GLOBAL POSITIONING SYSTEM

Market Projections and Trends in the Newest Global Information Utility

The International Trade Administration
Office of Telecommunications
U.S. Department of Commerce

Acknowledgments

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Any errors are solely the responsibility of the authors.

This report has been prepared for, and with the cooperation and support of, the International Trade Administration, Office of Telecommunications, U.S. Department of Commerce. Within the International Trade Administration, the Office of Telecommunications covers issues including (but not limited to): satellite telecommunications services (both fixed and mobile), direct broadcast satellite services, GPS, satellite manufacturing, satellite parts, and satellite ground equipment. The Office of Telecommunications acts to support the growth and competitiveness of the U.S. telecommunications (including satellite) industry by: promoting international trade and investment opportunities for the U.S. industry; providing business counseling to U.S. telecom firms seeking to enter specific country markets; advocating on behalf of U.S. telecom firms; and by conducting market research (such as this report on market trends and opportunities in GPS) and statistical analysis of the domestic and international telecom industry.

It is hoped that this report will help U.S. companies participating in or entering the industry to better gauge its growth both in terms of GPS applications and regional developments.

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Executive Summary

The Global Positioning System (GPS) is a constellation of satellites that broadcast signals that can be used to derive precise timing, location, and velocity information. The derived information (time, position, and velocity) may be combined with other systems such as communications devices, computers, and software to perform a variety of tasks. With appropriate equipment, ranging from small, hand-held receivers to large, rack-mounted electronics, anyone can utilize the Global Positioning System (GPS) signal, anywhere in the world, at any time. GPS was originally developed for the U.S. military and came to wider public awareness as a result of the 1991 Gulf War. Today, it continues to be a “dual-use” resource serving allied forces and a growing number of civilian users world-wide. In March 1996, President Clinton issued the first comprehensive statement of GPS policy in which the United States formally committed itself to providing civil GPS signals free of charge to the world.

GPS technology has made increasing contributions to the global economy in the last decade. 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. Like the Internet, GPS is an information technology that is part of the emerging Global Information Infrastructure. GPS-based precision time signals help synchronize global information networks of fiber optics, coaxial cable, copper wire, radio, and even communication satellites. GPS applications are generating both commercial products and information services which increase productivity in diverse public service applications and enhance national and even personal security.

The purpose of this report is to provide a current view of the commercial status and trends of the industry which developed since the Global Positioning System (GPS) signal was first made available to civilian users in 1984. One of the most widely published market estimates to date was done in 1995 by the U.S. GPS Industry Council (USGIC). In seeking to determine how GPS markets have evolved in the past three years both in terms of applications and regional trends , the USGIC, the Japan GPS Council, and individual companies participated in a market survey conducted for this report. In this survey, industry participants were asked to provide an overall market outlook and describe the key characteristics of this rapidly developing industry.

There is no standard definition of GPS market sectors, but the following sectors were identified for purposes of this study:

- Consumer/Recreational
- Military
- Avionics/Aviation
- Automotive/Intelligent Vehicle Navigation
- Tracking
- Public Safety
- Agriculture
- Mining
- Construction/Civil Engineering
- Marine (including Survey)
- Timing

The number and type of firms involved in providing GPS goods and services are as diverse as the GPS applications themselves. In 1997, a total of 301 firms listed themselves as providing some sort of GPS-related good or service compared to 109 in 1992; the year after the Persian Gulf War brought broad recognition to GPS. The number of firms counted is likely to be conservative as one moves away from those producing GPS-specific products to firms who use GPS but who do not identify themselves as GPS firms per se.

The GPS market is made up of a spectrum of competitors ranging from mid-sized commercial electronic companies; aerospace, first-tier automotive suppliers, and consumer product companies. GPS car navigation markets are dominated by first tier automotive electronic suppliers. The handheld equipment markets are led by three firms: Garmin, Magellan, and Lorrance. The military and aviation markets are largely served by aerospace firms such as Rockwell, Honeywell, Allied Signal, and Boeing. Commercial marine suppliers include the traditional heavy-industry suppliers such as Raytheon, Sperry, Krupp, Atlas, Furuno, JRC and Koden. Survey, construction, and tracking are commercially-driven and led by Trimble and Ashtech. Trimble is also very strong in the tracking market in which system integration skills are crucial, and is moving into control of heavy mobile machinery. In the relatively small timing market consists of commercial GPS companies working in alliance with larger companies to manage communication networks. The GPS manufacturing industry, including some semiconductor manufactures such as Motorola, is going through consolidation and substantial change. Direct manufacturing represents less than half of all industry revenues and this share is expected to decline in the future as system integration and value-added services grow in importance.

The following are highlights for the period 1998-2003:

- Total growth for the market is expected to remain robust with an average growth rate of just under 25% during 1998-2003.
- Global sales are on-track to exceed $8 billion by 2000 and are could exceed $16 billion by 2003.
- The relative U.S. share of the world market will decrease as a result of GPS consumer products being increasingly sold through multinational consumer product companies;
- During the early portion of the period, Japan's share should expand slightly as a result of increasing car navigation sales, but flatten later in the period as markets saturate;
- In Europe, rapid growth in car navigation is expected throughout the period while the defense market share declines after 2000; and
- The consumer GPS market will begin to build rapidly toward the end of the period as lower-priced GPS capabilities are embedded in mass market goods.

The cost of the basic GPS chipset has continued to decline steadily, leading to the relatively thin profit margins found in other areas of high-volume consumer electronics. High-margin GPS products tend to be those with specialized software content or where GPS provides crucial functionality to a high margin product or service. For example, a $65 chip set provided by a GPS OEM may be the core of a $600 car navigation device that pays for itself in saved time and driver convenience. Relatively few firms compete to provide the core GPS technology, but a large number of firms provide GPS-enhanced products, and an even larger number compete using GPS-based advantages. The vast majority of car navigation devices are manufactured in Japan and Europe.

As with many other areas of information technology, such as computers, the government played a crucial role in the initial research and development that led to the first working GPS receivers. Today, however, the military receiver market is a relatively small portion of overall product sales, and new GPS products and services are being driven by purely commercial market forces. GPS-based positioning and navigation are being blended with mobile communications services, currently cellular and, in the future, mobile satellite services. Users of GPS tend to become reliant on it for commercial as well as safety-of-life purposes and expect 24 hour per day, 7 day a week availability. Accuracy is addictive as well with consumer expectations that accuracy will never decrease and will hopefully increase in the future. Some, but not all, customers seem willing to pay for the enhanced accuracy that can be delivered through space and ground-based GPS augmentation systems.

The growth of civil GPS applications and user equipment represents a very pure form of market competition in that GPS signals are provided as a free public good. There is no limit to the number of potential users and the marginal cost to the system of an additional user receiving a GPS signal is zero. Unlike even air or water, GPS signals are not a resource which creates “haves” and “have nots.” Government has developed and bought GPS equipment for military purposes while commercial industry and customer investments have created the wide range of civil applications seen today.

The current role of government in global competition for GPS-related sales is relatively limited, largely involving regulatory matters such as certification of GPS in safety-of-life applications and export controls on military-grade GPS equipment. In terms of promoting the growth of commercial GPS markets, the most important U.S. government actions are those which enhance international confidence in the stability, reliability, and integrity of the basic GPS signal. This can take various forms, from obvious measures such as stable funding and careful technical management of the GPS constellation to more subtle factors such as protecting the international spectrum allocation for GPS and balancing military, civil, and commercial interests in creating enhancements and augmentations to the basic GPS signal.

Introduction

With appropriate equipment, ranging from small, hand-held receivers to large, rack-mounted electronics, anyone can utilize the Global Positioning System (GPS) signal, anywhere in the world, at any time. GPS is a pervasive, space-based signal that can provide precise timing, location, and velocity information. There is no limit on the number of people who can use GPS, just as any number of receivers can tune in to a commercial TV or radio station.

The first applications for GPS were for national defense and GPS remains an essential part of national defense for both the United States and its allies. In parallel with its military uses, the GPS signal has become an essential element of commercial enterprises as diverse as electric power distribution, land survey, car navigation, and the management of telecommunications networks. The explosive growth of the application of this information technology is still in an early stage of development and as this report indicates, can be expected to grow and evolve rapidly for the foreseeable future.

In commissioning this report, it was the intent of the U.S. Department of Commerce's Office of Telecommunications to provide a current view of the commercial status and trends of the industry which developed since the Global Positioning System (GPS) signal was first made available to civilian users in 1984. Various forecasts of GPS markets have been made over the years. One of the most widely published estimates was made by the U.S. GPS Industry Council (USGIC) in 1995. In seeking to determine how GPS markets have evolved in the past three years, the USGIC, the Japan GPS Council and individual companies furnished detailed information in response to a market survey conducted for this report. In conducting the survey, industry participants were asked to provide an overall market outlook and describe the key characteristics of this rapidly developing industry as they saw them.

GPS World, a major industry publication, made available its extensive database of industry participants and its latest version of the categories within which the industry classifies its business. This has been used in the survey (see Section II Market Development) to help better identify the scope and depth of the diverse commercial offerings found in the market. It is only through the cooperation of all participants that the market projections included in Sections I and II of this survey could have been prepared.

The following sections discuss how GPS and various augmentations to GPS work, what the current commercial markets look like, how they are expected to develop over the next few years, and what are likely to be the most important factors affecting the growth of commercial GPS markets.

How GPS Works

The GPS system is fully operational with 24 satellites, a master control station in Colorado, and five monitoring stations around the world. The satellites, developed by the U.S. Department of Defense (DoD), are in orbits 11,000 miles above the earth, circling the earth twice a day. This satellite constellation is designed so that there are at least four satellites above the horizon for every point on earth. The orbits are precisely maintained by the master control stations and the ground-based monitoring network. The “health status” of each satellite is continually updated and provided to receivers along with the GPS signal itself.

GPS satellites transmit two different signals: the Precision or P-code and the Coarse Acquisition or C/A code. The C/A is less accurate and easier to acquire than the P-code. The P-code is designed for authorized military users and provides what is called the Precise Positioning Service (PPS) with an accuracy of better than 20 meters. The C/A code is designed for use by non-military users and provides what is called the Standard Positioning Service (SPS), providing accuracies of about 100 meters or better.

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 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 (See Figure 1). GPS velocity measurements are made by taking the rate of change of pseudorange measurements over time. These pseudorange rate measurements are performed by noting the difference in phase measurements (i.e. the average Doppler frequency) over a given time interval.

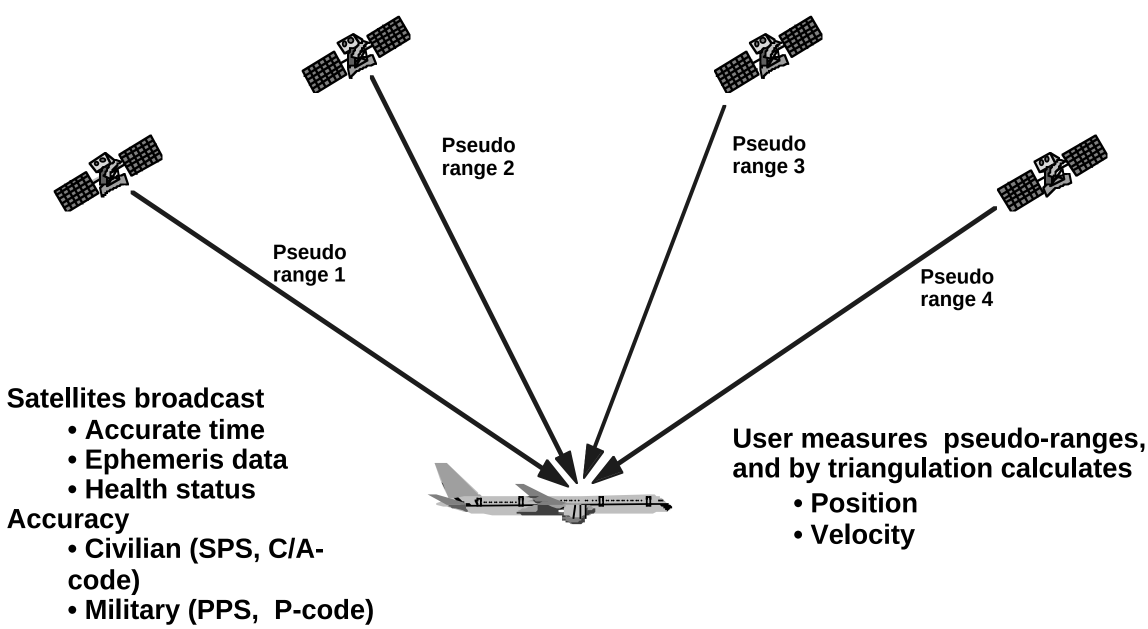

Figure 1 - How GPS Works

GPS receivers maintain an ‘almanac’ stored in their computer, which is used to determine where each satellite will be in the sky at any given time. Each of the satellites passes over one of the five monitoring stations twice a day. This provides the opportunity to precisely measure the altitude, position and speed of the satellites. Variations between the almanac and the actual satellite position are known as ephemeris errors. They are usually very minor and are caused by factors such as gravitational pull from the moon and sun and by the pressure of solar radiation falling on the satellites. Once a satellite’s position is measured, that data is relayed back to the satellite which broadcasts the corrections, if any, along with timing information. Thus the satellites transmit both a timing signal and a “data message” regarding exact orbital locations and the “health” of the satellite.

To assure that the satellite and receiver are synchronized, an accurate clock is needed. Each satellite has four precise atomic clocks while the receivers use less expensive, moderately accurate clocks. Even with accurate atomic clocks, some sources of error are inevitable - such as ionospheric and tropospheric delays. By using established models of the atmosphere, these errors can be largely eliminated by civilian GPS receivers. Military receivers, which can access the C/A code on two separate frequencies, are able to correct for actual atmospheric effects in real-time.

For many applications, greater accuracies are needed than is possible with GPS alone, e.g., positioning accuracies of a few meters of even centimeters. Differential GPS (DGPS) is a method of operating GPS that allows a user to obtain extremely high accuracies, as illustrated below (Figure 2). 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.

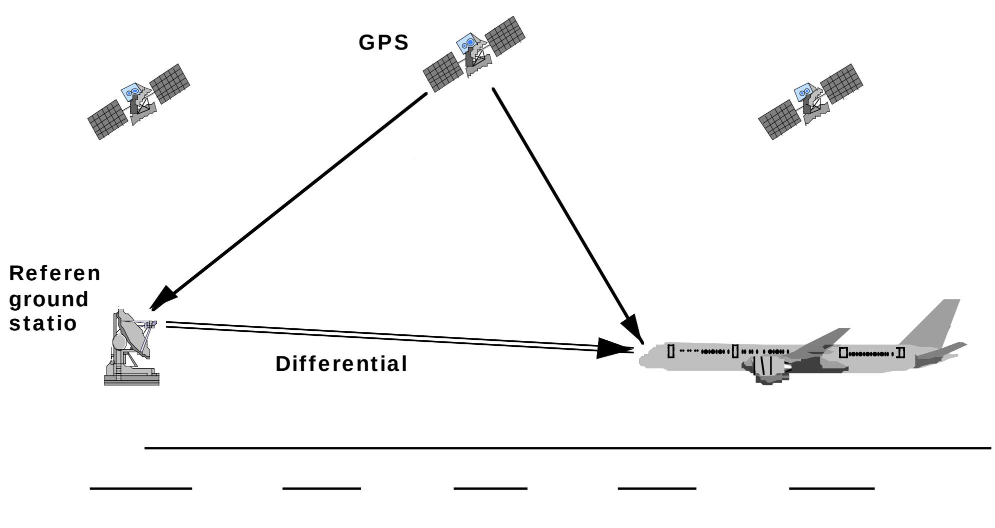

Figure 2 - Ground-based Differential GPS

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. Those correction terms allow the roaming user to eliminate the bias errors in the GPS signals from the satellites they are using. Reference stations can be relatively inexpensive, as in the case of a single station used for simple land surveys or part of extensive networks that provide accurate corrections over large areas for international transportation needs.

In the 1970s, tests of early GPS satellites showed that the civilian signal (using C/A code on a single frequency) was more accurate than expected. It was feared that this accuracy could be exploited by military forces hostile to the United States. As a result, the civil signal has been intentionally degraded by a technique known as Selective Availability (SA). SA introduces errors into the clock of each satellite ("dithering") which have components that vary both rapidly and slowly over time and it varies the orbital parameters reported in the GPS data message. Because both components of SA have slowly varying errors, it is difficult to distinguish between them. The net effect of SA is to make the pseudorange calculations less precise and create errors in calculated position. The spread of differential GPS systems has lessened the military effectiveness of SA, however, and the Department of Defense is reported to be preparing for a time in which SA will be turned to zero during peacetime, to occur no later than 2006.

GPS An Information Technology

GPS is a form of information technology in that it uses systems of hardware, software as well as information (time and ephemeris) transmitted from satellites to provide derived information to users. The derived information (time, position, and velocity) may be combined with other systems such as communications devices and computers (geographic information systems for example) to perform a variety of tasks. The first application began by answering the question of "Where am I?" and with the addition of communications was able to answer "Where are you?" questions. Most recently, GPS is being used to answer "Where is it?" for applications in tracking assets and discrete types of data.

"Where am I? applications involve the most visible kinds of GPS equipment such as hand-held receivers used by hikers, drivers, and pilots and surveyors. Information such as latitude, longitude, altitude and time are provided from a GPS receiver for further action by the user. The information may be translated into more easily understood forms, such as position relative to an existing map of terrain or streets; or used to provide relative information such as distances to user-defined "waypoints" e.g., positions that are specifically identified by the user. Applications by surveyors and hikers are mirrors of each other. In the case of a hiker, the person wishes to know his position relative to the terrain. In the case of a surveyor taking control points over an unknown area, a person wishes to precisely describe where he has been. Both applications use GPS-generated information directly.

"Where are you?" applications occur when GPS information for multiple users is 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. As noted above, the

GPS user may convert basic time and space information into a more useful form before it is communicated. Some insurance adjusters, evaluating fire damage in a residential neighborhood, have GPS receivers combined with laptop computers, digital cameras, and cellular phones. A standard form is filled in on the computer, a digital picture is attached to the file, and GPS is used to determine the location address of the damage. All of this information can then be communicated rapidly to a central location, allowing more efficient processing of claims. In some cases, an application need not require deliberate action by a GPS user. GPS receivers have been integrated into automobile airbag and cellular phone systems. In the event the airbag detonates, the phone automatically contacts emergency services and reports the location of the detonation relative to local highway maps.

“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. These applications may be thought of as variations on the previous two categories. GPS receivers may be used to ask “Where are you?” when the object is a scientific instrument or cargo that cannot communicate its position by itself and is out of direct human contact. GPS may be used to provide input to remote machinery that has some autonomy, as for example, when GPS-based navigation systems provide position updates to heavy equipment operating in an open pit mine. Self-correcting actions by remote machines can in turn lower the workload of central monitoring facilities by providing equipment status reports (e.g., calls for preventive maintenance or repair). In these case, GPS becomes deeply embedded in a large system and enhances productivity in a way that can be invisible to the human operator.

Like the Internet, GPS is a valued utility for the emerging Global Information Infrastructure. GPS is a distribution system for precision time signals that help synchronize global information networks of fiber optics, communication satellites, radio, coaxial cable, and copper wire. The use of precise GPS timing signals is largely invisible to the consumer in that the use of precise time is embedded in products, such as mobile computers as well as new generations of “smart” munitions. Most would be unaware that the financial data that we receive from domestic and international sources so readily is dependent on accurate synchronization of data streams providing such information. The precise GPS timing signal is increasingly necessary for this function. This is just one instance of the GPS signal being embedded in an application essential to daily commerce.

GPS has taken its place in contributing to the economy over the last decade. Hundreds of uses of GPS now exist including stand-alone applications such as surveying and navigation and theless recognized embedded applications. GPS applications are generating both commercial products and information services which increase productivity in diverse public service applications and enhance national and even personal security. Table 1 is a sampling of these applications. The following sections discuss the current status of commercial GPS markets and the forces driving them.

Table 1 Selected Applications of GPS

AVIATION

• Precision and non-precision all-weather approaches (WAAS)
Regional airlines, the fastest growing segment of the avionics industry, are using GPS to provide precision navigation for point-to-point flights, which saves time and fuel and also increases overall safety.

• Direct routing for aircraft fuel savings
Operational costs of airline fleets are reduced with more efficient real-time flight planning.

• Local, national and international enroute navigation
Airlines all over the world are retrofitting aircraft with GPS-based navigation systems.

• Closer aircraft separation standards for more efficient air traffic management.

• Precise airfield and landing aid to all airports, regardless of development

• Airport surface traffic management

• Inflight monitoring of position/location

• Arctic navigation
GPS is used for navigation near the magnetic pole, because compasses cannot be used, as well as GPS providing a navigation system that is not dependent on land-based radio systems.

• Seamless (global) air space management

• Monitoring of wing deflection in flight

• Wind shear detection

• Less expensive/more accurate avionics

• Enhanced Loran-C in-flight navigation

• Pilot instruction and education
Embry Riddle, one of the world's leading aviation training schools, uses GPS to provide guidance for flight training operations. GPS tracks actual flights and allows pilots to analyze their own performance.

• Search, location and rescue of downed aircraft and pilots
During the production of a television show called Braving Alaska," a small biplane went down just a few miles north of Vancouver, Canada. Rescue pilots would not have been able to find the crash in the dense forest growth without the GPS coordinates supplied by rescue workers on the ground. GPS was also instrumental in rescuing Air Force Captain Scott O'Grady, the American pilot downed in Bosnia.

• Flight procedure and navigational aid testing
GPS is used to test the accuracy of current aviation navigation aids. GPS receivers are used by the FAA in its flight inspection fleet.

• Affordable, accurate landing systems for developing nations and small and/or remote airports
In China, GPS is playing an important role in the modernizations of the country's air travel infrastructure. The airport at Juneau, Alaska is surrounded by a rugged mountain range and known for its difficult approaches. The installation of a differential GPS landing system has significantly increased landing safety.

Potential Civil, Commercial and Consumer use for GPS in aviation

COMMUNICATIONS

• Precise timing for network security protocols
GPS timing provides critical timing data for secure Internet messages, Public Safety Answering Point technology and setting times on computer networks.

• Wide-area synchronization of high-speed networks

• Precise timing and synchronization for wireless local loop systems

• Synchronization of power plant generators for electrical phase matching throughout power grids

• Validation of information transmission
A large, international investment bank users GPS to time trades on its worldwide network. The GPS information ensures the price of a trade by adding a precision time stamp to trade information.

• Tagging of information for time-delayed transfer to data ports

• Network management and control
A U.S. firm equips its paging network towers with GPS sensors to manage the time transfer of messages and get networks up and running quickly after failures.

• Timing of national broadcast programs with local advertising
CBS and its national affiliates use a GPS-based system to coordinate national broadcast programs, such as sports events or live news programs, with local commercials during programming breaks

• Home application/appliance timing

• Mobile use position determination for rapid linking to Personal Communication Systems (PCS)

• Cellular signal strength mapping
Using GPS and cellular testing equipment, network operators can map the strength of cellular signals and then use that information to increase system reach and capability.

• Stochastic networking among cooperative mobile platforms

• Differentiation of wireless mode: cordless, cellular, satellite, etc.

• Precise timing and synchronization for CDMA systems.

• Personal navigation and reporting

Potential Civil, Commercial and Consumer use for GPS in communication

ENVIRONMENTAL PROTECTION

• Ground mapping of ecosystems
GPS is used to map all manner of ecosystems, from eel grasses in the Puget Sound to coastlines in Louisiana.

• Overviews of environmental phenomena
Comprehensive views of deforestation, as well as environmental phenomena in lake, rivers and estuaries, are analyzed and through overviews of a variety of spatial features that are referenced to GPS-derived coordinates.

• Preventing ground water pollution
GPS is used to perform exact location inventories of wells and potential contamination sources and map the migration of toxic plumes in ground water.

• Monitoring health of the food chain
If microscopic plankton die, marine life higher on the food chain also perish. GPS is used to collect scientific samples for studies on the effects of ultraviolet radiation and other hazards on bacterioplankton.

• Air pollution measurement
GPS receivers were coupled with gas sensors to map positions of air pollution concentrations to correlate satellite data with ground-based samples.

• Mapping of sub-surface contamination
GPS was used to map pollutants in Arctic ice. Results showed that even in the remote arctic, industrial chemicals have penetrated into the ecosystem.

• River management to avert natural disasters
In Paraguay, GPS is used to detect natural canals and precisely determine the height of new channels to facilitate correct sediment deposit, and thereby controlling water flow and preventing floods.

• Flood control facilities
GPS is used to plan, design, construct, and maintain needed flood control and drainage facilities and to protect and increase the quantity and quality of groundwater in many parts of the Western United States.

• Oil spill tracking and cleanup
The National Oceanic and Atmospheric Administration (NOAA) uses GPS affixed to buoys to track the movement of oil spills and monitor how fast a spill is spreading. This information helps to manage the work of emergency crews more efficiently

• Management and maintenance of roads
Using GPS, Italian companies have developed a system of computers and imaging equipment to gather information about road networks with inventories of features and attributes required for administration and maintenance.

• Hazardous waste site investigation
With the protective gear necessary at a hazardous waste site, it is difficult to use conventional surveying techniques. GPS is often used to perform real-time surveys using digital terrain modeling at sites heavily contaminated with asbestos, lead dust, PCBs and other hazardous materials.

• Precise location of stored hazardous materials
GPS is used in Department of Energy efforts to stabilize nuclear wastes from the Rocky Flats nuclear weapons plant, which operated from 1950 to 1980. Surveyors and engineers used GPS to precisely map the locations of hazardous waste sites.

• Time-tagging of hazardous materials spills or other incidents

• Time-tagging of dredge dumping operations
GPS was used on drainage barges to tag location and time of dumping to ensure adherence to Environmental Protection Agency (EPA) regulations and public safety concerns.

• Monitoring of natural gas and oil pipelines
A German firm has used GPS to develop intelligent pipe corrosion detection tools. GPS provide extremely precise information on defect locations so that operators can quickly repair dangerous flaws and problems.

Potential Civil, Commercial and Consumer use for GPS in environmental protection

FORESTRY AND AGRICULTURE

• Forest area and timber estimates
GPS is used to map timber block cut areas to avoid costly traditional surveying and to verify instances of intentional over-harvesting.

• Protecting endangered species
GPS is used to map endangered species habitats and track migratory patterns.

• Instant mapping of fire perimeters
GPS mapping receivers are used in helicopters to fly the perimeter of fires for dynamic mapping, which allows more efficient use of firefighting resources, as well as saving forests and homes.

• Forest fire tracking and containment
Using GPS and weather service maps, fire fighting aircraft are able to investigate lightning strikes to see if a forest fire has been started. If a fire is found, the pilot records the location and then brings the data back so that fire containment operations can go right to the fire location.

• Precise plowing, planting, fertilizing and other farm uses
GPS data is collected in the field to control weeds and disease, as well as mapping field boundaries, roads and irrigation systems. Variable rate application of fertilizer in orchards and vineyards can be done in combination with GPS mapping. Minimizing application of fertilizer prevents ground water runoff into streams.

• Unmanned (robotic) harvesting and plowing
At Stanford University, graduate students are working on an experimental autopiloted tractor that could work in any weather, 24-hours a day.

• Precision crop dusting by aircraft
In Chile, crop dusters can spray pesticides on banana plantations without using row-end human flaggers to guide pilots. Instead, GPS guides the pilot showing when the end of a field or area has been reached. Workers avoid exposure to highly toxic agricultural chemicals. In California, GPS is used to help pilots control aerial application of pesticides and other chemicals on crops and minimize the spray drift of chemicals.

Potential Civil, Commercial and Consumer use for GPS in forestry and agriculture

<u>GROUND TRANSPORTATION</u>

• Intelligent Transportation System - ITS
In Albuquerque, New Mexico, the Transit Department used GPS to build an integrated ITS architecture that includes GPS Automatic Vehicle Location (AVL) systems, wireline and wireless communications and Geographic Information Systems (GIS) data. This intelligent transportation architecture provides tracking, monitoring and scheduling systems for fixed route buses, vans, and paratransit vehicles in the city.

• In-vehicle wireless voice systems
The Queensland, Australia train system uses an automated GPS-based system to announce stops to onboard passengers and provide train locations to waiting passengers.

• Truck fleet on-the-road management
More than 225,000 trucks worldwide are scheduled, tracked and monitored using satellite-based communications and GPS. These systems improve service and fleet communications. A Dutch trucking company uses GPS-based automatic vehicle location system to schedule and track trucks delivering perishable produce to market before it spoils. In the United States and Mexico, cement suppliers use GPS and fleet management software to more efficiently route cement trucks to work sites. This enables more efficient use of the trucks and improves service over a wider area.

• Courier dispatch services and vehicle location
A courier service streamlined its response time for customers by knowing where every delivery vehicle is at any time.

• Cargo fleet tracking and security
Truck fleets use GPS to achieve efficient routing and scheduling. In addition, trucks carrying dangerous or high-value cargo can be tracked to protect against hijacking.

• Commercial vehicle fleet communications and tracking
Vehicle fleet operations use GPS-based automatic vehicle systems to track everything from taxis to tow trucks. In Australia, GPS units include an emergency response system that protect driver safety. Pushing the button sends a location stamped message to dispatchers who can contact police with the exact location of the incident.

• Improved public services, including taxi and public transportation systems
In Singapore, callers to a taxi service use a system that automatically sends a message to the closest cab. GPS is used to constantly update the system on cab location so it can find the nearest vehicle to the caller. GPS-based AVL systems also improve scheduling and management of bus fleets, subways, monorails and other public transportation systems. In some cities, GPS is used to map and manage school bus routes for more efficient and safer student transportation.

• In-vehicle navigation and telematics
GPS-based systems integrated with computer technology provide drivers with traffic, weather and location information, including "You Are Here" mapping displays. In Japan, drivers use these systems to avoid or compensate for traffic jams and delays.

• Accident location studies
Some police departments are using a pen-based computer system to collect data on accidents. The system uses data provided by GPS units in police cruisers to accurately record the date, time and location of an accident and link that information to Emergency Medical Service (EMS) records. GPS mapped data is used to study high accident areas and develop potential solutions to improve highway safety.

• Highway construction
GPS is used in all phases of highway construction. Survey data is used to design construction projects. Real-time GPS data is used to provide precision guidance and monitoring to heavy machinery during construction.

• Monitoring status of bridges
High accuracy GPS survey receivers are installed at critical locations on bridges to measure deflection and deformation. This data is used to engineer reinforcements to ensure bridge integrity and safety.

• Railroad fleet monitoring
Positive train control is being implemented in the United States through the deployment of a nationwide differential GPS network based on vacated Air Force emergency communication sites.

• Train control and collision avoidance
A GPS-based separation system is being developed that will help trains avoid collisions. Using GPS information, the fully automated separation system will activate a warning aboard trains that are about to get too close to one another.

Potential Civil, Commercial and Consumer use for GPS in ground transportation

<u>HEALTH CARE</u>

• Tracking disease spread/distribution

• Immediate position/location of medical personnel and specialists

• Insect infestation mapping
The University of New Mexico mapped insect infestations in 11 Western states. The data yielded

patterns that enabled disruption of insect life cycle, saving crops and reducing the use of insecticides.

• Epidemiological mapping
In sub-Saharan Africa, malaria causes the deaths of more than 1.5 million children annually. In a 1995 study, the Center for Disease Control (CDC) in Kenya used GPS to create a GIS of households, mosquito breeding sites, local health clinics, and permanent and seasonal rivers. Entomology and childhood mortality databases are linked to the GIS so that researchers can study the relationships between disease data and geographic factors.

• Personal navigation for blind persons
A system that uses synthetic speech connected to GPS location data is being developed at University of California, Santa Barbara. This audio system will actually 'tell' sight impaired individuals where they are and will use volume to indicate proximity to a land-mark.

• Transportation of physically handicapped individuals
San Francisco-based Open Hand uses a GPS-based AVL system to schedule and track its fleet of vans.

• Tracking of Alzheimer and other patients
A Florida-based company has developed a GPS personal tracking system that tracks the whereabouts of the individuals wearing the device. This system is being used in a multitude of applications, including the tracking of Alzheimer's patients.

Potential Civil, Commercial and Consumer use for GPS in health care

LAW ENFORCEMENT AND SAFETY

• Dispatch of ambulance, police and fire department personnel and equipment
GPS-based AVL systems are used to improve the responsiveness and efficiency of emergency services. These systems save lives by shaving minutes off the time between a call and the arrival of an emergency team at an accident or incident site. GPS navigation reduces the occurrence of EMS vehicles becoming lost en-route to difficult addresses.

• Search and rescue operations
GPS-aided accuracy improvements enables greater resource concentration on the rescue itself. In Iceland, GPS-equipped snowmobiles are used in search and rescue operations. GPS allows emergency personnel to conduct rescues in bad weather and precisely guide medical care to victim locations.

• Locating contraband or illegal substances
Law enforcement agencies use GPS to track and locate narcotics operations. GPS is used to mark the locations of isolated marijuana fields from the air. Then agents can find the locations on the ground using the GPS coordinates.

• Tracking/recovery of stolen vehicles
GPS is used to help police find stolen and hijacked cars and vehicles.

• Locating disabled vehicles for road services
GPS-tagged cellular phone calls help towing services find disabled vehicles.

• Search and rescue
GPS positioning data is combined with virtual reality software to build three-dimensional models of search areas to assist rescue personnel in finding lost vehicles and aircraft. The California Rescue Dog Association used GPS to determine exactly where dogs have searched to identify areas that were not sufficiently covered.

• Bomb sniffing
Researchers in Washington, D.C., are developing sensor devices which, coupled with GPS equipment helps detect unexploded ordinance on military installations and remediation sites around the world.

• Enhanced 911 (E-911) services
Enhanced 911 provides information on caller loca-tions by querying a telephone company database of addresses matched to phone numbers. In Oregon, GPS was used to build highly accurate databases of mapped addresses that provide the foundation of the state's E-911 system.

• Security of high government officials and dignitar-ies while traveling
In high-risk countries GPS is used to provide security and safety for senior government officials. Similarly, GPS is used to track VIPs at large events, such as the World Cup championship games.

• Border surveillance

• Emergency evacuation planning.

• Natural disaster damage assessment
GPS systems help map and assess the aftermath of natural disasters, including floods, earthquakes and fires. GPS is particularly useful when recognizable landmarks have been destroyed.

• Volcanic eruption monitoring and prediction
In Italy, the active volcano at Mt. Etna is monitored using GPS. Deformation of the cone indicates rising magma and imminent eruption.

• Earthquake monitoring and prediction
High-accuracy GPS surveying receivers are being used to monitor the earth's crustal movements preceding earthquakes. In Japan, a network of hundreds of GPS stations is monitoring shifts of a few millimeters in fault lines. In the United States, GPS systems gather data for geology research projects related to land mass movement.

• Serial criminals apprehended using GPS
Police have used GPS to track the attacks of serial rapists, muggers, and robbers, leading to arrests by predicting the time and location of the next attack.

• Parolee monitoring and tracking
In Florida, law enforcement agencies are using a GPS-based system worn by parolees to track them. The system ensures that parolees do not violate their parole, and keeps constant track of their location in real-time.

Potential Civil, Commercial and Consumer use for GPS in law enforcement and safety

MARITIME AND WATERWAYS

• Emergency distress signals on the high seas
GPS and satellite communications systems are now required by the International Maritime Organization (IMO). By February of 1999, 40,000 ships will be required to carry a GPS-based system that can send out emergency distress signals that include location and time data.

• GPS and INMARSAT
Merging GPS and INMARSAT technologies has provided vessel operators and their land-based offices with a full-range of services, such as exact position data, two-way messaging, maritime safety information and emergency notification.

• Mapping underwater obstacles during hydrographic surveys
The HMNZ Ship Monowai used GPS to re-survey parts of the New Zealand coast to update navigational charts initially produced by the Royal Navy in the 19th century. GPS coastal and harbor surveys provided better than three-meter accuracies, and deep-water surveys were accurate to approximately 15 meters.

• Search and rescue
Within hours of the crash of TWA Flight 800, dozens of watercraft were on the site to provide search and rescue services. A NOAA vessel equipped with precision GPS technology was used to map the site and recover evidence. Rescue personnel use GPS help track search patterns to find drowning victims lost in rivers, lakes and oceans around the world.

• All weather harbor navigation approach
The U.S. Coast Guard and countries all over the world use GPS to provide navigation data for coastline and harbor navigation, as well as to position navaids and buoys on the coast and inland waterways.

• Vessel traffic services

• Precise navigation of inland waterways

• Harbor facility management
In Dubai (United Arab Emirates), GPS-based systems are used to schedule delivery and loading of containers at one of the busiest ports in the world. In Los Angeles, American Presidents Line is managing a brand new facility using a high-tech system that includes GPS-based container tracking.

• Locations of shipping containers and auto-piloted barges
GPS-based systems keep track of containers and auto-piloted barges to ensure cargo safety.

• Enhanced Loran-C marine navigation

• Dredging of harbors and waterways
GPS is being used in a dredging operation on the Panama Canal and at hundreds of other locations around the world.

• Offshore drilling research and exploration

• Ship trials and testing

• Monitoring icebergs and rouge flows

• Precision ice breaking operations

• Observing tides and currents.

• Location of commercial fishing traps and nets
GPS is used to map and navigate to oyster beds. Commercial fishing operations also use GPS to mark the location of productive fishing sites.

• Enforcement of international fishing rights
GPS data has been introduced in international courts to resolve disputed fishing claims. Boats caught poaching can also be required to install GPS-based tracking systems so they can continue to be tracked after they pay their fine.

Potential Civil, Commercial and Consumer use for GPS for maritime and waterways

MINING AND CONSTRUCTION

• Electronic marking of geological sites and events

• Accurate stockpile record keeping
Accurate, repeated GPS surveys of ore and coal stockpiles permit frequent volume calculations and greatly improved stockpile management.

• Precision location for mine surveying
In Indonesia, GPS is used for better scheduling and achieving better throughput at the terminal of unmanned coal barges from several remote areas. Scheduling is complicated by a variety of factors, such as different barge sizes, unloading into an area for the correct grade of coal, various barge journey times, varying loading times at the mines and terminal, and railroad scheduling at the terminal.

• Bridge and other marine construction operations
In Korea, GPS-based technology was used to install with centimeter precision the pre-built center-arched 150-meter span of the Seo-Kang Grand Bridge. An earlier span, incorrectly positioned, had failed and fallen into the river.

• Cost-cutting and increased productivity in open cut mines
Real-time surveys in Queensland, Australia are used for local planning and control, topographic and detail work in open cut mines. Machine guidance is the next step in GPS for mining, road construction, rough grading, land fill, trash and solid waste management, and other uses.

• Precision location for mining explosives
GPS-guided drilling machines follow CAD-generated plans for blast hole location. Higher precision results in more predictable blast patterns and improved productivity by blasting crews.

Potential Civil, Commercial and Consumer use for GPS in mining and construction

RECREATION/ARTS/ENTERTAINMENT

• Recreational boating and sport fishing
GPS allows boaters to know their precise position to avoid running aground, making sailing and boating safer. Allows mariners to navigate 24 hours a day in any kind of weather, including heavy fog.

• Tracking and monitoring of golfers and golf carts
ProShot Golf has developed a system that tracks golf carts and players, allowing golf courses to run more efficiently through better scheduling of tee off times and better monitoring of player locations on the course. GPS also informs golfers of the accurate distance to the cup, enabling them to better choose the correct club.

• Special effects and sound timing for film and video production
GPS is increasingly being used in filming special effects. During the production of the feature film "Daylight," GPS timing was used to mark actual footage so that special effects could be added at the right place in the film.

• GPS transfers reality into virtual reality
A San Francisco audience flew through an accurate virtual depiction of the City's terrain, including a trip across the Golden Gate Bridge in a virtual world created from GPS positioning data.

• Auto and bike race course planning
GPS is used to give some competitors an edge in pre-race planning by modeling the entire racing course.

• Navigation and safety for hikers, bikers and trekers
GPS has been used to guide many cross-continent and exploratory biking expeditions.

• Precision measurements and mapping for landscape architecture
Landscape architects use GPS to map land for planning and design of landscape architecture projects. GPS provides an inexpensive tool that produces much faster, more accurate results than hand mapping.

INFRASTRUCTURE DEVELOPMENT/MANAGEMENT

• Lower-cost, faster infrastructure development in underdeveloped countries
Using GPS, surveyors are able to quickly and accurately map large uncharted land masses and sea beds for natural resource harvesting, transportation infrastructure development and economically significant products.

• Development of geodetic survey networks
Engineers and surveyors in Russia, China, Puerto Rico, Brazil and Guam use GPS to build accurate survey networks to support development.

• Project to restore eroded beachfront
Surveys were launched by Auckland City Council in New Zealand to establish existing beach levels and to ensure correct sand replacement.

• Reducing costs on expensive ground surveys in swamps, marshes and rainforests
An oil and gas survey was conducted in Equatorial West Africa with greater accuracy using GPS.

• Oil pipeline development and monitoring
GPS was used during a to lay a 333 km pipeline in the Gulf of Thailand.

• Fiber optic cable communications
GPS positioning and navigation are used to lay fiber optic cables over thousands of miles of ocean and across undersea mountains and plains.

• Utility GIS development for strategic capital asset management
Utilities use GPS to map and manage geographically distributed capital assets. This information allows utilities to be more responsive when problems occur because the utility infrastructure is accurately mapped, and all assets are located and identified. A North Carolina utility outfitted mountain bikes with GPS mapping systems to approach and register 80,000 telephone poles and 60,000 other service features in their territory.

• GPS savings for the cable TV industry
Precise distance measurements via GPS reduce the time required to gather data for installing cable TV services.

• Development of county- and city-side GIS databases
In Dallas, TX, a city-wide GIS that includes boundary, infrastructure and demographic data is shared among 14 organizations. Using a single coordinate system for development and planning greatly lowers the cost of these activities. Researchers in New Mexico are using a GPS-based mapping system to map pueblos. Properties and facilities are mapped in an effort to improve not only tribal lands, but to improve service by law enforcement, fire, and rescue personnel.

• National Spatial Data Infrastructure
The United States is developing a common national reference system to support the many use of geospatial data by public and private agencies. GPS-based coordinate measures are a critical enabling technology for this effort.

WEATHER FORECASTING

• Measuring water vapor for weather forecasting and climate research
NOAA successfully investigated the use of measuring atmospheric water using GPS data as a reliable, continuous and low-cost measurement under any weather conditions. In this application, the highly accurate location information is disregarded. Instead, scientists study the time delay of GPS signals as they travel through the atmosphere to estimate water vapor conditions.

PUBLIC SAFETY

• The Riverside Flood Control District uses GPS to help plan, design, and maintain flood control and drainage facilities.

• The Metropolitan Water district of So. Califonia uses GPS to monitor the new Domenigoni Valley Reservoir Project, the largest earthen dam in the world.

• Lifeguard Systems Inc. uses GPS to help track search patterns to find drowning victims lost in rivers, lakes and oceans around the world.

•Landform Inc. combines GPS information with virtual reality software to build three dimensional models of search areas to assist rescue personnel in finding lost vehicles and aircraft.

Section I - GPS Market Projection 1998-2003

Industry Structure

The number and type of firms involved in providing GPS goods and services are as diverse as the GPS applications themselves. The GPS market is made up of a spectrum of competitors ranging from mid-sized commercial electronic companies; aerospace, first-tier automotive suppliers, and consumer product companies. GPS car navigation markets are dominated by first tier automotive electronic suppliers. The handheld equipment markets are led by three firms: Garmin, Magellan, and Lorrance. The military and aviation markets are largely served by aerospace firms such as Rockwell, Honeywell, Allied Signal, and Boeing. Commercial marine suppliers include the traditional heavy-industry suppliers such as Raytheon, Sperry, Krupp, Atlas, Furuno, JRC and Koden. Survey, construction, and tracking are commercially-driven and led by Trimble and Ashtech. Trimble is also very strong in the tracking market in which system integration skills are crucial, and is moving into control of heavy mobile machinery. In the relatively small timing market consists of commercial GPS companies working in alliance with larger companies to manage communication networks. The GPS manufacturing industry, including some semiconductor manufactures such as Motorola, is going through consolidation and substantial change. Direct manufacturing represents less than half of all industry revenues and this share is expected to decline in the future as system integration and value-added services grow in importance.

GPS markets are unique in the involvement of the largest U.S. aerospace and consumer electronics companies as well as venture-capital backed start-ups. There are a relatively small number of original equipment manufactures (OEM) who are capable of producing complete GPS user equipment, e.g., the integration and packaging of unique microchips and original software, such as the U.S. firms of Trimble Navigation, Orbital Sciences, Rockwell, and Motorola. There is only one company, Boeing Aerospace, which currently produces the GPS satellites themselves. On the other hand, there are a large number of firms who produce GPS-related components for the OEMs and their own lines of GPS equipment (e.g., car navigation, recreational boating) from parts produced by others. Finally, there are an even larger number of firms which use GPS to create valued-added services such as geographic information systems and land surveys.

The most comprehensive, if self-selected, listing of GPS-related firms can be found in the annual industry survey of *GPS World* magazine. In 1997, a total of 301 firms listed themselves as providing some sort of GPS-related good or service compared to 109 in 1992; the year after the Persian Gulf War brought GPS to wider public attention. The number of firms counted is likely to be conservative, and less accurate, as one moves away from those producing GPS-specific products to firms who use GPS but who do not identify themselves with the GPS market per se.

Table 2 depicts how the 301 companies in the *GPS World* database describe their participation in the market by categories of goods and services offered. The table also shows frequency of participation in major categories where a company may participate in several subcategories as well. The company participation by category without counting the multiple participation in subcategories is also shown, Table 3, in decending order of participation..

GPS Goods & Services Categories

	Total Number of Companies per Industry Segment	Actual Number of Companies per Industry Segment (Repeats removed)
	Total	Actual
ACCESSORIES	90	46
ANTENNAS	131	83
BANDPASS FILTERS	13	13
BUFFER BOXES	4	4
COMM DATALINKS	28	28
COMPUTER PERIPHERALS	21	17
DATALOGGER GPS	26	26
DIFFERENTIAL GPS	232	99
DIGITAL COMPASSES	10	10
DISPLAYS	69	46
ELECTRONIC BULLETIN BOARDS	4	4
ELECTRONIC CHARTS/MAPS	33	33
GLONASS HARDWARE/SOFTWARE	15	15
INTEGR GPS NAV EQUIP	160	87
INTEGR INSTRU W/GPS	272	117
IONOSPHERIC CALIBRATORS	2	2
LABORATORY TEST EQUIP	12	12
MAPPING	215	94
MARKET ANALYSES/REPORTS	6	6
SYSTEMS	15	15
PRECISE EPHEMERIS INFO	4	4
PUBS, GUIDES ETC.	13	13
RADIOMETERS	2	2
RECEIVER COMPONENTS	59	34
RECEIVER-PERFORM ANALY	8	8
RECEIVERS	527	148
SAT SIGNAL SIM/PSEUDOSAT	10	10
SECURITY CODE DECRYPT	5	5
SEMINARS/TRAINING	26	26
SOFTWARE	527	155
SPACE SYSTEMS	15	10
SURVEYING	61	35
SYSTEM DESIGN/INTEGRA	21	21
TIMING	75	33
VEHICLE LOC/TRACK WKSTATIONS/SYS	56	56
OTHER GPS PROD	53	53

301 total participants

Table 2

Data Source: GPS World Magazine (with permission)

GPS Goods & Services Categories - Descending Order of Participation

SOFTWARE	155
RECEIVERS	148
INTEGR INSTRU W/GPS	117
DIFFERENTIAL GPS	99
MAPPING	94
INTEGR GPS NAV EQUIP	87
ANTENNAS	83
VEHICLE LOC/TRACK WKSTATIONS/SYS	56
OTHER GPS PROD	53
ACCESSORIES	46
DISPLAYS	46
SURVEYING	35
RECEIVER COMPONENTS	34
TIMING	33
ELECTRONIC CHARTS/MAPS	33
COMMUNICATIONS DATALINKS	28
DATALOGGER GPS	26
SEMINARS/TRAINING	26
SYSTEM DESIGN/INTEGR	21
COMPUTER PERIPHERALS	17
GLONASS HDW/SOFTWARE	15
PHOTOGRAM/GPS INTEGR SYS	15
BANDPASS FILTERS	13
PUBS, GUIDES ETC.	13
LAB TEST EQUIP	12
DIGITAL COMPASSES	10
SPACE SYSTEMS	10
SAT SIGNAL SIM/PSEUDOSAT	10
RECEIVER ANALYSIS	8
MARKET ANALY/REPTS	6
SECURITY CODE DECRYP	5
BUFFER BOXES	4
ELECTRONIC BB	4
PRECISE EPHEMERIS INFORMATION	4
IONOSPHERIC CALIB	2
RADIOMETERS	2

301 total participants

Table 3

Data Source: GPS World Magazine (with permission)

This categorization represents the way in which the industry defines itself to its customers. The categories are the “terms-of-the-art” that they feel best identify their products to potential buyers. Such categorizations tend to overlap and in some cases may be redundant but serve as a measure of the diverse nature of the industry and the growth in participation. GPS firms listed in Appendix A shows that they are located throughout the world. In less than a decade a new industry has emerged and is sufficiently robust to have already developed substantial international as well as domestic competition.

The listing of current GPS firms (see Appendix A) and their product lines were reviewed to find industry leaders (see Appendix C). From our experience, the smaller and more specialized firms tend to concentrate on their own markets and customers. As a result, the survey and interviews were focused on GPS firms offering the widest range of products in order to get a broad picture of the market and trends. Through the cooperation of the GPS Industry Council (USGIC) a new composite estimate of the GPS market has been developed for the period 1997 through 2003.

Individual responses were blended into a single market projection to protect proprietary data and reviewed to create a consensus estimate. The overall revenue estimates in each market segment are largely driven by projections of unit sales based on differing rates of market penetration, price points, and production economies of scale and scope. Sales of GPS satellites, contracts for operating the space segment, and related launch services are not included as these areas are not subject to international commercial competition due to national security requirements. All other market segments, including military equipment, are open to full commercial competition.

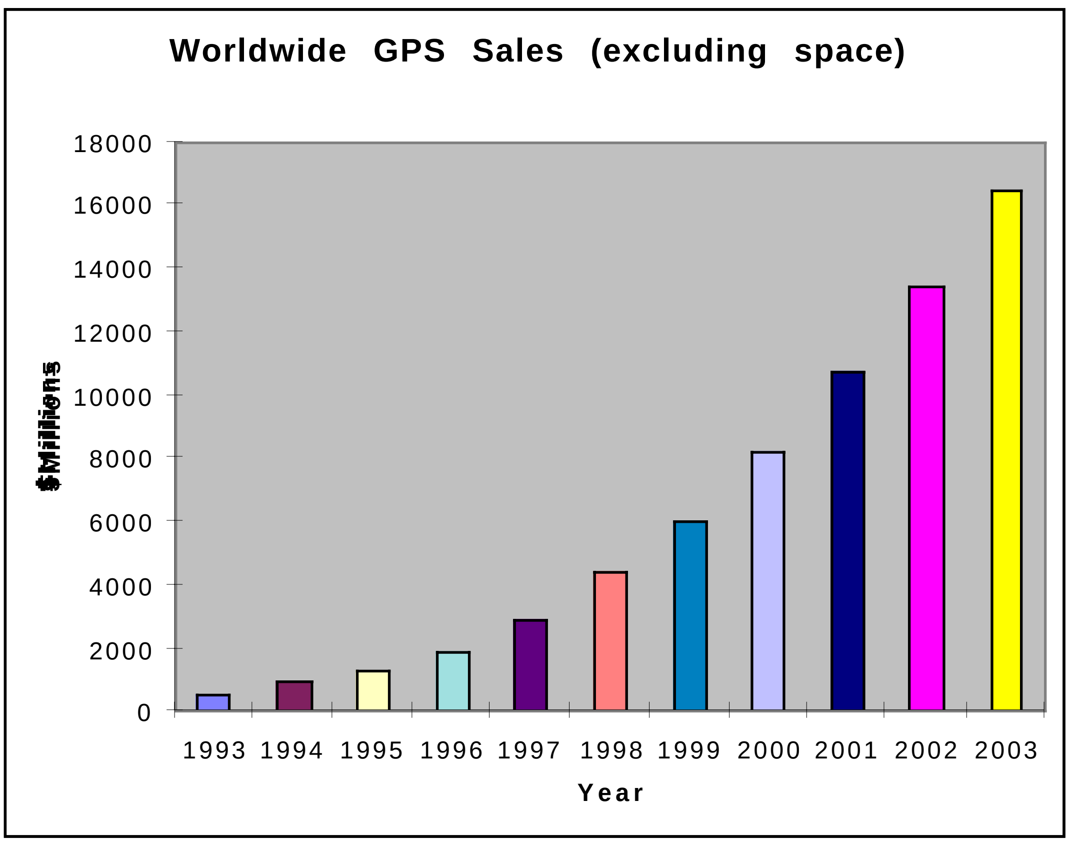

Figure 3

Table 4 - GPS Market Projections by Segment

millions of dollars

	1996	1997	1998	1999	2000	2001	2002	2003
Car navigation	520	900	1600	2300	2900	3600	4200	4700
Consumer	324	560	850	1200	1800	2400	3100	3800
Tracking/Machine Control	170	280	450	720	1100	1650	2300	3000
OEM	180	200	260	320	400	480	570	690
Survey/mapping/GIS	370	530	735	960	1300	1740	2320	3120
Aviation	125	160	220	300	380	500	600	710
Marine	120	130	140	155	165	180	195	210
Military	80	90	100	110	130	145	160	185
Total	1889	2850	4355	6065	8175	10695	13445	16415

Table 5 - Historical Data from 1995 USGIC Market Estimate

millions of dollars

1995 Market Estimates	1993	1994	1995
Car navigation	100	180	310
Consumer/cellular	45	100	180
Tracking	30	75	112
OEM	60	110	140
Survey/mapping	100	145	201
GIS	25	35	50
Aviation	40	62	93
Marine	80	100	110
Military	30	60	70
Total	510	867	1266

Results of Industry Survey

Figure 3 shows the overall market estimate (based on total sales) developed by the survey. Data used for this figure are given in Table 4. Historical information through 1995 was based on 1995 USGIC estimates, shown in Table 5. Figure 4, on the next page, further defines the growth of individual market segments for the period 1998 through 2003.

The horizon for this survey has been modest, to 2003, with the view commonly expressed that estimates beyond that range are highly speculative at best. It is noteworthy that in the three years since the 1995 USGIC estimate, further differentiation of the market has taken place and a consolidation of companies is underway. As a result, a few definitions have been changed from the 1995 USGIC estimate. The sector previously termed “consumer/cellular” has been changed to “consumer” or “recreational” to better reflect the segmentation that has occurred since 1995. “Machine control” has been added to the “tracking” category to reflect the increasing use of GPS and GPS signal simulators (termed “pseudolites” instead of satellites) in controlling large mobile machinery such as used in agriculture and open pit mining. The “mapping” and “GIS” functions have been combined with the older “survey” category to reflect the increasing integration and interdependency of these activities. In future estimates, we may see other emerging uses such as space-based applications where GPS is used to accurately determine the satellite position as well as providing precise timing functions.

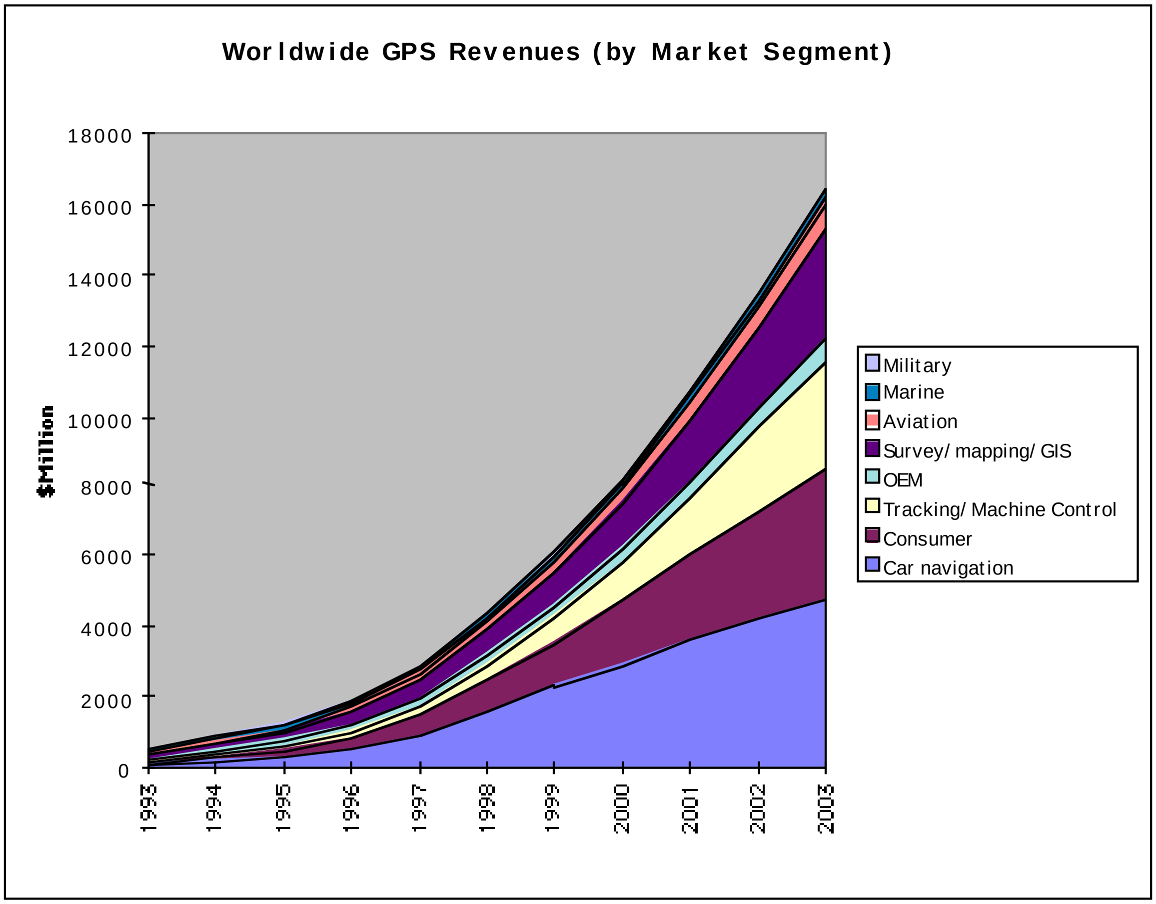

Figure 4

Figure 5 shows the relative sizes of GPS market segments. In the early 1990s, car navigation (in Japan) and survey and mapping (in the United States) were the leading market segments. Both segments are expected to continue to be important, but consumer and tracking/machine control functions are expected to join them in importance by the early 2000s.

Overall observations based on the market projection presented here include:

- Total growth for the market is expected to remain robust with an average growth rate of just under 25% during 1998-2003.
- Global sales are on-track to exceed $8 billion by 2000 and are could exceed $16 billion by 2003.
- The pattern of market segment growth will continue with new applications entering the market after 2001-2003;
- The growth in car navigation applications will be the driving GPS commercial application during the period and then slowing as markets saturate;
- Survey applications will remain strong, but with slower growth relative to newer market segments such as tracking and machine control;
- Aviation applications will increase after 2001 as new wide-area augmentation systems become available and GPS is accepted for use in a wider range of flight conditions.

- Military and marine applications will not decrease in absolute size, but will be an increasingly smaller part of overall GPS sales;
- A developing “commodities” level market is emerging (especially in the consumer or recreation area) where GPS is an embedded application with other information technologies. The growth of this market will be dependent on continued reduction in the cost of GPS electronic units (chip sets/boards) and the cost of their integration into a total system;
- Because GPS has become a pervasive information utility in numerous public safety applications and infrastructure support (e.g, network synchronization), the full import of the value of GPS to the national and international economy is likely to be underestimated by market revenue projections.

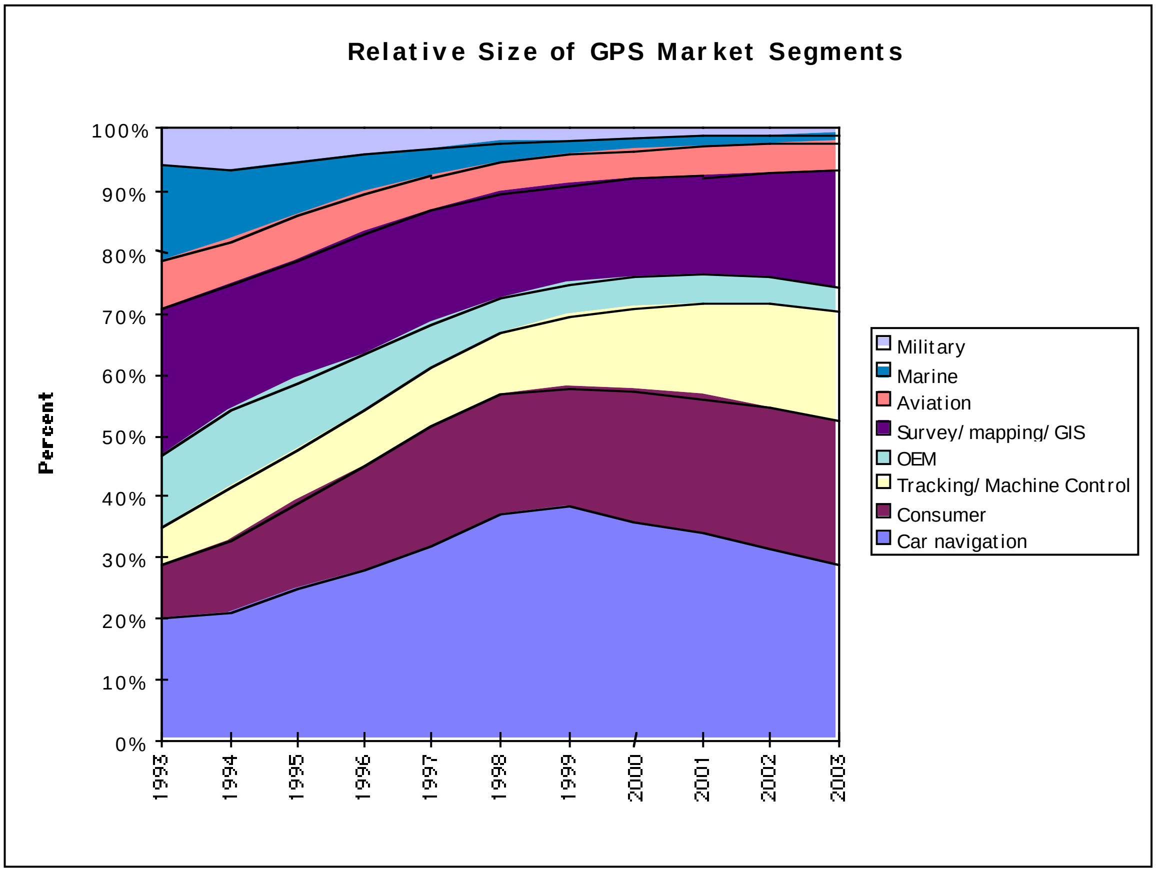

Figure 5

Market Share Trends

In 1997, three consulting firms made their own estimates of the future GPS market that provide another view of the situation. The Freedonia Group (Cleveland, OH) estimated the 1996 world GPS market at about $1.5 billion , growing to $6.5 billion in 2001 and $16.4 billion in 2006. This represents a 29% annual growth rate from 1992 to 1996 and a 34% growth rate from 1996 to 2001. The U.S. market share was estimated to be over one-third of the world total.

Similarly, Frost & Sullivan (Mountain View, CA) estimated that just the North American GPS applications market would grow from $366.2 million in 1996 to $3.5 billion by 2003. Automobile navigation and precision timing (e.g. for communications) were seen as having the fastest growth rates. The estimate did not, however, include recreational GPS receiver sales. Overall, the total North American applications market was expected to grow at a 26.6% annual rate from 1996 to 2003. There was no estimate of the world market in this study.

Finally, Booz-Allen & Hamilton (Paris, France) estimated that the European market for Global Navigation Satellite Services (GNSS) goods and services would have a ten year (1998-2007) cumulative value of 39 billion ECUs or over $42 billion. [1] This estimate included ground equipment, space systems, and services. It is also about one-third of the 1995 USGIC global estimate for the same time period. Annual growth rates were expected to be rapid in the near term (1998-2000), at 40-50%, starting with a small base, but then remaining relatively flat after 2000.

Based on the industry survey in this study, estimated market shares for 1998 and 2003 are shown in Figure 6. Market shares for the period 1998-2003 are not expected to change in a

Global GPS Market Share Projections

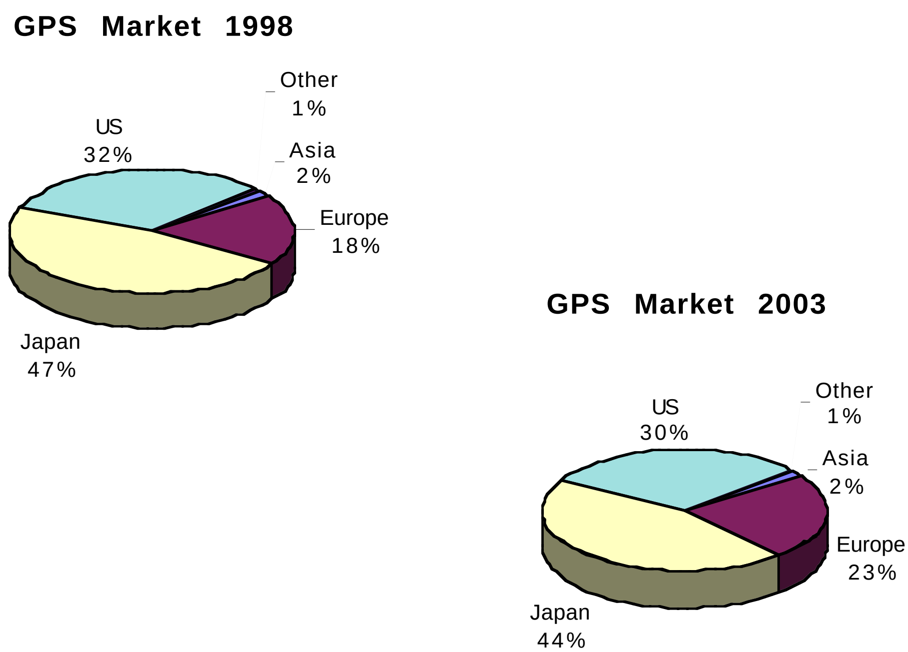

Figure 6

major way. It is important to note the relative shares are for a total international market of increasing size.

Currently, the USGIC estimates there is a commercial installed base of over three million GPS users. They further estimate that worldwide production of GPS systems is on the order of 250,000 units per month. They expect the user community to grow to the point of adding

[1] The European Currency Unit (ECU) is used for internal accounting purposes within the European Union. The ECU is made up of a basket of EU currencies and consists of a specified amount of each currency. The relative weighting of each currency in the ECU is meant to reflect the relative importance of the individual national economies. The ECU is now being viewed as the fore-runner of the Euro, the proposed single European currency.

about 2 million users per month by the year 2000. The margins on products sold to these users will likely be smaller as a greater portion of sales will be inexpensive "information utilities" within which GPS is embedded. On the other hand, higher margin product opportunities will present themselves as GPS is embedded in national infrastructures (e.g., public safety, aviation, maritime, telecommunications) where current penetration is estimated to be only about 5% of the addressable markets.

The following are highlights for the period 1998-2003:

- The worldwide GPS market will increase about four times in size over the current market during the next five years;
- The United States, Canada, and Japan, followed by Europe, will be the leading producers of GPS equipment.
- The relative U.S. share of the world market will decrease slightly but will increase in absolute terms during the next five years;
- During the early portion of the period, Japan's share should expand slightly as a result of increasing car navigation sales, but flatten later in the period as markets saturate;
- In Europe, rapid growth in car navigation is expected throughout the period while the defense market share declines after 2000; and
- The consumer GPS market will begin to build rapidly toward the end of the period as lower-priced GPS capabilities are embedded in mass market goods.

Regional Market Developments & Opportunities

North America, led by the United States, remains the dominant provider of GPS products and is expected to remain in that position through 2003 closely followed by Japan. The North American market, followed by Japan, is also the most advanced, in terms of size and breadth of GPS applications. The United States and Japan are roughly even in GPS manufacturing technology, with the United States having a slight lead in higher value-added products such as those with a high software content.

The size of regional markets, however, does not necessarily correspond to the size of firms based in those markets. Firms tend to specialize in particular market segments in response to regional differences in market segments. The following sections provide brief discussions of key regional developments.

The GPS market remains an evolving and expanding business opportunity. While consolidation continues, new opportunities are emerging which should attract entrepreneurial ventures that exploit new business opportunities or find ways to offer superior service and value in specific areas of need. Table 1, Section I indicates how new uses of GPS continue to emerge. The cost of entrance will vary widely in each of these applications of GPS but even small firms with minimum capital should find a relatively low capital barrier in at least some of these areas. More difficult to evaluate is how the consumer market will develop. But in all markets the degree of penetration is still small enough as to offer opportunity for those who can understand the market dynamics for the application they wish to sell.

North America

The overall U.S. industry leader is Trimble Navigation which offers GPS products in every segment of the GPS market. In 1991, it was the first GPS firm to go public with a business base in high precision survey equipment.[1] Trimble has formed a number of strategic alliances to address different market segments. It worked with the Japanese firm of Pioneer Electronics in the early development of car navigation products and a high-quality flexible manufacturing facility. Other partners include AT&T (communications), Honeywell (avionics), Caterpillar (agriculture equipment), and Microsoft (geographic information systems).

The GPS industry has been affected by the dramatic post-Cold War consolidation of the U.S. aerospace industry generally. An important example of this consolidation was the sale of Rockwell's Space Division, which builds the GPS Block IIF satellites, to Boeing Aerospace. While the total number of firms participating in the GPS market has increased, many smaller firms and GPS product lines have merged or been acquired in recent years.

In 1994 Orbital Sciences Corporation (OSC) acquired Magellan Systems, a leading manufacturer of personal, handheld GPS receivers. As a subsidiary, Magellan continues to manage a strong distribution network in which 30% of its sales are international. In 1997, Rockwell's Driver Information Systems business unit was sold to OSC as part of Rockwell's shedding of major aerospace and defense business lines. The major product acquired was the PathMaster car navigation line, widely available on Hertz car rentals. Rockwell retained its military GPS receiver business, however. Later in 1997, OSC merged Ashtech with Magellan. Ashtech was a leading supplier of high-precision GPS survey equipment, including combined GPS/ GLONASS receivers.

In early 1998, Motorola created a new "Telematics Information System" business to integrate its GPS, cellular, wireless messaging, and microprocessor design and production capabilities. The goal is to combine wireless voice and data communications in providing vehicle drivers with location information, emergency roadside assistance, and entertainment from a central service center. Some of these options, such as emergency assistance using GPS, are already offered on luxury cars from the United States and Japan. Emergency road assistance is expected to be particularly significant in improving response times in the case of rural accidents. The majority of fatal auto accidents occur in rural areas.

Car navigation has grown more slowly in North America than many analysts expected. This appears to have been due to the challenge of creating comprehensive, up-to-date digital maps and the market requirements for more sophisticated software that could provide reliable directions and not just show a vehicle's location on a map. As a result, Europe and Japan currently have the largest segment of the GPS-based car navigation industry worldwide. In Japan, the focus is on individual cars while Europe has focused on commercial trucks.

[2] NovAtel of Canada, which makes survey and mapping products, is the onlu other publicly traded GPS firm.

[3] "Launching of the JGPSC," *News Release of the Japan GPS Council*, 3-24-11 Yushima, Bunkyo-ku, Tokyo, 113 Japan, May 5, 1993.

Asia-Pacific

After the United States, Japan is a world leader in the development and application of GPS technology. In the United States, military GPS ground equipment sales were an important source of initial revenues. This was followed by the adoption of GPS in the survey and mapping market. In Japan, GPS has been traditionally thought of as a form of consumer electronics in which low-cost, high-quality mass manufacturing is the key to winning market share and commercial leadership. Thus Japanese firms have concentrated on mass markets such as automobiles and portable GPS receivers. The Japanese construction industry is shifting from older triangular net survey systems to GPS-based survey systems, a process the United States started over ten years ago. In 1998, Japanese government and industry leaders are expected to complete testing of "real-time kinematic" GPS techniques for certified use in cadastral land surveys. This is expected to boost the productivity of Japanese survey and construction projects.

The Japan GPS Council (JGC) is the Japanese counterpart to the U.S. GPS Industry Council. It was established in 1992 by eight GPS receiver manufactures, application suppliers, and users: ASCII, Central Japan Railway, Nippon Motorola, Mitsui & Co., Pioneer Electronic, Sharp, Sony, and Toyota Motor. By the end of the year, the Council had 72 corporate members and 15 supporting parties such as non-profit corporations and other technical associations. In addition to private firms, the JGC is sponsored by the Ministry of Posts and Telecommunications (MPT) and the Japan National Police Agency.[2] While the USGIC focused on OEMs, the JGC includes major users such as Japanese car manufacturers and railroads.

Car navigation is the largest single GPS market in Japan with low-end prices dropping to under ¥15000 per unit (or just over $100). Initially offered on luxury cars (e.g., Toyota Crown), car navigation units become popular "after-market" accessories. The combination of rapid sales and weak growth in the Japanese economy, however, may lead to domestic market saturation in a few years. As a result, Japanese firms are looking for export opportunities and moving into new GPS applications. In particular, there has been an increasing interest in the use of GPS in competitive fixed and mobile telecommunication networks as part of the Global Information Infrastructure (GII). Thus we may see new initiatives using GPS in both cellular telephone and mobile satellite communications in coming years.

China has some domestic GPS production capabilities and has tested land vehicle and marine navigation systems. It is not a major manufacturer or developer of GPS technology. China is a large potential user of GPS technology, especially for transportation, construction, communications, and other infrastructure development. Overall, China represents a limited market opportunity for the period 1998-2003, but international GPS firms are seeking to establish a presence in the market in anticipation of growth beyond 2003.

Other countries in the Asia-Pacific region have made use of GPS in specialized areas. For example, the Civil Aviation Authority of Fiji relies on GPS to provide all air navigation services around the island and for a large area of the Southern Pacific. In Singapore, a taxi service has added a new twist to hailing a cab. Callers use an automated system that automatically sends a message to the closest cab. GPS is used to constantly update the system on cab location so it can find the nearest vehicle to the caller. GPS-based Automatic Vehicle Location (AVL) systems also improve scheduling and management of bus fleets, subways, monorails and other public transportation systems.

The current financial crisis in Asia has resulted in slower sales growth for GPS car navigation units and other consumer applications, but has not harmed the industry generally. This seems to be the result of the still relatively low level of penetration of GPS equipment and services in Asian infrastructure, the concentration of current Asian GPS manufacturing in Japan (which exports heavily outside of Asia), and local government spending on infrastructure such as highways and earthquake monitoring networks which utilize GPS equipment.

Europe

The European GPS equipment market is largely supplied by U.S. and Canadian firms through direct sale of receivers or OEM board with GPS microprocessor "engines." There continues to be debate within Europe on the relative importance of GPS satellite technology as compared to receiver technology. Some argue that Europe already has the necessary technical capabilities to produce competitive GPS ground equipment while others argue that a stronger European position in space systems is necessary. This debate occurs against the backdrop of continuing efforts to restructure and privatize European aerospace and defense industries in which new satellite construction contracts are being sought.

Smaller European countries, especially in Scandinavia, appear to be taking a more entrepreneurial approach to GPS technology. Local firms are focusing on immediate applications in land survey, vehicle tracking, geographic information systems, and coastal navigation. In some cases this has led to European acquisition of U.S. firms such as the transfer of the Magnavox's GPS product line to the Swiss firm of Leica in 1994.

European participation is expected to continue to expand based on its already strong participation in GPS applications in oil exploration and recovery in the North Sea. For example, GPS receivers provide continual subsidence rate measurements to engineers on drilling platforms in the North Sea Ekofisk oil field, which is operated by Phillips Petroleum Company Norway. GPS is also being combined with communications services by European firms. Racal in the United Kingdom, and Fugro, in Holland, are presently the leading successful commercial models for the use of GPS space-based augmentations in the oil exploration industry. Differential GPS services are crucial to marine survey for work helicopter logistics support to the North Sea oil fields. The importance of this GPS application is realized considering that North Sea oil accounted for about 2.5% of the 1997 GDP of the United Kingdom.

Rapid buildup of GPS applications in Europe is expected to occur in step with the maturation of air and rail transportation networks in the London-Milan crescent, where about seventy percent of Western European population and industry is located. Such networks tend to be more highly integrated and dense than in North America. GPS is particularly useful for the "multi-modal" shipment of cargo from sea ports and air ports to trains and trucks. These transportation networks can be expected to expand into Eastern Europe as those economies develop. Poland and the Czech Republic are in the process of using GPS to create standard-ized geodetic control networks that can be used to update old land surveys. Such information can in turn facilitate European market integration by providing a common data base for transportation, communications, and energy infrastructure. The full potential of these developments is not expected to be seen until after 2003, however.

As this report was going to press, Frost & Sullivan (Mountain View, CA) was preparing to release a new study of the European GPS market. They estimated that the total GPS hardware market in Europe in 1997 was $228.7 million and that by 2004, it would total $960 million in sales. Marine applications accounted for most of the observed sales in the past while land-based uses (e.g., cars, trucks, and railways) are expect to account for about 75% of sales by 2004.

Other Participants

Other regions of the world do not as yet play a major role in GPS technology or manufacturing. However, the use of GPS to meet local needs helps drive the development of new application and software. Small and medium-sized enterprises can thus find commercial opportunities in exploiting existing technology and equipment in new ways.

In Latin America, Africa, and the Middle East, aviation applications should be the dominant GPS market through 2003. Aviation uses of GPS are in turn linked to broader transportation and shipping infrastructures. In Dubai (United Arab Emirates), GPS-based systems are used to schedule delivery and loading of containers at one of the busiest ports in the world. In addition, each of these regions has unique issues which can be resolved with the aid of GPS applications. The ability of commercial GPS firms to provide solutions to environmental management, infrastructure development and other critical local needs will determine the market leaders of 2000 and beyond.

In Latin America, GPS has been found to be useful in regional environmental management. In a project impacting Argentina, Paraguay and Bolivia, natural canals have been detected and accurately mapped using GPS. GPS has also been used to design the precise height of new channels to facilitate flow for the Pilcomayo River, which fills with sediment. These new channels will keep sediment moving through Patino Estuary by using river canals to restore the Pilcomayo’s flow. GPS is also used in the adjudication of border disputes through more accurate and reliable land surveys.

In transportation infrastructure, trucking fleets in Mexico, Brazil and other Latin American countries use GPS to achieve efficient routing and scheduling. In addition, trucks carrying dangerous or high-value cargo can be tracked to protect against hijacking. This helps lower theft losses and associated insurance premiums.

In sub-Saharan Africa, GPS is especially critical to the improvement of air safety in a region where air traffic management is very poor. GPS is also useful in addressing local health problems. For example, malaria causes the deaths of more than 1.5 million children annually in sub-Saharan Africa. In a 1995 study, the Center for Disease Control in Kenya used GPS to create a geographic information system (GIS) locating households, mosquito breeding sites, local health clinics, and permanent and seasonal rivers. Entomology and childhood mortality databases are linked to the GIS so that researchers can study the relationships between disease data and geographic factors. This enables local health officials to more efficiently target limited resources to reduce the incidence of malaria.

GPS infrastructure uses are not always directly obvious as in the case of transportation or construction. GPS tracking is used to manage game parks and track endangered species. Aside from ecological benefits, better game management helps promote international tourism, an important factor for many economies in the region.

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Section II - Current and Developing Market Sectors

Market Sectors

Since 1984, when GPS was first accepted in commercial surveying, the breadth and depth of civil GPS applications has rapidly multiplied. The "classical" market of location determination has grown into other functional applications such as navigation and timing which are in turn being combined with other capabilities such as communications and geographic information systems. This growth has been enhanced by the rapid development of other information technologies, such as microprocessors and software, and GPS augmentation such as differential correction networks. Many emerging markets involve the use of the GPS signal in an embedded application where the role of GPS per se is not generally recognized (see Table 1, Introduction). The use of the GPS signal is a fast growing market essential in many commercial, public safety, and defense applications. The U.S. guarantee of a free and reliable GPS signal is the cornerstone of what has become an essential global information utility.

Aside from building the GPS constellation itself, the first GPS products were military receivers. Like many other dual-use technologies, the government was the first purchaser. As GPS technology improved and the first commercial applications were found, professional and technical business customers emerged. GPS equipment was still expensive, but it could be justified on the basis of its productivity benefits. Finally, as costs dropped even further, personal and mass market uses became possible and individual consumers emerged as customers. This progressive expansion of GPS markets followed the decreasing prices and increasingly capable applications, not any change in the GPS signal or constellation.

For U.S. economic statistical purposes GPS equipment is included within the Standard Industrial Classification (SIC) 3829: *Measuring and Controlling Devices, Not Elsewhere Classified*. Because of the GPS heritage of being developed from within the aerospace industry, it is logical that GPS would be identified by this SIC classification where aerospace is the dominant industry. However, the characteristics of the GPS industry have rapidly diverged from that of the aerospace industry because of the rapid growth of diverse non-military applications. Thus the SIC classification which describes the aerospace industry no longer adequately describes the nature or trends of GPS and the substantial commercial industry that has grown up around it. Only the military portion of the GPS industry can easily be described within the current SIC classification. Given these changes in the marketplace, it would be helpful to market analysts if the characterization of the GPS industry could be improved to assure that its domestic and international role is better understood and easier to monitor.

The following sections briefly discuss trends in various GPS market sectors as they exist today and developments which can be expected in the near future.

Consumer/Recreational

U.S. industry estimates that there are about 40 million potential users in the United States alone for consumer and recreational GPS equipment. This includes fishermen, campers, hunters and other outdoor recreational participants. Like other mass markets, this sector is characterized by strong demand elasticity and requirements for ease of use. Current retail price points are in the range of \$150-300 and are expected to fall below \$100. The decline in the cost of GPS electronics is feeding this market and is expected to continue to do so through 2003. While price declines have led to greater sales and economies of scale, they have also put greater pressure on profit margins.

Recreational users would welcome greater accuracy if there was no increase in cost. While desiring greater accuracy, consumers are typically price sensitive and have not been willing to purchase differential GPS equipment or services in large numbers. Thus recreational users have expressed support for turning Selective Availability to zero. Whether recreational users benefit from the addition of a second civil signal will depend on whether user equipment can be modified within existing price points.

Another use of consumer GPS is in improving the productivity of recreational facilities. For example, golf cart rentals can make up 40% of the revenue of a course and GPS equipment is increasingly available as a cart option. Players like the position location service and advice provided by a "smart" cart, the course is able to charge a slight premium for equipped carts, and players tend to complete the course faster, thus increasing the number of fees than can be charged per day.

Finally, recreational GPS is also becoming another "embedded" application. One example, is its use in the creation of more realistic computer games. GPS survey equipment was used to map major automobile racetracks around the United States, including features such as pavement, curbs, fence lines, pits, paint lines, etc. This data was then incorporated into Microsoft's Precision Racing Indy Car Simulator to recreate each course in three-dimensional simulations accurate to within a few centimeters.

Military

The evolving defense market will remain a small, but important, sector throughout the 1998-2003 period. U.S. allies are increasingly reliant on GPS in order to maintain modern, interoperable military forces. The military market, while captive to government contracts, adds to the total technology and manufacturing base for GPS production, whether military or civil. The largest users of military GPS equipment are located in the NATO countries of Europe and Canada, followed by Israel, Australia, New Zealand, Korea, and Japan.

GPS is required on virtually all U.S. military vehicles, whether on land, at sea, or in the air or space. When placing GPS on such platforms, the cost of integrating GPS on-board is typically the largest cost, not the equipment itself. The Army is the largest purchaser of GPS receivers for infantry, artillery, and armored units. The Army is also the most similar to a consumer market in stressing the need for low cost and ease of use in its GPS equipment. While military applications continue to grow rapidly, the civil installed base currently exceeds military applications by approximately 3 to 1 and is expected to grow to 8 to 1 in less than a decade. As a result, government R&D spending on user equipment has declined steadily from the late 1980s. Thus opportunities in the military sector are focused on implementing solutions to military needs rather than developing the basic technology.

GPS is also being embedded inside of munitions themselves and sales of GPS systems for munitions are expected to increase through 2003 and beyond. As defense budgets decline or stay flat, individual munitions are having to become "smarter" and more lethal to accomplish missions with smaller forces. Such munitions include; AGM-130, AGM-154 Joint Service

Standoff Weapon (JSOW), Joint Air-To-Surface Standoff Weapon (JASSW), Joint Direct Attack Munitions (JDAM), other GPS-aided munitions and advanced artillery shells.

Avionics

There are an estimated one million pilots and 400,000 aircraft in the United States alone. There are major differences, however, in the needs of domestic general aviation and international commercial aviation. General aviation has much the same characteristics as the marine small boat field, with a potentially large number of users (estimated as 20 million vessels worldwide) in a highly price elastic market. Current price points range from $500-$1700, falling to an average of less than $1000.

The Commercial aviation industry is concerned that international air traffic control systems need to be modernized drastically in the next few years in order to improve capacity and improve (if not maintain) safety. Airlines such as United, Continental, and American advocate an approach termed “free flight” in which satellite navigation and communications systems allow aircraft to make more direct, fuel-efficient flights, land in poor/no visibility conditions, and maintain safe separation from other aircraft and terrain. “Free flight” would also allow the retirement of older, expensive-to-maintain, navigation aids.

GPS is recognized as both cost effective and resource efficient by commercial carriers and military airlift organizations. While a necessary technology, GPS-based avionics alone are not sufficient to achieve all accuracy, integrity, and availability requirements. As a result, assuring the reliability and integrity of GPS and its augmentations is more significant to the growth of GPS aviation markets than price alone. Providing necessary signal assurances to aviation authorities worldwide and the rapid development of equipment standards and certifications remain essential market growth.

The most immediate threat to this market is a European proposal at the International Telecommunications Union to reallocate and share a portion of the current GPS spectrum with Mobile Satellite Services. Such sharing would be incompatible with the use of GPS in aviation safety-of-life applications due to the risk of interference. This proposal was opposed at the last World Radiocommunication Conference (WRC-97) by the United States, the International Civil Aviation Organization, and the European Commission DG VII (Transport), and others. It is expected that this proposal may be presented again at WRC-99.

Automotive/Intelligent Vehicle Navigation

GPS-aided car navigation is a major market in Japan and is growing in Europe. Semiconductor chip sales for cars reached 1.14 million units in 1996 and are expected to approach 11.3 million units in 2001 according to a 1997 Dataquest study. Similarly, in the same study, the total semiconductor manufacture for car navigation worldwide was projected to grow to almost $1.7 billion in 2001, up from $246 million in 1996. In 1997, almost 90% of car navigation market sales were concentrated in Japan. The largest sales region for GPS navigation semiconductors is Japan, at $318 million in 1997, Europe at $41 million in sales, the United States was only $4 million.

The 1997 issue of the *Hanson Report on Automotive Electronics* estimated that only 6,000 navigation systems will be sold in the United States in 1997 (excluding emergency-call equipment, such as Ford's Rescu), compared with 50,000 in Europe and more than one million in Japan. During the next five years, the market for car navigation systems is expected to saturate in Japan while the rest of the world will continue to expand and thus maintain this sector as an important one for the foreseeable future. In contrast to the highly price sensitive automobile market, U.S. firms appear to be focusing in the near term on the automatic control of large vehicles used agriculture, open pit mining, and construction.

A significant issue in this sector is whether GPS will be used for automatic guidance of highway vehicles. Reliable, high-integrity decimeter accuracy would be essential for "intelligent transportation systems" that would provide automatic guidance for individual vehicles. In a 1997 report by Driscoll/Wolfe Marketing and Research Consulting, a series of focus group studies were conducted to assess consumer interest in services such as emergency notification, roadside assistance, stolen vehicle recovery, navigation assistance, real-time traffic alerts, and mobile "yellow pages" Overall consumer interest was highest for location-based emergency notification and stolen vehicle recovery. In contrast to earlier visions of large-scale government investment in intelligent transport systems, car navigation in the United States will likely evolve as a market-driven response to consumer desires for personal safety and convenience.

Tracking

Tracking of everything from people to packages can be expected to grow in significance as the price of tracking systems decline in parallel with the decline of electronic chip/board prices. In contrast to vehicle navigation, tracking is a more passive function that is typically conducted from a central fixed site. Tracking allows for more efficient management of a total transportation system inventory of cargo and vehicles, as well as reduced losses due to theft or accidents. Accuracy requirements vary depending on the specific application. In some cases, reliable sub-meter accuracy is required for tracking and controlling vehicles for collision avoidance (e.g., agriculture, construction, rail).

Examples include:

- The International Maritime Organization (IMO) has mandated GPS tracking for all of the estimated 20,000 internationally-registered ships expected to be operating in 1999.
- The port authority of Singapore uses differential GPS to track every ship and cargo container with relatively few people.
- The Queensland, Australia train system uses an automated GPS-based system to announce stops to onboard passengers and provide train locations to waiting passengers.
- In Guadalajara, Mexico, a local cement company increased its productivity and service area by using GPS to better match changing construction site needs with the status and location of its truck fleet.

GPS is being considered for new tracking applications such as enhanced 911 services for mobile phone users. When dialing 911 from a fixed location, the address of the caller can be easily identified. This is not the case for mobile phones, whether they are cellular or satellite-based. As a result, emergency services have a more difficult time locating mobile 911 callers. Enhanced 911 service would address this problem, but doing so raises privacy concerns such as the possibility of a mobile phone being tracked without the owner's knowledge. Experiments have already been conducted on using GPS to track persons on parole or otherwise subject to other legal restrictions through tamper-resistant ankle bracelets. A key problem for GPS, however, is the very limited ability of the signal to penetrate buildings. Other communications links, such as FM radio waves, may provide a substitute carrier for GPS-like signals in limited areas.

Public Safety

Public safety also is benefiting from GPS through better resource management and vehicle dispatch of emergency service, and should continue to grow. GPS tracking and navigation reduces response times and enables more efficient utilization of expensive vehicles used by emergency services such as police, fire, and search and rescue. GPS can also be combined with communications to coordinate the actions of multiple ground, sea, and air emergency vehicles. Differential GPS systems can also be deployed to emergency locations to guide individuals, such as firemen working inside a burning building.

The Federal Emergency Management Agency uses GPS-based geographic information systems to inventory damage from natural disasters such as hurricanes, earthquakes, floods, and tornadoes. The same information is then used to target relief services and monitor reconstruction efforts.

Agriculture

Three areas which can be expected to see substantial technological evolution during 1998 to 2003 are agriculture, mining, and construction/civil engineering. The ability to apply centimeter accuracy to the guidance and control of machinery opens new opportunities for these industries.

“Precision agriculture” is a term applied to a group of technologies, including GPS, that enable more productive farming techniques. For example, the precise applications of chemicals and fertilizer to fields can currently yield savings of $20-24 per acre while lowering environmental impact of waste water runoff. To achieve this, however, GPS vehicle guidance must be combined with geographic information systems that integrate yield monitoring and mapping data, grid soil sampling, and crop production models. Education and training of farmers and students is crucial to effective use of GPS in agriculture as well as strong after-market support services.

Mining

Centimeter-level accuracy from differential GPS networks can be used for machine guidance and control in open pit mines. GPS can be used to in real-time surveys for planning and control of topographic and detail work. Precise knowledge of machine operations can be used by a central facility to monitor production factors such as the amount of earth moved and ore extracted. Precise machine positioning and tracking can enable unmanned, automatic operation as well as unmanned operations in hazardous conditions (e.g., blasting). As with agricultural machines, multiple technologies are needed in addition to GPS, but with the common purpose of increase safety and productivity.

There are also experimental efforts in the use of GPS signal "repeater networks" to enable precise machine positioning and tracking in underground mines.

Construction/Civil Engineering

The first successful commercial sector was the use of GPS-based land surveys in construction and civil engineering. When the GPS constellation was only partially complete in the 1980s, surveyors could schedule survey times for times when a sufficient number of satellites were available and in view. GPS was proven to enhance productivity 100-300% in allowing smaller survey teams to more accurately cover wider areas in greater detail. As a result, the cost of control survey point dropped from an average of $10,000 in 1986 to $250 in 1997 — unadjusted for inflation. Accurate surveys enable safer, more effective construction techniques. In Korea, GPS-based technology was used to install with centimeter precision the pre-built center-arched 150-meter span of the Seo-Kang Grand Bridge. An earlier span, incorrectly positioned, had failed and fallen into the river.

Survey equipment sales generated cash flow that enabled GPS firms to invest in R&D and exploit advances in microelectronics and signal processing. This led to real-time measurements at the sub-meter and then the centimeter level. With post-processing effort, consistent measurements at the sub-centimeter level became possible. Such accuracy levels today allow scientific users to use equipment descended from the first survey receivers to measure the movement of tectonic plates. In both Southern California and Japan, large numbers of survey receivers are linked together in large networks to monitor crustal motion in an effort to provide earthquake warnings.

Survey equipment sales are expected to continue to be strong for 1998-2003, but declining in size relative to the overall GPS market as newer GPS applications grow.

Marine Survey

As on land, GPS enables lower cost, accurate survey at sea. Accurate coastal and harbor measurements are needed around the world to support dredging operations and other activities necessary for safe ship handling in port. In the case of marine survey, however, operations are more difficult to achieve as a fixed survey network may be difficult or impossible to install. An example of marine survey is the work of HMNZ Ship Monowai. This ship used GPS to re-survey parts of the New Zealand coast to update navigational charts initially produced by the Royal Navy in the 19th century. GPS coastal and harbor surveys provided better than three-meter accuracies, and deep-water surveys were accurate to approximately 15 meters.

The precise positioning of large mobile structures, such as oil rigs, and fixed objects, such as undersea cables, led to further requirements for centimeter accuracy without a DGPS network. This was accomplished with new generation of real-time kinematic GPS equipment. (A brief technical description of various GPS techniques and augmentations is given in the following section.) Marine survey using GPS is integral to all modern off-shore oil exploration, installation of international fiber optic cables, oil spill containment and cleanup, mine removal, etc. Demand for GPS-based marine services is expected to remain strong over the next five years, despite the current softening of world oil prices.

Timing

The most fundamental information provided by the GPS signal is precise time. It is from precise timing that all other information, such a location, velocity, and navigation are derived. Precise time has commercial, as well as scientific applications. It is used to synchronize wired networks such as telephones, video conferences, the Internet, local computer networks and long distance power grids. It is also used to synchronize wireless communication networks such as digital paging, cellular telephones, some types of mobile satellite services. Precise time stamps are used in managing data flows for international financial transactions, and power line fault detection. While these "fixed-installation" systems may have internal atomic clocks, GPS time signals constitute a low-cost, accurate primary reference source.

The direct market for specialized GPS timing equipment is relatively small. Yet the economic importance of precision timing to the entire global information infrastructure is huge. Without the free GPS signal, wired networks could fall back on internal atomic clocks, but that option is not likely to be practical for handheld wireless communications. As market demand for high bandwidth applications continues to grow, e.g., mobile Internet access or wireless video conferences, precision time signals from GPS will be increasingly necessary.

The increased functionality of information infrastructure, (i.e. savings resulting from avoiding power grid instability, and securing data stream stability in financial transactions),both enabled by GPS, are not easily accounted for in the economic value of GPS to the world economy. Thus, as pointed out earlier, deriving figures to accurately reflect direct revenue from GPS goods and services is likely to underestimate of the economic significance of this information technology. The next section discusses the most significant trends in the current evolution of GPS technology.

GPS Technology Evolution

Today, a typical GPS receiver consists of three major parts: a 1.5 GHz radio frequency (RF) receiver, a specialized baseband chip, and a general purpose processor. The baseband chip extracts the GPS signal's time stamp and a low-bit data stream which contains ephemeris data on each satellite. The time stamp allows the receiver to calculate the difference in flight times (using the speed of light as a constant) for signals coming from several different satellites. Finally, the general purpose processor assembles ephemeris data from the data stream, identifies the satellites being received, and computes the position of the receiver. The processor also typically controls system interfaces such as keypads and displays, performs power management, and other chores.

Given position data, the processor can calculate the derivative of the position information as it changes over time to compute the velocity of the GPS receiver. This information can then be merged with stored mapping data to display navigation information. Combined with other information inputs, such as inertial navigation and other communication channels, it will create a system that is more accurate and resistant to interruptions of the GPS signal. Of course, each of these combinations adds to the weight, cost, and complexity of the GPS receiver.

It is possible to integrate the baseband chip and general purpose processor into a single unit. Integrating the first RF stage with the digital electronics is more difficult. If a system has computing power to spare, GPS capability could be achieved by adding the RF front end to a fairly sophisticated digital signal processing (DSP) chip. RF front ends are not typically power efficient, however, and power consumption results in relatively short battery life and, in some applications, heat rejection problems.

The GPS signals at 1.5 GHz signals are weak, attenuated by moisture, do not travel far through forest canopy or glass, and can be blocked by buildings or rough terrain. In urban environments, the signals reflections from buildings can result in "multipath" effects where the GPS receiver has difficulty in picking out direct GPS signals from delayed reflections. After signal processing, antenna design is a key technology issue for GPS equipment. Antennas not only have to reliably and quickly acquire weak signals, but as GPS becomes increasingly embedded in other systems, the antenna must be kept small and unobtrusive.

Continuing software developments that maximize understanding of GPS signal characteristics, and embed them in microprocessor chips, are a major driver of GPS technology advances. For example, military GPS receivers currently have full access to two GPS signals, the L1 and L2, while civilian receivers have full access to only the L1. Some sophisticated civilian receivers are dual-frequency in that they can track the characteristics of the L2 signal without access to the military P-code. This enables these receivers to almost fully correct for the effects of ionospheric distortion just as the military receivers do.

Today, there are almost a thousand published patents on GPS worldwide. U.S. and Japanese companies are the leaders, with U.S. patents tending to be more "fundamental" given the early U.S. position in the technology. The rise in U.S. patents began about the same time as government R&D spending for GPS user equipment began a long-term decline. It is difficult to say whether the decline in government R&D spending "caused" the rise in commercial patents, or if the decline was the result of a strong commercial industry willing to conduct R&D that the government could no longer afford. Nonetheless, the U.S. commercial technology position as measured by patents does not appear to depend on continued government investment in user equipment R&D. Ironically, U.S. government patents on GPS were not registered internationally and thus their commercial value has been zero.

Overall, there are two major technological trends that have driven new GPS applications. The first is a continuous 30% per year decline in the cost (tending towards zero), power, and size of the electronics hardware necessary to exploit GPS signals. In 1983, the first commercial receivers cost over $150,000 and weighed over a hundred pounds. The next year a portable receiver was introduced that weighed only 40 pounds and cost $40,000. In 1998, a consumer handheld receiver costs $100 and weighs less than 12 ounces.

Figure 7, provided by the USGIC, shows the size, power consumption, and cost of basic GPS "engines" declining with time. Similar curves can be drawn for personal computers and telecommunications equipment. These curves are not unusual for information technologies,

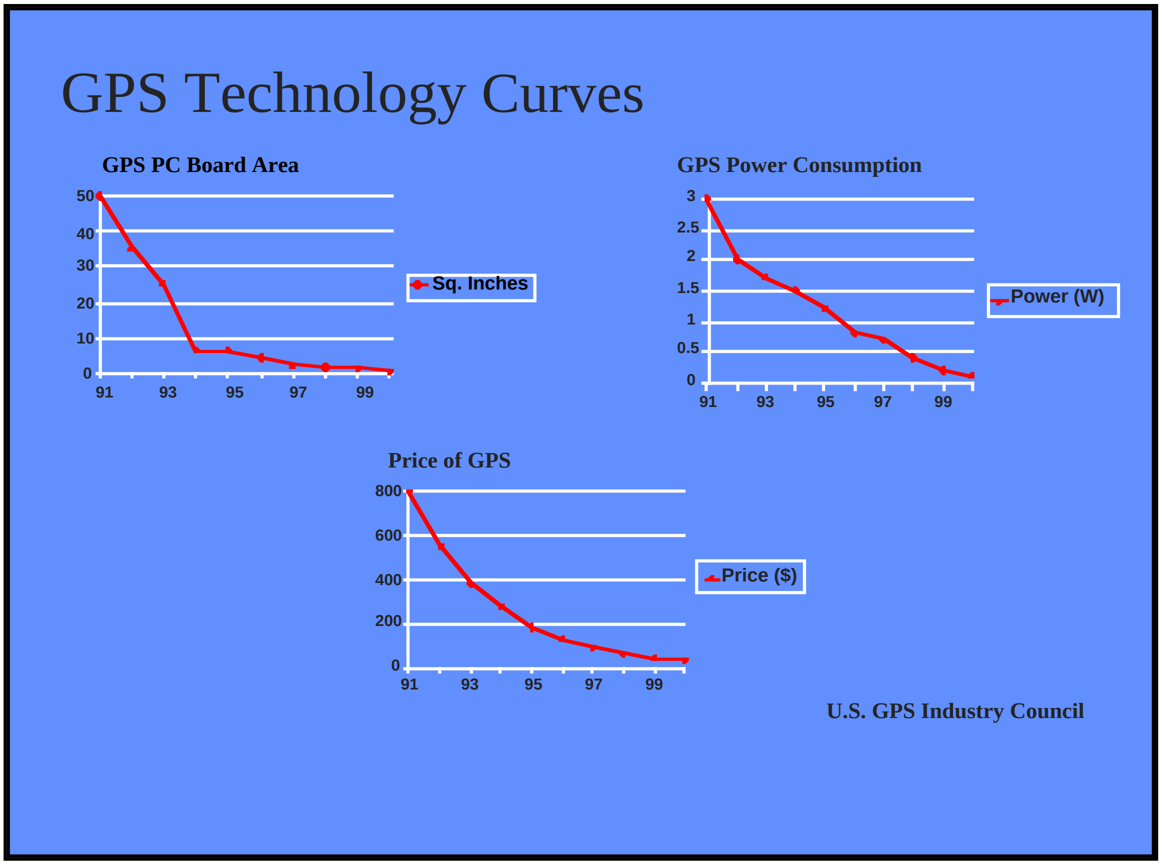


Figure 7

especially those in which microprocessor design and signal processing are critical. U.S. firms typically price GPS business and professional products as a percentage of the user's productivity gains. Such gains are determined by return on investment data that are known within 6 - 12 months of product deployment. As a result, user demand is driving product evolution with product cycles of 12 - 18 months,which also is typical of an information technology.

The second trend is the increasing contribution of embedded software to the user application. The ultimate value of GPS to the user is in the application of the information which is largely recovered from the GPS signal by software. GPS hardware is shrinking and disappearing as it becomes integrated into the silicon structure that encompasses communications and computation. In commercial markets, the increased software content is the fundamental driver for productivity increases and therefore acts to stabilize unit prices. In the consumer markets, the software is less of a cost factor and the traditional erosion of hardware prices is reducing the price at retail levels.

There has been increasing press attention to what has been called the "Year 2000 problem" or "Y2K" for all software-driven systems and products. In order to save memory, early software developers often ignored the first two digits in counting years. Thus 1980 was treated as "80". In the year 2000, however, "00" may be mistaken for "1900." Potential problems arising from this mistake have generated a major domestic and international effort to fix millions of lines of software.

The GPS Joint Program Office conducted a review of the software controlling the GPS constellation and problems were found and are being fixed. An additional consideration for GPS is that it has a unique date management scheme in which “rollover” does not occur at the same time as a standard calendar. GPS time is based on epochs of 1024 GPS weeks and the GPS week rolls over from week 1024 to week 0001. This will occur at 0000 hours UTC (universal time) on August 21-22, 1999. An improper account of the first epoch could cause an invalid GPS time stamp.[4]

Current U.S. GPS manufacturer software appears to be Y2K resistant, but this cannot be guaranteed for all manufacturers in the world. The rapid pace of technical evolution in GPS may be mitigating the problem as systems with older software are being abandoned rapidly. Y2K may also be problem for older commercial software systems in which GPS is embedded or “legacy” government systems which cannot be replaced and must be fixed.

GPS Augmentations

In many situations, the basic GPS signal does not meet user requirements. As a result, a wide variety of GPS augmentations have been developed that build on the basic GPS signal. These augmentations can provide better real-time accuracy, integrity monitoring, better availability, and more robust signal corrections. The area of operation for these augmentations can vary widely, from a local building site with a portable ground-based system, to most of a hemisphere with a space-based system.

Augmentations may also be needed to compensate for unusual operating locations. GPS does not work inside buildings, underground, or underwater since the signal does not penetrate well. The need for position location in such environments has led to the use of repeater networks and other augmentations. GPS signals have been exploited for operations underground and on the ocean floor. Engineers have developed “smart” buildings in which an external GPS antenna is combined with an internal radio network to allow position location and navigation indoors.

Local Differential Stations

Local differential systems monitor the GPS signals and develop integrity and differential correction information for broadcast to receivers in a local area of at most a few hundred kilometers. Each station consists of one or more monitoring receivers, a central processor where the broadcast information is developed, and a radio transmitter. The central processor processes the monitor measurement data, develops differential corrections and integrity parameters, and codes the messages for the radio broadcast. By applying the corrections obtained from the broadcast, mobile receivers can obtain meter-level accuracy. The types of radio broadcasts include FM subcarrier transmission, VHF and UHF data links and data broadcasts.

Radiobeacon Networks

Radiobeacon networks are now deployed worldwide to broadcast differential corrections using medium frequency signals that propagate by ground waves. They are deployed primarily to support harbor and harbor entrance marine navigation in close quarters. These networks typically cover the nations’ coastal waters, but since the broadcast signals are received several hundred kilometers inland as well, they are used extensively by land vehicles, including highway vehicles, agricultural vehicles, and geographic information systems.

Commercial Differential GPS Networks

There are a number of commercial networks around the world that operate in a similar manner to the government-constructed Satellite Based Augmentation Systems (such as the Federal Aviation Administration's proposed Wide Area Augmentation System or WAAS). These include OmniStar, owned and operated by Fugaro, and LandStar and SkyFix, operated by Racal. These are regional systems which are permanently in place in the Gulf of Mexico, the North Sea, and the China Sea respectively. This type of system can be deployed within a few weeks in other areas of opportunity throughout the world. While these networks primarily serve the oil exploration market, e.g., seismic surveying, they are also used for agricultural and other vehicle navigation, and for vehicle guidance applications.

Local Area Kinematic Broadcast Systems

Local differential stations can also function as broadcast stations to support real-time kinematic applications such as dredging and precision agriculture, where decimeter accuracy guidance is required in a situation where the GPS receiver is in motion. Local area kinematic stations broadcast carrier phase and code phase measurements for both L1 and L2 frequencies, and perform reference measurements at the ground stations. The mobile receiver then processes these measurements by differencing them against its own measurements. Two-frequency codeless cross-correlation processing of the P-code signals is essential to quickly resolving what are called carrier phase integer ambiguities, e.g., in one or two minutes. Once the ambiguities are resolved, processing of the differenced measurements yields a relative vector estimate between the mobile and kinematic station antennas which is accurate to under a decimeter. Recently developed techniques make it possible for the mobile receiver to resolve the ambiguities quickly, even when it is in motion, thus providing extremely accurate positioning and navigation to mobile receivers in real-time.

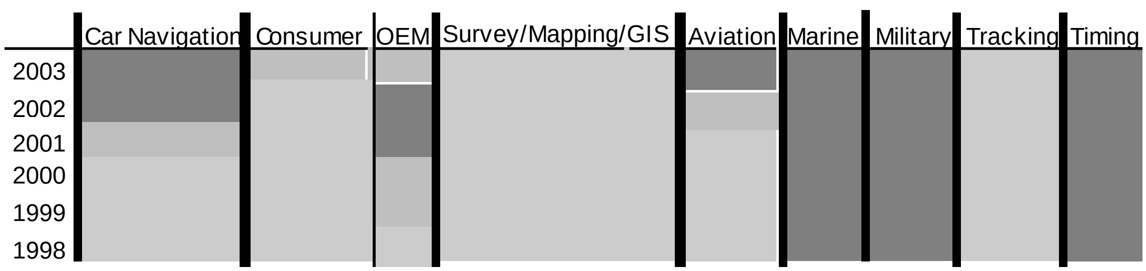
Section III - Market Opportunities and Risks

This section briefly discusses the opportunities and potential risks to the growth of GPS applications in global markets.

Opportunities

Due to the variety of GPS applications (see Table1 Introduction), it is likely that entirely new

GPS Business Growth Rates
1998-2003



Growth		
High -2		greater than 25%
High -1		20% to 25%
Intermediate		10% to20%
Low		0% to 10%

GIS - Graphical Information systems
OEM - Original Equipment Manufacturer

Table 4

innovative applications of GPS will continue to be added to the list of business opportunities for those seeking to make GPS a part of their product or to offer a new GPS software or hardware based product. Table 4 ,offers a qualitative look at where the fastest growing markets are expected in the period 1998 through 2003. If the past decade is any guide, it is likely that more applications will emerge which will increase opportunities for market participation.

- Car navigation devices are expected to show continued rapid growth for the next few years, eventually slowing as the market saturates.
- OEM markets will continue to show steady growth, but declining prices for chips will put pressure on manufacturing profit margins.
- The survey and mapping market is relatively mature in developed countries. Growth opportunities primarily will be in developing countries, particularly Asia.
- Consumer and tracking applications will show strong growth, with better profit margins in the software-intensive tracking and machine control segments.

- The aviation market is relatively small, but it should experience rapid growth as international air traffic management systems shift to GPS-based augmentation around 2001.

•The timing market is small, but crucial to many other types of information infrastructure and should see slow, but steady growth as high-bandwidth, mobile communications become more common.

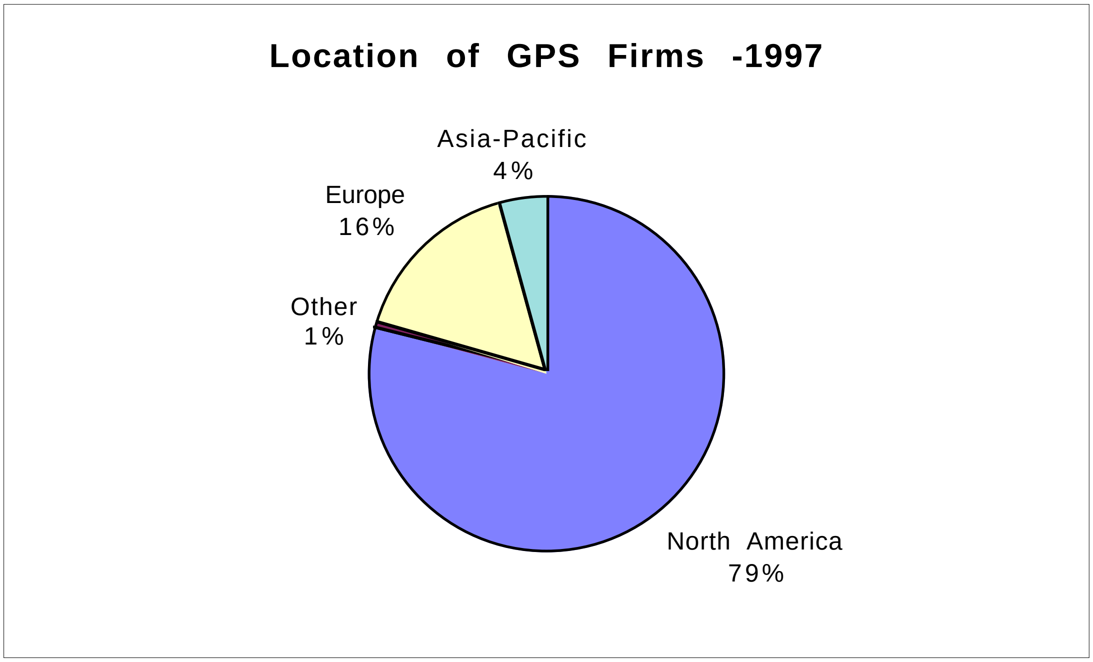


Figure 8

The cost of the basic GPS chipset has continued to decline steadily, leading to the relatively thin profit margins found in other areas of high-volume consumer electronics. High-margin GPS products tend to be those with specialized software content or where GPS provides crucial functionality to a high margin product or service. For example, a $65 chip set provided by a GPS OEM may be the core of a $600 car navigation device that pays for itself in saved time and driver convenience. Relatively few firms compete to provide the core GPS technology, but a large number of firms provide GPS-enhanced products, and an even larger number compete using GPS-based advantages.

Not surprisingly, U.S. firms were the first to experiment with commercial applications of GPS. They were soon followed by firms in Japan and Europe. Figure 8, above, shows the location of the GPS firms listed in the *GPS World* database. The largest number of firms were located in the United States and Canada (North America), as might be expected for a U.S.-based, English language publication. The second largest number of firms were located in Europe. There were a smaller number of firms located in the Asia-Pacific region, primarily in Japan. The number of firms shown is quite a bit less than the number of members in the Japan GPS Council (which includes over 80 firms). The reason is that the Japan council includes firms that use and depend on GPS, as well as suppliers of GPS products and services. Appendix A includes a listing of Japan council members, which includes firms engaged in automobile manufacturing, consumer electronics, banking, railroads, air transportation, commercial fishing, etc.

Aside from the diversity of firms interested in GPS, the structure of the industry shows that the basic technology required to exploit civil GPS signals is widespread and not limited to the United States. Furthermore, the ability to compete in GPS markets does not require participation in building the GPS satellites themselves, as exemplified by Japan's experience but also by the number of non-aerospace companies in the market. Many countries have built local area DGPS networks and Japan, Europe, and the United States are building wide-area DGPS networks for international aviation. Interestingly, the European firms of RACAL and Fugro already supply wide-area DGPS signals bundled with communication services in many parts of the world; largely for maritime and oil exploration purposes.

Often it is difficult to see the direct connection between applications of technologies for government sponsored programs and the development of commercial businesses using the same technology. GPS is a clear example of one-to-one application of the same technology to both public needs and commercial enterprise. However, the business applications of the GPS signal extend considerably beyond government programs as a result of the robust commercial markets discussed in the previous two sections. The circumstances that shaped GPS for defense needs, e.g., worldwide broadcast and no limit on the number of possible users, also created the opportunity to share the signal internationally and without cost.

Opportunities in Emerging Capabilities

The view was expressed in survey responses that there is a pervasive need for GPS signals in a wide variety of infrastructure applications. This view also was embodied in language adopted by the Congress as part of the FY 98 defense authorization (PL 105-85) which stated that "The (GPS) ... makes significant contributions to the attainment of the national security and foreign policy goals of the United States, the safety and efficiency of international transportation, and the economic growth, trade, and productivity of the United States."

The latest market opportunity stemming from emerging infrastructure application of GPS is the deployment of the Nationwide Differential GPS (NDGPS) in the United States. The NDGPS has been proposed by the Department of Transportation as a low cost means of providing nationwide access to public safety benefits of the U.S. Coast Guard's Maritime Radiobeacon System which, at the present time, only covers one-third of the nation. As currently constructed, the Coast Guard system uses low cost equipment to receive the basic navigation information from GPS satellites and transmits differentially corrected navigation signals via Coast Guard radiobeacons to maritime users.

The NDGPS involves extending the Coast Guard radiobeacon system inland via civilian use of a deactivated military infrastructure known as the Ground Wave Emergency Network (GWEN) towers. These towers provide a platform for Coast Guard equipment to transmit differentially-corrected navigation information for a wide variety of safety-of-life applications including positive train control, emergency 911 response, search and rescue, and disaster management applications. User equipment and services would be supplied by competing commercial firms. This is a good example of public-private synergies in which the former has a unique role in creating infrastructure which expands the usefulness of GPS and thus provides additional safety and financial benefits to federal, state and local governments, as well as the general public.

The continued evolution of GPS to include a second and third civil frequency as well as the elimination of peacetime use of Selective Availability have the potential to increase commercial GPS sales. The addition of new civil frequencies will benefit international navigation actions while the elimination of SA will most obviously benefit consumer and recreational users. Ironically, these improvements to GPS itself will likely reduce some of the competitive advantages now held by U.S. GPS firms while leveling the field for international competitors. This is due to the fact that U.S. manufacturers have developed and marketed sophisticated GPS equipment and software that provide most of the benefits of a second civil frequency already. The value of this investment will be reduced if a second civil frequency is available to anyone. DGPS equipment and software are already capable of removing much of the effect of SA, but at price points above that of typical consumer markets. The removal of SA will slightly reduce some of the need for DGPS, particularly in price-sensitive recreational markets. However, predominant commercial requirements are such that DGPS accuracies (e.g., submeter and centimeter levels) will still be needed even after SA is turned to zero.

The growth of commercial satellite communications and the growth of GPS applications has led some to speculate that GPS itself could be a commercial activity with the government as a relatively small but important customer. Such speculation overlooks some of the key differences between GPS and satellite communications in areas such as pricing and liability. For example, its would be virtually impossible to assess user charges on the current installed base of GPS users unless government tax powers were used. This would impose an unequal burden on U.S. versus foreign GPS users and slow the adoption of GPS as a global standard. Since GPS is used for public safety functions, a private operator would likely require government liability protections. Finally, DoD involvement is seen by GPS firms as a crucial "badge of quality" which supports customer confidence in GPS goods and services worldwide. The required combination of tax powers, liability shields, and market confidence makes it difficult to imagine how the government could actually reduce its current stewardship role except by abandoning GPS entirely.

While there are commercial opportunities in supplying DGPS products and services, there does not appear to be a business case for supplying the basic GPS signal. Based on informal discussions with representatives of the investment community, it is highly unlikely that the private sector could have secured the non-recurring investment to build such a system, let alone build a credible business model for generating a profitable venture. Aside from a continuing government interest in GPS for national security and public safety reasons, the system itself meets the classic definition of a public good.

Managing Government Risks

The predominant market risks to the growth of GPS applications are those found in any commercially-driven information technology. In the case of GPS, there is not a single market, but many different markets at various levels - OEMs, integrators, value-added resellers, etc. Firms have to understand customer needs and develop competitive solutions to their problems. Each market segment will have its own unique risks and applicable business models.

The most difficult market risks are not financial or technical, however, but those which are uncertain and for which it is difficult to prepare alternative business strategies. Examples of these types of risks are changing government regulations and international trade agreements.

There is inherant political risk from domestic and international governmental actions for GPS. Since GPS application markets are overwhelmingly commercial, and not driven by government procurements, the primary political risk comes from government regulations, taxes, and potential restrictions to GPS use. The U.S. government has relatively few regulations specific to GPS. One of the most obvious are export controls on military GPS receivers. A military GPS receiver is defined as one which is capable of providing navigation information at speeds in excess of 1000 nautical miles per hour and at altitudes in excess of 60,000 feet (e.g., as with ballistic missiles), has a "null steering" antenna to overcome jamming, or which has an encryption device such as the kind needed to access the GPS P-code. Civilian receivers are classed as "general destination" items and face few, if any, U.S. export restrictions.

Some countries impose special taxes or restrictions on GPS equipment in addition to import tariffs typical for other types of electronic equipment. Germany, for example, used to require the registration of GPS receivers and the payment of a monthly fee to the national phone system. Other countries, such as Saudi Arabia, limit the ownership of GPS receivers to members of the royal family or persons conducting official business. Similarly, China restricts the operation of GPS receivers in Tibet to those on official business. Some countries bar or limit the movement of GPS-equipped vehicles. Commercial trucks using GPS as a navigation tool are often stopped at the borders of Russia and Bulgaria. The concern seems to be that such vehicles could collect precise location information that may be militarily sensitive. In 1997, a U.S. engineer was detained in Russia in the course of using GPS surveying equipment to locate sites for cellular phone towers. In part, this was due to Russian law which categorizes geodetic information with better than 30 meter accuracy as sensitive and controlled. This does not necessarily represent a regulatory issue with the GPS equipment itself, but with the information created by the equipment.

Finally, regulatory restrictions can limit the use of GPS for certain purposes. The use of GPS for safety of life purposes, such as international navigation, require certifications by competent national and international safety bodies (e.g., the Federal Aviation Administration and the International Civil Aviation Organization, respectively). The use of certain GPS techniques may be subject to local legal restrictions. For example, real-time kinematic GPS is a technique which allows the acquisition of very precise (sub-meter) location data while moving. Originating in the United States, this technique has greatly increased the productivity of land surveys worldwide. Lack of appropriate government regulations for this technique has, however, hindered its acceptance in the case of Japanese cadastral land surveys. Such surveys define official land boundaries and thus are quite important legally. The Japanese government is currently conducting RTK field tests in cooperation with U.S. and Japanese firms to support new regulations that will enable the legal acceptance of GPS RTK-generated survey data.

The United States and Europe have negotiated a Mutual Recognition Arrangement (MRA) to facilitate trade in information technology goods such as computers and telecommunications equipment. A similar model agreement has been developed within APEC (Asia Pacific Economic Cooperation) for the Asia-Pacific region, with bilateral negotiation of it specific implementation clauses. Such agreements enable participating countries to recognize member's conformity assessment procedures, including testing and certifications, and therefore minimize the number of technical and administrative trade regulations. The inclusion of GPS in MRAs would facilitate exports of GPS receivers from one market to another and aid in the removal any non-tariff barriers. Likewise, industry is hopeful that Information Technology Agreements can successfully establish zero tariffs on all information technology products, including GPS receivers and related equipment.

The most serious threat to GPS applications would be interference with the clear reception of the GPS signal itself. The spectrum used by GPS signals is allocated through an international organization, the International Telecommunications Union (ITU). Every two years, the ITU holds a World Radiocommunications Conference to consider proposals to modify existing spectrum allocation and make new allocations of the limited resource that is the electromagnetic spectrum. At the 1997 conference (WRC-97), the radionavigation spectrum was threatened by an unprecedented effort to overlay commercial mobile satellite services on the safety-of-life GPS signal. WRC-97 produced a call for technical studies on the issue of whether the GPS signal could co-exist with a commercial application. Public and private sector users of GPS for public safety, commercial, and national security purposes see the need to assure GPS spectrum protection at the next conference in 2000.

In addition to the spectrum required for the basic GPS signal, the transmission of differential corrections also requires spectrum. DGPS signals are transmitted on a wide variety of frequencies depending on the particular area of operation, local licensing regulations, and what service area is desired. Some industry members have called for international efforts to harmonize the spectrum allocations available for DGPS communications in order to promote interoperability and gain economies of scale in addressable markets. Given intense competition for usable spectrum worldwide, however, such discussions are likely to be very difficult without government-to-government initiatives.

Areas Where Governments Can Help or Hurt

As with many other areas of information technology, such as computers, the government played a crucial role in the initial research and development that led to the first working GPS receivers. Today, however, the military receiver market is a relatively small portion of overall product sales, and new GPS products and services are being driven by purely commercial market forces. GPS-based positioning and navigation are being blended with mobile communications services, currently cellular and, in the future, mobile satellite services. Users of GPS tend to become reliant on it for commercial as well as safety of life purposes and expect 24 hour per day, 7 day a week availability. Accuracy is addictive as well with consumer expectations that accuracy will never decrease and will hopefully increase in the future.

Early on in the development of GPS, the government committed itself to encouraging non-defense uses of the system, such as international aviation safety. The technical nature of GPS signals (one-way broadcast) and the need to have an easily acquired signal (i.e., the C/A code) led, in part, to the decision not to impose direct user fees or other types of specific taxes on the system. Another consideration was that taxes would have slowed the adoption of the new technology by non-government users and undermined the promotion of intended public safety benefits. Indirect fees, such as the use of ticket and fuel taxes, would be allowed for GPS augmentations that benefited specific groups of users. This approach, similar to the practice of giving away some types of computer software, resulted in the rapid establishment of GPS as a worldwide utility. The open and free access to the GPS signal enabled entrepreneurs to generate applications based on the precise time stamp and accurate position/navigation attributes of GPS.

The current role of government in global competition for GPS-related sales is relatively limited; largely involving regulatory matters such as certification of GPS in safety-of-life applications and export controls on military-grade GPS equipment. In terms of promoting the growth of commercial GPS markets, the most important U.S. government actions are those which enhance international confidence in the stability, reliability, and integrity of the basic GPS signal. This can take various forms, from obvious measures such as stable funding and careful technical management of the GPS constellation to more subtle factors such as protecting the international spectrum allocation for GPS and balancing military, civil, and commercial interests in creating enhancements and augmentations to the basic GPS signal.

In the short term, the most immediately achievable commercial opportunity for government action would be to facilitate international trade in GPS equipment and services through Mutual Recognition Arrangements and inclusion of GPS in Information Technology Agreements. It was clear from the survey that industry is keenly interested in making processes such as equipment certification, international sales clearance and other export procedures as simple as possible. More effort on the part of government and industry to reduce the time to completion of these transactions will aid in the expansion of commercial GPS markets. It would also help if, for economic statistical purposes, GPS products could have a more specific Standard Industrial Classification. At present, GPS is covered by (SIC) 3829: *Measuring and Controlling Devices, Not Elsewhere Classified*.

In the long-term, public and private investment decisions in GPS will depend on perceptions of U.S. capability and competence to manage a dual-use, global information utility. There are various indicators that international observers might look for and it is difficult to predict which will be dominant at any particular time. From discussion to date, the ability of the United States to gain international support for protecting the GPS spectrum allocation within the ITU is the most important long-term indicator. Closely coupled with the spectrum allocation is the demonstration of U.S. commitment to evolving and modernizing GPS to meet increasingly sophisticated user needs — especially in the area of public safety, followed by military and scientific needs. Since commercial forces are already driving user equipment, there appear to be no purely commercial requirements for changes to the basic GPS signal and constellation.

In addition to spectrum and trade concerns, industry is also looking to government to create the regional agreements called for in the 1996 Presidential Decision Directive on GPS and law (e.g., P.L. 105-85). The U.S. State Department is currently holding discussions with Japan, Europe and Russia to establish a framework for promoting acceptance of GPS as an international standard and addressing related economic, security, legal, and political issues that may arise. One international concern is the desire for independent integrity monitoring of the GPS signal to ensure it is safe to use or that warnings are given if it is not. Another concern is the need for government leadership in establishing standard requirement definitions to facilitate multi-modal development and certification of international transportation systems using GPS. This is especially true in the case of international aviation and maritime GPS applications in which the United States already has a leadership role.

Continued DoD leadership of GPS, while a political issue for some foreign governments, appears to be necessary to maintaining international market confidence in GPS. Thus an important long-term policy requirement will be the protection of national security equities in a system that is increasingly known by its non-military applications. GPS is a rapidly growing information technology that can be aided or hurt, but not entirely controlled by government actions. Its continuing, rapid commercial penetration into a wide variety of infrastructures means that the market survey done here is at best a conservative estimate of the global economic significance of this dual-use technology.

Appendix A - Commercial GPS Suppliers

The listing of GPS-related companies organizations largely derived from the GPS World magazine database and used with permission. In addition, we have included a listing of the members of the Japan GPS Council, which includes not only GPS businesses, but firms which use GPS in their daily operations.

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Zycom Corporation
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Bedford, MA 01730-0369
Phone: (617) 274-1222
Fax: (617) 274-9866
E-mail: zycom@ma.ultranet.com.

U.S. GPS Industry Council Members

Boeing
Honeywell
Lockheed Martin
Magellan Inc.
Motorola
Rockwell International
Trimble Navigation Ltd.

Japan GPS Council Members

Aero Asahi Corporation
Aisin Seiki Co., Ltd.
Alpine Electronics Inc.
Ascii Corporation
Asia Air Survey Co., Ltd.
Central Japan Railway Company
Clarion Co., Ltd.
Funai Electronic Co., Ltd.
General Research of Electronics Inc.
Hitachi Limited
Honda R&D Co., Ltd.
Icom Incorporated
Japan Petroleum Exploration Co., Ltd.
Japan Radio Co., Ltd.
Japan Traffic Management Technology Association
Kawasaki Heavy Industries, Limited
Kenwood Corporation
Koden Electronics Co., Ltd.
Kokusai Denki Engineering Co., Ltd.
Kokusai Kogyo Co., Ltd.
Kyushu Matsushita Electric Co., Ltd.
Maspro Denkoh Corporation
Matsushita Communication Industrial Co., Ltd.
Matsushita Electric Works, Limited
Mazda Motor Corporation
Mitsui O.S.K. Lines, Limited
Mitsui & Co., Ltd.
Mitsubishi Electric Corporation
Mitsubishi Plastics Industries
NEC Corporation
NEC Home Electronics, Limited
NHK (Japan Broadcasting Corporation)
Nihon Tsushinki Co., Ltd.
Nippon Denso Co., Ltd.
Nippon Mail Transportation Co., Ltd.
Nippon Motorola Limited
Nippon Senpaku Tsushin K.K.
Nishio Rentall Co., Ltd.
Nissan Motor Co., Ltd.
Nissho Iwai Corporation
NTT Data Communications Systems Corporation
NTT Mobile Communications Network Inc.
Lines (Nippon Yusen Kabushiki Kaisha)
Oki Electric Industry Co., Ltd.
OmniTRACKS Corporation
PASCO Corporation
PIA Corporation
Pioneer Electronic Corporation
Railway Technical Research Institute
Rockwell International Japan Co., Ltd.
Sanyo Electric Co., Ltd.
SECTA (Security Electronics & Communications Technology Association)
Sharp Corporation
Sokkia Co., Ltd.
Sony Corporation
SPC Electronics Corporation
Sumitomo Corporation
Sumitomo Electric Industries, Limited
Taisei Corporation
Technical Services of Information Co., Ltd.
Tokyo Cosmos Electric Corporation
Topcon Corporation
Trimble Navigation (Japan) Limited
Toshiba Corporation
Toyota Motor Corporation
Victor Company of Japan, Limited
Xanavi Informatics Co., Ltd.
Yokogawa Navitec Corporation
Zenrin Co., Ltd.
All Japan Fishery Radio Association
All Japan Radio Taxi-Cab Organization
Japan Fisheries Association
Keidanren (Japan Federation of Economic Organization)
Land Mobile Radio Association Corporation, Japan
Marine Radio Inspecting Association
NASDA (National Space Development Agency of Japan)
NORC (Nippon Ocean Racing Club)
Radio Equipment Inspection and Certification Institute
R&D Center for Radio Systems
SUIYOKAI Marine Radio Manufacturers Association
The Japanese Ship Owners' Association
The Sakura Bank Ltd.
Zenkoku Idou Musen Center Kyougikai

Appendix B - GPS Web Sites and Bibliography

In addition to the bibliography provided below, the reader is directed to the following publications which provide an overviews of the policy, management, and technical issues affecting the future evolution of Global Positioning System applications:

Pace, Scott, et. al, *The Global Positioning System - Assessing National Policies*, RAND, 1995.

National Research Council, *The Global Positioning System - A Shared National Asset*, National Academy Press, 1995.

National Academy of Public Administration and National Research Council, *The Global Positioning System - Charting the Future*, National Academy of Public Administration, 1995.

Lists of GPS-related links

For current information the reader will find the following URLs useful in searching the World Wide Web of the Internet:

Links to Multiple GPS Sites

Descriptions of GPS-related companies
http://www.yahoo.com/Business_and_Economy/Companies/Navigation/Radio/Global_Positioning_Systems/

Descriptions of GPS-related applications
http://www.yahoo.com/Science/Geography/Navigation/Global_Positioning_System/

GPS World magazine
http://www.gpsworld.com/

GPS Strategic Directions
Global Positioning & Navigation News
GPS Directory
http://www.phillips.com

<u>Individual Web pages with GPS-links</u>

http://www.inmet.com/~pwt/gps_gen.htm

http://www.ghgcorp.com/wagenx/gps.htm

Universities and Associations

University of Texas Overview of GPS Operations and Technology http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

University of New Brunswick - Survey and Geodetic Applications
http://degaulle.hil.unb.ca/Geodesy/ CANSPACE.html

Institute of Navigation
http://www.ion.org

U.S. Government Offices and Agencies

U.S. Department of Commerce
Office of Telecommunications
http://infoserv2.ita.doc.gov/ot/

U.S. Department of Commerce
Office of Air & Space Commercialization
http://cher.eda.doc.gov/oasc.html

GPS Joint Program Office
http://www.laafb.af.mil/SMC/CZ/homepage/index.html

U.S. Coast Guard Navigation Information Center
http://www.navcen.uscg.mil/

National Geodetic Survey
http://www.ngs.noaa.gov/FGCS.html

U.S. Naval Observatory - Timing Applications
http://tycho.usno.navy.mil/gpsinfo.html

U.S. Department of Transportation
http://www.dot.gov/

The Russian GLONASS System

http://www.rssi.ru/SFCSIC/SFCSIC_main .html

http://www.rssi.ru/SFCSIC/SFCSIC_main .html

Bibliography

Books and Reports

Booz-Allen & Hamilton, S.A., *Survey of the Satellite Positioning Industry in Europe*, Final Report prepared for the European Commission Directorate General III, Paris, France, October 21, 1997.

Chairman of the Joint Chiefs of Staff, *CJCS Master Navigation Plan*, CJCSI 6130.01, May 20, 1994.

Clarke, Bill, *Aviator's Guide to GPS,* McGraw-Hill, Inc., NY, 1994.

Commission of the European Communities, *Satellite Navigation Services: A European Approach*, COM(94) 248 final, Brussels, 1994.

DeBolt, Robert O., et al., *A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services*, U.S. Department of Commerce, National Telecommunications and Information Administration and U.S. Department of Transportation, NTIA Special Publication 94-30, December 1994.

Dyment, Michael J., *North American GPS Markets: Analysis of SA and Other Policy Alternatives*, Final Report to the National Academy of Sciences, Committee on the Future of the Global Positioning System, May 1, 1995.

Electronics Industry Association of Japan, *Report on the Japan GPS Market* (in Japanese), Tokyo, Japan, June 3, 1994.

Frost & Sullivan, *North American Global Positioning System Markets*, Mountain View, CA, 1997.

General Accounting Office, *Global Positioning Technology: Opportunities for Greater Federal Agency Joint Development and Use*, RCED 94-280, Washington, D.C., September 1994.

Government of Japan, Ministry of Transport, Civil Aviation Bureau, Multi-functional Transport Satellite (MTSAT) Aeromission, Tokyo, 1994.

Hester, Edward D., *Global Positioning Satellites: U.S. Products & Applications*, The Freedonia Group, Inc., Cleveland, OH, February 1997.

Japanese Technology Evaluation Center, *Electronic Manufacturing and Packaging in Japan*, National Technical Information Service, ISBN 1-883712-37-8, Washington, D.C., 1995.

Logsdon, Tom, *The Navstar Global Positioning System*, Van Nostrand Reinhold, New York, 1992.

Mogee Research & Analysis Associates, *Global Positioning Systems Technology: An International Patent Trend Analysis*, Great Falls, VA, April 6, 1995.

National Research Council, *Forum on NOAA's National Spatial Reference System*, National Academy Press, Washington, D.C., 1994.

Parkinson, Bradford W. and James J. Spilker, ed., *Global Positioning System: Theory and Applications*, American Institute of Aeronautics and Astronautics, Washington, D.C. 1996

Preiss, George, et al., *Organising the Consultative Process for European GNSS User Requirements*, Commission of the European Communities, Brussels, December 19, 1994.

Turner, David A., and Marcia S. Smith, *GPS: Satellite Navigation and Positioning and the DoD's*

Navstar Global Positioning System, CRS Report for Congress, 94-171 SPR, 1994.

U.S. Congress, Office of Technology Assessment, *Assessing the Potential for Civil-Military Integration: Technologies, Processes, and Practices*, OTA-ISS-611, U.S. Government Printing Office, Washington, D.C., September 1994.

U.S. Department of Commerce, Institute for Telecommunications Sciences, *A National Approach to Augmented GPS Services*, NTIA Special Publication 94-30, December 1994.

1996 Federal Radionavigation Plan, National Technical Information Service, DOT-VNTSC-RSPA-97-2 /DOD-4650.5, Springfield, VA, July 1997.

Articles

Adamson, Lee, "A Star to Steer By," *Ocean Voice*, January 1995, pp. 10-1 1.

"AF Says GPS Fully Operational," *GPS World Newsletter*, May 22, 1995, pp.1, 5.

"Agency Initiatives Push Civil GPS Requirements, Agenda," *GPS World Newsletter*, October 27, 1994, pp. 1-2.

"Air Force Solicits Industry Comments on Plan to Change GPS Satellite Navigation Message," *GPS World*, November 1994, p. 16.

Anselmo, Joseph C., "'Smart Highway' Business Attracts Aerospace Firms," *Aviation Week & Space Technology*, January 31, 1994, pp. 56-57.

"Around the Industry...: The Freedonia Group, Inc.," *GPS World*, July 1997, p. 56.

"Ashtech Merges with Magellan," *GPS World Newsletter*, November 28 - December 6, 1997, pp. 1, 4-5.

"Ashjaee Returns to GPS Marketplace," *GPS World Newsletter*, January 30, 1998, p. 4.

"Aviation Markets Forge GPS Allies," *GPS World Newsletter*, December 29, 1994, p. 3.

Baig, Edward, "On the Road Again—With a Digital Map," *Business Week*, June 20, 1994, p.187.

Boyer, William, "Randy Hoffman—President and Chief Executive Officer, Magellan Systems Corp.," Space News, January 10-16, 1994, p. 22.

"Car Navigation Expected to Spark GPS Growth," *Space News*, March 13-19, 1995.

"Car Navigation Semiconductor Market to Grow," *GPS World*, October 1997, p. 62.

"Car Navigation Chips to Be $1.7 Bln Industry," *Reuters*, August 4, 1997.

Cerullo, Bob, “You’ll Never Get Lost Again,” *Parade Magazine*, January 25, 1998, p. 10.

Collier, W. Clay, and Richard J. Weiland, “Smart Cars, Smart Highways,” *IEEE Spectrum*, April 1994, pp. 27-33.

Cooper, Pat, “Navy Satellite System Aims to Deter ID Mishaps,” *Defense News*, August 8-14, 1994, p.26.

Cope, Lewis, “Satellites Help Mayo Medicine,” *Star Tribune*, March 22, 1994, p. 1B.

Day, Kathleen, “The Highway of the Future,” *Washington Business*, March 14, 1994, pp. 1, 14-15.

————, “Orbital to Buy Positioning Firm,” *The Washington Post*, November 29,1994, p. C3.

de Selding, Peter B., “Europeans To Pledge GPS Funds,” *Space News*, May 1-7, 1995, pp. l, 20.

“Dividends in Space,” *GPS World*, June 1995, p. 16.

Divis, Dee Ann, “GPS Patents and U.S. Patent Policy,” *GPS World*, November 1996, p. 14.

“DGPS Nets: China and Finland,” *GPS World Newsletter*, December 29, 1994, p. 4.

”EC Satnav Study Proposes Building on GPS GLONASS,” *GPS World*, February 1994, p.18.

”European Agencies Set Budget for GNSS Program,” *GPS World Newsletter*, May 22, 1995, pp. 1, 5.

“Executive Order 12906 Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure,” Federal Register, Vol. 59, No. 71, April 13, 1994, pp. 17671-17674.

“FAA Chief Renews GPS Pledge to ICAO,” *GPS World Newsletter*, October 27, 1994, p. 5.

“FCC invites E-911 Comments,” *GPS World Newsletter*, March 13, 1998, pp. 1-2.

Field, David, “U.S. to let Airliners Navigate by its Satellites,” *The Washington Times*, March 28,1995, p. B7.

“Firm Sketches GPS Auto Nav Market,” *GPS World Newsletter*, August 8, 1997, pp. 1, 5.

Fisch, Al, “GPS Timing Signals Support Simulcast Synchronization,” *Mobile Radio Technology*, May 1995.

Foster, Anthony P., “GPS Strategic Alliances, Part I: Setting Them Up,” *GPS World*, May 1994, pp. 34 42.

————, “GPS Strategic Alliances, Part II: Dealing With the Legal Issues,” *GPS World, June* 1994, pp. 28-32.

“Frost & Sullivan: GPS Markets,” *GPS World Newsletter*, March 7, 1997, pp. 1, 4.

Gibbons, Glen, “Passport to Telecoms,” *GPS World*, March 1998, p. 10.

“Global Positioning System Use on The Rise - Report,” *Newsbytes News Network*, March 4, 1997.

“GLONASS: New Launch, Info Center, Web Home,” *GPS World*, April 1995, p. 18.

“GM Oldsmobile Will Be First in U.S. With GPS,” *GPS World*, February 1994, p. 18.

Gouzhva, Yuri G., et al., “GLONASS Receivers: An Outline,” *GPS World*, January 1994, pp.30-36.

“GPS World Buyers Guide 1997,” *GPS World*, June 1997, pp. 46-73.

“GPS in Year 2000: $8 Billion,” *GPS World Newsletter*, April 11, 1995, p. 1.

“GPS Timing Applications Grow,” *GPS World Newsletter*, December 29, 1994, p. 3.

“GPS gets Playful with Computer Games,” *GPS World Newsletter*, December 23, 1997, p. 4.

Griffiths, John, “Smart Car Boom for Electronics Suppliers,” *Financial Times London Edition*, November 7, 1997, p. 7.

Groves, Martha, “The Cutting Edge,” *Los Angeles Times*, March 10, 1997.

Hamilton, David P., “Navigation Systems Set Course for U.S.,” *Wall Street Journal*, February 13, 1995, pp. Bl, Bl0.

Hewish, Mark, “Sensor Integration For Navigation and Survey,” *International Defense Review*, No. 4, 1994, pp. 49-55.

Hughes, David, “Air Navigation Due for Dramatic Change,” *Aviation Week & Space Technology*, October 31, 1994, pp. 51-59.

In Japan They May Never Ask for Directions Again,” *Wall Street Journal*, January 7, 1994.

“Inmarsat Invites Bids for GNSS Augmentation,” *GPS World*, October 1994, p.18.

“Inmarsat-3s Offered for Navigation,” *Space Business News*, September 13, 1994, p. 4.

“It’s 8 a.m. Do You Know Where Your Kids Are?,” *GPS World Newsletter*, March 13, 1998, p. 5.

“ITS/GPS Roundtable Says, ‘Show Us the Money!’,” *GPS World*, October 1997, pp. 44-52.

“Japan Leads its Market, Many Follow,” *Automotive Environment Analyst*, August 1, 1997, pp. 9-10.

“Japanese GPS Receiver Market: $240 Million and Climbing Fast,” *GPS World Newsletter*, December 29, 1994, pp. 1,4.

“Japanese Official Comments on GPS,” *GPS World*, May 1997, p. 21.

Jewett, Dale, “Siemens Eyes Onbarod Market,” *Automotive News*, May 19, 1997, p. 22+.

Johnson, Nicholas L., “GLONASS Spacecraft,” *GPS World*, November 1994, pp. 51-58.

Kane, Francis X., “Navstar GPS & Satellite Communications,” *Satellite Communications*, 1994, pp. 44 46.

————, “GPS Benefits Space Canopy,” *Space News*, May 12-18, 1997.

Klass, Philip J., “GLONASS-M Readied,” *Aviation Week & Space Technology*, December 12-19,1994, p. 59.

————, “GPS To Be Tested for Cat-3 Landings,” *Aviation Week & Space Technology*, Vol. 142, No. 7, February 13, 1995, pp. 62-63.

Koprowski, Gene, “NSF Sets Up Smart-infrastructure Workshop,” February 16, 1998.

Krakiwsky, Edward J., and James F. McLellan, “Making GPS Even Better with Auxiliary Devices,” *GPS World*, March 1995, pp. 46-53.

Krawczyk, Thomas, “Outsmarting Traffic Jams,” *Technology in Review*, February/March 1994, p.14.

Kursinski, Rob, “Monitoring the Earth’s Atmosphere with GPS,” *GPS World*, March 1994, pp. 50-54.

Lachow, Irving, “The GPS Dilemma: Balancing Military Risks and Economic Benefits,” *International Security*, Vol. 20, No. 1 (Summer 1995), pp. 126-148.

Lavitt, Michael O., “GPS Attitude Determination,” *Aviation Week & Space Technology*, February 7, 1994, p. 13.

Leary, Warren E., “Civilian Uses Are Proposed for Satellites,” *The New York Times*, June 1, 1995, p. A23

Loh, Robert, “Seamless Aviation: FAA’s Wide Area Augmentation System,” *GPS World*, April 1995, pp. 20-30.

“Magellan introduces new GPS/GLONASS units,” *GPS World Newsletter*, March 13, 1998, p. 6.

Marks, Peter, “For a Few Lucky Motorists Guidance by Satellite,” *New York Times*, April 2,1994, pp. A1, A24.

McDonald, Keith, “Situation Critical: GPS Modernization for Civil Use,” *GPS World*, January 1998, p. 32.

McHale, Tom, “GPS Market Poised For Rapid Growth,” *Electronic Buyers News,* July 15, 1996, p. 20.

————, “GPS Finally Seems Poised to Hit The Mass Commercial Markets,” *Electronic Buyers News*, September 8, 1997, p. 32.

Miller, Brian, “Cellular Revolution Threatening E-911,” *Government Technology*, October 1994, pp. 16-17.

Mills, Mike, “Cellular Phone Firms Zero In on Tracking,” *The Washington Post*, pp. F1, F9.

“Motorola combines GPS, Wireless, Mobile Data for Telematics Business,” *GPS World Newsletter*, February 13, 1998, pp. 1, 5.

“New Frost Study says GPS applications market will grow to $366.2 million by 2003,” *Global Positioning & Navigation News*, October 8, 1997, p. 5.

Nordwall, Bruce, “Enhanced GPS Spawns Innovative Applications,” *Aviation Week & Space Technology*, November 21, 1994, pp. 94-95.

————, “Quartz Fork Technology May Replace INS Gyros,” *Aviation Week & Space Technology*, April 25, 1994, pp. 50-51.

————, “Small GPS Receivers Open New Possibilities,” *Aviation Week & Space Technology*, December 5, 1994, pp. 57-58.

“NRC Advises Precision Ag Action,” *GPS World Newsletter*, September 12, 1997, pp. 1-2.

“OSC to merge Magellan subsidiary with Ashtech,” *Global Positioning & Navigation News*, December 3, 1997, pp. 1-2.

“Orbital completes Magellan-Ashtech merger; combined company offers broadest line of satellite access procducts,” *PRNewswire via NewsPage*, January 5, 1998.

Parkinson, Bradford W., “GPS Eyewitness: The Early Years,” *GPS World*, September 1994, pp. 32-45.

Patterson, Lee, “A Mode Less Traveled,” *Forbes ASAP*, February 24, 1997, p. 110.

Pollack, Andrew, “Computers let Japan’s Drivers Play in Traffic,” *New York Times*, October 6, 1997, p. D1.

Proctor, Paul, “Real-Time Fire Mapping,” *Aviation Week & Space Technology*, August 25, 1997, p. 13.

"Production Underway for Smaller, Yet More Powerful Antenna," *Aviation Week & Space Technology*, February 23, 1998, pp. 114-115.

Reason, Tim, "GPS on Capitol Hill: Policy and Progress, an interview with Senator Jim Exon," *Professional Surveyor*, July/August 1994, pp. 18, 21.

Reed, J.D., "Making Contact," *Time Digital*, November 3, 1997, pp. 51-52, 57.

Rip, Michael Russel, and David Lusch, "The Precision Revolution: The Navstar Global Positioning System in the Second Gulf War," *Intelligence and National Security*, Vol. 9, No. 2, 1994, pp. 167-241.

"Rockwell to Sell GPS Auto Nav Unit," *GPS World Newsletter*, March 21, 1997, pp. 1, 5.

Sakelaris, Linda Kay, "RCR Focus On: GPS: Location Wireless Technologies Merge for Business and Safety," *RCR Radio Communications Report*, March 4, 1996, p. 8.

Salisbury, David F., "Tracking the Expanding Uses of GPS," *Aerospace America*, May 1997, pp. 46-51.

Sasaki, Sei, "Japanese Car Navigation," *The Nikkei Weekly*, June 2, 1997, p. 9.

"Satellites Will Steer Us To Millennium - Report 8/1/97," *Newsbytes News Network*, August 1, 1997.

Seitz, Patrick, "Sony Sells Dashboard Navigator Tying GPS to Travel Data," *Space News*, January 9-15, 1995, p. 16.

Shank, Chris, and John W. Lavrakas, "Inside GPS: The Master Control Station," *GPS World*, September 1994, pp. 46-54.

Shuldiner, Herb, "Guiding Lights for Your Car," *Car & Travel*, March/April 1997, pp. 6-7.

"SIC Effort Could Make GPS an Official Industry," *GPS World Newsletter*, October 13, 1994, pp. 1-2, 6.

Skinner, Liz, "Global Positioning Systems' Place on Infobahn," *Washington Technology*, December 1994, p. 18.

————, "GPS Future Lies in Navigation Markets," *Washington Technology*, March 23, 1995, p. 16.

"Study Notes Satellite Market Trends," *Newsbytes News Network*, February 11, 1997.

"Study Updates Location-based Markets," *GPS World Newsletter*, November 28 - December 6, 1997, pp. 11-12.

Stutzman, Warren L. & Dietrich, Carl B. Jr., “Moving Beyond Wireless Voice Systems,” *Scientific American*, August, 1998, p. 92-93.

Testa, Bridget Mintz, “The Global Positioning System: Never Get Lost Again,” *Current Technology*, October 1997, pp. 14, 16, 19.

“Trimble and Honeywell Sign Agreement for Strategic Alliance on GPS,” *PRNewswire via NewsPage*, June 12, 1995.

“Trimble Discusses GPS Markets, Applications at the FCC,” *Global Positioning and Navigation News*, May 30, 1995.

“U.S. Commerce Department Predicts Rapid GPS Growth,” *Global Positioning & Navigation News*, January 27, 1994, p.5.

“U.S. Formally Pledges Free Use of GPS,” *Aerospace Daily*, October 19, 1994, p.92.

Wilson, Ron, “Embedded Apps are Target as Global Positioning Satellite Receivers Move from Board to Chip Level — Higher Integration Drives GPS ‘under cover’,” *EE Times*, December 22, 1997.

“Worm Holes in GPS Coverage Raise Interference Concerns,” *Aviation Week and Space Technology*, June 5, 1995, p.32.

“Yeoman Chief Sizes GPS Consumer Biz,” *GPS World Newsletter*, November 28 - December 6, 1997, pp. 1, 8.

In addition to the works cited above, the following periodicals provided regular coverage of GPS-related development and applications:

Aviation Week & Space Technology
Global Positioning and Navigation News
GPS World
GPS World Newsletter
Space News
Washington Technology

Appendix C - Survey Document

This document was used for all survey discussions and was furnished to all participants and was used by the Japan GPS Council as the basis for their inquiry with fifty of their member companies .
****

Survey of Commercial/Civil Global Positioning System (GPS) Applications, Augmentations and Related Activities

Note: The U.S. Department of Commerce appreciates your taking the time to respond to this survey. It is a part of the effort of the International Trade Administration's Office of Telecommunications to maintain and strengthen data on the state of the GPS industry. This survey will assist in assuring that the government is tracking issues of relevance to the future competitiveness of this growing industry sector.

A member of the study team will be contacting you soon to arrange for a teleconference or meeting. If you wish to designate someone other than yourself as a contact person, please let one of the study team members know. A copy of the final report will be provided to all participants and appropriate arrangements can be made for the protection of any proprietary materials that arise in discussions.

Questions or comments may be directed to:

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A. Applications of GPS

Typically, the GPS industry has been divided into the following groupings:

Car navigation
Consumer/Cellular
Tracking
OEM
Survey/mapping
GIS
Aviation

Marine
Military

1. Do you believe that the above categorizations still adequately capture the broad divisions of the GPS market?

2. In which of these markets do you currently provide GPS hardware, software or services?

3. Which aspects of the GPS signal are most valuable to your business applications ? Other than providing a high accuracy, unencrypted signal, what signal enhancements would be most valuable to your business development ?

4. Please help us estimate the economic value of the GPS market by completing the following table:

Note: You may find that this method of arriving at an estimate for total market value does not conform to your approach. To the extent possible, please give us your best estimates of market value and advise us as to your methodology.

cell value for total market: (ave. no. units x ave. cost)

	1997	1998	1999	2000	2002	2003	2004
Car navigation							
Consumer/Cellular							
OEM							
Survey/mapping							
GIS							
Aviation							
Marine							
Military							
Tracking							
Other (specify)							

Using the matrix below, or your alternative, please estimate the relative market contribution (percentage of market) of the following geographic areas:

Asia
Europe
Japan
U.S.
Other

Note: You may find that this method of arriving at an estimate for total market share does not conform to your approach. To the extent possible, please give us your best estimates of market share and advise us as to your methodology.

cell value: (% participation by geo. area)

	1997	1998	1999	2000	2002	2003	2004
Car navigation							
Consumer/Cellular							
OEM							
Survey/mapping							
GIS							
Aviation							
Marine							
Military							
Tracking							
Other (specify)							

5. In the GPS market sectors in which you organization participates who are the most significant competitors?

6. Where do you anticipate the greatest market growth opportunities may be may be?

B. GPS Augmentations

GPS augmentations are taken to mean uses of GPS signals in conjunction with other signals to improve the accuracy and availability or other aspects of the signal for users, commonly referred to as differential GPS or DGPS.

1. Which sectors of the global GPS market will benefit most from applications of DGPS?

2. Are there new DGPS opportunities which could materially alter the GPS market in the near (next five years) or long term (beyond five years) future?

3. To what extent do possible government DGPS systems effect your market outlook?

4. Do you anticipate participating in providing any DGPS hardware or services? If so, what would be the nature of that participation ?

C. Government/Industry Interaction

1. Are there specific government actions which would increase the value of your GPS related business?

2. Are there specific government practices which now effect either positively or negatively your competitiveness in the GPS market?

3. Government, in the GPS and other industry sectors, is a customer, R&D patron, regulator, operator and international advocate. How do you view these roles and there evolution in the GPS sector over the next few years?

D. Related Activities - Research & Development

1. Does your organization or an affiliate conduct research and development in any of the GPS market segments or in potentially new GPS market segments?

2. Does your organization realize any benefit from government sponsored research and development in your development of GPS hardware or software?

3. What areas of government research and development activity are potentially most beneficial to the development of the GPS industry?

D. Technology

GPS applications appear to be emerging as part of information technologies which are essential to the functioning of a modern world community.

1. To what extent has the nature of the GPS applications changed in the past five years? What change do you anticipate, if any, in the nature of the industry in the next five years ?

2. Are there any technologies which could potentially alter the fundamental nature of the GPS industry in the near term (next five years) or long term (beyond five years)? What are the potential impact of these technologies?

3. Do to you see the application of GPS as an information technology expanding to new areas in the near (next five years) and longer (beyond five years) term? Will such applications be embedded in broader information systems or stand alone?

Appendix D - Chronology of GPS Events

1920s
Origins of radio navigation

Early WW II
LORAN, the first navigation system to employ time difference-of-arrival of radio signals, is developed by the MIT Radiation Laboratory. LORAN was also the first true all-weather position-finding system, but is only two-dimensional (latitude and longitude).

1959
TRANSIT, the first operational satellite-based navigation system, is developed by the Johns Hopkins Applied Physics Laboratory (APL) under Dr. Richard Kirschner. Although Transit was originally intended to support the U.S. Navy's submarine fleet, the technologies developed for it proved useful to the Global Positioning System (GPS). The first Transit satellite is launched in 1959.

1960
The first three-dimensional (longitude, latitude, altitude) time-difference-of-arrival navigation system is suggested by Raytheon Corporation in response to an Air Force requirement for a guidance system to be used with a proposed ICBM that would achieve mobility by traveling on a railroad system. The navigation system presented is called MOSAIC (Mobile System for Accurate ICBM Control). The idea is dropped when the Mobile Minuteman program is canceled in 1961.

1963
The Aerospace Corporation launches a study on using a space system as the basis for a navigation system for vehicles moving rapidly in three dimensions; this led directly to the concept of GPS. The concept involves measuring the times of arrival of radio signals transmitted from satellites whose positions are precisely known. This gives the distances to the known satellite positions—which, in turn, establishes the user's position.

1963
The Air Force begins its support of the Aerospace study, designating it System 621B. By 1972, the program has already demonstrated operation of a new type of satellite-ranging signal based on pseudorandom noise (PRN).

1964
Timation, a Navy satellite system, is developed under Roger Easton at the Naval Research Lab (NRL) for advancing the development of high-stability clocks, time-transfer capability, and 2-D navigation. Timation's work on space-qualified time standards provided an important foundation for GPS. The first Timation satellite is launched in May 1967.

1968
DoD establishes a tri-service steering committee called NAVSEG (Navigation Satellite Executive Committee) to coordinate the efforts of the various satellite navigation groups (Navy's Transit and Timation programs, the Army's SECOR or Sequential Correlation of Range system). NAVSEG contracted a number of studies to fine-tune the basic satellite navigation concept. The studies dealt

with some of the major issues surrounding the concept, including the choice of carrier frequency (L-Band versus C-Band), the design of the signal structure, and the selection of the satellite orbital configuration (a 24 hour figure 8s constellation versus “Rotating Y” and “Rotating X” constellation).

1969-1972
NAVSEG manages concept debates between the various satellite navigation groups. The Navy APL supported an expanded Transit while the Navy NRL pushed for an expanded Timation and the Air Force pushed for an expanded synchronous constellation “System 621B.”

1971
L2 frequency is added to the 621B concept to accommodate corrections for ionospheric changes.

1971-1972
User equipment for the Air Force 621B is tested at White Sands Proving Ground in New Mexico. Ground and balloon-carried transmitters simulating satellites were used, and accuracies of a hundredth of a mile demonstrated.

April 1973
The Deputy Secretary of Defense determines that a joint tri-service program be established to consolidate the various proposed positioning/navigation concepts into a single comprehensive DoD system known as the Defense Navigation Satellite System (DNSS). The Air Force is designated the program manager. The new system is to be developed by a joint program office (JPO), with participation by all military services. Colonel Brad Parkinson is named program director of the JPO and is put in charge of jointly developing the initial concept for a space-based navigation system.

August 1973
The first system presented to the Defense System Acquisition and Review Council (DSARC) is denied approval. The system presented to DSARC was packaged as the Air Force’s 621B system and therefore not representative of a joint program. Although there is support for the idea of a new satellite-based navigation system, the JPO is urged to broaden the concept to include the views and requirements of all the services.

December 17,1973
A new concept is presented to DSARC and approval to proceed with what is now known as the NAVSTAR GPS is granted, marking the start of concept validation (Phase I of the GPS program). The new concept was really a compromise system negotiated by Col. Parkinson that incorporated the best of all available satellite navigation system concepts and technology. The approved system configuration consists of 24 satellites placed in 12-hour inclined orbits.

June 1974
Rockwell International is chosen as the satellite contractor for GPS.

July 14,1974
The very first NAVSTAR satellite is launched. Designated as Navigation Technology Satellite (NTS) number 1, it is basically a refurbished Timation satellite built by the NRL. The second (and last) of the NTS series was launched in 1977. These satellites were used for concept validation purposes and carried the first atomic clocks ever launched into space.

1977
Testing of user equipment is carried out at Yuma, Arizona.

February 22,1978
The first Block I satellite is launched. A total of 11 Block I satellites were launched between 1978 and 1985 on the Atlas-Centaur. Built by Rockwell International as developmental prototypes, the Block Is were used for system testing purposes. One satellite was lost as a result of a launch failure.

April 26,1980
The first GPS satellite to carry Integrated Operational Nuclear Detonation Detection System (IONDS) sensors is launched.

1982
A decision to reduce the GPS satellite constellation from 24 to 18 satellites is approved by DoD following a major program restructure brought on by a 1979 decision by the Office of the Secretary of Defense to cut $500 million (approximately 30 percent) from the budget over the period FY81-FY86.

July 14,1983
The first GPS satellite to carry the newer Nuclear Detonation Detection System (NDS) is launched.

September 16,1983
Following the Soviet downing of Korean Air flight 007, President Reagan offers to make GPS available for use by civilian aircraft, free of charge, when the system becomes operational. This marks the beginning of the spread of GPS technology from military to civilian aircraft.

April 1985
The first major user equipment contract is awarded by the JPO. The contract includes research and development as well as production options for 1-, 2-, and 5-channel GPS airborne, shipboard, and manpack (portable) receivers.

1987
DoD formally requests that the Department of Transportation (DoT) assume responsibility for establishing and providing an office that will respond to civil user needs for GPS information, data, and assistance. In February 1989, the Coast Guard assumes responsibility as the lead agency for the Civil GPS Service.

1984
Surveying becomes the first commercial GPS market to take off. To compensate for the limited number of satellites available to them early in the constellation’s development, surveyors turned to a number of GPS accuracy enhancement techniques including differential GPS and carrier phase tracking.

March 1988
The Secretary of the Air Force announces the expansion of the GPS constellation to 21 satellites plus 3 operational spares.

February 14,1989
The first of 28 Block II satellites is launched from Cape Canaveral AFS, Florida, on a Delta II booster. The Space Shuttle had been the planned launch vehicle for the Block II satellites built by Rockwell. Following the 1986 Challenger disaster, the JPO reconsidered and has since used the Delta II as the GPS launch vehicle. Selective availability (SA) and anti-spoofing (AS) become possible for the first time with the Block II design.

June 21,1989
Martin Marietta (after buying out the General Electric Astro Space division in 1992) is awarded a contract to build 20 additional "replenishment" satellites (Block IIR). The first Block IIR satellite will be ready for launch as needed at the end of 1996.

1990
Trimble Navigation, the world leader in commercial sales of GPS receivers, founded in 1978, completes its initial public stock offering.

March 25,1990
DoD, in accordance with the Federal Radionavigation Plan, activates SA—the purposeful degradation in GPS navigation accuracy—for the first time.

August 1990
SA is deactivated during the Persian Gulf War. Factors that contributed to the decision to turn SA off include the limited three-dimensional coverage provided by the NAVSTAR constellation in orbit at that time and the small number of Precision (P)-code receivers in the DoD inventory at the time. DoD purchased thousands of civilian GPS receivers shortly thereafter to be used by the Allied forces during the war.

1990-1991
GPS is used for the first time under combat conditions during the Persian Gulf War by Allied forces. The use of GPS for Operation Desert Storm proves to be the first successful tactical use of a space-based technology within an operational setting.

August 29,1991
The U.S. government revises export regulations, making a clear delineation between military and civil GPS receivers. Under the revised regulations, military receivers continue to be treated as "munitions" with strict export restrictions, while civilian receivers are designated "general destination items" available for export without restrictions.

July 1, 1991
SA is reactivated after the Persian Gulf War.

September 5, 1991
The United States offers to make GPS standard positioning service (SPS) available beginning in 1993 to the international community on a continuous, worldwide basis with no direct user charges for a minimum of ten years. The offer was announced at the Tenth Air Navigation Conference of the International Civil Aviation Organization (ICAO).

September 1992
The United States extends the 1991 offer at the 29th ICAO Assembly by offering SPS to the world for the foreseeable future and, subject to the availability of funds, to provide a minimum of six years advance notice of termination of GPS operations or elimination of the SPS.

December 8,1993
The Secretary of Defense formally declares Initial Operational Capability of GPS, signifying that with 24 satellites in orbit, GPS is no longer a developmental system and is capable of sustaining the 100-meter accuracy and continuous worldwide availability promised SPS users.

February 17,1994
FAA Administrator David Hinson announces GPS as the first navigation system approved for use as a stand-alone navigation aid for all phases of flight through nonprecision approach.

April 11, 1994
Executive Order 12906 signed by President Clinton creating a National Spatial Data Infrastructure and a National Geospatial Data Clearinghouse. GPS is an enabling technology for this effort.

June 2,1994
FAA Administrator David Hinson announces termination of the development of the Microwave Landing Systems (MLS) for Category II and III landings.

November 1994
Orbital Sciences Corp., agrees to purchase Magellan Corp., a California-based manufacturer of hand-held GPS receivers, in a stock swap worth as much as $60 million, bringing Orbital closer to its goal of becoming a satellite-based two-way communications company.

June 8,1994
FAA Administrator David Hinson announces implementation of the Wide-Area Augmentation System (WAAS) for the improvement of GPS integrity and availability for civil users in all phases of flight. Projected cost of program is $400-500 million; it is scheduled to be implemented by 1997.

October 11,1994
The Department of Transportation Positioning/ Navigation Executive Committee is created to provide a cross-agency forum for making GPS policy.

October 14,1994
FAA Administrator David Hinson reiterates the United States' offer to make GPS-SPS available for the foreseeable future, on a continuous, worldwide basis and free of direct user fees in a letter to ICAO.

March 16,1995
President Bill Clinton reaffirms the United States' commitment to provide GPS signals to the international civilian community of users in a letter to ICAO.

January 30, 1996

U.S. Coast Guard Maritime DGPS achieves Initial Operating Capability (IOC). Full Operational Capability (FOC) expected by October 1998.

March 26, 1996
Presidential Decision Directive (PDD) on national GPS policy.

April 22, 1996
Multiyear Contract Awarded to Boeing North American for follow-on satellites after the Block IIR series.

August 7-8, 1996
U.S. interagency team visits Tokyo to begin GPS Consultations.

November 25, 1996
Preliminary Discussions with the European Commission in Washington on GPS Consultations.

December 17-20, 1996
U.S. interagency team visits Moscow to begin GPS Consultations.

January 28, 1997
Air Force Space Command takes the lead for the U.S. Air Force to define requirements for the near, mid, and far term modernization in the context of the 1996 PDD.

March 1997
Memorandum of Agreement signed between the Federal Railroad Administration, U.S. Coast Guard, and Air Force signed to used decommissioned Air Force communication sites in tests of a Nation-wide DGPS Network.

July 22, 1997
First successful launch of GPS Block IIR satellite.

July 23, 1997
DoD/DoT Memorandum of Agreement signed to identify a second coded civil signal frequency and transition plan by March 1998.

October 23, 1997
Congress supports the PDD in passage of the National Defense Authorization Act for Fiscal Year 1998 (P.L. 105-85).

October 27, 1997
Congress establishes Nationwide Differential GPS Network in the Transportation Department Appropriations bill for Fiscal Year 1998 (P.L. 105-66)

November 6-21, 1997
Protection of GPS spectrum from mobile satellite service interference debated at the World Radiocommunications Conference (WRC) in Geneva, Switzerland.

March 30, 1998
Vice President Gore announces that future Block IIF GPS satellites will have two additional civil frequencies to provide better accuracy for aviation, maritime, and scientific users.

Appendix E - Acronyms

AGPS	Augmented Global Positioning Systems
AVL	Automatic Vehicle Location
C/A Code	Coarse Acquisition Code
CAD	Computer-Aided Design
Cat	Category
CDMA	Code Division Multiplex Access
CEP	Circular Error Probable
CGSIC	Civil GPS Service Interface Committee
CRPA	Controlled Radiation Pattern Antenna
CW	Carrier Wave
dB	Decibel (X = 10 Logl0 X Db)
dBW	Decibel Watts
DGPS	Differential Gps
DMA	Defense Mapping Agency
DME	Distance Measuring Equipment
DoD	Department Of Defense
DoP	Dilution Of Precision
DOT	Department Of Transportation
DRMS	Distance Root Mean Squared
EIRP	Effective Isotropic Radiated Power
EMS	Emergency Medical Services
ERP	Effective Radiated Power
FAA	Federal Aviation Administration
FRP	Federal Radionavigation Plan
GDOP	Geometric Dilution Of Precision
GLONASS	Global Navigation Satellite System (Russia)
GIS	Graphical Information System
GMT	Greenwich Mean Time
GNSS	Global Navigation Satellite System (ICAO)
GPS	Global Positioning System
GPSIC	GPS Information Center (U.S. Coast Guard)
HDOP	Horizontal Dilution Of Precision
HoW	Hand over Word
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
IMO	International Maritime Organization
IMU	Inertial Measurement Unit
INMARSAT	International Maritime Satellite Organization
INS	Inertial Navigation System
IOC	Initial Operating Capability
ION	Institute Of Navigation
IVHS	Intelligent Vehicle Highway Systems
J/S	Jamming-To-Signal Ratio
L1	GPS Frequency, 1575.42 MHz
L2	GPS Frequency, 1227.6 MHz
LADGPS	Local Area Differential GPS
MCS	GPS Master Control Station
MHz	Megahertz (1 Million Hz)
MLS	Microwave Landing System
MoA	Memorandum Of Agreement
MoU	Memorandum Of Understanding
MSL	Mean Sea Level
NAS	National Airspace System
Nav-Msg	Navigation Message
NDB	Nondirectional Beacon
NSA	National Security Agency
OEM	Original Equipment Manufacturer
P-Code	Precision Code
PDOP	Precision Dilution Of Precision
Pos/Nav	Positioning And Navigation
PPS	Precise Positioning Service

PRN	Pseudo Random Noise
RAIM	Receiver Autonomous Integrity Monitoring
RDSS	Radio Determination Satellite Service
RF	Radio Frequency
RMS	Root Mean Squared
RTK	Real-Time Kinematic
SA	Selective Availability
SEP	Spherical Error Probable
SPS	Standard Positioning Service
SSPK	Single-Shot Probability Of Kill
SV	Satellite Vehicle
TACAN	Tactical Air Navigation
UE	User Equipment
UHF	Ultra High Frequency
USC	United States Code
USCG	United States Coast Guard
USNO	U.S. Naval Observatory
UT	Universal Time
UTC	Universal Time Coordinated
VOR	Very High Frequency Omnidirectional Range
WAAS	Wide-Area Augmentation System
WADGPS	Wide-Area Differential GPS
WGS-84	World Geodetic System 1984