History of the GPS Program

The Global Positioning System (GPS) is the principal component and the only fully operational element of the Global Navigation Satellite System (GNSS). The history of the GPS program pre-dates the space age. In 1951, Dr. Ivan Getting designed a three-dimensional, position-finding system based on time difference of arrival of radio signals. Shortly after the launch of Sputnik scientists confirmed that Doppler distortion could be used to calculate ephemerides, and, conversely, if a satellites position were know, the position of a receiver on earth could be determined. Within two years of the launch of Sputnik the first of five low-altitude "Transit" satellites for global navigation was launched. In 1967, the first of three "Timation" satellites demonstrated that highly accurate clocks could be carried in space. In parallel with these efforts, the 621B program was developing many of the characteristics of today's GPS system.

In 1973 these parallel efforts were brought together into the NAVSTAR-Global Positioning System, managed by a joint program office headed by then-colonel Dr. Brad Parkinson at the United States Air Force Space and Missile Systems Organization. This office developed the GPS architecture and initiated the development of the first satellites, the worldwide control segment and ten types of user equipment. Today, it continues to sustain the system as the Global Positioning System Directorate of the Space and Missile Systems Center.

All performance parameters for the system were verified during ground testing by 1978. Ten development satellites were launched successfully between 1978 and 1985 and the initial ground segment that would provide the critical uploads to the satellites was also developed. The initial constellation of 24 operational satellites was deployed between 1989 and 1994 and the system was declared "fully operational" in 1995. It has been sustained at that level or higher ever since.

The initial operational satellites transmitted authorized signals on two frequencies, designated L1 and L2, and a signal intended for open (civilian) use on the L1 frequency. GPS is currently engaged in a modernization program that will bring new and improves services to the global user community through new generations of satellites, referred to as Blocks. With the first Block IIR-M satellite (in 2005), a second civil signal was added (to L2) improving the quality of the system for civil users. Seven of these satellites are on orbit. With the first Block IIF satellite (in 2010), a third signal (L5) was added to help ensure the availability of GPS to civil aeronautical and search-and-rescue users (called the safety of life signal). The next generation of GPS satellites, GPS Block III, is in production. They will transmit another new civil signal on L1 that will provide more power and enable greater civil interoperability with other global and regional elements of the GNSS, such as Europe's Galileo system, Japan's Quazi-Zenith Satellite System and others.

In 1983, following the shoot-down of KAL-007 after straying off-course into prohibited airspace, the President of the United States directed that GPS would be made available for civilian use as a common good. The GPS civil signal was initially slightly degraded due to its potential military implications. However, in 2000, the President directed that the quality of the signal available to civilian users would no longer be degraded. In 2004, the President released a new U.S. National Space-based Positioning, Navigation, and Timing Policy. The 2004 policy placed the GPS system under the oversight of a National Space-based Positioning, Navigation and Timing Executive Committee that is co-chaired by the US Deputy Secretaries of Transportation and Defense, and made up of nine Departments and Agencies across the U.S. Government.

Although GPS was originally viewed as a unique capability, other nations have recognized the importance of this technology to their critical infrastructures and economies and are now in various stages of implementing GPS-like systems of their own. The GPS program has worked hard to ensure these multiple satellite-based navigation and timing systems can operate with compatibility, interoperability and transparency for all open signals. GPS made major technical contributions to analysis techniques that predict compatibility, so systems can share spectrum for interoperability while ensuring radio frequency compatibility is attained. In bilateral working groups and multinational fora, the U.S. Government and representatives from Japan, Europe, India, Russia, and China and other nations have moved toward common signal designs on L1 and L5 frequencies that will be used by civil signals in almost every system of the GNSS.

GPS has become a ubiquitous utility, required to be available to civil users around the world, at no cost, providing unprecedented timing, position and navigation accuracies with almost incalculable human benefits, it was developed initially as a military system. It is now the underpinning of incredibly broad civil applications and also, in keeping with its origins, amazingly accurate precision strike systems. This also has significant human benefit, since when conflict cannot be avoided, the history of the last two decades has shown that collateral damage and civilian casualties resulting from military actions are significantly less than was seen in pre-GPS conflicts.

Organizations to be Recognized

Many persons and organizations have made major contributions to today's Global Positioning System. The Global Positioning System Directorate of the Space and Missile Systems Center will be recognized as representing the countless participants, including: the cofounders (Drs. Ivan Getting and Bradford Parkinson), the many industry partners responsible for the GPS Satellites, the worldwide control segment and many varieties of stand-alone and embedded GPS receivers; the operational organizations that launch and control the system; and the many U.S. government organizations that are involved in ensuring the quality of the signal, providing information about the system that is essential to users worldwide, and conducting consultations with foreign nations in promoting the compatibility and interoperability of GPS with all the other GNSS systems that are now being implemented across the globe.

Human Benefit of the Global Positioning System (GPS)

No other single space project, program or system has led to human benefits that are even remotely close to those that have resulted from GPS. It is no exaggeration to say that billions of persons benefit from GPS on a daily basis, whether using modern communications that rely on GPS timing, flying in commercial or private aircraft, navigating at sea, surveying, mapping, farming, providing disaster support, geolocating personal vehicles, guiding heavy machinery and many more applications. A brief description of some of these applications and benefits is provided below. However, this summary barely begins to convey the benefits GPS brings to humans in every country, on every continent and on navigable waters around the world.

Agriculture. The development and implementation of precision agriculture and farming has been made possible by combining the GPS and geographic information systems (GIS). GPS-guided tractors routinely achieve position accuracies of 10 centimeters or better. Farmers were initially skeptical, but annual worldwide sales of related equipment now exceed $450 million. GPS-based applications in precision farming are being used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications, and yield mapping. A recent study on the effects of precision machine guidance on agriculture in Australia demonstrated increases in annual yield of 10%, 52% reduction in fuel costs and 67% reduction in labor costs.

In the past, it was difficult for farmers to correlate production techniques and crop yields with land variability. This limited their ability to develop the most effective soil/plant treatment strategies that could have enhanced their production. Today, the use of GPS allows more precise application of pesticides, herbicides, and fertilizers, and better control of the dispersion of those chemicals through precision agriculture, thus reducing expenses, producing a higher yield, and creating a more environmentally friendly farm. Most importantly, precision agriculture using GPS is changing the way farmers and agribusinesses view the land. Where farmers may have once treated their fields uniformly, they are now seeing benefits from micromanaging their fields that have been estimated to be between $5 and $14 per acre.

Crop advisors use rugged data collection devices with GPS for accurate positioning to map pest, insect, and weed infestations in the field. Pest problem areas in crops can be pinpointed and mapped for future management decisions and input recommendations. The same field data is used by aircraft sprayers for accurate swathing of fields without use of human "flaggers" to guide them. Crop dusters equipped with GPS are able to fly accurate swaths over the field, applying chemicals only where needed, minimizing chemical drift, reducing the amount of chemicals needed, thereby benefiting the environment.

Although many expect that the benefits of precision agriculture can only be realized on large farms with huge capital investments and experience with information technologies, such is not the case. There are many inexpensive and easy-to-use methods and techniques that are used in the developing world. Through the use of GPS, farmers can now achieve additional benefits by combining better utilization of fertilizers and other soil amendments, determining the economic threshold for treating pest and weed infestations, and protecting the natural resources for use by future generations.

Aviation. The use of GPS in civil aviation throughout the world has a growing impact on increasing the safety and efficiency of global travel as well as profitability. Although initially visualized as an area navigation aid, by 1992 full Category III blind landings had been demonstrated using GPS alone. With its accurate, continuous, and global capabilities, GPS offers seamless satellite navigation services that satisfy many of the requirements for aviation users. Space-based position and navigation enables three-dimensional position determination for all phases of operations: Departure, en route, arrival and airport surface movement. Virtually all of the evolving air traffic management systems in the future will rely on space-based navigation – initially GPS but eventually many other systems that are being fielded to complement (and in some cases operate independently, but interoperable with) GPS.

The trend today in the Next Generation Air Traffic Management System is toward an Area Navigation concept known as RNAV, with an even greater role for GPS. Area Navigation allows aircraft to fly user-preferred routes from waypoint to waypoint, where waypoints do not depend on ground infrastructure. The accuracy provided by space-based navigation systems increase safety in flight and on the ground. Terrain Awareness and Warning System performance is enhanced; GNSS-enabled ADS-B (Automatic Dependent Surveillance-Broadcast) significantly improves in-flight aircraft avoidance and ground operations (especially runway incursions). RNAV implementation at Juneau, Alaska has enabled 75% lower arrival minimums compared to Standard. In many cases, aircraft flying over data-sparse areas such as oceans have been able to safely reduce their separation between one another, allowing more aircraft to fly more favorable and efficient routes, saving time, fuel, and increasing cargo revenue. GPS also serves as an essential component for many other aviation systems, such as the Enhanced Ground Proximity Warning System that has proven successful in reducing the risk of Controlled Flight into Terrain, a major cause of many aircraft accidents in the past.

In some regions satellite signals are augmented or improved for special aviation applications, such as landing during poor visibility. In those cases, even greater precision operations are possible. Improved approaches to airports, which significantly increase operational benefits and safety, are now being implemented even at remote locations where traditional ground-based services are unavailable. New and more efficient air routes and optimum profile descents have been made possible by GPS resulting in vast savings in time and money. For example, a recent demonstration of single optimal profile descent into San Francisco airport resulted in a savings of 1600 lbs of fuel with a corresponding reduction of 2 metric tons of carbon dioxide. In the United States today there are now more FAA-certified GPS approaches (2300+) than conventional beam-steering.

The reliance on GPS as the foundation for today and tomorrow's air traffic management system is a major part of many national plans. Aviation authorities that are moving forward with GPS have observed and documented reductions in flight time, workload, and operating costs for both the airspace user and service provider. In simple terms, the precise navigation available from GPS for aviation increases system capacity, facilitates all-weather operations, increases safety and provides for better flow management. These have a direct impact on the operability of the air traffic management systems, the profitability of the industry and the overall experience of the air traveler.

Marine. GPS provides the fastest and most accurate method for mariners to navigate, measure speed, and determine location. This enables increased levels of safety and efficiency for ships and boats worldwide. While at sea, accurate position, speed, and heading are needed to ensure the vessel reaches its destination in the safest, most economical and timely fashion that conditions will permit. As the vessel departs from or arrives in a port, the need for accurate position information becomes even more critical where vessel traffic and other waterway hazards make maneuvering more difficult and the risk of accidents becomes greater, especially in poor weather.

Many nations also use GPS for operations such as buoy positioning and dredging to improve harbor navigation. Governments and industrial organizations around the world are working together to develop performance standards for Electronic Chart Display and Information Systems, which use GPS positioning information. These systems are revolutionizing marine navigation and are leading to the replacement of paper nautical charts.

GPS information is embedded within the Automatic Identification System (AIS), which is endorsed by the International Maritime Organization and is used for vessel traffic control around busy seaways. This service is not only vital for navigation, but is increasingly used to bolster the security of ports and waterways by providing governments with greater situational awareness of commercial vessels and their cargo. AIS uses a transponder system capable of communicating ship to ship as well as ship to shore, transmitting information relating to ship identification, geographic location, vessel type, and cargo information -- all on a real-time, wholly automated basis. The safety and security of vessels using this system is significantly enhanced.

GPS is playing an increasingly important role in the management of maritime port facilities. The efficient management and operation of container placement in many of the world's largest port facilities are becoming increasingly dependent upon GPS technology and geographic information system (GIS). GPS facilitates the automation of the pick-up, transfer, and placement process of containers by tracking them from port entry to exit. With millions of container shipments being placed in port terminals annually, GPS has greatly reduced the number of lost or misdirected containers thus significantly lowering associated operation costs.

Railroads. Ensuring high levels of safety, improving the efficiency of rail operations, and expanding system capacity are all key objectives of today’s railroad industry. Integral to the efficient operation of rail systems is the requirement for accurate, real-time position information of locomotives, rail cars, maintenance-of-way vehicles, and wayside equipment. Rail systems in many parts of the world are increasingly using the GPS in combination with various sensors, computers, and communication systems to improve safety, security, and operational effectiveness.

Unlike most other modes of transportation, there is little flexibility in managing rail traffic. Most rail systems are comprised of long stretches of a single set of tracks. Trains must simultaneously share the use of these single line tracks. It is therefore critical for safety and efficiency reasons to know the position and performance of these trains both individually and system-wide. Only the skill of the crews, accurate timing, a dynamic dispatching capability, and a critical array of “meet and passes” locations on short stretches of parallel tracks, allow rail dispatchers to guide their trains safely through.

When coupled with other location and navigation devices to account for time in tunnels, behind hills, and other obstructions, GPS can provide a reliable and accurate position-locating capability for rail traffic management systems, and has become an essential element of the Positive Train Control (PTC) concept now being adopted in many parts of the world. This involves providing precise railroad position information to sophisticated command and control systems to produce the best operating plan, to include varying train speed, re-routing traffic, and safely moving maintenance crews onto and off tracks. PTC increases operational efficiency, allows higher track capacity, enhances crew, passenger, and cargo safety, and also results in a safer environment for personnel working on the track. In short, GPS helps to reduce rail accidents, delays, operating costs, and dangerous emissions, while increasing track capacity, customer satisfaction, and cost effectiveness.

Roads and Highways. The availability and accuracy of the GPS offers increased efficiencies and safety for vehicles using highways and streets, and for mass transit systems. It is estimated that delays from congestion on highways, streets, and transit systems throughout the world result in productivity losses in the hundreds of billions of dollars annually. Other negative effects of congestion include property damage, personal injuries, increased air pollution, and inefficient fuel consumption.

Many of the problems associated with the routing and dispatch of commercial vehicles, mass transit systems, road maintenance crews, and emergency vehicles are significantly reduced or eliminated with the help of GPS. . GPS-enabled automatic vehicle location and in-vehicle navigation systems are widely used throughout the world today, significantly reducing time lost and environmental impacts due to mis-routing or unfamiliarity with locales. By combining GPS position technology with systems that can display geographic information or with systems that can automatically transmit data to display screens or computers, a new dimension in surface transportation is realized.

Today geographic information systems (GIS) store, analyze, and display geographically referenced information provided by GPS. Mass transit systems use this capability to track rail, bus, and other services to improve on-time performance. Instant car pools are feasible since people desiring a ride can be instantly matched with a vehicle in a nearby area. Using GPS technology to help track and forecast the movement of freight has made a logistical revolution, including an application known as time-definite delivery. In time-definite delivery, trucking companies use GPS for tracking to guarantee delivery and pickup at the time promised, whether over short distances or across time zones.

Many nations use GPS to help survey their road and highway networks and identify the location of features on, near, or adjacent to the road networks. These include service stations, maintenance and emergency services and supplies, entry and exit ramps, damage to the road system, etc. This helps transportation agencies reduce maintenance and service costs and enhances the safety of drivers using the roads. In the future, GPS will provide for even more effective systems for crash prevention, distress alerts and position notification, electronic mapping, and in-vehicle navigation with audible instructions.

Survey and Mapping. GPS is rapidly being adopted as the standard by professional surveyors and mapping personnel throughout the world. Using the near pinpoint accuracy provided by the GPS and its augmentations, highly accurate surveying and mapping results can be obtained very rapidly, significantly reducing the amount of equipment and labor hours required with conventional surveying and mapping techniques. Today, it is possible for a single surveyor using GPS to accomplish in one day what used to take weeks with an entire team. The cost estimate for doing a control survey point with the older traditional methods is estimated at $10,000. The estimated cost now using GPS is $250.

Unlike traditional techniques, GPS surveying is not bound by constraints such as line-of-sight visibility between reference stations, and the spacing between stations can be increased. The increased flexibility of GPS also permits survey stations to be established at easily accessible sites rather than being confined to hilltops as previously required. Remote GPS systems may be carried by one person in a backpack, mounted on the roof of an automobile, or fastened atop an all-terrain vehicle to permit rapid and accurate field data collection. With a GPS radio communication link, real-time, continuous centimeter-level accuracy makes possible a productivity level that is virtually unattainable using optical survey instruments.

Timing. Precise time is crucial to many business activities throughout the world. Communication systems, electrical power grids and financial networks all rely on precision timing for synchronization and operational efficiency. The heart of the GPS system is the family of atomic clocks carried on each satellite and continually updated from an ensemble of ground atomic clocks. That is compared with the world-standard maintained by the US Naval Observatory to an accuracy of one nanosecond. As a result, the Universal Coordinated Time (UTC) is disseminated globally by GPS, specified accurate to within 100 nanoseconds but in practice accurate to within 10 nanoseconds.

The applications of this incredibly accurate, universal timing signal have resulted in GPS becoming one of the world most critical infrastructures and the only one that is provided at no cost to users everywhere. Among them are frequency standards for 50 and 60 hertz power systems; synchronization of computer networks for billing and communications; use by communications systems for frequency and phase timing; simultaneous observations by astronomic radio and optical observatories and very long baseline interferometry systems.

This free, highly accurate time has manifested itself in the cellular networks, satellite communications, ATM machines and many other "consumer" services and the underlying banking, data handling and public utilities that are part of everyday life. Companies worldwide use GPS to time-stamp business transactions, providing a consistent and accurate way to maintain records and ensure their traceability. Major investment banks use GPS to synchronize their network computers located around the world. Large and small businesses are turning to automated systems that can track, update, and manage multiple transactions made by a global network of customers, and these require accurate timing information available through GPS.

Power companies and utilities also have fundamental requirements for time and frequency to enable efficient power transmission and distribution. Repeated power blackouts have demonstrated to power companies the need for improved time synchronization throughout the power grid. Analyses of these blackouts have led many companies to place GPS-based time synchronization devices in power plants and substations. By analyzing the precise GPS timing of an electrical anomaly as it propagates through a grid, engineers can trace back the exact location of a power line break.

Environment. To sustain the Earth's environment while balancing human needs requires better decision making with more up-to-date information. Gathering accurate and timely information has been one of the greatest challenges facing both government and private organizations that must make these decisions. GPS now helps to address those needs.

Data collection systems provide decision makers with descriptive information and accurate positional data about items that are spread across many kilometers of terrain. By connecting position information with other types of data, it is possible to analyze many environmental conditions from a new perspective. Position data collected through GPS can be imported into geographic information system (GIS) software, allowing spatial aspects to be analyzed with other information to create a far more complete understanding of a particular situation than might be possible through conventional means. Last year, Trimble Navigation completed a study on Fleet Management Systems such as Fed Ex and UPS. Many of these vehicles use GPS to improve the efficiency of their operations to improve route selection and reduce engine idle time, which all reduce fuel consumption. With 20.8 million vehicles in Fleet Management Systems across the U.S., the use of GPS in these fleets of vehicles could reduce fuel consumption by 5.4 billion gallons valued at over $16 billion. From an environment perspective, this also would reduce CO2 emissions by 54 million metric tons per year.

Aerial studies of some of the world's most impenetrable wilderness are conducted with the aid of GPS technology to evaluate an area's wildlife, terrain, and human infrastructure. By tagging imagery with GPS coordinates it is possible to evaluate conservation efforts and assist in strategy planning. Some nations collect and use mapping information to manage their regulatory programs such as the control of royalties from mining operations, delineation of borders, and the management of logging in their forests. The migratory patterns of endangered species are tracked, such as the mountain gorillas of Rwanda. In the United States, moose, wolves and other species are also tracked and mapped using GPS, helping to preserve and enhance declining populations. In addition, the proliferation of GPS tidal tracking sites and resulting improvement in estimating the vertical component of a site's position from GPS measurements present a unique opportunity to directly observe the effects of ocean tides. GPS receivers mounted on buoys track the movement and spread of oil spills.

Meteorology. GPS technology also supports efforts to understand and forecast both weather and changes in the environment by meteorologists. By integrating GPS measurements into operational methods used, GPS is being used to develop more accurate understanding of the water cycle and the role of water vapor in climate which greatly improves weather forecasting. Since water vapor is the most plentiful greenhouse gas, changes in water vapor concentration can be measured through space-based GPS occultation and ground-based slant-path signal delay. Six COSMIC (Constellation Observing System for Meteorology Ionosphere and Climate) satellites were launched in 2006. These and other deployed systems provide raw data for initialization of numerical weather models and can reduce model moisture bias by 50%. Better understanding and availability of precipitable water atmospheric content on rainfall predictions will be extremely valuable in providing warning of local flooding. Water vapor is also thought to be a sensitive indicator of temperature. If the correlations can be established, GPS-based measurements of water vapor will provide global, timely data on temperature changes much more easily than traditional temperature measurements.

Public Safety and Disaster Relief. The use of GPS in public safety and disaster response to include search and rescue has changed these activities in fundamental ways and saved countless lives around the globe. One of the greatest challenges in search and rescue, performing accurate, comprehensive and efficient search, has become almost routine with GPS-equipped aircraft or search parties. Once located, either by search or by a GPS-aided emergency locator beacon or other signaling device, rescue teams can be deployed quickly to the exact location where they are needed.

GPS has played a vital role in relief efforts for global disasters such as the tsunami that struck in the Indian Ocean region in 2004, Hurricanes Katrina and Rita that wreaked havoc in the Gulf of Mexico in 2005, and the Pakistan-India earthquake in 2005. By knowing the precise location of landmarks, streets, buildings, emergency service resources, and disaster relief sites using GPS, support teams were geolocated on a real-time basis across the entire scene, allowing for mutual support and avoiding duplication of effort. Further, search and rescue teams used GPS along with geographic information systems (GIS) and remote sensing technology to create maps of the disaster areas for rescue and aid operations and to assess damage. Another important area of disaster relief is in the management of wildfires. To contain and manage forest fires, aircraft combine GPS with infrared scanners to identify fire boundaries and "hot spots." Within minutes, fire maps are transmitted to a portable field computer at the firefighters' camp. Helicopters also use GPS to map the perimeter of forest fires and have become critical to the effective and efficient management of fire fighting resources in saving lives, homes, and resources.

As the international industry positioning standard for use by emergency and other specialty vehicle fleets, GPS has given managers a quantum leap forward in efficient operation of their emergency response teams. The ability to effectively identify and view the location of police, fire, rescue, and individual vehicles or boats, and how their location relates to an entire network of transportation systems in a geographic area, has resulted in a whole new way of doing business. Location information provided by GPS, coupled with automation, reduces delay in the dispatch of emergency services. In addition, today's widespread use of GPS systems in passenger cars provides another leap in developing a comprehensive safety net. This information, when coupled with automatic communication systems, enables a call for help even when occupants are unable to do so. In short, GPS has become an integral part of modern emergency response systems throughout the world--whether helping stranded motorists find assistance or guiding emergency vehicles.

An adjunct to surveying applications is the use of GPS for real time monitoring of earth-crustal movement. In California, USA, there is a network of over 250 precision GPS receivers that measure fault movement with accuracies of a millimeter better in three dimensions. This allows scientists to observe the buildup of stresses in the earth crust that leads to earthquakes. Other earthquake prone areas around the Pacific Rim are using GPS in a similar way. Japan has established a network of over 600 precision monitoring stations. Precise predictions of earthquakes are not yet possible, but, using GPS, the risk probabilities can be assessed more accurately.

Recreation. GPS has eliminated many of the hazards associated with common recreational activities by providing a capability to determine a precise location. GPS receivers have also broadened the scope and enjoyment of outdoor activities by simplifying many of the traditional problems, such as staying on the "correct trail" or returning to the best fishing spot.

Outdoor exploration carries with it many intrinsic dangers, one of the most important of which is the potential for getting lost in unfamiliar or unsafe territory. Hikers, bicyclists, and outdoor adventurers are increasingly relying on GPS instead of traditional paper maps, compasses, or landmarks. GPS technology coupled with electronic mapping has helped to overcome much of the traditional hardships associated with unbounded exploration. GPS handsets allow users to safely traverse trails with the confidence of knowing precisely where they are at all times, as well as how to return to their starting point.

SUMMARY

The above overview of GPS applications is by no means comprehensive in describing how GPS benefits the lives of countless people around the world. Every day, new uses of GPS are being discovered or invented and are limited only by the creativity and ingenuity of the human imagination. GPS is projected to enable a $70B global industry by 2013. The human benefits are incalculable. Our world has been changed forever by GPS.

No other single space project, program or system has led to human benefits that are even remotely close to those that have resulted from GPS.