers. Some offices are purchasing the hand-held type of receiver for lower accuracy positioning.

Applications for using GPS in Illinois are:

- Geodetic control to densify the National Geodetic Survey system.
- Control of all photogrammetry projects in horizontal and vertical.
- Navigation and control of aerial camera for photograph acquisition.
- Roadway inventory video vans have GPS included in their system.
- Illinois State Police are purchasing receivers for the locating of accidents.
- Location of the 500+ open mines and quarries in the State.
- Receivers are being used in many other GIS applications.
- Many recreational uses (fishing, hiking, hunting, etc.).

INDIANA

Contact: Andrews, Mike
Title:
Affiliation: Indiana Department of Transportation, Information Services Division/Graphics Engineering
Telephone: (317) 232-7275
Fax: (317) 232-5169
E-mail: mandrews@indot.state.in.us
Reference:

The Indiana Department of Transportation (INDOT) and the Data Processing Oversight Commission are working in conjunction with the State Geographic Information Council and the Federal Geographic Data Committee to survey various agencies in Indiana on what they are doing in the area of Geographic Information. This information will enable State, county, local, public, and private entities to ascertain what geospatial data is being collected and where it is located. Moreover, this information will be used in a national database that will be part of the National Spatial Data Infrastructure.

Several GIS initiatives that utilize GPS technology are taking place in Indiana. Examples of these projects are:

- CASPER – Computer-Aided Snow Plow Efficiency Routing was designed to create the best route for winter snow removal, providing the most efficient utilization of human resources, equipment, and material.

- All Interstate, U.S., and State roads; railroads; incorporated city boundaries; unincorporated city/town locations; road symbols; section corners; township outlines/names; reference posts; county outlines/names; and various other features.

- Fatality location and vehicle type are linked to the GIS map.

INDOT is continuing to bring more and more diverse data into the State's GIS map through cooperation with State, county, and local governments, along with other public and private entities. According to an INDOT official, "The future is limitless and the possibilities are endless."

IOWA

Contact: Trainum, Matthew
Title: Geologist
Affiliation: Iowa Department of Transportation, Soils Design Section, Office of Design
Telephone: (515) 239-1476
Fax: (515) 239-1873
E-mail: mtranium@max.state.ia.us
Reference:

The Project Development Division in the Iowa Department of Transportation (Iowa DOT) is presently using GPS in four areas covering the process of highway design:

- Surveying/Photogrammetry

  The preliminary survey section uses GPS to establish project control along all projects that require field surveying, except small culvert and small bridge replacement projects. The data is collected with five Z-12 Ashtech receivers, using the static process. A GPS control network is adjusted to a local project coordinate system, accurate to the first-order standards. All other GPS users that collect GPS data associated with these projects, with the exception of Soils Design, use this project control. The Transportation Centers (six in Iowa) use the project control to establish cornerstone coordinates and to establish new right-of-way. Real-time kinematic (RTK) GPS receivers are used by the Transportation Centers to collect stone monument positions. It is anticipated that within a year, the preliminary survey will use RTK to collect control data for the photogrammetric surveys.

- Soils Survey

  The soil survey crews conducting the soil investigation for a project use Trimble mobile backpack GPS units, relying on the U.S. Coast Guard (USCG) DGPS corrections signal for locating and recording the position soil borings. The coordinates recorded are the State plane coordinates, which are relatively the same as the survey's project coordinates. The accuracy of the mobile units is approximately 1 m in the horizontal plan. The use of GPS technology for locating soil boring will be incorporated into soil design plans by reading the database into the Computer-Aided Design and Drafting (CADD) design.

- Roadside Development (Wetland Delineation and Mitigation)

  The Wetland Unit of Roadside Development is using GPS for reporting the coordinates of wetland impacts due to road construction to the U.S. Army Corps of Engineers so that the impact sites can be mapped with greater confidence. GPS technology is being used for geo-referencing sample points taken in the field during wetland delineation. The Wetland unit uses a Magellan hand-held GPS unit with a post-processing differential accuracy of 3 to 5 m. A future use of GPS technology will be geo-referencing of sample points within wetland mitigation sites

for navigation back to the same point during later monitoring visits and determining the boundaries of wetland mitigation sites for use in GIS mapping and area determinations.

- Development Support

  The Office of Development Support uses GPS equipment (sub-centimeter accuracy) to locate specific features at sites where regulated substances are known or suspected to be present. For example, a former service station property acquired by the DOT may have used GPS to locate building corners, underground storage tanks, fill pipes, vent pipes, monitoring wells, dispenser islands, utility node, and fire hydrants. This information is used to facilitate any site remediation and/or monitoring that may be required by regulatory agencies.

The Iowa DOT Office of Road Design, in cooperation with several State agencies and federal entities, conducted a study into ways to automate the Soil Design Process. The study evaluated two soil design methods. The first relies on conventional methods, i.e., scaling and taping, while the second method utilizes real-time DGPS correction from the USCG DGPS network. The results of the study stated that using real-time DGPS to locate borings resulted in a 60- to 70-percent reduction in time. The workers achieved a locational accuracy within 1 m, even though the USCG advertises an accuracy of better than 10 m. Moreover, the study concluded that DGPS has the potential of more benefits, especially if the proposed borings are moved and when the weather and terrain are not favorable. Cold weather, muddy ground, or deep snow cover would decrease scale and tape performance, but adverse weather would not affect locating borings using DGPS. Timber or rough terrain would further increase the time required for taping. This method requires several trips back and forth across the ground. Therefore, the effect of those conditions and the resultant fatigue would decrease performance much more than with the DGPS method. The potential for crop damage in mature corn crops would also be reduced with DGPS, since the need to cut line-of-sight for taping would be eliminated.

KANSAS

Contact: Hughes, B.
Title:
Affiliation: Kansas Department of Transportation, Information Services Division/Graphics Engineering
Telephone: (785) 296-3841
Fax:
E-mail: bhughes@dtdsob4.wpo.state.ks.us
Reference:

The most advanced GPS/GIS program in Kansas is implemented in the videolog system. The videolog data collection includes a latitude/longitude for each picture. This provides tracking of points along each route. The Kansas Department of Transportation (KDOT) videologs each Interstate, Kansas highway, and U.S. route on a 3-year cycle. So far, one-third of the State has been completed. The data collection includes the county, route, and the distance from the county line.

The State started on a project to evaluate travel time using a pilot vehicle equipped with a GPS receiver. By logging position data in 1-s intervals, travel speed can be calculated at each point along a route. The State plans to make this data part of the Corridor Management System.

The Highway Patrol has started a project to outfit all patrol vehicles with a GPS unit for locating accidents and other distress calls. This will tie into a specialized GIS to provide mile-marker references. The system is also connected to the Highway Patrol 800-MHz communications network. The system provides DGPS correction “on demand” (only when an incident is identified is a differential correction calculated).

Other uses of GPS/DGPS technology include locating pavement sections chosen for testing in the Pavement Management System and the development of an Automatic Vehicle Location (AVL) system to locate city buses in Kansas City.

LOUISIANA

Contact:
Title:
Affiliation:
Telephone:
Fax:
E-mail:
Reference: Development of a Congestion Management System Using GPS Technology , *by Darcy Bullock and Cesar A. Quiroga*

The Louisiana Department of Transportation and Development (LDOTD) sponsored a study to demonstrate the feasibility of using GPS/DGPS and GIS technologies to measure travel-time and speed data on urban highways. The study was carried out by the Louisiana Transportation Research Center and was completed in April 1997. Specific objectives of the study were:

- Development of an efficient travel-time data-collection methodology.
- Development of an efficient procedure for producing GPS-based highway network maps suitable for travel-time studies. These directional centerline network maps allow for an accurate mapping of GPS travel-time data to highway segments.
- Development of a procedure and accompanying software to link GPS-derived travel-time and speed data to highway segments.

The procedures and the results of the study concluded that it was possible to provide a sound methodology, based on GPS/DGPS and GIS, to conduct the type of macro travel-time studies needed to develop congestion management systems for metropolitan areas such as Baton Rouge, Shreveport, and New Orleans.

MAINE

Contact: LeSiege, Timothy
Title: PE / Photogrammetric and Control Engineer
Affiliation: Maine Department of Transportation
Telephone: (207) 287-2330
Fax: (207) 287-8357
E-mail: tim.lesiege@state.dot.me.us
Reference:

The Survey Unit of the Maine Department of Transportation (MDOT) uses GPS for setting geodetic control, laying out alignments (on occasion), locating wetlands, coordinating aerial targets, obtaining base information for airborne GPS, and other locational needs as requested.

Currently, the Information Management Division of the Bureau of Planning, Research, and Community Services uses GPS to capture new road data as well as to update existing road alignment data that has been hand-digitized into the GIS. A Trimble ProXR is used to collect uncorrected data at near highway speeds. Due to intermittent poor reception of Radio Technical Commission for Maritime (RTCM) services links, the data is differentially corrected in the office primarily using Internet connections to CORS sites. Trimble's Pathfinder office software is used for differential corrections and exporting.

The Office of Environmental Services has budgeted to purchase some GPS equipment to be able to locate wetlands and other environmentally sensitive sites.

MARYLAND

Contact: White, Joseph
Title: GPS / GIS Specialist
Affiliation: Maryland Department of Transportation, State Highway Administration
Telephone: (410) 545-5538
Fax: (410) 209-5033
E-mail: jwhite4@sha.state.md.us
Reference:

Several government departments, agencies, and administrations within Maryland use or plan to use GPS applications. Details of specific projects are described below.

- Department of Natural Resources (DNR) – Maryland Geological Survey (MGS)

The Maryland Geological Survey (MGS) has been using the civilian GPS service, along with the DGPS service from CORS stations and the U.S. Coast Guard, to analyze environmental conditions for the last 5 years. Specific projects that are currently underway consist of hydrographic surveying of the Chesapeake Bay, drinking water reservoirs, coastal shoreline change mapping, water well location and monitoring, and sinkhole location mapping. Without the aid of GPS technology, all of these projects would not be able to be performed to the degree of accuracy needed to form sound scientific conclusions.

Typically, the MGS is working in areas that have seen a population density change over recent years. These changes are not represented on USGS topographic maps. This makes the need for GPS even stronger for the field worker who needs to annotate locations on maps that do not accurately reflect the current landscape. GPS allows the user to survey, map, and return to the same site with precision.

- DNR – Wildlife and Heritage Division

This division is currently using GPS to guide us to various ground locations sited on air-video flights for vegetation classification. Once located, field staff using GPS mark the sites. These will be used as ground control points within the GIS. Other staff members are using GPS to track sites for species surveying (birds, reptiles, etc.). Most of the surveys include x/y locations; only one or two have mapped areas. One of the field biologists is using GPS to track the shoreline of a receding island on the Eastern Shore of the Chesapeake Bay.

- DNR – Public Lands Division

Uses GPS to map park trails within State park boundaries.

- State Highway Administration (SHA) – Office of Materials and Research (OMR)

The Office of Materials and Research, Pavement Division collects GPS data as part of their Annual Road Condition Inventory. This information is incorporated, along with the Road Performance information, and can be used to identify deficient road locations.

- SHA-OMR – Geotechnical Explorations

GPS has been very beneficial to their department, saving time and providing them with a more accurate way of locating borings, areas, and other objects. They are using GPS to locate borings prior to drilling, thus eliminating measuring from the topography from the plans, which, in turn, eliminates slight errors that are multiplied over a distance. It has also been used to locate borings that have already been drilled so that they can be more easily and accurately plotted on plans. Another beneficial way GPS is being used is to collect boundaries of potential problem areas, such as sinkholes, unconsolidated fills, and low saturated areas.

- SHA – Office of Environmental Design (OED)

GPS is being used to provide survey and analysis of various reforestation, wildflower, wetland, and natural regeneration sites, and to assess State rights-of-way for future mitigation. Arc-view shape files of mitigation areas with informational data about each site are created. This information is to be used in the future planning of road construction, highway maintenance, mitigation, and needs assessment.

- SHA – Office of Preliminary Planning and Engineering (OPPE) – Highway Information Services Division (HISD)

GPS is being used for new county roads and highway alignment data for the collection and verification of the county highway improvement packages. GPS is also being used to verify the positional location of new features and existing roads. The GPS data is overlaid against existing grid maps, aerial photography, and satellite images to ensure quality and verify positional accuracy of the existing mapping maintained by the SHA. The data is then used in the grid map updating procedure.

The statewide grid maps are also used as the basis for the Maryland State Highway Administration's GIS.

The Highway Information Services Division is now investigating electronic road inventorying to automate the downloading of GPS data into their databases. One of the procedures that would change in GPS data collection would be the use of DGPS instead of post-processing. This would eventually save more time with the map and database updates.

- SHA – Plats and Surveys Division

The Division of Plats and Surveys use survey-grade GPS receivers to establish survey control for their highway-related projects to yield sub-centimeter accuracy. A single-frequency receiver using a USCG beacon is used for locating wetlands and utilities, rectifying photogrammetry, and establishing positioning on new benchmarks. Annual subsidence studies in Anne Arundel County are performed for the Maryland Geological Survey.

GPS usage grows more and more within Maryland as the technological advancements are introduced. Data is being collected at a faster rate, saving the user time and money. The growth

of DGPS has been slowed in the Western Counties of Maryland due to the lack of availability of a signal. In time, we hope this will change with the expansion of NDGPS.

Now that GPS is being used for various forms of data collection, standards are needed. Surveyors are using GPS for sub-centimeter accuracy and GIS data is being collected in a range of 1 to 10 m of accuracy. If a different level of standards is not created, a misrepresentation of surveys and GIS/GPS collected data could occur.

MICHIGAN

Contact: Shaw, Larry
Title:
Affiliation: Michigan Department of Transportation
Telephone: (517) 335-2911
Fax:
E-mail: shawl@mdot.state.mi.us
Reference:

The Michigan Department of Transportation (MDOT) is presently working on or plans to begin working on several projects that utilize GPS/GIS technology. In 1996, a demonstration project known as the "Eaton County Demonstration Project" was conducted to evaluate GPS as a tool in collecting data and creating a Centerline Roadway Network that could be used in a GIS map. According to MDOT staff, "The results of this pilot study exceeded our expectations and it was evident that GPS is an efficient and accurate methodology for collecting roadway attribute information."

Currently, several projects in Michigan utilize real-time DGPS available in areas covered by the U.S. Coast Guard (USCG) DGPS network. Some problems occurred in the middle of the State where reception of the USCG DGPS signal is poor and unreliable. In these areas, GPS data has to be post-processed using the Continuously Operating Reference Station (CORS) network. Set forth below is a description of a few projects that utilize GPS technology.

- Non-Trunkline Federal Aid Survey – MDOT is evaluating the takeover of all or part of the Non-Trunkline Federal Aid System and has no current data on pavement condition or what bridges are located on this system. This data is considered to be of vital importance to management in making decisions and determining the cost of maintaining this system. Therefore, a three-county pilot "GPS/Road Condition and Bridge Location Inventory Survey" was initiated to collect this data and has been completed successfully. MDOT is preparing a Request for Proposal (RFP) to hire a consultant to collect the information on the remaining 37,014 km (23,000 mi) of the Non-Trunkline Federal Aid System in Michigan. MDOT wishes to obtain the following products from this study:

  < Road Condition Database – This database will contain road conditions, pavement types, and lane information.

  < Identification of Bridge Locations and Structure ID Numbers – This information provides a link to the Critical Bridge File, thereby allowing the determination of the bridges on the system and their structural condition.

  < GIS Centerline Network – This study would produce an accurate computer network of the Non-Trunkline Federal Aid System. This network will allow for display and analysis of this system's roads and bridges.

- GPS Centerline Survey of the Trunkline System – The purpose of this survey would be to

determine exactly how many pavement lines of road MDOT owns. Also, it would collect exact locations of the control sections' beginning and ending milepoints and the Michigan Accident Location Index (MALI) Primary Route (PR) beginning and ending milepoints, and it would collect accurate coordinates for all bridges. MDOT goals include obtaining the following products:

< Trunkline Mileage File – Precise data on the mileage of the roads that MDOT owns.

< Documented Point File – A documented GPS Waypoint file containing description, latitude, and longitude of all beginning and ending points of Control Section and MALI PR locations.

< Control Section/MALI PR Conversion File – An accurate conversion of Control Section milepoints to MALI PR milepoints.

< GIS Trunkline Centerline Network – A computerized digital network of the trunkline system, which would have meter accuracy.

< Bridges Locations – Centerline point coordinate file for all bridges owned by MDOT.

- Environmental Section GPS Demonstration Project – This is a joint project with the environmental section to evaluate GPS technology as a utility for conducting environmental surveys. These surveys will include mapping the following as related to the existing or proposed trunkline stationing: endangered species populations/critical plant and animal habitat, delineating natural wetland boundaries, delineating habitats, and size verification of created wetland mitigation sites. GPS technology could be used during all general surveys, during the draft Environmental Assessment (EA) or Environmental Impact Statement (EIS) stage, and for determining proper positioning along the alignment while performing a survey. The objective of this project is to obtain the following products:

  < I-96 Webster Road Wetland Delineation – This wetland will have all habitat types delineated and the size verified for each habitat.

  < Plant Protected Area Map/Critical Habitat Map – A trail map will be created for one Plant Protected Area, which will include the plants' locations within the right-of-way and the critical habitat present in relationship to the alignment.

  < Wetland Size and Type Impact Map – Wetland impact, including size and type, will be evaluated for one project that is currently being evaluated for mitigation purposes.

- Bus Route/Bus Stop Inventory Demonstration Project – The objective of this project is to evaluate GPS technology in locating and inventorying multi-modal transportation systems. This study was conducted in cooperation with the Detroit DOT. Following the completion of this demonstration, Detroit DOT decided to use GPS technology to inventory all the bus routes and bus stops in the Detroit Metropolitan area. Products of this study included a GIS network of

bus routes; location of bus stops; and an inventory of the bus stop furniture, such as benches, signs, and shelters.

- GPS Roadway Attribute Demonstration Project – The goal is to evaluate the efficiency of GPS in collecting roadway attributes such as guardrails, signs, light posts, median barriers, and signals.

MINNESOTA

Contact: Gorg, Dave
Title: PE / Geodetic Engineer
Affiliation: Minnesota Department of Transportation
Telephone: (651) 296-5710
Fax: (651) 297-1521
E-mail: dave.gorg@dot.state.mn.us
Reference:

The Minnesota Department of Transportation (MnDOT) made its first use of GPS technology in 1985 when GPS was used to make precise geodetic control measurements to replace the traditional angle and distance measurements. Since then, MnDOT has purchased enough GPS receivers so that all nine of its district survey offices and the Geodetic Unit in the Central Office own at least one set of GPS equipment (four receivers) that is capable of measuring to millimeter accuracy. In addition to the survey-accuracy receivers, MnDOT owns many hand-held GPS receivers used for positioning or navigating to objects in a 1- to 5-m accuracy range.

Because of its early involvement in GPS technology, MnDOT became active with other State and local government agencies to promote applications and to provide technical support for GPS-related activities. Besides surveying and mapping GPS activities at MnDOT, other GPS applications include:

- Location of drainage structures along highway corridors for maintenance and facilities management applications.
- Fleet management of the "Highway Helper Vehicles" operating on the Twin City Metro freeway system.
- Photolog inventory vans use GPS to geo-reference the photolog images.
- The Office of Railroads and Waterways utilized GPS to position railroad crossings.
- Soil boring crews will soon be using GPS to navigate to, or to determine the coordinates and elevations of, the test holes.
- The Safe Truck project is using centimeter-accuracy DGPS data in real time to remotely control a semitruck-tractor so that it can steer itself.
- Seventy-nine weather information sites have been positioned by GPS.

According to an article in the May 1998 issue of *GPS World*, the University of Minnesota's Department of Mechanical Engineering and Center for Transportation and MnDOT are working to develop a system that takes control of a vehicle if loss of manual control is evident. This effort is part of a project to investigate truck-based, safety-oriented technologies. The project utilizes DGPS, making it the first steering control system that uses DGPS to stay in the lane of normal roads.

The above list of GPS applications is not all-inclusive; new applications are being discussed and implemented on a continuing basis.

MONTANA

Contact: O'Mara, John
Title:
Affiliation: Montana Department of Transportation
Telephone: (406) 444-6307
Fax:
E-mail:
Reference:

The Western Transportation Institute (WTI) is working on the Greater Yellowstone Rural ITS Corridor project. WTI's staff is using GIS to create layers of accident types, traffic volumes, major recreational destinations, services, emergency response time, rail and modal transfer points, communications infrastructure, planned construction improvements, hazardous materials, existing ITS components, and geometric alignment data for the corridor. This is a nationally significant rural transportation corridor between Bozeman, Montana and Idaho Falls, Idaho that includes:

- Three States: Montana, Wyoming, and Idaho.
- Two national parks: Yellowstone and Grand Teton National Parks.
- A variety of rural transportation facilities.
- Full Interstate and freeway to low-volume rural highways.

The Montana Department of Transportation (MDT) is using GPS to inventory 41,842 km (26,000 mi) of roadway. This inventory is currently about 90-percent complete. The roadway was digitally filed and the x, y, and z coordinates were taken every 10 m. The coordinates are in State plane and are currently available in Arc/Info format. Routers were created on the coverage in order to perform a linear reference of data to the roadway. This data can be referenced via mile marker, accumulated distance, or by State plane coordinates.

Last summer, the Utilities Division inventoried a number of railroad crossings throughout the State using a GPS receiver. They will use this data in a GIS map to query information associated with the conditions of a crossing.

There have been a number of county/city government agencies that have used GPS to inventory their roads, utilities, and other government-owned assets. These agencies are in the process of creating a GIS database from the inventoried items. Some uses of the road inventory will be emergency services, best routes for maintenance, and map display. Other uses include placing land ownership records into this GIS map to keep track of right-of-way, especially when new areas are bought for new road projects.

NEVADA

Contact: Yearer, Patrick E.
Title: PLS / Chief Land Surveyor
Affiliation: Nevada Department of Transportation
Telephone: (702) 888-7486
Fax: (702) 888-7203
E-mail:
Reference:

In 1996, the Nevada Department of Transportation (NDOT) began using GPS equipment. Since then, GPS technology has been used on every project. NDOT has four Trimble 4000 receivers and four Trimble 4600 LS receivers, and 10 Trimble Geo-Explorer GPS units. Two of the 4000 receivers and two of the 4600 LS receivers are placed in the northern regions and the other two 4000 receivers and two 4600 LS receivers are placed in the southern regions. These receivers are dedicated to survey-grade operations within High-Accuracy Reference Network (HARN) extensions taking place on each project as needed. The 10 Trimble Geo-Explorer units are dedicated to GIS collection for continuous updating of the GIS statewide database.

The following types of GPS collection techniques are used statewide:

- Static.
- Fast-Static.
- Stop-and-Go Kinematics.
- Kinematics.
- Continuous Kinematics.
- Real-Time Kinematics.

The assessment of the current GPS applications is primarily for HARN densification and conversion to NAD83/94 coordinate systems from the existing NAD27 and NAD29 datum. Control for aerial mapping projects and R.O.W. acquisition are other primary uses for GPS technology.

NDOT has budgeted for an increase in survey-grade GPS equipment to add two Trimble 4000 SSi receivers to supplement GIS data collection, and money is budgeted for a GPS receiver and software to allow the aerial camera and plane to possibly be used for airborne kinematic surveys.

A cooperative effort in Las Vegas Valley between Clark County, NDOT, the City of North Las Vegas, City of Las Vegas, City of Henderson, Las Vegas Valley Water District, and private users to establish and locate a control network was undertaken and completed.

Transportation systems are a controlling factor in a statewide GIS database, the referencing of which is to collect latitude/longitude data points for engineering works statewide. NDOT expects continuous expansion of GPS applications for all engineering and geophysical fields, in addition to political district boundaries and educational district boundaries, and emergency routes for fire and police departments.

NEW HAMPSHIRE

Contact: Fowler, Dennis R.
Title: GIS Applications Engineer
Affiliation: State of New Hampshire Department of Transportation
Telephone:
Fax:
E-mail:
Reference:

The State of New Hampshire Department of Transportation (NHDOT) has been using GPS since 1985 when a survey crew used rented GPS equipment to lay out the control for a project in Pittsburg, NH. In 1991, NHDOT purchased its own GPS equipment and the use of GPS technology in NHDOT has grown continuously ever since.

NHDOT uses GPS equipment and technology on a wide array of activities, including control geodetic, aerial photographic positioning, mapping and positioning of wetlands, environmental sites, town boundary crossings, preliminary centerline layouts, and control point recovery. Currently, NHDOT is developing and updating the base map for GIS efforts and the staff is using GPS roving receivers to verify and update the roadway centerline. The road inventory crews record the GPS positioning of the roadway networks they travel. Also, NHDOT staff is using GPS data collected by the State's emergency 911 mapping people. The staff achieves an accuracy of 3 to 5 m using the post-processing technique. Such accuracy is well within the needed accuracy of 1:24000 scale mapping.

Currently, NHDOT is not using real-time DGPS; however, NHDOT does maintain a GPS base station that collects correction data 24 hours a day, 7 days a week.

NEW YORK

Contact: Roden, Steve
Title:
Affiliation: New York State Department of Transportation
Telephone: (518) 485-1385
Fax:
E-mail: sroden@gw.dot.state.ny.us
Reference:

At the present time, the New York State Department of Transportation (NYSDOT) uses GPS in the following activities:

- Geodetic Network Control Surveys, under the supervision of the National Geodetic Service (NGS).
- Geodetic Horizontal and Vertical Control Surveys for NYSDOT highway projects.
- Wetland delineation surveys.
- GIS mapping projects.

Other GPS activities that are taking place around New York include:

- Department of Environmental Conservation – Control surveys for real estate property acquisitions, habitats, wetlands, and resource mapping.
- Office of General Services – Inventory and facilities management.
- Adirondack Park Agency – Wetlands location and GIS mapping.
- NY City Department of Environmental Protection – NY City watershed management.
- Niagara Mohawk Power Corp. – Inventory and GIS mapping.
- City of Saratoga Springs, Engineering Office – Inventory and GIS mapping.

Several other area programs have expressed interest in GPS and are working toward using GPS technology for the following:

- Emergency Management and the Department of Corrections – Fleet tracking, search and rescue.
- State Police – Accident locations.
- DOT – Linear referencing (inventory) of all State highways and thermal mapping of State highways.

Currently, New York State is only partially covered by real-time DGPS signals from the USCG Differential Beacon network. With the conversion of two former Ground Wave Emergency Network (GWEN) Sites in Hudson Falls, NY and Hawk Run, PA, New York State will have 100-percent redundant real-time DGPS coverage statewide. This should enhance and promote New York State ITS programs requiring real-time GPS.

NORTH DAKOTA

Contact: Meier, DeLane R.
Title: RLS / Surveys and Photogrammetry Head
Affiliation: North Dakota Department of Transportation, Surveys and Photogrammetry
Telephone: (701) 328-2640
Fax: (701) 328-4545
E-mail: dmeier@pioneer.state.nd.us
Reference:

The North Dakota Department of Transportation (NDDOT) uses augmented GPS in its highway surveys of road construction. This information is the basis for the design of improvements and the purchase of rights-of-way. It is worth noting that there are no real-time DGPS reference stations in North Dakota. Therefore, most data files must be post-processed to get the desired position accuracy. Post-processing is a lengthy process and is not adequate for many applications that require real-time differential corrections.

The NDDOT has initiated a comprehensive highway inventory program and highway reference marker location utilizing augmented GPS technology. NDDOT has a goal of developing the highway network as the foundation for the computer-generated highway mapping and attribute data to assist the NDDOT, counties, cities, and planning districts in the mapping of the State's entire system of highways. Consultants and engineers use augmented GPS for boundary and construction surveys. The Health Department, Agriculture Department, and ND Geological Survey use GPS for data collection in their respective areas.

Proposed Uses of GPS/DGPS in North Dakota

NDDOT would use DGPS to enhance its collection of highway inventory programs to replace destroyed highway reference markers. Other uses would include accident location, emergency vehicle tracking, environmental concerns and data collection, intelligent highway systems, and surveys.

Several State government entities have future plans to use DGPS correction:

- Department of Transportation – NDDOT will continue to use GPS to enhance its collection of highway inventory data, replace destroyed highway reference markers, and relocate highway survey reference points. Other uses include locating accidents, emergency vehicle tracking, intelligent highway systems, airborne GPS mapping, and surveys. Another application is to conduct environmental surveys. These surveys would include mapping the following: critical plant and animal habitats, delineating wetland boundaries, and verifying created wetland mitigation sites. Soil boring crews will use DGPS to navigate to, or determine the coordinates and elevation of, test holes.

- Highway Patrol – Future plans include the installation of GPS/DGPS receivers in all patrol vehicles (when they receive mobile data computers). The benefits of GPS/DGPS receivers

include:

- < Increased Officer Safety – The dispatcher could locate officers quickly, especially if an officer needs assistance, as well as dispatch the closest officer to assist.

- < Improved Response Time – Officers on the scene of an emergency can relay their exact location for a quicker response for assistance from other law enforcement, fire, and ambulance (both air and ground) services.

- < Improved Statistical Data – Determine exact location of accidents, which will aid NDDOT in addressing possible engineering concerns.

- Health Department – Continue geo-referencing, with better accuracy, all department monitoring and regulatory compliance points.

- Geological Survey – There were plans to use it for locating geothermal wells and fossil sites, as well as coal wells, and for any locations on which soil probes are used.

- Game and Fish Department – Enforce boating and hunting laws and accident investigations.

OKLAHOMA

Contact: Johnson, Gordon
Title: PE, PLS / Chief of Surveys
Affiliation: Oklahoma Department of Transportation
Telephone: (405) 521-2621
Fax: (405) 522-0364
E-mail: gjohnson@odot.org
Reference:

Oklahoma has been using GPS equipment for 5 years and is purchasing additional units.

- The Survey Division of the Oklahoma Department of Transportation (ODOT) has 14 location survey crews using GPS for project engineering.
- The Construction Division is investigating the use of GPS.
- The Traffic Division purchased 80 hand-held units to help locate control boxes at intersection and other traffic facilities.
- The Railway Division uses GPS to locate all highway/rail intersections and are now locating off-system intersections.
- The Department of Public Safety (Highway Patrol) uses GPS in their cruisers.
- The four largest cities in Oklahoma – Oklahoma City, Tulsa, Lawton, and MacAlester – use GPS.
- Nearly all land surveyors in private practice in Oklahoma use GPS.

On the National Oceanic and Atmospheric Administration (NOAA) and NGS websites, you will find an Oklahoma tower map.

OREGON

Contact:
Title:
Affiliation:
Telephone:
Fax:
E-mail:
Reference:

The users of GPS in Oregon are as varied and comprehensive as in most States. Users include members of State and local governments, as well as the private sector. Search and Rescue (S&R) personnel are using GPS and the State Police are using GPS and GIS to develop a rural emergency 911 addressing system. Many individuals in Oregon are using GPS for personal recreational navigation when hiking, boating, or flying, and have come to depend on GPS signals.

SOUTH DAKOTA

Contact: Allen, Greg
Title: Analyst
Affiliation: South Dakota Department of Transportation
Telephone: (605) 773-6645
Fax: (605) 773-4870
E-mail:
Reference:

South Dakota is one of the few States that are pioneering statewide integration of GPS/GIS. Currently, there are several activities relying on GPS/GIS in South Dakota, including:

- The South Dakota Department of Transportation (SDDOT) Road Mapping Project – Started in 1995 to record actual mileage for all of the roads in the State and to produce updated county highway maps. GPS units were used to record the actual location of roads, as well as surface type, width, condition, number of lanes, speed limit, and other information used by SDDOT. The units were also used to collect point features, such as bridges, mile reference markers, power substations, and other relevant data. The use of GPS/GIS technology makes collection of information quicker and more accurate than ever before and it gives the State and local governments something they never had – a geographically referenced roadmap layer that can be used in conjunction with other layers created by other entities. The State's entire road system should be in a GIS format (based on GPS) within 3 years. A post-processing technique is being used.

- Emergency 911 System – Employs GPS/GIS technology to identify the location of structures, vehicle routing, and associated data for emergency responders. The goal is to collect GPS data points and integrate them with GIS maps for all counties statewide. Some of the planning districts are using GPS and GIS to address rural counties using SDDOT data. This is important for emergency 911 systems and emergency management.

- Property Data Management – The goal is to better manage private property since the city staff believes that Yankton was losing thousands of dollars each year in missed special assessments because manual methods of calculating property taxation were inefficient.

- Rural Water System Data Management – The Bon Homme-Yankton (B-Y) Water District serves a five-county area and gets its water from the Missouri River. The district serves a 9323-km^2 (3,600-mi^2) area and manages more than 4184 km (2,600 mi) of pipeline and 19 reservoirs. South Dakota and many of the western States have a semi-arid climate. The availability of quality water is a limiting factor for livestock raising and other rural development activities. The B-Y Water District needed to compile a comprehensive database for all of its project areas and facilities to better manage its infrastructure. It needed accessible information on pipeline characteristics, pumping and storage capabilities, and general repair activities. This is where GPS/GIS comes IN to solve this problem quickly, accurately, and efficiently.

- Land Use Planning – Some of the districts have used GPS data for planning and zoning purposes.

Several other State agencies are using or planning to use GPS and GIS with different applications. In the Sioux Falls area, the South Eastern Council of Governments (SECOG) has completed the data-gathering phase for their survey of all highway attributes in six southern South Dakota counties. They have begun production of GIS products from the GPS data and plan to complete the GIS production process later this year (1998). SECOG is using some of the GPS data to develop comprehensive plan information for comprehensive planning in small communities. In addition, SECOG has been involved in rural addressing for their region. Other users of GPS data, including the Sioux Falls Airport Authority and local tracking and delivery services, exist in Sioux Falls.

TENNESSEE

Contact: Tolar, Ben
Title:
Affiliation: Tennessee Department of Transportation
Telephone: (615) 741-3406
Fax: (615) 532-0353
E-mail:
Reference:

The Tennessee Department of Transportation (TDOT) began research and development activities for the utilization of GPS technology for mapping and GIS in 1987. The initial project was to develop and equip two vans with data-collection capabilities. In 1990, TDOT completed the collection of 21,726 km (13,500 mi) of highway centerline data with an embedded link to TDOT's Tennessee Roadway Information Management System (TRIMS). The data was not of sufficient quality for use in mapping and GIS at scales of 1:63,360 or larger. Typical use was on a smaller scale of 1:253,440. With this quality issue came a need for data that was differentially corrected and smoothed to eliminate the errors that sometimes occur with the collection of GPS data.

In 1994, TDOT began a new research project to develop and refine the process of field data collection and utilize other technology solutions along with GPS. This research and development has provided a GPS inventory van that brings GPS data, gyroscope data, and barometric altimeter data together to provide the best solution for the highway alignment data, while maintaining linkage to the TRIMS Linear Reference System (LRS) identification number. The solution also provides valuable elevation and slope data for the highways.

TDOT collected data for approximately 32,186 km (20,000 mi) of State highways and local collector highways. The plan is to collect the remaining data (approximately 24,140 km [15,000 mi]) for this class of highway and then to proceed to collect the data for all local roads. There are 136,791 km (85,000 mi) of highways and roads in Tennessee. The plan is to collect data for all these highways and roads and load the data into GIS.

The collected GPS data is given the LRS identification number for GIS as the data-collection process is performed. The data is corrected differentially in real time. The gyro and altimeter data are incorporated into the processing to fill time-loss gaps and smooth alignment when GPS data alone provides an unacceptable solution.

Once all post-processing tasks have been completed, ensuring an exact tie-in for all intersections and at county boundaries, the data is batch-loaded into the GIS. The data is then incorporated into the GIS database using a GIS tool for processing and maintaining coordinate data for the spatial network. The final process is the creation of a State coordinate file for all the highways. This coordinate file provides the unique and basic requirement for TDOT – a GIS with dynamic segmentation capabilities.

The application of this technology to the creation of a GIS database for transportation would not have been possible without the support of FHWA through the research program. The expansion of the Research and Technology Transfer Program would be helpful, as these new technologies become more applicable in the civilian sector. Several utility companies and cooperatives throughout Tennessee are utilizing GPS as a tool for locating infrastructure assets. Some use the centerline data files created by TDOT as the base map for these systems.

TEXAS

Contact: Schroeder, Gene
Title:
Affiliation: Texas Department of Transportation
Telephone: (512) 416-3309
Fax:
E-mail:
Reference:

Texas has initiated a statewide GPS/GIS effort. In 1994, there were several State agencies using GPS to gather GIS locational data and perform surveying tasks. The Texas Department of Transportation (TxDOT) has the largest inventory of GPS equipment and is the most experienced user with more than 10 years of GPS experience. TxDOT operates a network of base stations strategically located around the State to provide post-processing differential correction for their applications. Differential correction data from the base stations is available to other State and local government agencies and the public for use in correcting GPS positions. Texas, recognizing the importance of GPS technology and its augmentations, planned to develop its own low-frequency beacons to cover the entire State. However, the frequency requested is protected since the primary user is the USCG.

Other State and local government agencies using GPS include:

- Texas Parks and Wildlife Department.
- Railroad Commission of Texas.
- Texas Natural Resources Conservation Commission.
- Texas Water Development Board.
- Various university departments, such as the University of Texas Bureau of Economic Geology.

These agencies are using GPS receivers to collect position data for their GIS databases.

GPS applications include verifying and obtaining the location of the following:

- Oil and gas wells.
- Public drinking water resources.
- Hazardous waste facilities.
- Hydrographic surveying sites.
- Sampling sites for geologic and hydrologic studies.
- Sampling sites for use in classifying imagery.
- Ground control for aerial photographs.
- Endangered species habitats.
- Water sources for wildlife.

UTAH

Contact: Glazier, Chris
Title:
Affiliation: Utah Department of Transportation
Telephone: (801) 965-4381
Fax:
E-mail:
Reference:

The Utah Department of Transportation (UDOT) is taking an active role in investigating and utilizing GPS technology in various transportation applications. Set forth below is a description of several of these efforts:

- UDOT is conducting a research study on the time-savings and usefulness of survey-level GPS data collection. Initial layout of projects may be accomplished more rapidly and with fewer personnel using GPS data-collection equipment. This project is funded at less than $60,000 and should be completed in 12 months.

- UDOT is contracting with InGeo for GPS data-collection services in Region 1 for 37 maintenance feature items. InGeo provides sub-meter accuracy for the location of maintenance feature items. InGeo has previously completed a sign inventory/management project that provides work-order-driven updates, remote database access, geographic displays, and queries on inventory items. This project is funded at $200,000 in multiple phases.

- UDOT is collecting GPS coordinates in the Mandli Corp. Photolog Van. GPS tracks seven satellites with gyro override. No post-processing is performed. Photolog images are scheduled to be transferred to the Redundant Array of Independent Disks (RAID) from analog laser disk over the next 3 years. Images transferred to RAID can be accessed in GIS for display on the network by either route/milepoint or latitude/longitude. The funding requested is $390,000.

- UDOT is tracking snowplow operations in Regions 1 and 2 using GPS transponders in real time. The data is to be used in snowplow route optimization in conjunction with National Weather Service and UDOT Remote Weather Information site prediction of storm intensity and direction. The data collected to date has been of marginal value. The lack of experience of what data is required and how data is to be collected has slowed progress on this project. Funding continues to be less than $20,000.

- UDOT is mapping pavement condition data, safety data, accident data, and traffic data by linear referencing systems located by GIS dynamic segmentation. GPS location has been proposed as a solution to linear referencing problems. GPS data collection in this area requires only 10- to 20-m accuracy for evaluation of condition and accident analysis. Vehicles are currently being outfitted with GPS receivers. The funding for this project is ongoing and as needed or approved.

- UDOT is collecting GPS data for stockpiles (salt, gravel, sand, etc.), as well as maintenance shed locations in an anticipation of re-allocation of manpower and equipment resources. Work continues in unfunded categories.

Other GPS uses within UDOT include connecting several GPS units to laptop computers for data collection to be used in traffic congestion management and travel delay. Data is directly input into modeling programs. Speeds are recorded and used in Urban Air Shed Models. Salt Lake Valley has now been classified as an Air Quality Maintenance Area, but the Utah Valley Area remains in a non-attainment classification for air quality. Additional GPS data collection may help modelers anticipate congestion and provide alternatives. This work continues unfunded as tests continue on various manufacturers' equipment.

VERMONT

Contact: Martin, Daniel J.
Title: Geodetic Program Supervisor
Affiliation: Vermont Agency of Transportation
Telephone: (802) 825-2813
Fax:
E-mail: dan.martin@state.vt.us
Reference:

Historic Overview

The Vermont Agency of Transportation (VAOT), in cooperation with the National Geodetic Survey (NGS), established the Vermont High-Accuracy Reference Network (HARN) in 1992. This network was established to be the reference for all future GPS work within the State. Since that time, a Geodetic Survey office was formed within VAOT (VTGS) and an additional 800 GPS points have been established. By this time next year, there will be more than 1,000 GPS points in the State. All geodetic information has been made available in GIS.

These points have served to control orthophotography base mapping of the State and VAOT highway projects. It is the policy of VAOT to tie all highway projects to the Vermont State Plane Coordinate System.

In 1993, a GPS base station was established and has since been incorporated into the Federal Continuously Operating Reference System (CORS) network. The Vermont CORS is used by VAOT as additional control for projects. The CORS data is made available via the Internet, and is accessed by federal, State, local, and private groups to control their GPS surveys.

To date, the vast majority of GPS work done by VAOT has been in the static and rapid static environment, since the primary goal was to densify the State with precise, permanent monumentation. However, some work has been done using resource-grade methods for the purpose of wetland mapping and road centerline location.

A real-time DGPS system was added to the videolog van with the intent of capturing geographic positions on the video frames. Currently, the only differential signal available in Vermont comes from a Canadian Coast Guard Beacon, and only serves the northern part of Vermont. It is our hope that the Nationwide Differential GPS system (NDGPS) will provide full differential coverage in the near future.

The VTGS office has been working cooperatively with the NGS in the area of GPS-derived heights. The eventual intent will be to replace conventional geodetic leveling activities with the more cost-effective GPS methodology. So far, the results of the studies have been very encouraging.

State and Local Government Surface Transportation

GPS was used by a consultant in the data-collection phase for Vermont's emergency 911 system. Under an agreement with the E-911 Board, the VTGS will collect the centerlines of new roads to be

added to the E-911 database.

The Regional Planning Commissions in Vermont use resource-grade GPS in their data-collection activities. This consists of wetland location, bridge location, and preliminary area surveys to name a few.

The VTGS uses GPS to establish horizontal and vertical control to support VAOT highway projects and the Vermont Mapping Program's digital orthophotography program. They also use resource-grade GPS to navigate to existing geodetic control marks and to update the positions of NGS benchmarks.

The VAOT Traffic Research Unit logs real-time DGPS into its videolog product. Future applications of this product would be to incorporate the videolog in a GIS. Another application that is being talked about is to use the GPS positions collected during videologging to produce grade and profile information that would be included on the route logs.

There are currently no GPS activities in the ITS area. ITS is currently in the development stage in Vermont.

The Vermont Agency of Natural Resources has been investigating the use of DGPS in its electric car program. The idea is to use the position information to correlate energy use of their electric vehicle based on road grade.

Transportation Benefits

GPS has enabled the Agency to cost-effectively tie all projects to the Vermont State Plane Coordinate System. Having all projects tied to a common reference system has allowed the agency to reuse information collected for one project for any other project. This reduces the amount of field surveying needed when one project overlaps another.

The use of GPS has been instrumental in the collection of GIS data. Currently, the State's GIS is at the point where it will start to incorporate different types of data. In the process, data-collection standards will be drafted, and the use of GPS will probably be part of the process.

The future benefits from the mobile DGPS system for the videolog van are many. Once the data is made available, it can be used for a multitude of purposes. Possible applications already being discussed are sign inventory, guardrail inventory, grade and profile, and bridge location. The possibilities are practically endless.

The future availability of statewide DGPS through the NDGPS, and the second and third civil frequencies, will be tremendously beneficial to the State as the need for post-processing of resource-grade data becomes a non-issue. We believe this will prompt more groups to collect data using GPS. This, in turn, will make people's data more compatible and aid in the population of GIS databases.

FHWA Involvement

FHWA's primary involvement should be the implementation of the DGPS infrastructure and the second and third civil frequencies. FHWA should also continue to be involved in ITS and the promotion of the use of GPS in transportation projects, initiatives, and research.

VIRGINIA

Contact: Rao, Murali
Title:
Affiliation: Virginia Department of Transportation
Telephone: (804) 786-9702
Fax:
E-mail: rao_murali@vdot.state.va.us
Reference:

The Virginia Department of Transportation (VDOT) is using DGPS and GIS to inventory the State's highway structures (e.g., cantilever signs, bridge-mounted signs, high-mast lights, and several other structures). VDOT will use the database for maintenance and repair purposes. The sources of the DGPS signal used by VDOT are:

- USCG DGPS radio-beacon reference station east of I-95.
- VDOT-owned base station in Richmond.
- VDOT-owned base station in Fairfax County.
- Trimble vendor in Charlottesville.

VDOT is tentatively planning to erect a base station on 4 to 5 hectares (10 to 12 acres) of land near Lynchburg or Roanoke. VDOT has a goal to provide DGPS coverage for the entire State.

Other uses of GPS/DGPS include:

- Tracking hazardous waste (vehicles and sites).
- Mapping wetland boundaries.
- Automatic Vehicle Location (AVL) for snowplows.

Virginia highway officials are experimenting with a device that will aid in tracking which roads have been cleared during traffic-strangling snowstorms. This winter, VDOT has equipped 80 snowplows in northern Virginia with the satellite navigation technology known as GPS. The GPS-based system will tell highway supervisors in Fairfax County the location of the snowplows down to which lane of traffic they are in and whether they are plowing, spreading salt or chemicals, or not operating. If the GPS-based system works as expected, VDOT workers will be able to report which roadways have been plowed, which are closed, and how long it will be before a road is cleared.

The Maintenance Division of VDOT is in the preliminary planning stage of starting an Integrated Maintenance Management Program (IMMP). IMMP consists of several systems: the Inventory and Condition Assessment System, Pavement Management System, Bridge Management System, and

Integrated Maintenance Management System. The goal of this program is to inventory all maintainable assets that are managed by VDOT's maintenance program.

WASHINGTON

Contact: Iverson, Kurt
Title: Survey Supervisor
Affiliation: Washington State Department of Transportation
Telephone: (360) 709-5532
Fax: (360) 709-5599
E-mail: iversok@wsdot.wa.gov
Reference:

Background and Historical Use of GPS in Washington State

The Washington State Department of Transportation (WSDOT) has been using the Global Positioning System (GPS) since 1985 in conjunction with conventional surveying and coordinate geometry techniques for the purpose of controlling various maps for right-of-way, record of monumentation, alignments for design and construction, and Geographic Information Systems (GIS).

During the past 10 years, the use of GPS technologies within WSDOT has been limited to the Survey Section of Geographic Services. The exceptions during this period have been the use of GPS (Trimble Pro SL receivers) by the Environmental Affairs Office and the Transportation Data Office. Also, centimeter-level real-time kinematic (RTK) GPS topographic surveys are ongoing in the Eastern Region near Spokane. Recently, the South Central Region, based in Yakima, purchased four Leica survey-grade receivers for controlling design projects. At this time, the demand to obtain GPS technology and skills is increasing on the regional and headquarters levels. This interest has been fueled by reductions in the per unit cost of GPS receivers at all degrees of positional accuracy and an expanded knowledge base of applications/techniques that provide geospatial data at cost reductions that far exceed any traditional positioning methods. Under the current de facto implementation of GPS in WSDOT, the sole source of geodetic, mark maintenance, and photogrammetric-quality surveys (accuracy in centimeters) is limited to the cost-recovery activities of the Geographic Services Survey Section.

The Transportation Data Office (TDO) has purchased two GPS receivers for videologging and geospatial attribute data collection (roadside hazard). The Data Office use of GPS is at the Resources Mapping-level accuracy (sub-meter to 5 m). The data collected is most often post-processed; however, real-time GPS applications utilize CORS and OmniStar systems. The Environmental Affairs Office is using similar equipment for the inventorying of wetlands and other environmental features. As the use of GIS becomes more prevalent within the department, the proliferation of GPS receivers involved in GIS data collection will probably exceed, numerically, the units employed for geodetic and construction surveying applications.

The first GPS survey of significance in Washington State was performed by the National Geodetic Survey (NGS) in 1985. The work was performed under contract by WSDOT's Photogrammetric Branch (renamed Geographic Services). Over the years, GPS users realized that the published values of the National Geodetic Reference System (1:100,000) were not of sufficient accuracy to accommodate the high level of precision inherent within the GPS system. A GPS Users Group was formed in 1988 (spearheaded by NGS Advisor Dennis Wegenast) to address the feasibility of a

Washington State High-Precision Geodetic Network (HPGN) that would upgrade and readjust coordinates of the geodetic control stations representing the North American Datum of 1983 (NAD83). In 1990, an Order B survey (1:1,000,000) was performed with GPS by the NGS and was funded by a coalition of State and federal agencies, cities, counties, and other private entities. Very-Long Baseline Interferometry (VLBI) was included in the survey for the purpose of global reference. The acronym HPGN then evolved into High-Accuracy Reference Networks (HARN), which is currently divided into Federal Base Networks (FBN) and Cooperative Base Networks (CBN).

Upgrades to the Washington State HARN were performed in 1998 as data from Continuously Operating Reference Stations (CORS) provided improved ellipsoid height determination. Four CORS sites – at Fort Stevens on the mouth of the Columbia River, Appleton at the east end of Columbia River Gorge, Point Robertson on Vashon Island, and the Naval Air Station on Whidbey Island – were used as base fiducial stations as Order A (1:10,000,000) GPS surveys were performed on FBN stations and Order B (1:1,000,000) GPS surveys were performed on CBN stations.

Because of the increased number of GPS users and the appeal of the increased accuracy of ellipsoid heights, the Washington State GPS Users Group supported the re-observation effort by again putting together a coalition of State and federal agencies, cities, counties, and various public and private entities to assist the NGS in the HARN re-observation. Cooperative efforts in the 1998 HARN survey were directed by NGS Advisor Gary Perasso. Trimble geodetic-quality, dual-frequency GPS equipment was used exclusively throughout all groups for all observations. As the re-observed HARN station values become available, the Geographic Services Survey Section will readjust WSDOT coordinates accordingly.

Geographic Services Survey Section

The WSDOT Geographic Services Branch is managed by a team consisting of one supervisor each from the aerial photography, photogrammetry, cartography, geographic information systems, and survey sections.

The Geodetic Survey Section's Mission Is:

To provide geodetic primary control throughout the State as required for WSDOT projects and to act as a resource center to the public for geodetic information. The purpose is to achieve monumentation of Washington's highways by ensuring that the department's survey procedures: (1) preserve and perpetuate previously established monuments and (2) contribute to the body of public records (eliminate duplication of survey work) by establishing monuments and recording monuments that are tied to a State plane and to a standard vertical datum.

The Geodetic Survey Section's Vision Is:

To utilize the latest technology to maintain the Washington State High-Accuracy Reference Network, the densification of primary control from it, and to help ensure that all divisions throughout WSDOT are trained and equipped to fully utilize geodetic products in the interest of increasing quality and efficiency.

The Geodetic Survey Section's Values Are:

To maintain the highest standard of accuracy and precision possible, meeting requirements based on the long-term needs of the department and its customers.

The section is the only unit within WSDOT that provides primary geodetic surveys. The group is also the only unit within the State with the expertise and equipment to maintain the Washington HARN, the geodetic framework for the State-legislated horizontal datum of NAD83/91 and the federally mandated vertical datum of NAVD 88.

The geodetic field crew operates 10 Trimble 4000 SSi GPS receivers with real-time kinematic (RTK) capability. All projects originate from the Washington HARN. Concrete monumentation is used as a standard for all primary control. Data reduction is accomplished on Pentium workstations and the output is backed up on magnetic and hardcopy media. In addition to GPS information, the in-house database consists of second- and third-order barcode leveling, as well as benchmark resets. All field work is done to Federal Geodetic Control Subcommittee (FGCS) specifications and classified as to National Spatial Data Infrastructure (NSDI) standards. The database is available via Internet at www.wsdot.wa.gov/monument.

The Geodetic Survey section is currently involved with three important programs: Highway Monument Surveying, Primary Control Monument Program, and the Datum Point Adjustment and Archival Program.

Highway Monument Surveying Program

The objective of the Highway Monument Surveying Program is to help maintain the monumentation of the geometric framework that is used for the planning, design, and construction of surveys by re-establishing and updating existing and establishing new primary control (including HARN stations and federal benchmarks).

Accomplishments of the 1997-1999 Biennium:

- Formed a partnership with the National Geodetic Survey to re-observe 120 geodetic control stations that consist of the Federal Base Network, a part of the National Spatial Reference System.

- Conducted research, inventorying, and verification of primary survey control for the purpose of building a database as the spatial framework for the department's Geographic Information System. More than 1,000 monuments were physically searched for, recovered, and updated or listed as destroyed.

- In addition to conducting several horizontal and vertical control surveys to upgrade geodetic networks where large distortions previously existed, six National Geodetic Survey Vertical Control elevation benchmarks were re-established.

Primary Control Monument Program

The objective of the Primary Control Monument Program is to implement a procedure that replaces a project-by-project data-collection system with a more cost-effective systematic approach for supplying geodetic control along Washington's highways.

Datum point development is now based on a prioritization process using the "Plan for Highways of Statewide Significance" and 2-, 6-, and 20-year plans. Increased quality and savings are gained as protracted lengths of highways are densified as one project rather than a series of smaller projects. Technically, large survey network adjustments are superior to that of forcing the adjustment of a succession of previously unconnected small projects. It is estimated that the department can increase the number of datum points by 35 percent if datum point information is collected on a planned, sequential basis.

The Primary Control Monument Program has been a valuable asset to WSDOT and its customers as it provides the basic framework for the environmental mapping of salmon habitat rehabilitation; noise wall/air quality; wetland land bank; and the design, construction, right-of-way delineation, geographic information, and maintenance inventory of infrastructure.

Since July 1999, Geographic Services prioritized GPS geodetic projects networking all of Spokane, Pend Oreille, and Stevens Counties, as well as large segments of Kitsap, Grays Harbor, Pacific, Thurston, and Pierce Counties. These projects, which have produced some 218 Order C monuments, were scheduled and surveyed in advance of engineering for environment, design, and construction. The spacing and density of control lends itself to serve as targeted mapping control for photogrammetric reconnaissance missions, as well as for secondary surveys supporting land surveys and construction. All of the data output is available to the public and private sectors via the Geographic Services Monument Database on the Internet.

As related to WSDOT's Strategic Plan, the Primary Control Monument Program:

- Further enhances public confidence by improving an already popular survey datum point and database program. Currently, 50 percent of the users will be experiencing an estimated 35-percent increase in the number of needed and available datum points.

- Redefines roles and responsibilities as resources are transferred to more effectively meet State transportation needs. Also, pursues technical excellence by utilizing large network adjustments that are superior to that of a succession of previously unconnected small projects.

- Enhances stability throughout the biennium, rather than a highly fluctuating and stressful work environment, and ensures the success of a diverse core workforce capable of responding to peak needs.

- Maximizes the use of existing funds by emphasizing efficiency though better planning.

Datum Point Adjustment and Archival Program

Scientific and technical advancements have prompted the National Oceanic and Atmospheric Administration (NOAA) to upgrade the coordinates and heights of the federal reference system WSDOT employs to provide primary datum point information for highway construction projects and resource management.

In the interest of maintaining consistency with State law (RCW 58.20, WAC 332-130), federal regulation, and departmental standards, the Geographic Services Survey section must utilize current reference systems upgrades when surveying for new construction projects. As a result, a total of 700 survey projects, consisting of 4,000 WSDOT primary datum points, will need readjustment on an individual basis in order to satisfy legal requirements. Development of a GPS Vector Information Database will eliminate the need to readjust individual projects for this purpose in the future.

As related to the WSDOT's Strategic Plan, the Datum Point Adjustment and Archival Program:

- Best serves the public's interest by using a visionary and innovative method to solve an ethical and legal engineering problem. Agency accountability is improved by the ability to efficiently comply with the requirements of RCW 58.20 and WAC 332-130.

- Further enhances public confidence as legal responsibilities are addressed and expertise or resources move swiftly to meet State transportation needs.

- Emphasizes efficiency, resulting in future cost-avoidance, while maximizing the use of existing funds. Anticipated periodic changes in the federal reference system will be manipulated 83 percent more efficiently with this improvement.

Utilizing GPS for Geophysical Studies in the Pacific Northwest

The landscape of the Pacific Northwest is shaped by the processes of plate subduction, uplift of the Cascade Range, Columbia River Plateau volcanism, and Columbia Basin and Cascade Range faulting. Although these processes operate at slow rates, building obvious structures only over geological time, modern surveying methods utilizing GPS satellites may discern deformation due to these processes in just a few years. With the goal of measuring millimeter-scale displacements within the Pacific Northwest region, there is a collaborative project known as the Pacific Northwest Geodetic Array (PANGA). This team has deployed an extensive network of GPS tracking sites that are measuring tectonic activity in the region.

The need for a permanent GPS array in this region has long been recognized. Geodetic results from 12 new permanent GPS sites installed as part of the array are being integrated with existing sites and analyzed at Central Washington University (CWU) using software tools developed by the Jet Propulsion Laboratory (JPL) and the National Aeronautics and Space Administration (NASA).

Geodetic and geologic results from CWU will be used to constrain two-dimensional kinematic modeling and three-dimensional geodynamic modeling of the western United States. A data

analysis facility developed at CWU will reduce and distribute on-line and CD-ROM geodetic data products to the geophysical community.

Diverse sources are supporting installation and operation of the GPS network. Funding for six or more CWU receivers and five University of Washington (UW) receivers is currently in hand as part of a recent National Science Foundation (NSF) initiative to disseminate GPS technology in an assortment of related networks that monitor Pacific Rim tectonic processes on a greatly improved scale and spatial resolution. Most of the receivers will be used in permanent sites, but at least one from each university will be put into a monthly rotation using a campaign strategy called Multimodal Occupation Strategy (MOST).

CWU, the University of Washington, and the U.S. Geological Survey (USGS) will maintain the network over the life of the current proposal. The USGS is developing support for long-term network maintenance, with CWU committing to permanent technical data analysis beyond the current proposal.

All monuments are drilled, braced, and deeply anchored. The monument consists of a vertical, schedule 80 galvanized pipe mounted in non-shrink grout in a 114-mm- (4.5-in-) diameter hole drilled to approximately 12 m (40 ft) deep, laterally stabilized by four additional rods welded to the top of the monument, each anchored to a minimum depth of 12 m (40 ft) in 114-mm- (4.5-in-) diameter holes. Each anchor hole will be cased in the upper 3.7 to 4.3 m (12 to 14 ft), with 63.5-mm- (2.5-in-) diameter schedule 80 polyvinyl chloride (PVC) wrapped with 19.1-mm- (¾-in-) thick refrigeration foam protected by layers of strapping and duct tape.

The GPS instrumentation used are Trimble 4000 SSi receivers with choke-ring antennas mounted on stainless steel recoverable plates modified by JPL and Scripps. Plexiglas radomes are geometrically centered on the phase center of the antenna, while the antenna cables are buried and encased in liqutite conduit or as liqutite armored cable. The conduit and cable connections are protected by encapsulated shrink tubing.

All of the sites have secure and covered facilities. The enclosures contain the Trimble receiver, a U.S. Robotics 56-kbps modem, Trimble Office Support Module (OSM), and heavy-duty surge protectors.

Operating Institutions of PANGA are:

- Department of Geology, Central Washington University.
- Pacific University Geoscience Center, Geological Survey of Canada.
- College of Atmospheric and Oceanic Sciences, Oregon State University.
- Cascade Volcano Observatory, U.S. Geological Survey.
- Geophysics Program, University of Washington.

Collaborating or Participating Institutions:

- University of Alaska, Fairbanks.
- Department of Geology and Geological Engineering, University of Idaho.
- Department of Geological Sciences, University of Oregon.
- University of Navstar Consortium.

Supporting Programs:

- Department of Natural Resources, Canada.
- National Earthquake Hazards Reduction Program, U.S. Geological Survey.
- National Science Foundation.

Other Public and Private Entities

Other State agencies using GPS for surveying purposes include the Department of Natural Resources, the Department of Ecology, and the Department of Fish and Wildlife. The primary uses of survey-grade GPS at the Departments of Natural Resources and Fish and Wildlife are cadastral-related. These two agencies are heavily involved in conducting boundary surveys of public lands. GIS applications are heavily supported by GPS throughout the State government.

The Department of Ecology has recently completed a joint GPS project with the U.S. Geological Survey (USGS). The purpose of the survey, which included a 129-km (80-mi) geodetic network along the Pacific Coast, was to monitor the increasing problem of beach erosion. Geographic Services was instrumental in designing the network that implemented the NGS Height Modernization Program procedures for 2-cm accuracy for ellipsoid heights. The monuments along the shoreline were set at approximately 3.2- to 6.4-km (2- to 4-mi) intervals and were designed to act as fiducial marks for real-time kinematic GPS operation to profile tidal zones and nearby uplands.

In addition to these State agencies, federal users such as the U.S. Forest Service, Bureau of Land Management, and Bonneville Power Administration actively use GPS for land surveying purposes. City and county organizations are also actively involved in utilizing GPS to tie local cadastral systems to the National Spatial Reference Network for GIS purposes.

The private sector surveying and engineering firms utilize GPS survey- and resource-grade receivers for a multitude of applications ranging from geodetic surveys to inventory surveys.

The proliferation of GPS receivers involved in GIS data collection (sub-meter resource grade) exceeds the number of units employed for geodetic, land boundary, and construction surveying applications. The ability to efficiently collect spatial information on GIS-related features has been the driving force behind

every GIS/spatial product. With the advent of CORS stations in Washington State, the use of real-time kinematic applications has risen sharply.

Conclusion

The use of GPS in Washington State began early (1985) when GPS technology development was in its infancy. Washington State was one of the first half-dozen States to form a GPS Users Group under the guidance of the National Geodetic Survey Advisor Program and to produce a High-Precision Geodetic Network. Today, the use of GPS in Washington State is commonplace.

The challenge GPS users face today is not how to utilize the technology or how to process the data, but rather how to maintain a system of datum references and data bank systems in which to store GPS information. The 1998 NGS/HARN re-observation project and the high number of volunteers are great examples of how important increasing the accuracy of three-dimensional geodetic references has become. The advent of the CORS stations has played a significant role in developing increased accuracy, especially in ellipsoid height determination – a key to the height modernization process. CORS's ability to provide DGPS real-time signals is instrumental in the development of many GIS mapping applications. These benefits are, of course, in addition to the original intent of providing a navigation service.

As the number of CORS stations increases, the number of applications will also increase. Until the recent addition of a CORS site in Appleton, the eastern half of Washington State had no provision for real-time applications, which negatively impacted many GIS operations severely. The further addition of CORS stations at proposed sites in Spokane and Wenatchee will be welcomed by almost all GPS users in Washington State.

WISCONSIN

Contact: Haverberg, John
Title: P.E. / Director, Bureau of Highway Development
Affiliation:
Telephone: (608) 266-0075
Fax: (608) 267-1862
E-mail:
Reference:

The Wisconsin Department of Transportation (WisDOT) first became aware of GPS as a possible location tool in 1983 through involvement with national organizations. WisDOT started contracting for GPS geodetic surveying horizontal location services in 1985 and also rented some equipment for use by its staff. In Spring 1989, WisDOT purchased five geodetic-quality GPS receivers. In 1991, Wisconsin completed the third State High-Accuracy Reference Network (HARN) in the country using GPS consultant services for horizontal point locations for 100 stations. WisDOT continued to upgrade its geodetic-quality receivers and surveying procedures to provide horizontal control for projects. In addition, WisDOT has been providing some counties with technical assistance toward densifying the HARN. WisDOT has purchased some limited numbers of non-geodetic GPS receivers, which are used to obtain non-precise locations of objects for GIS applications. In Spring 1998, WisDOT purchased a set of real-time kinematic (RTK) GPS receivers and associated radios for each of the eight district offices, plus a spare set for development and loan to be used for recording topographic information. One RTK GPS receiver has been installed in aerial photography aircraft.

WisDOT utilizes GPS technology in several current and planned activities. Different projects require various levels of accuracy. Set forth below is a list of current applications that use GPS technology:

- Geodetic Surveying Quality (± a few centimeters):

  < Densifying the HARN.
  < Replacing destroyed HARN stations.
  < Surveying horizontal locations of photogrammetric targets.
  < Determining bridge pier relative movement.
  < Topographic field surveys.
  < Staking of right-of-way.

- Non-Geodetic Surveying Quality (sub-meter to several meters):

  < Location of salt storage sheds.
  < Roadway centerline location from photolog van.
  < GIS-level location of features such as wetland boundaries, well heads, etc.
  < Navigation of the aerial photography aircraft to fly predetermined flight lines and provide general locations of photograph centers.

- Near-Future Geodetic-Quality Applications:

- < Vertical location of benchmarks.
- < Vertical location of aerial targets.
- < Precise determination of aerial photograph centers, reducing the need for aerial target location.
- < Location of mobile laser ranging platforms for digital terrain model creation.
- < Accident site location information – both where it happened and in a reconstruction of what happened.

• Near-Future Non-Geodetic Applications:

- < Sign inventory location information.
- < Assistance in real estate negotiations.
- < Locations of pictures from hand-held ground-based cameras.
- < Photolog camera locations to be used for absolute location of points in photolog images.

• Other Surface Transportation Applications:

- < Milwaukee is using GPS to track its buses for safety and routing reasons.
- < The U.S. Coast Guard is using GPS on the Great Lakes bordering Wisconsin for ship navigation, especially at port sites.
- < The trucking industry is starting to use GPS to keep track of the location of its fleets.
- < Emergency vehicle routing, including 911 emergency call direction.

WYOMING

Contact: Clabaugh, Curtis
Title: PE / Photogrammetric and Surveys Engineer
Affiliation: Wyoming Transportation Department
Telephone: (307) 777-4086
Fax: (307) 777-3888
E-mail: cclaba@state.wy.us

The Wyoming Transportation Department (WYTD) has been involved with GPS for about 10 years. This involvement has been for positioning purposes and has been nearly exclusively the domain of the Photogrammetry and Surveys Section. The Photogrammetry and Surveys Section sets project control monuments with GPS; WYTD has to determine the geodetic coordinates and related datum adjustment factor for the design and construction work to be done on a common plane.

The WYTD work strategy is to use a localized coordinate system that is project-specific and closely emulates the project surface. WYTD traditionally ties project control to the State's HARN and tries to complete some type of HARN-quality densification work with each project due to the long interval spacing that currently exists.

Other uses of GPS have evolved from project control work. Through testing of equipment and procedures, WYTD found that this technology has proven to be very beneficial for the photographical control work required for the Photogrammetry Unit.

The other major benefit that has come from GPS is in the land-surveying activities. While WYTD does not perform much of the necessary cadastral surveying in-house, WYTD requires that its consultant surveyors tie their work to project control for incorporation into project mapping. The majority of these firms use GPS as the primary survey tool for this work.

Other activities and any use of GPS by others within WYTD have not yet taken hold. Due to the expertise we have, we are encouraging other to take advantage of the benefits of GPS. WYTD is currently working toward implementation activities in the GIS realm. We have encouraged some of the members of this group to look at spatial referencing rather than linear referencing.

As for other GPS activities, WYTD is an active participant in the Civil GPS Service Interface Committee (CGSIC) group and in working toward having two NDGPS sites established in the State for the benefits they will bring. Exposure and actual working applications will inherently lead to broader acceptance and use.