ArcView Tracking Analyst: Complete Tracking Solutions

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An ESRI White Paper

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Introduction

ArcView® Tracking Analyst brings temporal capabilities to the ArcView GIS environment. Both new and existing applications can benefit greatly from these additions. Until now, ArcView GIS has been restricted to applications with data that only represented static time. This restriction has now been removed by the creation of a new, fully integrated theme type called a tracking theme. ArcView Tracking Analyst provides the capability for the visualization and analysis of time-related data by defining "geoevents" that consist of time, position, and attributes. In addition to a visual tracking presentation, ArcView Tracking Analyst software's temporal nature enables playback capabilities for research, trend analysis, and so forth.

ArcView Tracking Analyst extends temporal analysis capabilities with a variety of tools that allow users to track real-time positional data. For example, a city may monitor its snowplow fleet to check which streets have been plowed or salted based on real-time data received from vehicles in the field. The Tracking Analyst extension is not limited to monitoring automobiles; other possibilities include road and engine sensors; tracking trains, wildlife, and airplanes; and monitoring the status of traffic signals.

While ArcView Tracking Analyst is a powerful analysis tool, it does not provide a total solution for real-time tracking. Some method of gathering data, transmitting data, and importing data is required. This document is designed to aid the reader in developing a complete solution built around ArcView Tracking Analyst. This paper will familiarize the reader with an overview of the various components of a complete solution from sensor/receivers through the variety of options of communications through the ArcView Tracking Analyst software. In addition, this paper will provide examples of some of the more popular tracking applications. Finally, tips have been included that will guide the user in developing a complex tracking solution.

Tracking Solution Technology Overview

Enabling Technology

The ability to track items, whether real-time or with static updates, has long been hampered by the lack of sufficient communications and sensor technology. However, the recent advent of multiple layered communication strategies using advanced cellular and satellites has enabled the creation of worldwide real-time tracking applications. Sensor technology has also dramatically increased in capability while decreasing in size—thus

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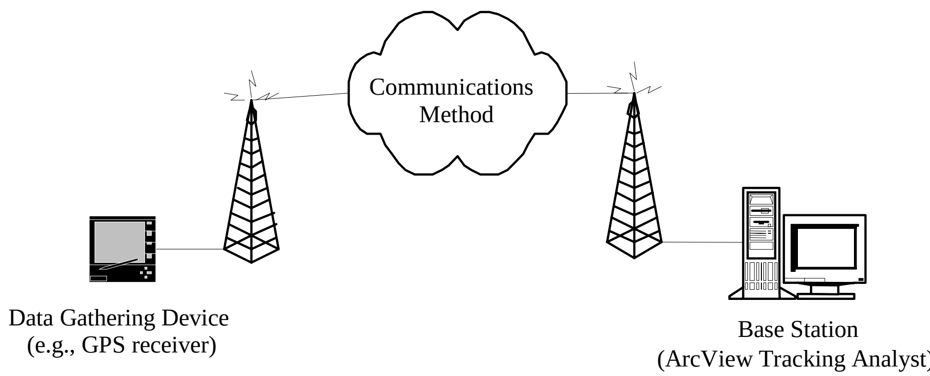
expanding the types of possible tracking applications. While some tracking technology remains expensive, ever-increasing coverage areas and increased usage will quickly drive down the price of the enabling technology.



Global Positioning Primer

Key among the tracking enabling technologies is the global positioning system (GPS). GPS is a form of information technology that uses systems of hardware and software, as well as information (time and ephemeris) transmitted from satellites to provide derived information to users. This derived information (time, position, and velocity) may then be combined with other systems such as communications devices and ArcView Tracking Analyst.

The first GPS applications began by answering the question "Where am I?" and later, with the addition of communications, were able to answer "Where are you?" type questions. Most recently, GPS is being used to answer a "Where is it?" type question for applications in the tracking of assets.

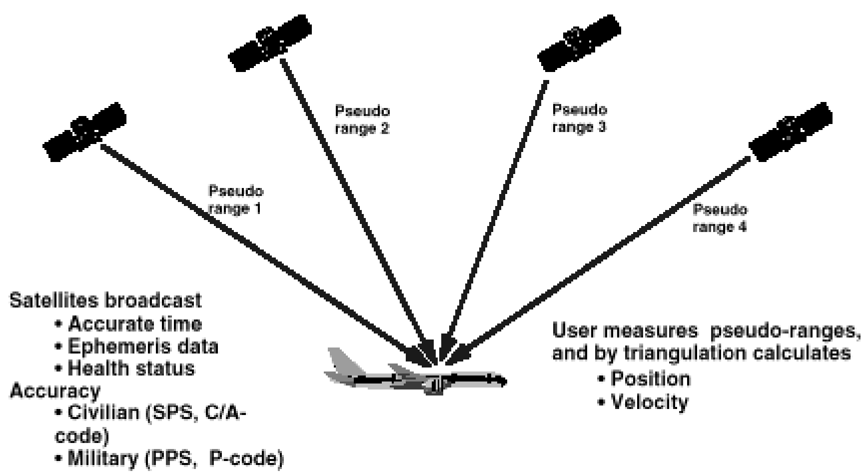
"Where am I?" applications involve the most visible kinds of GPS equipment such as handheld receivers used by hikers, drivers, pilots, and surveyors. Information, such as latitude, longitude, altitude, and time, is provided from a GPS receiver for further action by the user. The information may be translated into more easily understood forms, such as a position relative to an existing map, or used to provide information such as distances to user-defined "waypoints" (e.g., positions that are specifically identified by the user).

"Where are you?" applications are those that have GPS information for multiple users communicated to another party. For example, a manager of a trucking fleet can use GPS and mobile phone communications to stay in touch with the drivers. At a very sophisticated level, GPS and mobile communications can be used in managing international air traffic with hundreds of aircraft moving in complex patterns at all times.

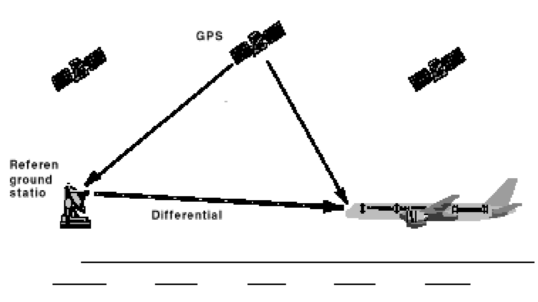
"Where is it?" applications are ones in which GPS is used to track assets, such as cargo shipments, or manage data packets in dense information networks.

GPS works by timing how long it takes coded radio signals to reach the earth from its satellites. A receiver does this by generating a set of codes that are identical to those being transmitted by the system's satellites. It then calculates the time delay between its codes and the codes received from the GPS satellites by determining how far it has to shift its own codes to match those transmitted by the satellites. This travel time is then multiplied by the speed of light to determine the receiver's distance to the satellites.

A GPS receiver could, in theory, calculate its three-dimensional position by measuring its distance from three different satellites, but in practice a fourth satellite is necessary because there is a timing offset between the clocks in a receiver and those in a satellite. The fourth measurement allows a receiver's computer to solve for the timing offset and eliminate it from the navigation solution.



For many applications, greater accuracy is needed than is possible with GPS alone (e.g., positioning accuracy of a few meters or even centimeters). Differential GPS (DGPS) is a method of operating GPS that allows a user to obtain extremely high accuracy.



A reference receiver is placed at a surveyed location. The GPS signals that arrive at that location contain errors (e.g., atmospheric delays and satellite clock errors) that misrepresent the receiver's position. These errors can be estimated by comparing the site's known position with its position according to GPS. Once the errors are identified, correction terms can be communicated to nearby users with other "roaming" GPS receivers. Each satellite monitored and in view of both the reference and roaming receivers will generate its own error corrections.

Hundreds of uses of GPS now exist from stand-alone applications, such as surveying and navigation, to more integrated, embedded applications in which GPS is just one component.

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Tracking System Components

Integrating the various components of a tracking application requires an understanding of the data acquisition, data communications, and data integration components. This section defines the critical tracking solution components as well as examples of specific technology offerings.

Remote Sensors and Receivers

Technology progress in the remote sensor and GPS receiver field has exponentially grown in recent years. Sensors can now acquire data on many facets of biometrics (body temperature, heart rate, blood pressure), natural resources (agriculture, forestry, geology), temporal variations (urban growth, sea ice and icebergs, ocean waves and currents, shipping and fishing), disasters (oil spills, floods, fires), and transportation (road, traffic signals, engine, tolls). Given the diverse nature of these applications, as well as their associated nuances, the state of sensor characteristics now include

- Modularity and interoperability
- Wireless transducers
- Onboard intelligence
- Improved flexibility through reprogrammability
- Transducer-independent architecture
- Ability to command remotely

The key technology drivers that support achieving these characteristics and dictate the capability of the next generation of sensors are

- Improved power sources, especially batteries
- New low-power microprocessors
- Enhanced communications systems
- Ability to perform in strenuous operating environment conditions

Examples of commercially available sensors include animal tracking collars, personnel ankle bracelets, road sensors, and cargo tags. However, it should be noted that many of these sensors/receivers utilize proprietary encoded data strings that must be decoded with the vendor's matching base station receiver.

Communication Media Options

For most tracking applications, four communication media types can support communications requirements between the sensor(s) and the base station. They are wireline (fixed-to-fixed), wide area wireless (fixed-to-mobile), dedicated short-range communications (fixed-to-mobile), and vehicle-to-vehicle (mobile-to-mobile). Each application could have different communications needs that match the particular requirements for frequency, distance, data size, and so forth. As an example, some of the more popular communications methods are presented below for the following application areas:

Application Type	**Communications Media**
911	Proprietary Wireless
Automatic Vehicle Location	CDPD, Radio, Satellite
Remote Sensing	Wireline, RF
Animal Tracking	UHF
Maritime	INMARSAT

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Wireline

There are numerous wireline technology options for fixed-to-fixed communications requirements. For example, traffic management applications can use leased or owned twisted wire pairs, coaxial cable, or fiber optics to gather information and to monitor and control traffic surveillance sensors, traffic signals, changeable message signs, and so forth. In other applications, it may be more advantageous to use terrestrial microwave links, spread spectrum radio, or an area radio network to provide communications between a management center and remote controllers. Although these are wireless communications technologies, they are used to provide fixed-to-fixed communications in the examples cited; consequently they are often referred to as wireline communications media.

Wireline network options include private networks, public shared networks, or a mixture of the two. Private network technologies include Ethernet, Fiber Distributed Data Interface (FDDI), Synchronous Optical NETwork (SONET), and Asynchronous Transfer Mode (ATM). Public shared network technologies include leased analog lines, leased digital lines, frame relay, Integrated Services Digital Network (ISDN), metropolitan Ethernet, Internet, and Switched Multimegabit Data Service (SMDS).

Wireless

Wide Area Wireless

There are two distinct categories of wireless communications based on range and area of coverage—wide area and short range.

Wide area wireless (fixed-to-mobile) communications are suited for services and applications where information is disseminated to users who are not located near the source of transmission and who require seamless coverage. Wide area wireless communications are further differentiated on whether they are one-way or two-way. An example of a one-way broadcast transmission is the traffic reports we currently receive over AM or FM radio. A mobile traveler who requests and receives current traffic information from an information service provider is an example of two-way communications.

Two-way wide area wireless technologies include Global System for Mobile Communications (GSM), Special Mobile Radio (SMR), Enhanced Special Mobile Radio (ESMR), Personal Communications System (PCS), ARDIS, RAM, Geotek, 220 MHz, Metricom, Tetherless Access Ltd. (TAL), two-way paging, and Cellular Digital Packet Data (CDPD). CDPD, one of the more popular technologies, allows TCP/IP data transmission over analog cellular systems and takes advantage of unused cellular spectrum.

One-way broadcast communication technologies include AM subcarrier, FM subcarrier, and Highway Advisory Radio (HAR). FM subcarrier systems assessed included Subcarrier Traffic Information Channel (STIC), Data Radio Channel (DARC), High Speed FM Subcarrier Data System (HSDS), RBDS, ALERT, and SCA. Associated issues include the limited coverage of the currently available systems, the proprietary hardware and interfaces of the high data rate systems (HSDS, STIC, and DARC), and the high data rate capacity limitations.

Short-Range Wireless

Short-range wireless communications are concerned with information transfer that is of a localized interest. There are two types of short-range wireless communications, vehicle-to-vehicle and Dedicated Short-range Communications (DSRC). Vehicle-to-vehicle (mobile-to-mobile) short-range wireless communications are required to support the Automated Highway System (AHS) and, most likely, intersection collision avoidance implementations. Appropriate applications for DSRC (fixed-to-mobile) include toll collection, parking fee collection, roadside safety inspections, credential checks, in-vehicle signing, intersection collision avoidance, and selected AHS communications (e.g., safety checks, access authorization, and system status updates). Other applicable technologies include radio frequency (RF) and Infrared (IR) short-range wireless beacon/tag communications for the DSRC requirement.

Satellite Systems

Satellite communication is line-of-sight from space and, as such, provides excellent coverage for outdoors. However, satellite systems provide little or no coverage in tunnels or dense forests.

There is an array of satellite systems suitable for tracking applications. These include a variety of Little (data only) and Big (voice and data) low-earth-orbit (LEO) systems, as well as more conventional medium-earth-orbit (MEO) and geosynchronous orbit (GEO) systems. Many of these systems are not yet deployed; however, they are projected to be in service within the next few years. These systems include ORBCOMM, STARSYS, VITASAT, MSAT, Constellation, GLOBALSTAR, IRIDIUM, TELEDESIC, Ellipso, Odyssey, Skycell, VSAT, and OmniTRACS. Availability and cost of the service, coupled with the cost of the terminals, are common issues that must be addressed in fielding a tracking application.

Summary of Communication Options

Based on our current tracking application experiences, the following summary of communications options is provided:

- A large set of the tracking data communication methods are best supported by commercially available mobile wireless data networks operated in the packet switching mode. Prominent among these are GSM, RAM, ARDIS, and CDPD.

- Although GSM is not significantly deployed in the United States, it is extensively used in Europe and should be considered as an alternative communications service.

- Of the new communication technologies being deployed, CDPD's technical performance has been validated through simulation and through operational field trials. CDPD's coverage is expected to cover the entire footprint of the cellular system. Another version of CDPD, which extends Internet Protocol (IP) capabilities to regular AMPS cellular channels and the PSTN, called "Circuit Switched CDPD," will be used to extend CDPD service to areas that do not have the full CDPD overlay implementation.

- RAM and ARDIS coverage is focused on the major metropolitan areas where there is significant business activity. However, RAM and ARDIS provide little or no coverage in rural areas.

- Metropolitan area network type wireless data systems, such as systems by Metricom and TAL, are targeted at the nonmobile user. Because of their simplicity, these systems offer price advantages over mobile wireless data systems.

- Two-way paging (narrow band PCS) can be used for tracking applications that are not time critical and that do not require a real-time response. Particularly suitable would be messages for which predefined responses are adequate.

- Because of the higher costs for services and equipment, satellite systems would be most appropriately used where terrestrial alternatives are not available. Among the satellite systems, little LEO choices seem to be the most appropriate since they are targeted specifically at short burst data transactions.

Importing Tracking Data

Unlike other segments of the GIS industry, little effort has been made to standardize communication protocols and data formats for tracking information. In order to utilize the data that was transmitted to the base station, a data extraction filter must be written. Filter complexity is a factor of the proprietary communications protocol and the type of data being transmitted. Most filters are not terribly complex to write and many are available from ESRI, Litton/TASC, and various receiver manufacturers.

Application Areas

ArcView Tracking Analyst provides advantages over other tracking applications by being fully integrated into the powerful ArcView GIS. These features, when combined with the proper sensors and communications technology, can enhance tracking applications such as in the following areas.

Automatic Vehicle Location

Automatic vehicle location (AVL) systems, using GPS, show the location of any vehicle in a network or fleet. AVL applications can be used to track cars or trucks, cargo units, marine vessels, or airplane movement within a given area. In addition to displaying this real-time AVL movement data, ArcView Tracking Analyst enables the storage of tracking data for subsequent analysis using its unique temporal replay features.

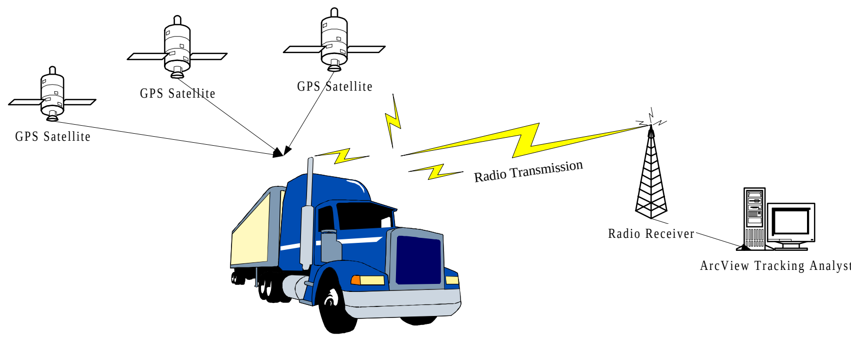
In order to use AVL, all vehicles in a network must be equipped with a mobile radio transceiver or modem, a GPS receiver, and a GPS antenna. The base must have a PC computer station with a receiver and ArcView Tracking Analyst. At the base station, the ArcView Tracking Analyst operator will physically see the location of any vehicle and its movement on a digitized map.

Organizations implement AVL systems to realize benefits such as faster response times, improvements in field personnel safety, and better utilization of resources that can save time and lower costs. AVL is being used today in many application areas including fleet management, emergency response, vehicle security, roadside assistance, and vehicle navigation systems.

Fleet Management

AVL technology has enabled companies to know where their trucks are at all times; to communicate with drivers; or to know the status of the engine, power train, or trailer temperature. In addition to the vehicle location information, sensors can also provide characteristics of the driver's performance such as driving too fast, too slow, riding the brakes, making too many stops, or not stopping enough. In doing so, this tracking information can help companies improve customer response time, navigational assistance, assist in the recovery of stolen vehicles, reduce vehicle miles traveled, decrease fleet maintenance costs, and improve safety.

Fleet tracking applications require an intelligent remote unit to be located in the vehicle and monitoring software, such as ArcView Tracking Analyst, to be used at a base station. The remote unit includes an onboard processor, GPS receiver, and a cellular or RF radio modem that continuously collects and stores data about the vehicle including its position (latitude/longitude coordinates), speed, and heading. The data (either on demand or at scheduled intervals) is then downloaded from the remote units to the base station and loaded into ArcView Tracking Analyst where it can be viewed and analyzed.



Emergency Response

A major goal of public safety agencies is to make emergency response time as fast as possible. When an emergency erupts, an extra second or two can mean the difference between a life saved and a life lost. A dispatcher must make vital decisions regarding which units to dispatch based on current unit location, road conditions, traffic flow, and other factors.

AVL systems have greatly enhanced the ability of emergency response organizations to quickly respond with the most effective capability available. Using AVL, dispatchers have all of the vital information displayed on the digital maps right in front of them. Dispatchers can see an entire city on a digital map allowing 911 calls to be pinpointed instantly. Emergency response vehicles can be displayed as icons to make the type of unit readily apparent. ArcView Tracking Analyst can display a wealth of other related information including vehicle status, the location of fire hydrants, street directions, street width, current capacity of medical facilities, and so forth.

By taking advantage of GPS and by having the tools to immediately identify the best unit to respond, dispatchers will be able to trim seconds—if not minutes—off response times, saving countless lives.

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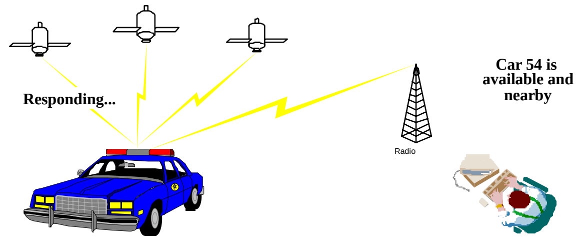

Vehicle Security, Concierge, and Roadside Assistance Services

AVL technology has enabled automobile and service companies to provide a series of roadside safety and assistance options to travelers. Locating their customers is possible by combining cellular phone and GPS satellite technology, sophisticated onboard vehicle electronics, and ArcView Tracking Analyst.

An onboard computer linked to GPS via a receiver (can be trunk-mounted) typically can pinpoint a vehicle location to within 100 feet. When activated by the driver, the system transmits data via cellular phone to a monitoring center with the vehicle's location, direction, and speed, as well as the vehicle identification number (VIN). An operator at the center can verify the nature of the call; confirm the vehicle location; and relay the information to local medical, police, or fire departments or to a roadside assistance center.

Services that these types of applications provide are

- Emergency services including police, fire, and ambulance
- Roadside assistance
- Routing and location assistance
- Automatic notification when the air bag is deployed
- Remote door unlocking
- Theft detection/notification and tracking of stolen vehicle
- Access to personal services such as ATM location and reservations for airlines, hotels, and restaurants

Intelligent Transportation Systems

A broad range of diverse technologies, known collectively as intelligent transportation systems (ITSs), have been integrated in order to address world transportation problems including saving lives, saving time, and saving money. ITS is comprised of a number of standards and technologies including information processing, communications, control, and electronics.

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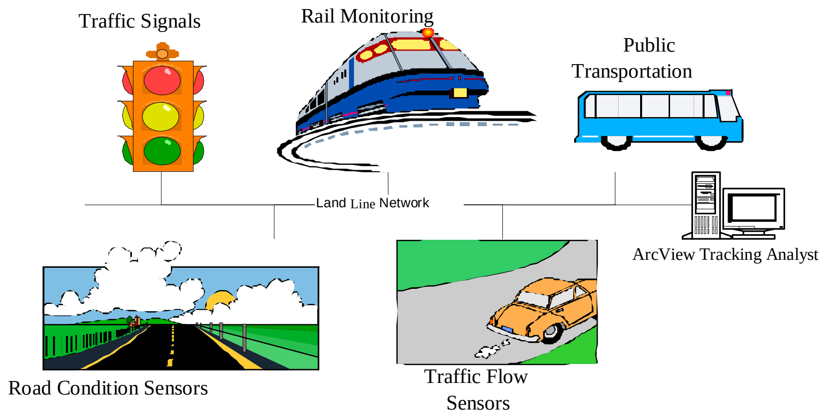


The use of ITS in Japan, Europe, and Australia has been greatly accelerated through mutual cooperation of the public and private sectors. Yet, unlike the state-mandated cooperation found in many countries, the United States requires voluntary cooperation between the public and private sector. In response, the Intelligent Transportation Society of America was established to coordinate that cooperative effort.

ITS provides the intelligent link between travelers, vehicles, and infrastructure. ITS technologies will primarily enable users to

- Collect and transmit information on traffic conditions and transit schedules for travelers before and during their trips. Travelers will be alerted to hazards and delays so they can change their plans to minimize inconvenience and additional strain on the system.

- Decrease congestion by reducing the number of traffic incidents, clearing them more quickly when they occur, rerouting traffic flow around them, and automatically collecting tolls.

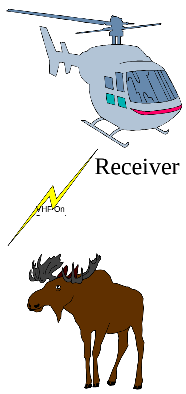
- Improve the productivity of commercial, transit, and public safety fleets by using automated tracking, dispatch, and weigh-in-motion systems that speed vehicles through much of the red tape associated with interstate commerce.

- Assist drivers in reaching a desired destination with navigation systems enhanced with pathfinding or route guidance.

ArcView Tracking Analyst can play a critical role in ITS applications through the monitoring of stationary object status, tracking of mobile objects, overlaying data onto city grids, and applying real-time data to gain a complete perspective of the traffic management situation. ArcView Tracking Analyst software's ability to handle multiple input feeds of data concurrently is particularly well suited for the variety of information available from an ITS.

Wildlife Monitoring

ArcView Tracking Analyst provides an ideal tool to track and monitor wildlife movements. Not only can scientists monitor wildlife positions and attributes as they change, but they can also replay the past positions of the animals to perform detailed analysis of daily movements or migratory patterns. The ability to study the animals' movement through time in ArcView Tracking Analyst is further enhanced with the ability to incorporate other types of related information into the analysis. Examples of wildlife analysis that can be performed with ArcView Tracking Analyst include urban encroachment, effects of habitat loss, reintroduction of species, or the effects of environmental conditions.



Animal with Broadcasting Tracking Collar

The ability to accurately track animals has benefited from the advent of GPS technology. As an example, mammal collars, designed for operation at extreme temperatures and under very wet conditions (including total immersion), provide GPS positioning, temperature, and activity reports from the animal's natural habitat.

Because the scientist is usually remote from the animal receiver, long-term data storage on the animal, bidirectional communication link for data retrieval, and remote control are common. In addition to real-time geographical coordinates, the data available from the animal unit consists of date and time as well as optional sensor information (ambient temperature and animal activity). In normal operation this data is usually stored cumulatively in a dedicated bank of nonvolatile random access memory (RAM). Two-way communication between the animal unit and the ArcView Tracking Analyst user is usually handled by UHF modems in the collar and the system command unit on the user end of the link (typically located in an aircraft).

Animal location applications often have unique characteristics such as the size and weight restrictions of the collars and the service life of the batteries. As an example, battery life is a function of power consumption by the GPS receiver, modem, beacon, and "housekeeping" (data handling and control). Maximizing battery life may require that the modem and beacon be turned off during periods when no access to the animal is required (typically at night).

Wireless Location Services—E911

The FCC adopted a Report & Order that established performance goals and timetables for the identification of a wireless caller's phone number and physical location when dialing the 911 emergency services telephone number. These rules apply to cellular, broadband PCS, and select SMR carriers. Under Phase I of the E911 implementation, wireless carriers must be able to identify the telephone numbers of their subscribers and locate subscribers to the nearest cell site. Under Phase II of E911 implementation, wireless communications carriers must be able to locate 911 callers within one-tenth of a mile in 67 percent of all cases. ArcView Tracking Analyst, together with GPS, can enable mandatory 911 tracking applications. Given the analysis features of ArcView Tracking Analyst, compliance with these FCC regulations can easily be monitored.

Building Your Own Tracking System

Unlike other more mature information system application areas that offer full commercial off-the-shelf turnkey solutions, tracking applications remain almost exclusively fully customized applications. Complete tracking applications generally involve microelectronics, satellite or telecommunications, software development, data management, and procedural management. As a consequence, the number of system integrators that specialize in fielding complete tracking applications is very limited. Generally, the burden of integrating complex technologies resides with user organizations.

In order to create a tracking application, all of these pieces must be brought together. The application developer must understand the domain of the tracking application or what is to be tracked and why. Given that information and basic cost constraints, the developer can assemble components and services for the sensor, communications medium, and end user software.

There are many companies that provide one of these services. There are many GPS manufacturers, communications hardware manufacturers, and communications providers to choose from. Some companies may provide more than one solution such as a company that provides both a communications service and the hardware to access it. Researching these companies to find devices and services that solve the problem and are compatible with each other can be difficult, if only for the wide variety of options available. Some ESRI business partners specialize in this area and are a good source for solutions.

The ArcView Tracking Analyst software system is a very versatile and powerful system. It provides users with a wide variety of tools for tracking objects and performing GIS analysis on those objects and other data. ArcView Tracking Analyst provides an open specification for input data, so almost any input device can be supported. This does require some software development to accomplish, and several resources are available for help. These include ESRI's business partners and the Tracking Analyst Web site at www.esri.com/trackinganalyst.

For more than 30 years ESRI has been helping people manage and analyze geographic information. ESRI offers a framework for implementing GIS in any organization with a seamless link from personal GIS on the desktop to enterprisewide GIS client/server and data management systems. ESRI GIS solutions are flexible and can be customized to meet the needs of our users. ESRI is a full-service GIS company, ready to help you begin, grow, and build success with GIS.

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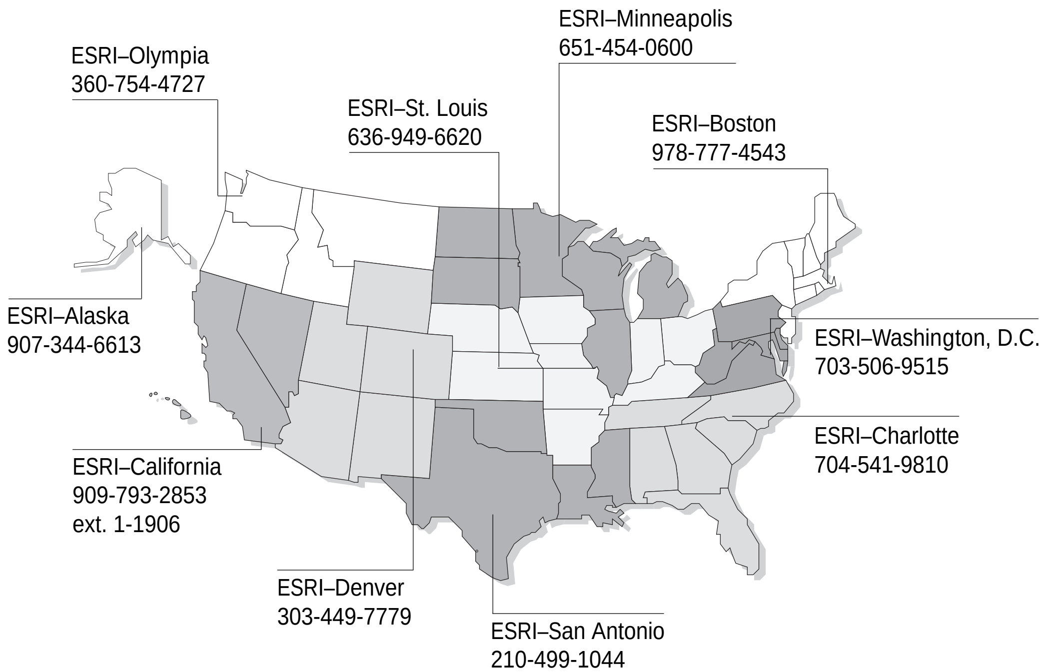

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