Highway Maintenance Goes High Tech: The GIS/GPS Link

In 1865, when the first steamboat approached Fort Benton in north-central Montana, waterways were a fast and economic way to transport goods and passengers. However, when the state paved its first road in 1923, that all changed, and today more than 16,453 miles of surfaced highway have been completed throughout Montana's mostly mountainous terrain.

Despite the advantages it offered, the roadway network had to be updated and maintained, unnecessary tasks when using a natural waterway. That responsibility was given to the Montana Department of Highways, which tracked the highways manually using U.S. Geological Survey quad maps as a base. These paper maps provide approximately 15 meters of accuracy for latitude and longitude.

"The maps are fine for an overall perspective of highway monitoring. However, highway features, such as road surface changes or passing zones, were never scaled to the maps at all because the agency doesn't have the time and personnel to detail maps to that level," explains Don Cromer, rural planning supervisor for the Montana Department of Highways. "We desperately need a system to create digital maps, with the potential for inventorying highway attributes."

Although many departments of transportation (DOTs) have tried to double up the duties of a computer-aided design (CAD) system for maintaining road data, these systems have inherent shortcomings. A CAD system relies on mathematical parameters to create graphic features. It has no way to manage geographic data with the topological features.

"Many of the DOTs that originally had automated mapping with CAD are now looking for add-on GIS programs to complete the inventorying tasks that have become so important," explains Cromer. "We had seen GIS demonstrated effectively in some DOTs and decided that it was the most practical solution for our needs. With that decision, we began seeking the most cost-effective method to build a reliable GIS database."

In January 1990, the Montana Department of Highways embarked on a pilot project in cooperation with GeoResearch, Inc. (Billings, Montana), to use geographic positioning system/geographic information system (GPS/GIS) technology combined in a system called GeoLink. The pilot project was to establish the costs, benefits, potentials, and limitations of the sophisticated technology.

GeoLink incorporates PCARC/INFO with Trimble Navigation's Pathfinder Navigation software, combined with GeoResearch GPS receiver. Combined with GeoResearch software, the system records positional attributes while creating digital maps. The GeoLink system records another attributes about each point, such as pavement type.

"We simply send a technician out in a car with a laptop computer and a GPS receiver to locate attributes such as bridges or speed limit signs on the highway. As the operator passes by the structure or point, he pushes a button on the receiver, and the information is recorded into the GIS at whatever scale we require."

"At the end of the day, we have produced a map of the highway with accurately georeferenced and internally time-stamped coordinate data for clear update histories. All of the attributes along the highway are organized and quickly available to us electronically through the GIS," says Cromer.

After the database is established, field technicians can see and track positions on an existing map while making updates, he says, eliminating data processing time.

According to Cromer, the pilot project highway inventory database was centered on 104 miles of highway in and around Billings. Approximately 25 attributes were selected to demonstrate benefits of the system, including restricted passing zones, road and railway intersections, surfacing changes, rock slide areas, irrigation or drainage controls, county lines, turning lanes, and major changes in the pavement width.

In the project's beginning, the department spent time developing a database design to test. The consequence was a well-integrated GIS database that identified all aspects of the highways, including location, construction, sign age, and structures relating to the highway within or affecting the right of way.

Montana's database is comprised of two basic layers: linear features, such as the roadway jurisdiction, route number, lanes, and guardrails; and point features, such as signs, beacons, junctions, drains, mileposts, irrigation structures, and intersections. This makes it easy for users to visualize characteristics of the road and enter and retrieve data.

Highways are represented by a series of line segments characterized by attributes, with each segment described by information in four principal categories—highway identification, lane structure, parallel structures, and surface. The attributes in the various fields are features of the highway which can be simultaneously present.

For instance, a particular stretch of highways can be identified by any number of attributes—jurisdiction, route number, presence of guardrails, slide areas, or whether the surface is graded. Point features are represented as points with attributes and are connected to linear features by reference to the road jurisdiction, route number, and mile number.

Each point feature is identified as to the type of feature, and then described by three descriptive fields—identification, type, and detail. Identification locates the feature within the network, such as jurisdiction or route number. The type..."
describes the type of feature, such as a speed limit sign. Detail lists specific information regarding the feature, such as an intersection description would include cross roads, direction of approach, and turning lanes.

“Our database structure allows for uniform treatment of a wide variety of features, future expansion of the system, and extraction of feature classes into subsidiary databases for specific analysis,” explains Cromer.

His department also noted that the dual structure of the GIS linear and point features does not limit the database. Queries with either one are handled with the same ease and accuracy.

With an established database design, the highway department was ready to begin applying the GIS/GPS link. “We began by having someone drive the designated route and record the attributes of the road with the GPS. We had predefined these attributes and assigned keys on the keyboard to each to reduce the necessary operator keystrokes. After some experimentation, we found we could pick up 15 attributes driving at 35 mph,” explains Cromer.

“As we drive the road, locating mileage markers, a highway map is being created. The technology has solved our requirements for position information and digital map data, and we can obtain all of the other highway features that we have never been able to efficiently track before,” explains Cromer.

When the GPS receiver records the position information, the data are run through a conversion program that allows the user to read the data into an ARC/INFO coverage. ARC/INFO consists of the ARC system, which stores the cartographic data, and INFO, the relational database, which becomes the information manager for attribute data. Subsequent queries to the database display a layer representing all bridges in the state, or in the city of Billings, for instance, whichever the user desires.

To obtain accuracies to within two to five meters, the Pathfinder receiver requires static reference points at known locations. The highway department is cooperating with federal agencies to develop high-precision control points at known locations. Therefore, they can play the remote file obtained while you were driving with the control point data to come out with a differentially corrected remote file. The control points essentially offset the errors created through satellite recording.

Cromer says that highway department officials have used the pilot project to answer formerly unanswerable inventory questions, such as inquiries on culvert inventories, as well as the more common federal requirements, such as bridge inventories. He adds that one of the potential tasks of the system might be to inventory no-passing zones. For years, no-passing zones have been designated by simply painting the highway. However, paint wears off, and a more practical and long-term solution will be to put signs up, he says.

With the automated GPS/GIS, maintenance personnel could quickly query the database within a certain highway length, display pertinent information, such as location, and develop a maintenance plan to efficiently place the signs in appropriate locations. “Not only can we develop efficient strategy, but because the system is PC based, maintenance personnel can log each task as it is completed at the time of completion. The addition of GIS makes the already sophisticated software of GIS mobile, allowing us to track work as it’s being done in the field,” says Cromer.

Another task for the new system might be maintaining highway mileage statistics. “We hope to further enhance the system in the future by possibly purchasing a department van that will gather data for not only highway monitoring, but at the same time allow our statistics department to track highway mileage, and our management department to track highway features. The bridge department could use the system to more efficiently determine the beginning and ending points of bridges and accurately record structural information for federal highway requirements or local highway needs.

“The accuracy alone is a big plus for the GPS. Now departments traditionally relying on temporary help in the summer to complete surveying tasks can complete the task with one or two people instead of an entire survey crew,” explains Cromer.

The department says the GPS/GIS gives them the most practical solutions to their highway maintenance inventorying problem. Cromer says, “GPS gives GIS that added extra that eliminates the once-tedious task of finding and digitizing up-to-date geographic data. Our only limitation will be the currently small satellite window of less than seven hours beginning in early evening. However, within the next year, that window will expand and cover our eight-hour work day.”

The highway department says that with the emphasis changing from building to maintaining highways, systems such as GeoLink are becoming the future of highway inventory programs—a long way from the days when the river’s depth or current determined how a transportation route could be traveled.

Understanding GPS

What do a man tracking the flight of a weather
balloon and the Bureau of Land Management have in common? They both need to know where they or their respective points of interest are or have been on earth.

That is what GPS was developed to do.

Technically, a GPS receiver locates a position by measuring the time required for a signal to travel from a satellite to the receiver. The travel time is then converted to a range measurement by multiplying it by the speed of light.

Using what is called satellite ranging, a receiver measures the distance from itself to each of several GPS satellites—with the precise satellite location known. To obtain location information such as latitude, longitude, and elevation, the receiver must track at least four satellites.

There are a variety of ways of making and using these measured distances, differing in accuracy and complexity. Arthur F. Lange, Ph.D., GPS/GIS marketing manager at Trimble Navigation, says that there are two basic groups of receivers with different tracking capabilities—those that can track four or more satellites simultaneously and ones that sequence between satellites. Each has specific applications and varies significantly in price, with simultaneous or parallel tracking being much more expensive.

Sequencing receivers vary from single-channel receivers to two-channel receivers. Single-channel receivers are portable and inexpensive, but they must read data from one satellite at a time, which decreases accuracy and limits them to static conditions, such as using the receiver while hiking. However, two-channel receivers, such as Pathfinder, provide all the capabilities of the single channel, plus they can monitor position data on one channel and acquire the next satellite on the other channel. Of course, accuracy and update capabilities vary among manufacturers.

A two-channel receiver is also ideal for dynamic situations, so it will work at up to 600 knots (particularly good airplane applications) and at 2 g's acceleration, with a 1-second update capability. Two-channel receivers such as this are designed to be high-performance, low-cost machines that provide for the broad band of applications that require reasonable accuracy in a brief amount of time. Naturally, a majority of the current users are in land resources management.

Some sequencing receivers are capable of obtaining more accuracy by applying differencing methods. By setting up known locations or base stations, a user can record information from the four satellites. Because it is a known location, position corrections can be relayed to the satellites, corrected, and used to eliminate or negate some of the satellite source errors. The user can then play that information with their remote file obtained while, for example, driving to come up with a differentially correct remote file.

Capabilities for differential accuracy vary with vendor software. Parallel tracking receivers are by far the most accurate system available to commercial industry. The availability of four or more channels and more sophisticated software allow the user to receive instantaneous position information accurate to within centimeters. Of course, the disadvantage to all of that accuracy is cost, approximately $40,000 compared with $10,000 for sequencing receivers.

Lange emphasizes the importance of the user understanding his or her own requirements in evaluating products on the market. He explains, "Before a customer can purchase the right type of GPS receiver, he must know how much accuracy he needs, the data format, how quick of a response he needs, and whether the system requires dynamic performance capabilities."

For example, one of the reasons GeoLink incorporates Pathfinder is so the system can be used in a moving vehicle. Lange says the receiver must have frequent update and position fix capabilities (Pathfinder outputs one position per second).

Accuracy of most sequencing receivers is about two to five meters when operated in the differential mode. Better accuracy, which might be needed in surveying applications, for instance, can be obtained with centimeter accuracy, but requires longer lengths of time and more expensive equipment.

Lange says, "Potential customers of GPSs should determine whether a receiver requires initial time and position data before calculating or if the receiver can establish the fix from a cold start. Other considerations should be adaptability to computers or instruments such as GIS."

Another important factor might be transportability. Although many receivers today are small and relatively lightweight, they are not all capable of running for an eight-hour day on one battery—important for applications in the field.

GPS receivers are available with a wide range of speed, accuracy, and purpose, and at a wide range of prices. Ranges go from approximately 100 meters for the simplest receiver to one centimeter for the most sophisticated.

The current satellite window for GPS varies depending on what time of day and where the receiver is located. The system or satellites is not scheduled to be fully operational (21 satellites total) until 1992, which limits how many satellites are within receiver range. However, two-dimensional information is currently available from three satellites—providing latitude, longitude, and time—for a large part of the 24 hours, and three-dimensional position data, which includes altitude, is available for a smaller portion of 24 hours, depending on where the user is located.

As the satellite window continues to increase, and with cost reductions due to competition and availability, more and more people will have the opportunity to realize the benefits of GPS—that's sure to include users from hikers to highway survey crews, Lange says.

For more information, contact GeoResearch at 406-248-6771.