Chapter 17

NAVSTAR, the Global Positioning System: A Sampling of Its Military, Civil, and Commercial Impact

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Historical Background

The NAVSTAR[1] Global Positioning System (GPS), the first satellite navigation system that enabled users to determine precisely their location in three dimensions and time within billionths of a second, grew from a concept into a fully operational system in slightly more than two decades. This is not to suggest, however, that selling the idea was easy. As early as 1969–1970, Aerospace Corporation president and GPS pioneer Ivan Getting had suggested to Lee DuBridge, President Richard Nixon's science advisor, that a presidential commission be created to review how satellite navigation ought to proceed, because there were so many potential users. After thinking about it for several weeks, DuBridge concluded that execution of Getting's proposal would be too difficult. He told Getting, "There are too many people, too many bureaucracies, too much politics, and too many agencies involved. Why don't you just have the Air Force develop it the way we always did?"[2]

By 1972, both the U.S. Air Force (USAF) and the U.S. Navy had been studying for several years the possibility of improved satellite-based radio navigation. Three earlier space-based navigation systems or programs contributed to GPS: The Johns Hopkins University Applied Physics Laboratory (APL) Transit, otherwise known as the Naval Navigation Satellite System; the Naval Research Laboratory's Timation satellite program, led by Roger Easton; and USAF Project 621B. Colonel Bradford

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[1] Over time, some people identified "NAVSTAR" as an acronym derived from either "Navigation Signal Timing and Ranging" or "Navigation Satellite Timing and Ranging." Apparently, TRW had once advocated a navigational system for which NAVSTAR was an acronym (NAVigation System Timing And Ranging). Bradford W. Parkinson, "GPS Eyewitness: The Early Years," *GPS World 5* (9 September 1994): pp. 32–45, explained that his team at the Joint Program Office never considered "NAVSTAR" an acronym but "simply a nice-sounding name."

[2] Jacob Neufeld, ed., *Research and Development in the United States Air Force* (Washington, DC: Center for Air Force History, 1993), pp. 91–92.

Parkinson, USAF director of the newly formed multi-service Joint Program Office (JPO) for GPS, assembled about a dozen members of the JPO over Labor Day weekend in 1973 and directed them to synthesize the design for a new satellite navigation system by drawing the best ideas and technology from everything then available.[3]

From that point, GPS developed at a reasonably steady pace. By June 1974, the JPO had selected Rockwell International as the satellite contractor. The JPO oversaw deployment of the initial control segment at the Army's Yuma Proving Ground in Arizona, followed by the launch of the first operational prototype in February 1978. Eleven years later, in February 1989, the USAF launched the first fully operational Block 2 version. Although a complete constellation of 24 Block 2 satellites existed in December 1993, GPS did not officially achieve full operational status until April 1995. It had cost $10–$12 billion to field the system, and the USAF estimated the cost annually of sustaining minimal GPS services at $400 million.[4]

The main reasons for GPS development were the need to deliver weapons precisely on target and to reverse the proliferation of navigation systems in the U.S. military. From the beginning, however, the Department of Defense (DOD) recognized the usefulness of GPS to the worldwide civilian community. To withhold full accuracy from enemies but provide GPS service to civilian users, the USAF designed the system with a protective feature called "selective availability" (SA) that, when used, gave the U.S. military and its allies significantly more precise satellite signals than what other users received. After Korean Airline Flight 007 went astray in September 1983 and Soviet fighters shot it down, President Ronald Reagan reassured the world that the coarser signal would remain continually and universally available at no cost once GPS became fully operational. As GPS approached that status in the early 1990s, civilian and commercial users, who already had 10 times as many GPS receivers as the military, mounted an increasingly vocal campaign for unrestricted access to the more precise satellite signals. Many GPS equipment manufacturers, anticipating a multitude of applications, had begun forming strategic alliances with outside companies in such fields as communications, Geographic Information Systems (GIS), computing, and transportation. Finally, in May 2000, President William Clinton acknowledged the global utility of GPS and directed immediate discontinuation of SA, thereby giving millions of nonmilitary users access to the more precise GPS signals.[5]

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[3] Bradford W. Parkinson, "Introduction and Heritage of NAVSTAR, the Global Positioning System" in *Global Positioning System: Theory and Applications, Volume I*, Bradford W. Parkinson and James J. Spiker, Jr., ed. (Washington, DC: American Institute of Aeronautics and Astronautics, 1996), pp. 3–28; Ivan A. Getting, *All in a Lifetime: Science in the Defense of Democracy* (New York: Vantage Press, 1989), pp. 574–599; Richard Easton, "Who Invented the Global Positioning System?" *The Space Review* (22 May 2006), *http://www.thespacereview.com/article/626/1* (accessed 12 September 2006).

[4] Michael Russell Rip and James M. Hasik, *The Precision Revolution: GPS and the Future of Aerial Warfare* (Annapolis, MD: Naval Institute Press, 2002), pp. 68–79.

[5] Parkinson, "GPS Eyewitness," pp. 42–44; Rip and Hasik, *The Precision Revolution*, pp. 9–10 and 429–441; Anthony R. Foster, "GPS Strategic Alliances, Part I: Setting Them Up," *GPS World 5* (5 May 1994): pp. 34–42; National Research Council, *The Global Positioning System—A Shared National Asset: Recommendations for Technical Improvements and Enhancements* (Washington, DC: National Academies Press, 1995), pp. 1–12.

With increasing demand for accuracy beyond what GPS alone yielded, users found ways to augment it. For small areas, those included pseudolites (ground-based transmitters that could be configured to emit GPS-like signals) and differential GPS (DGPS), which required a high-quality GPS "reference receiver" at a known, surveyed location. Wide Area DGPS (WADGPS), involving reference receivers at multiple monitor stations and a master-control hub, would achieve similar results over a broader region. An example of WADGPS was the Wide Area Augmentation System (WAAS), which the Federal Aviation Administration (FAA) believed would eventually provide the integrity, reliability, time availability, and accuracy to permit pilots and air traffic controllers to rely confidently and safely on GPS as their primary navigation system.[6] By 2006, continuously operating reference stations (CORS), coordinated across the United States by the National Geodetic Survey, enhanced GPS services to millions of users.[7]

Meanwhile, other countries and geographic regions had begun developing their own GPS augmentation systems: the European Geostationary Navigation Overlay System (EGNOS); India's GPS and Geostationary Augmentation Network (GAGAN); Australia's Ground-based Regional Augmentation System (GRAS); and Japan's Multi-transport Satellite Augmentation System (MSAS). In addition, Russia operated its own Global Navigation Satellite System (GLONASS); China experimented with its Beidou navigation satellites; and Europe pressed hard toward launching the Galileo satellite navigation system. Whether all those capabilities could be melded into a fully integrated Global Navigation Satellite System (GNSS) remained a question without an immediate answer, but the military, civil, and commercial utility of GPS was unquestionable. Since a full accounting of the GPS's societal impact would require hundreds of pages, what follows is merely suggestive. [8]

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[6] Bradford W. Parkinson and James J. Spilker, Jr., eds., *Global Positioning System: Theory and Applications, Volume II* (Washington, DC: American Institute of Aeronautics and Astronautics, 1996), pp. 3–142; Robert O. DeBolt et al., *A Technical Report to the Secretary of Transportation on a National Approach to Augmented GPS Services* (U.S. Department of Commerce, NTIA Special Publication 94-30, December 1994), *http://www.navcen.uscg.gov/pubs/gps/gpsaug/auggps.doc* (accessed 13 September 2006).

[7] James Stowell, "GPS Reference Stations: 24/7, High Accuracy, Differential Data in Your Own Backyard," CE News (May 2002), *http://www.leica-geosystems.com/us/articles/2002/CE%20News_May%202002_GPS%20Reference%20Stations.pdf* (accessed 12 September 2006); "Continuously Operating Reference Stations," National Geodetic Survey—CORS, h*ttp://www.ngs.noaa.gov/CORS/* (accessed 12 September 2006).

[8] Rosalind Lewis et al., *Building a Multinational Global Navigation Satellite System: An Initial Look* (Santa Monica, CA: RAND Corporation, 2005); "New U.S. Policy for Positioning, Timing and Navigation (PNT) Services," Embassy of the United States, Spain (12 January 2005), *http://barcelona.usconsulate.gov/emba/pntpolicyb.html* (accessed 12 September 2006); Brian Evans, "Setting a Course: Beyond GPS," Aviation Today (1 May 2006), *http://www.aviationtoday.com/cgi/av/show_mag.cgi?pub=av&mon=0506&file=beyondgps.htm* (accessed 12 September 2006).

MILITARY APPLICATIONS

The first weapon in the U.S. arsenal to become operational using GPS navigation was the Conventional Air-Launched Cruise Missile (CALCM) or AGM-86C. Its development began in June 1986 when Boeing Company received a 12-month contract for rapid conversion of existing ALCMs, the inaccuracy of which had resulted in accidentally bombing the French Embassy during Operation Eldorado Canyon, a night attack against Libya two months earlier. A loosely coupled integration of GPS capabilities with the missile's existing inertial navigation system (INS) permitted Boeing to deliver the first CALCMs to the U.S. Air Force in June 1987. During the initial hours of the air campaign for Operation Desert Storm in January 1991, seven B-52G bombers flying from Barksdale Air Force Base, Louisiana, delivered a total of 35 CALCMs against eight high-value targets in Iraq and achieved 85 percent to 91 percent success, including several exact hits.[9]

In the 1990s, the U.S. military fielded a host of air-dropped munitions that used GPS to one degree or another. Foremost among them, the Joint Direct Attack Munition (JDAM) turned fundamentally "dumb" bombs into high-precision ordnance capable of destroying multiple targets in a single sortie any time of day or night, in any kind of weather, no matter how adverse. During Operation Allied Force, the NATO air campaign against Serbia in 1999, U.S. B-2 Spirit bombers dropped more than 500 relatively inexpensive JDAMs with such great success that U.S. military strategists foresaw the possibility of unguided bombs completely disappearing from the arsenal. Other GPS-aided U.S. aerial weapons that debuted in the 1990s included the AGM-154 Joint Stand-Off Weapon (JSOW), the AGM-130 air-to-surface missile, the BGM-109 Tomahawk cruise missile, and the SLAM-ER (Stand-off Land Attack Missile—Enhanced Response).[10]

A suite of technologies known as Advanced Spinning-Vehicle Navigation (ASVN) permitted GPS/INS guidance in smaller and smaller munitions. By 2001, the U.S. Army planned to use it in artillery shells; the U.S. Navy had similar plans for rocket-assisted projectiles fired from its deck guns. The Army's howitzer-fired, 155-mm XM982 Excalibur round underwent a demonstration at Yuma Proving Ground, Arizona, on 15 September 2005 in which its accuracy was better than 33 ft (10 m) at a distance of 9 mi (15 km). Excalibur tests continued into February 2007, with operational fielding scheduled for later that year. A Navy contract with Raytheon Missile Systems, primary designer of the Army's Excalibur, called for development of the 5-in (13-cm) MK-171 Extended-Range Guided Munition (ERGM). Although achieving satisfactory ERGM performance proved harder than

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[9] John Tirpak, "The Secret Squirrels," *Air Force Magazine* 77, no. 4 (April 1994), *http://www.afa.org/magazine/perspectives/desert_storm/0494squirrels.asp* (accessed 5 September 2006); John T. Nielson, "The Untold Story of the CALCM: The Secret GPS Weapon Used in the Gulf War," *GPS World* 6, no. 1 (January 1995): pp. 26–32.

[10] Rip and Hasik, *The Precision Revolution*, pp. 233–264.

for Excalibur and delayed its operational deployment, flight demonstrations at White Sands Missile Range, New Mexico, on 16 February 2005 proved the ERGM could achieve great accuracy at a distance of more than 40 nautical miles. In both cases, these new projectiles offered greater lethality and lower collateral damage, with increased range and a considerably reduced logistical burden for deployed forces.[11]

In early 2003, the public became aware of GPS guidance for precision airdrops. The U.S. Army Operational Test Command employed GPS in two different instrument packages—one to verify the optimal parachute rigging for heavy cargo pallets, and the other to evaluate new troop-parachute designs. Within months, the U.S. military operationally tested Onyx, an autonomously guided parachute system developed by Atair Aerospace, for delivering payloads ranging from 75 to 2,200 lbs (34 to 998 kg) within 246 ft (75 m) circular error probable from altitudes up the 35,000 ft (10,668 m) in darkness and other extreme conditions. On 9 August 2004, U.S. Marines near Camp Korean Village, Iraq, witnessed the first operational use of a GPS-assisted Sherpa parafoil cargo delivery system, a key component of the Joint Precision Airdrop System (JPADS) technology demonstration program, in a combat zone. Two years later, the first joint Air Force-Army operational drop using JPADS in Southwest Asia supplied ammunition and water to troops in Afghanistan. Meanwhile, design and testing of GPS-equipped navigation units for paratroopers proceeded. In 2005, the French Military Agency (DGA) and Army Special Forces in Singapore were using more than 200 GPS-assisted Operational Paratroopers Navigation System (OPANAS)

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[11] James H. Doty, "Revolution in GPS: Advanced Spinning-Vehicle Navigation," *GPS World* (September 2004), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=120802* (accessed 14 August 2006); Lawrence L. Wells, "GPS Guidance for Projectiles," *GPS World* (October 2001), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=1806* (accessed 14 August 2006); Raymond Sicignano, "Picatinny Support the Warfighter: New Picatinny-Developed Smart Artillery Munition Could Reach Troops by March," *The Voice* 18, no. 18 (7 October 2005), *http://w4.pica.army.mil/Voice2005/051007/051007%20Smart%20artillery.htm* (accessed 14 August 2006); Raytheon News Release, "Successful Flight Test of GPS-guided Artillery Projectile Puts Raytheon-Bofors Excalibur Closer to Fielding," 26 September 2005, *http://www.prnewswire.com/cgi-bin/micro_stories.pl?ACCT=683934&TICK=RTN7&STORY=/www/story/09-26-2005/0004131807&EDATE=Sep+26,+2005* (accessed 14 August 2006); Staff Writers, "Testing Of GPS-Guided Projectile Puts Raytheon-BAE Excalibur Closer To Fielding," *GPS Daily* (21 August 2006), *http://www.gpsdaily.com/reports/Testing_Of_GPS_Guided_Projectile_Puts_Raytheon_BAE_Excalibur_Closer_To_Fielding_999.html* (accessed 21 August 2006); Raytheon News Release, "Raytheon's Excalibur Successfully Completes Final Testing, Clearing the Path for Early Fielding," *http://www.prnewswire.com/cgi-bin/micro_stories.pl?ACCT=910473&TICK=RTNB12&STORY=/www/story/03-08-2007/0004542432&EDATE=Mar+8,+200* (accessed 31 July 2007); Raytheon News Release, "Raytheon's ERGM Guides into Success," 17 February 2005, *http://www.prnewswire.com/cgi-bin/micro_stories.pl?ACCT=683934&TICK=RTN7&STORY=/www/story/02-17-2005/0003027460&EDATE=Feb+17,+2005* (accessed 14 August 2006); Dan Coskren, Tim Easterly, and Robert Polutchko, "More Bang, Less Buck: Low-Cost GPS/INS Guidance for Navy Munitions Launches," GPS World (September 2005), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=180139* (accessed 14 August 2006); John Pike, "EX-171 ERGM Extended-Range Guided Munition," *http://www.globalsecurity.org/military/systems/munitions/ergm.htm* (accessed 14 August 2006); Rupert Pengelley, "Guided Artillery Projectiles Turn the Corner," Jane's International Defence Review 39 (February 2006): pp. 57–61.

Onyx autonomously guided parachute system using GPS navigation.

units produced by SSK Industries, and North Atlantic Treaty Organization (NATO) countries were testing OPANAS for high-altitude, high-opening (HAHO) jumps. These new capabilities ensured more accurate landings for both cargo and troops in all kinds of conditions and, by permitting releases from altitudes above 25,000 ft (7,620 m), protected aircraft and personnel from hostile forces armed with inexpensive surface-to-air missiles.[12]

After 2000, a rapidly expanding family of autonomous or remotely controlled robotic military systems relied on GPS navigation to perform a wide variety of tasks on land, at sea, underwater, and in the air or outer space. Unpiloted aerial vehicles (UAVs) equipped with GPS, which had been under development since the 1980s, flew reconnaissance and surveillance missions over Bosnia and Kosovo during the late 1990s and, thereafter, proliferated among military organizations worldwide. In 2001–2002, Predator drones carrying AGM-114 Hellfire missiles attacked Taliban and Al Qaeda forces in Afghanistan.[13] On 25 January 2002, a GPS-Aided Inertial Navigation System (GAINS) on the third stage of an SM-3 interceptor launched from a U.S. Navy Aegis cruiser helped successfully demonstrate the exo-

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[12] Joseph Strus et al., "15 Tons. 1500 Feet. 4 Gs.—Airdrop Behavior of Parachuted Cargo Pallets," *GPS World* (April 2003), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=53305* (accessed 17 August 2006); Nanker Phelge, "Take the Plunge—Navigating from 35,000 Feet," *GPS World* (August 2003), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=65593* (accessed 17 August 2006); Bill Lisbon, "GPS-Guided Paradrop," *Special Operations Technology 2*, no. 6 (2004): pp. 29–31; Tom Vanden Brook, "'Smart' Airdrops May Save Lives of U.S. Troops," *USA Today*, 8 January 2007; Joseph Strus et al., "Stand Up. Hook Up. GO!—Instrumenting Paratroopers," *GPS World* (April 2003), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=53449* (accessed 17 August 2006); Jason I. Thompson, "A Three Dimensional Helmet Mounted Primary Flight Reference for Paratroopers," Master's thesis, Air Force Institute of Technology, March 2005), pp. 1–8.

[13] Defense Airborne Reconnaissance Office, "UAV Annual Report FY 1997," (6 November 1997), *http://www.fas.org/irp/agency/daro/uav97/toc.html* (accessed 17 August 2006); John Pike, "RQ-1 Predator MAE UAV," 6 November 2002, *http://www.fas.org/irp/program/collect/predator.htm* (accessed 17 August 2006); Greg Loegering, "The Global Hawk Advantage," *GeoIntelligence Magazine* (November 2004), *http://www.geointelmag.com/geointelligence/article/articleDetail.jsp?id=134277* (accessed 17 August 2006).

atmospheric interception of an incoming target missile.[14] During Operation Iraqi Freedom in 2003, the U.S. Navy ordered the first wartime deployment of the GPS-equipped, Remote Environmental Monitoring Units (REMUS) autonomous underwater vehicle (AUV) to locate suspected mines in the port of Umm Qasr.[15] By November 2004, the DOD had contracted with Applied Perception, Inc. (API) to build two interrelated, GPS-enabled robotic prototypes—a 3,500-lb (1,588-kg) Robotic Evacuation Vehicle (REV) and a 600-lb (272-kg) Robotic Extraction Vehicle (REX)—for the safe recovery and transport of wounded soldiers from the battlefield to a nearby field hospital. Clearly, such vehicles could have numerous other military and nonmilitary applications ranging from logistical supply, ordnance disposal, surveillance, and assault to fire fighting, crowd control, soil sampling, pest abatement, and exploration of hazardous environments.[16]

Perhaps the most pervasive U.S. military application of GPS by 2006 involved the tracking and coordination of various battle elements in real time using the GPS-enabled Force XXI Battle Command, Brigade-and-Below (FBCB2) satellite-based tracking system and its Blue Force Tracking (BFT) variant. American soldiers had suffered roughly a quarter-million casualties in the twentieth century due to so-called friendly fire, primarily because of the difficulty during intense conflict of discriminating quickly between friend and foe. As early as springtime of 1987, engineers and scouts from the U.S. Army's 4th Infantry Division used two 17.5-lb (8-kg) GPS manpacks during exercises in the Pinõn Canyon training area of southern Colorado to maneuver through "enemy" lines in snow, rain, fog, and darkness to accomplish their objective. Four years later in Operation Desert Storm, with only 16 satellites in the constellation, GPS aided positioning and maneuvering of large troop formations, plus precision bombing, artillery fire support, and special operations in relatively featureless desert terrain. Coalition forces relying primarily on more than 12,000 personal receivers, each costing about $3,500, prevented countless casualties by reducing the so-called fog of battle.[17]

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[14] James L. Anders et al., "From View to Kill—Integrated System Guides Ballistic Missile Intercept," *GPS World* (May 2003), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=57971* (accessed 17 August 2006).

[15] Ken Jordan, "REMUS AUV Plays Key Role in Iraq War," UnderWater Magazine (July/August 2003), *http://www.diveweb.com/rovs/features/034.01.htm* (accessed 17 August 2006); Kevin McCarthy, "REMUS—A Role Model for AUV Technology Transfer," *International Ocean Systems* 7, no. 6 (November/December 2003), *http://www.hydroidinc.com/pdfs/Hydroid_REMUS.pdf* (accessed 17 August 2006); Marty Whitford, "In the Swim—GPS Guides Autonomous Underwater Vehicles," *GPS World* (April 2005), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=154866* (accessed 17 August 2006).

[16] Marty Whitford, "Robotic Rescue—No One Gets Left Behind," *GPS World* (November 2004), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=131750* (accessed 17 August 2006); Paul J. Lewis et al., "Applications Suitable for Unmanned and Autonomous Missions Utilizing the Tactical Amphibious Ground Support (TAGS) Platform," *http://www.autonomoussolutions.com/Press/SPIE%20TAGS.html* (accessed 17 August 2006).

[17] "U.S. Army Trains on New System—Exercise in Piñon Canyon Teaches Usefulness of GPS," *Space Trace* (29 May 1987): p. 2.

A decade after Desert Storm, U.S. forces conducting war games in California and Florida located and tracked troops, aircraft, and assorted equipment in real time using an Inexpensive Range Instrumentation System (IRIS). That experimentation demonstrated that low-cost, commercial off-the-shelf hardware could be used to coordinate ground and air activities, thereby enhancing the safety of friendly forces. By 2005, U.S. and allied forces in Kosovo, Afghanistan, and Iraq relied on more than 8,000 GPS-enabled FBCB2 units and another 2,000 FBCB2-BFT units to track their own positions, neighboring friendly forces, and spotted enemy forces along with the location of bridges, mine fields, and other potentially dangerous geo-points. In 2006, Globecomm Systems won a $7.8 million contract to provide NATO forces with a similar BFT capability. The enhanced situational awareness provided by FBCB2 and its BFT variant also allowed battlefield commanders to plan and coordinate maneuvers—offensive and defensive—with unprecedented precision. [18]

NAVIGATION

The most rapidly expanding area of GPS use for civil, commercial, and personal purposes was probably location-based services (LBS)—positioning and navigation. Land-based users include automobile drivers, railroads, fleet managers of trucks, delivery vehicles, and public transportation; emergency responders such as fire, ambulance, and police; and recreational activities such as hiking, hunting, skiing, biking, and golfing. According to Alan A. Varghese from ABI Research in Oyster Bay, New York, shipments of recreational GPS devices alone rose from 3.2 million in 2002 to 5 million in 2003, with a predicted annual growth of 31 percent until 2009. Sea-based applications ranged from recreational sailing, fishing, and managing shipping fleets, to assisted steering, risk assessment, and hazard warning. Pilots of all varieties—airplane, helicopter, hot-air balloon—relied increasingly on GPS for monitoring their flight path, for collision avoidance, and for landing. Search-and-rescue personnel on land, at sea, and in the air all came to view GPS as indispensable. Ultimately, scientists and engineers experimented with using GPS for launch and on-orbit operation of spacecraft.[19]

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18. James Madeiros, "New Tracking System Keeps Eye on Troops," *Air Force Link* (25 October 2001), *http://www.af.mil/news/Oct2001/n20011025 1525.shtml* (accessed 26 October 2001); Marty Whitford, "Friend or Foe?—FBCB2 Enhances Battle Planning, Reduces 'Friendly Fire'" *GPS World* (February 2005), *http://www.gpsworld.com/gpsworld/article/articleDetail.jsp?id=146087* (accessed 17 August 2006); Tony Skinner, "NATO Orders GPS-Based Blue Force Tracking System," *Jane's Defence Weekly* 43, no. 33 (16 August 2006): p. 31.

19. Joe Mehaffey, "Recreational and Car Navigator GPS Sales and Sales Projections" (15 May 2005), *http://gpsinformation.us/joe/gpssalesprojections.html* (accessed 30 August 2006); "GPS Applications" (20 May 2003), MSU Global Positioning System (GPS) Laboratory, *http://www.montana.edu/places/gps/* (accessed 21 August 2006); Martin J. Unwin, "Experience with the Use of GPS in a Low Earth Orbit," *Satellite Communications* 13, no. 1 (1995): pp. 25–34.

When GPS receiver technology and cellular phones started to become more affordable during the mid-1990s, industry analysts and entrepreneurs perceived LBS as an emerging multibillion-dollar market. By 2002, however, only two automotive companies—General Motors (OnStar) and Mercedes (TeleAid)—offered consumers telematic LBS; such factors as cost, technological drawbacks of early-generation systems, and privacy concerns had led to slower than expected market growth. Nonetheless, an April 2002 nationwide survey of 20,000 U.S. households revealed strong consumer interest in using GPS for security-related purposes, especially for stolen vehicle tracking, with more moderate interest in services such as real-time traffic alerts, navigation assistance, and monitoring family vehicles. By 2006, North American sales of GPS-equipped navigation systems built into many different makes of automobiles, in portable devices, and in cell phones totaled 4.5 million units, with an increase of nearly 50 percent anticipated for 2007. Demand for up-to-date digital maps, derived in large part using GPS, of 7.3 million miles of North American highways caused the revenues of Tele Atlas and Navteq Corporation, the two principal competitors, to grow by 57 percent and 26 percent, respectively, in 2005. Meanwhile, after a decade of work, developers were ready to begin marketing in the United States and Canada an in-vehicle navigation system (IVNS) that promised to save private motorists billions (in terms of gallons, hours, and dollars) by integrating real-time data on traffic incidents, construction, and traffic flow to suggest alternate routes.[20]

Use of GPS-aided technology for management of vehicle fleets has saved governments and businesses hundreds of millions of dollars by enabling more efficient planning of routes, monitoring misuse by employees, or locating stolen vehicles.[21] The proliferation of organizations and conferences promoting development of automatic vehicle location (AVL) systems and intelligent vehicle/highway systems (IVHS) began in the late 1980s and fostered a veritable parade of specific projects in the early 1990s. By 1993, cities including Denver, Colorado, and Dallas, Texas, had begun installing GPS-based AVL systems in their buses and other city vehicles to keep riders informed of projected arrival times, to assist mobility-impaired riders, and to expedite response time in emergency situations.[22] Meanwhile, Netherlands-based

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[20] Clement Driscoll, "What Do Consumers Really Think?" GPS World (1 July 2002), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=25975* accessed 30 August 2006); Rafe Needleman, "Navigation PDAs Look for Their Market," *Business 2.0* (19 June 2003), *http://www.business2.com/subscribers/articles/web/0,1653,50392,00.html?cnn=yes* (accessed 24 October 2003); "The New Navigation," *The Gazette* (Colorado Springs, CO), 11 June 2006; Business 2.0 Staff, "Nowhere to Hide: GPS is Spreading," *Business 2.0* (March 2002), *http://www.business2.com/subscribers/articles/mag/0,1640,37777,00.html?cnn=yes* (accessed 24 October 2003); Marty Whitford, "Unstuck in Traffic," *GPS World* (1 June 2005), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=165057* (accessed 30 August 2006).

[21] W. Eric Martin, "Mobilizing the Fleet," *Mobile Government* (May 2003): pp. 6–9.

[22] Glen Gibbons et al., "Automatic Vehicle Location: GPS Meets IVHS," *GPS World* 4, no. 4 (April 1993): pp. 22–26; Paul Ledwitz, "DART AVL Hits Transit Bull's-Eye with GPS," *GPS World* 4, no. 4 (April 1993): pp. 29–34; Steve Blacksher and Tom Foley, "Boulder HOPs Aboard GPS Tracking," *GPS World* (1 January 2002), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=7782* (accessed 5 September 2006).

Büchner Transport, which owned 50 trucks and specialized in delivery of house plants, fruits, and vegetables under controlled temperatures throughout Europe, had experimented with a GPS-assisted AVL system in two of its trucks from December 1991 to June 1992 and decided, despite the high price of the hardware, to begin equipping its entire fleet over the next five years.[23] During 1988–2004, San Diego-based Qualcomm, the largest AVL supplier worldwide, installed its position-reporting system on more than 500,000 commercial vehicles belonging to more than 1,500 trucking firms. By autumn of 2004, the Defense Transportation Tracking System used GPS-derived location reports to monitor annually more than 47,000 arms, ammunition, and explosives shipments by commercial motor carriers in the continental United States.[24]

Emergency responders found GPS capabilities invaluable. In January–May 1992, Amoco tested a GPS-aided response system in its large Crossfield natural gas field north of Calgary, Alberta, and concluded that it offered noteworthy cost and safety improvements over earlier systems by "providing nearly immediate identification of an alarm site and the nearest field personnel, as well as detailed maps that show the best route to the scene of an alarm."[25] The San Francisco Bay Area's Freeway Service Patrol (FSP), a special team of approximately 40 tow-truck drivers who patrolled the most congested freeways during peak commute hours, began using a GPS-supported AVL system in August 1993 to assist stranded motorists. On average, FSP trucks arrived at the scene of a breakdown within seven minutes, almost six times faster than regular tow services.[26] Also, in 1993, Doug Baker, founder and president of LaSalle Ambulance Service of Buffalo, New York, adopted a GPS-equipped tracking and dispatch system for his fleet of 42 vehicles, two aero-medical helicopters, and one fixed-wing aircraft to ensure speedier response times and, consequently, save more lives.[27]

Recovery of stolen vehicles became much more likely with GPS. Founded in 1998 by Pakistani crime fighter and businessman Jameel Yusuf, Trakker Pvt. Limited used GPS technology to track and recover more than 1,000 stolen rental cars and private vehicles in Karachi by October 2003. By then, the Trakker system had been installed in 12,000 Pakistani vehicles and attracted roughly 500 new customers

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[23] J. A. J. Beerens, "Fleet Monitoring with GPS and Satellite Communications," *GPS World* 4, no. 4 (April 1993): pp. 42–46.

[24] Clement Driscoll, "Finding the Fleet: Vehicle Location Systems and Technologies," *GPS World* 5, no. 4 (April 1994): pp. 66–70; Glen Gibbons, "HAZMAT Keeps on Truckin'," GPS World (1 October 2004), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=126157* (accessed 31 August 2006).

[25] Edward J. Krakiwsky and Donald Chalmers, "Emergency Response with GPS in Oil and Gas Fields," *GPS World* 4, no. 4 (April 1993): pp. 48–51.

[26] Michelle Morris, "High-Tech White Knights on the Freeway," *GPS World* 5, no. 4 (April 1994): pp. 54–59.

[27] Margaret Ferrentino, "Code Red: GPS and Emergency Medical Response," *GPS World* 5, no. 4 (April 1994): pp. 28–38.

per month, each paying up to $750 for installation and $17 monthly for service.[28] Meanwhile, in January 2002 a thief stole a taxicab in Colorado Springs, Colorado, when the driver left the engine running while he went inside a 7-Eleven. In the first incident of its kind locally, a Yellow Cab dispatcher used the vehicle's on-board tracking system to update police on the car's location, and they arrested the culprit a short while later.[29] During less than a year with integrated GPS/cellular tracking systems, Lieutenant Tim Stewart of the North Texas Auto Theft Task Force reported in 2004 that his agency had recovered more than $6 million worth of property, including more than 50 truck tractors and 75 trailers—many filled with stolen equipment or merchandise.[30]

Among the recreational uses for GPS, golfing became prominent. In 1997, Darryl Sharp's Geodetic Services, Inc., began using GPS technology for three-dimensional mapping of premier golf courses in the United States and, by May 2002, had mapped 55 U.S. courses. Sharp estimated he would have lost $5,000–$6,000 per job without GPS but, with advances in GPS equipment, he had tripled his production. Under a five-year contract, videogame manufacturer EA SPORTS used Sharp's data to make playing simulated golf on some of the country's top-ranked courses stimulating and amazingly realistic for anyone with a personal computer or PlayStation. PGA TOUR later contracted with Geodetic Services to map courses for its new ShotLink scoring and statistics system that brought television or cyberspace fans closer to the game by reporting real-time information on every shot by every player in every tournament.[31]

Professional, amateur, and casual golfers all latched onto GPS-aided technology to improve their performance, and course managers enthusiastically supported the demand by purchasing GPS-equipped golf carts. In addition to recording exact yardage with each stroke and displaying actual yardage to the green, which aided club selection, personal GPS systems helped golfers maintain the pace of play. After courting by the electronics industry and a couple of years testing equipment such as the handheld SkyCaddie, the United States Golf Association finally permitted "distance-measuring devices, including GPS-based systems and laser range finders" by local rule starting in 2006. As demand for GPS-equipped golf carts surged in early 2006, UpLink Corporation, one of the three largest suppliers of golf-related GPS equipment, signed up 26 new courses with its system after a single trade show,

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[28] Reuters, "Satellites Help Slash Karachi Car Thefts, Kidnaps," CNN.com/Technology (24 October 2003), *http://www.cnn.com/2003/TECH/ptech/10/24/satellite.tracking.reut/index.html* (accessed 24 October 2003).

[29] Anslee Willett, "Global Satellite System Tracks Down Suspect in Theft of Taxicab," *The Gazette* (Colorado Springs, CO), 18 January 2002.

[30] Marty Whitford, "Thief Relief—GPS/Cellular Combo Acquires Abducted Assets," *GPS World* (1 October 2004), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=128322* (accessed 30 August 2006).

[31] Krista Stevens, "GPS Fore the Golf Course," *Point of Beginning* (30 April 2002), *http://www.pobonline.com/CDA/Archives/6c07817cac0f6010VgnVCM100000f932a8c0* (accessed 30 August 2006).

thereby generating $7.4 million in sales. UpLink technology allowed course managers to track every golf cart in their fleet, a financially important capability considering that golf-cart rentals yielded the largest source of revenue outside green fees at most courses. For example, a 2005 progress report from the mayor of South Bend, Indiana, mentioned that golf-cart revenue from GPS was more than $70,000.[32]

AGRICULTURE

Use of GPS for precision farming (i.e., site-specific management) commenced in the early 1990s and rapidly took a variety of forms. These included planting or cultivating crops at night; locating weed, insect, and disease infestations; applying fertilizer or pesticides at a variable rate; preventing skips or overlaps when fertilizing; monitoring and mapping crop yield; and pinpointing crop damage due to hail or drought. John Ruth, chief executive officer of Amana Farms in Iowa, explained in a 1992 interview, "With GPS, we'll be able to determine crop yield by the square foot and not by the traditional bushels per acre . . . . This will dramatically change the way farmers plant, fertilize, apply weed killers and harvest crops."[33] To further improve efficiency and increase the profitability of their operations, farmers also used GPS for detailed base-mapping of physical features such as borders, fence lines, wells, buildings, landscape features, irrigation canals or pipelines, and wetlands.[34]

Montana State University (MSU) began research and planning in 1986 for a GPS-assisted navigation system that would enable agricultural producers to apply variable amounts of seed and fertilizer exactly where needed to maximize crop yield in the most cost-effective manner. In August 1990 MSU researchers used the first GPS-guided agricultural fertilizer application system in a field trial near Power, Montana.[35] Two years later, agronomist Mitch Schefcik and electrical engineer William Bauer

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[32] Doug Pike, "High Tech Takes a Big Step Forward," *Houston Chronicle*, 18 October 2005, *http://www.uplinkgolf.com/cms/website/mediacoverage/HoustonChron10_18_05.pdf* (accessed 30 August 2006); Mayor Stephen J. Luecke, "South Bend, Indiana—Progress Report, 2005," *http://www.southbendin.gov/doc/Comm_ProgressReport2005.pdf* (accessed 30 August 2006); Roger Graves, "From the Dailies—Golf Cars Drive up Course Revenues with New Models, Technology," *PGA Magazine* (26 January 2006), *http://www.pgamagazine.com/article.aspx$id=2750* (accessed 30 August 2006); Tim Schooley, "Tracking a New Market—Global Positioning Systems Find Their Way into Golf Carts, Providing Much More than Distance Readings," *Pittsburgh Business Times* (12 June 2006), *http://pittsburgh.bizjournals.com/pittsburgh/stories/2006/06/12/focus1.htm*l (accessed 30 August 2006); Pat Dailey, "GPS System Welcome Addition," *Branson Daily News*, 29 August 2006, *http://www.bransondailynews.com/story_print.php?storyID=1540* (accessed 30 August 2006); SkyCaddie advertisement, Sky Mall (Early Spring 2006): p. 31; GolfPS Personal GPS Golf System Web site, *http://www.golfps.com/index.htm* (accessed 30 August 2006).

[33] Mark W. Brown, "GPS Helps Farmers Reap Higher Crop Yields," *Space Trace* (November 1992): p. 4.

[34] "GPS Applications" (20 May 2003), MSU Global Positioning System (GPS) Laboratory, *http://www.montana.edu/places/gps/* (accessed 21 August 2006); Robert "Bobby" Grisso et al., "Precision Farming Tools: Global Positioning System (GPS)," July 2003, Virginia Cooperative Extension, *http://www.ext.vt.edu/pubs/bse/442-503/442-503.html* (accessed 21 August 2006).

[35] Carolyn Peterson, "Precision GPS Navigation for Improving Agricultural Productivity," *GPS World* 2, no. 1 (January 1991): pp. 38–44.

combined their expertise to devise a DGPS/Geographic Information System (GIS) system to vary the herbicide application rate on sugar-beet fields in western Nebraska, thereby increasing crop yield while satisfying government chemical application regulations. Experimentation by the Agricultural Research Service of the U.S. Department of Agriculture (USDA) found DGPS extremely useful for mapping initial, variable applications of nitrogen fertilizer and evaluating the effect on crop yields in irrigated central Nebraska cornfields during 1995. Improvement in nitrogen fertilizer management also offered the prospect of improved groundwater (i.e., drinking water) quality, something much desired by the U.S. Environmental Protection Agency.[36]

One expert estimated in 1994 that only 5 percent of U.S. farms, mostly in the corn-producing states of the Midwest, used GPS-derived reference points for soil-specific management, but the technology was "booming." A study of soil-specific management in Stoddard County, Missouri, during that period showed reductions in fertilizer costs of $18.70 per acre with no loss of crop yields.[37] By 2003 University of Florida researchers touted GPS/GIS technology's great value for locating and managing site-specific crop losses (more than $77 billion worldwide in 1987) due to plant-parasitic nematodes.[38] According to an Associated Press story in late November 2004, up to 15 percent of U.S. farmers had GPS-controlled tractors or combines and were saving as much as 5 percent in fertilizers and pesticides by using precision guidance systems. Farmers in Kentucky, where rolling terrain led to both high and low production in the same field, realized a cost saving of $30/acre by using GPS-enabled yield monitors. Meanwhile, under a NASA grant, researchers at Ohio State University worked to perfect a GPS-enabled tomato-picking robot that could significantly reduce labor costs on large corporate farms.[39]

To meet demand for greater accuracy, lower labor costs, and documentation of spraying, the USDA began in the early 1990s to explore GPS-aided navigation for precision aerial applications to control insects on cropland or rangeland. During the autumn of 1992, the Plains Cotton Growers Diapause Program in Texas had used a GPS flight guidance system from Satloc, Inc., to spray more than 450,000 acres of cotton for boll weevils. That application offered savings by eliminating the need for approximately 170 ground flaggers. Based on that program's success, the USDA's Grasshopper Integrated Pest Management (GHIPM) Project near Watford City in northwestern North Dakota tested a DGPS system in 1993 on a 6,400-acre (2,590-hectare) section of rangeland. Chief pilot Tim Roland for the USDA's Animal and Plant Health Inspection Service, Plant Protection and Quarantine (APHIS/PPQ)

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[36] William D. Bauer and Mitch Schefcik, "Using Differential GPS to Improve Crop Yields," *GPS World* 5, no. 2 (February 1994): pp. 38–41; Tracy M. Blackmer and James S. Schepers, "Using DGPS to Improve Corn Production and Water Quality," *GPS World* 7, no. 3 (March 1996): pp. 44–52.

[37] Hale Montgomery, "GPS Down on the Farm," GPS World 5, no. 9 (September 1994): p. 18.

[38] Jim Rich et al., "Using GIS/GPS for Variable-Rate Nematicide Application in Row Crops," University of Florida IFAS Extension, *http://edis.ifas.ufl.edu/IN464* (accessed 21 August 2006).

[39] Associated Press, "GPS Goes Down on the Farm—Technologies Can Help Some Farms Cut Costs," 29 November 2004, MSNBC, *http://www.msnbc.msn.com/id/6608881/* (accessed 21 August 2006).

division subsequently remarked, "We're just getting our foot in the door with GPS, but I'm so confident [about the] equipment that I'd recommend it to support any of our programs."[40] When the accuracy of Loran-C navigation proved inadequate to meet the parallel-swathing requirements of California's Cooperative Medfly Project during 1993, Roland recommended DGPS guidance. In California's war against the Mediterranean fruit fly, which could cause more than $1 billion in damage annually to fruit, nut, and vegetable crops, not to mention the loss of thousands of jobs, DGPS brought significant savings and provided a previously unavailable element of quality control to aerial treatments.[41]

DISASTER RELIEF AND RECOVERY

Use of GPS in conjunction with GIS, cartographic mapping, and other technologies proved beneficial in disaster relief and recovery efforts. After Hurricane Andrew devastated Florida in 1992, the Federal Emergency Management Agency (FEMA) contracted with survey crews to experimentally inventory the damage using GPS/GIS technology instead of the traditional, manual assessment that involved house-by-house interviews. Based on encouraging results from that experiment, FEMA, the U.S. Army Corps of Engineers, and a private contractor with GPS/GIS expertise formed a team in July 1993 to produce maps for disaster response, recovery efforts, and risk mitigation in the wake of severe Mississippi River floods that inundated more than 13 million acres, destroyed billions of dollars in crops, and left hundreds of people homeless. Following a GPS-equipped helicopter survey, a pair of two-person ground observer teams with GPS/GIS handheld receivers inspected and inventoried structures in approximately 75 communities south of Quincy, Illinois. More than 1,500 maps/data sheets were produced within a week of the teams' initial transfer of data to the Corps of Engineers' Rock Island, Illinois, base station. Prior to GPS/GIS, it would have taken a team of 50 people years to complete the same task. With the maps quickly delivered to FEMA decision makers, they began meeting with local officials and citizens to discuss assistance and requirements to rebuild above the 100-year flood elevation.[42]

When New York City officials faced the daunting cleanup of "Ground Zero" after the 11 September 2001 terrorist attacks on the World Trade Center, they found multiple applications for GPS. As Fire Department teams and others began the monumental task of sifting through the rubble to recover and manually catalog thousands of pieces of evidence at the crash site, which was also a crime scene, it became obvious the process was too time-consuming and too error-prone. To

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[40] Mike W. Sampson, "Getting the Bugs Out: GPS-Guided Aerial Spraying," *GPS World* 4, no. 9 (September 1993): pp. 28–34.

[41] Mike W. Sampson, "No Small Affair: DGPS Battle the California Medfly," *GPS World* 6, no. 2 (February 1995): pp. 32–38.

[42] Harry Bottorff, "Rapid Relief: GPS Helps Assess Mississippi River Flood Damage," *GPS World* 5, no. 3 (March 1994): pp. 22–26.

automate it, the city gave a handheld device equipped with a GPS receiver and an attached bar-code reader to one person on each of the eight recovery units working at the 16-acre site at any given time. Searchers put a bar-coded tag on each significant piece of recovered evidence; scanned the tag to create an electronic record that included the exact location, date, and time; and selected an item description from a scroll-down list programmed into the handheld device. At the end of each shift, searchers placed their handhelds into a cradle to download their information to a central database, from which the city produced maps that helped investigators pinpoint where various kinds of vehicles, equipment, and personnel were when the buildings collapsed. The fire and police departments could analyze that information to improve their response to future emergencies.[43]

A second challenge related to the September 11 disaster involved learning how various buildings in a 10-square-block area surrounding the World Trade Center survived, because that knowledge would permit the design and construction of more damage-resistant structures. The solution lay in modification of a GPS/GIS software application for a Palm Pilot developed by Georgia Institute of Technology civil engineering professor David Frost and graduate student Scott Deaton. This handheld damage assessment technology, which Frost had conceived while surveying damage from a 1999 earthquake in Izmit, Turkey, allowed researchers to capture digital images and select an option from a list of damage descriptions, at which time the information was automatically linked to GPS coordinates. The collected data could be uploaded periodically to a single, spatial database. In approximately four days during mid-October 2001, Frost, Deaton, and master's student Prateek Goel documented and mapped in nearly real time most of the structures in the study area. A team using more traditional methods would have taken at least a month just to enter all the data into a computer for mapping and analysis.[44]

Yet another GPS application in disaster recovery efforts at Ground Zero involved debris removal. Hauling away 1.8 million tons of debris efficiently became a top priority, because experience suggested this would be the most expensive aspect of the recovery effort. New York City's Department of Design and Construction employed a team of contractors led by Criticom International Corporation of Minneapolis, Minnesota, to devise a GPS-based management system for debris removal. The contract team quickly assembled and installed commercial off-the-shelf components in 235 trucks and a control center, thereby creating a management system that integrated GPS-based positioning with communications, camera monitoring, and Internet data. This first use of GPS-based AVL to manage debris removal in a disaster

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[43] John Rendleman, "GPS Aids Recovery Effort," *InformationWeek* (12 November 2001), *http://www.informationweek.com/showArticle.jhtml;jsessionid=YH2WRBQHCAKCCQSNDLPSKH0CJUNN2JVN?articleID=6507967* (accessed 12 September 2006).

[44] Beth Bacheldor, "Damage Assessment: Lessons from Ground Zero," *InformationWeek* (18 March 2002), *http://www.informationweek.com/showArticle.jhtml;jsessionid=YH2WRBQHCAKCCQSNDLPSKH0CJUNN2JVN?articleID=6501464* (accessed 12 September 2006).

Artistic rendition of GPS Block 3 satellite.

recovery operation contributed substantially to finishing the removal project four months earlier than originally predicted and at a cost of $750 million, far less than the $7 billion city officials initially estimated.[45]

During and after Hurricane Katrina in August 2005, experts found further applications for GPS. Military pilots flew into the approaching hurricane to deploy GPS-enabled dropsondes, first used in 1996–1997, that helped scientists predict the strength, speed, and direction of the storm with greater precision than allowed by previous systems. After Katrina hit the Gulf Coast, the Urban and Regional Information Systems Association (URISA) GISCorps, a volunteer organization, went there to support U.S. Coast Guard operations by translating distressed survivors' addresses or locations into GPS coordinates, which enabled dispatch of rescue helicopters. Within two weeks after the storm, major ports in the Gulf region reopened, due in large measure to Nationwide DGPS (NDGPS) allowing the Coast Guard to precisely reposition 1,800 buoys and fixed aids to navigation; the Army Corps of Engineers to survey and dredge 38 critical waterways; and commercial pilots to navigate even when they could not "read" silt-clouded waterways. The National Park Service used NDGPS to map areas rendered unsafe by hazardous materials and to mark safe passageways; the Department of Agriculture used it help locate disposal sites for animal carcasses and to map areas where blocked drainage demanded future clearing. Despite problems with keeping the NDGPS signal available in the aftermath of Hurricane Katrina, it proved crucial to relief and recovery efforts.[46]

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[45] Raymond J. Menard and Jocelyn L. Knieff, "GPS at Ground Zero: Tracking World Trade Center Recovery," GPS World (2 September 2002), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=30686* (accessed 12 September 2006).

[46] Marty Whitford, "Hurricane Hunters: GPS Dropsondes Trace Katrina's Course," *GPS World* (1 October 2005), *http://mg.gpsworld.com/gpsmg/content/printContentPopup.jsp?id=262187* (accessed 13 September 2006); Bob Henson, ed., "Hurricane!" *SN Monthly* (October 1998), *http://www.ucar.edu/communications/staffnotes/9810/hurricane.html* (accessed 13 September 2006); "The Nationwide Differential Global Positioning System's Role with Hurricane Katrina's Recovery," U.S. Coast Guard Navigation Center, January 2006, *http://www.navcenter.org/misc/HurricaneKatrina.pdf* (accessed 13 September 2006).

TIMING

People generally think of GPS as a navigation system and, consequently, do not fully comprehend its usefulness in the dissemination of precise time, time intervals, and frequency. Because a GPS receiver location is established through simultaneous ranging of signals from several GPS satellites, every signal from each satellite includes time of transmission. Atomic clocks on every satellite ensure that system time is closely synchronized through cesium and rubidium frequency standards. By providing timing and frequency accuracies in the range of 100 nanoseconds and a few picoseconds, respectively, to receivers worldwide 24 hours a day, GPS quickly became a boon to specialists in a wide variety of fields ranging from science, satellite tracking, and industrial plant operations to power distribution, television broadcasting, and banking.[47]

The Bonneville Power Administration (BPA), which supplies about half of all electrical power used in the Pacific Northwest, began gradually integrating GPS technology into its various operations in 1988. Its ultimate goal was a GPS-based infrastructure for measuring voltage and current at selected generation and transmission sites and for time-tagging that information with microsecond precision to more effectively and efficiently stabilize the electrical grid, thereby minimizing system disturbances that potentially could cascade into major blackouts. In 1989, BPA began using GPS in its power-line fault location system and in solving problems associated with standard time distribution across the grid. Meanwhile, it started investigating GPS as a source of precise time for its phasor measurement units (PMUs), which computed the phase angle between points on various circuits to provide a good representation of the power system's "health." During 1991–1992, BPA tested two GPS-synchronized prototype PMUs on a 260-mile section of a main transmission link, the resulting data being more accurate and less noisy than comparable analog information. A new GPS-based Central Time System (CTS) with triple redundancy went into the BPA Dittmer Control Center in 1994. By 2005, BPA was touting its Wide Area Control System (WACS), a demonstration project that BPA engineers predicted could route $7.2 million worth of additional power—enough for 20,000–60,000 typical homes—from the Pacific Northwest to California and could prevent a system blackout costing more than $1 billion.[48]

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[47] Peter H. Dana and Bruce M. Penrod, "The Role of GPS in Precise Time and Frequency Dissemination," *GPS World* 1, no. 4 (July/August 1990): pp. 38–43; Harold Hough, "A GPS Precise Timing Sampler," *GPS World* 2, no. 9 (October 1991): pp. 33–36; Edgar W. Butterline, "Reach Out and Time Someone," *GPS World* 4, no. 1 (January 1993): pp. 32–40; Hewlett-Packard Company, "GPS and Precision Timing Applications," Application Note 1272 (1996), *http://www.fgg.uni-lj.si/~/mkuhar/Zalozba/HP1272.pdf* (accessed 10 September 2006).

[48] Kenneth E. Martin, "Powerful Connections: High-Energy Transmission with High-Precision GPS Time," *GPS World* 7, no. 3 (March 1996): pp. 20–36; Dennis C. Erickson and Carson Taylor, "Pacify the Power: GPS Harness for Large-Area Electrical Grid," GPS World (1 April 2005), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=154868* (accessed 8 September 2006).

The explosive growth of computer networks from the 1980s onward made high-quality time synchronization essential for proper functioning and for rendering failures more manageable. GPS-enabled time synchronization directly affected network operations in several key areas ranging from file time stamping and directory services to access security, log file accuracy, and fault diagnosis and recovery; it also affected applications in numerous areas from transaction processing and e-mail to software development and legal or regulatory requirements.[49]

At the beginning of the twenty-first century, financial institutions relied on millions of networked computers to execute billions of transactions per second involving extremely rapid changes in value. On 14 November 2001, for example, during the closing minutes of trading on the New York Stock Exchange, a single stock—Intel—averaged six transactions/second and as high as 20/second during intense trading. With traders frequently calling their brokering institution to dispute the recorded value of a particular transaction among countless others, computer-system clock resolution had to be less than the minimum transaction composition and transmission time—hence, 5- to 20-millisecond resolution. An international investment banking firm already had begun using a Palisade network time protocol (NTP) synchronization kit, introduced by Trimble Navigation Ltd. in 1999, to ensure simultaneous recording of transactions at its London, New York, and Tokyo offices. By mid-2002, the New York Stock Exchange, the World Bank, and other major financial institutions used Symmetricomm (formerly TrueTime), Spectracom, or other corporations' GPS-based NTP products to synchronize their computer systems at the required level of accuracy. Experimenters at Ireland's University of Galway had installed Trimble's newer Acutime 2000 GPS synchronization kit to create what they called a Stratum-1 (defined as micro-second accurate) NTP server that other European servers and clients used for time synchronization. So important had GPS become as a time-reference standard for the world's aggregate financial network that the Heritage Foundation advised designating it a critical infrastructure. [50]

As wireless communication networks expanded at the end of the twentieth century, GPS receivers replaced less reliable timing technologies. So-called smart GPS antennas in base stations synchronized transmitter sites to precisely the same time, which prevented a

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[49] Paul Skoog, "The Importance of Network Time Synchronization," TrueTime (2001), *http://www.truetime.net/pdf/imp_netsync.pdf* (accessed 8 September 2006).

[50] Timble Navigation Ltd., "Trimble Launches GPS Clock for Micro-Second Synchronization of Network Computers and Internet Applications," Directions Magazine (27 July 1999), *http://www.directionsmag.com/press.releases/index.php?duty=Show&id=742&trv=1* (accessed 10 September 2006); "Trimble Offers Internet GPS Time Standard," *Space Daily*, *http://www.spacedaily.com/news/gps-99j.html* (accessed 10 September 2006); Fact Sheet, "Acutime 2000 GPS Smart Antenna for Precise Timing and Synchronization," Trimble Navigation Ltd. (2000), *http://www.navgeocom.ru/oem/download/main/sync/a2000/acutime2k_info.pdf* (accessed 10 September 2006); Alan Cameron, "Billions per Second: Timing Financial Transactions," *GPS World* (31 July 2002), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=30096* (accessed 10 September 2006); "GPS Tutorial—Timing," Trimble Navigation Ltd. (2006), *http://www.trimble.com/gps/gpswork-timing.shtml* (accessed 10 September 2006).

user from receiving the same cellular telephone, pager, or other wireless signal multiple times. In August 1996 at the Republican National Convention in San Diego, California, Pacific Bell Mobile Services (PBMS) implemented a new type of all-digital, wireless telephone network called personal communications service (PCS), which relied on relatively low-cost, GPS-based time synchronization. By early 1997, PBMS had begun building on that success by installing an identical capability in Las Vegas, Nevada.[51]

Wireless positioning and tracking also benefit immeasurably from the accuracy of GPS timing. A caller's handset, for example, can be located by calculating and triangulating the time differences in arrival of its signal at cell towers whose positions are accurately known. In 1993, the Federal Communications Commission (FCC) took regulatory interest in extending enhanced-911 (E911) emergency service, including automatic location of a caller, to wireless mobile subscribers; in October 1999 Congress passed the Wireless Communications and Public Safety Act mandating that manufacturers incorporate E911 features in cell phones and, thereafter, the FCC stipulated that 95 percent of all new digital cell phones must have the automatic location identification (ALI) feature by 1 October 2002. The FCC later extended that deadline three years when wireless carriers appealed for more implementation time. At the beginning of 2005, Nextel Communications, Inc., was the only national wireless provider offering GPS services, and nearly all carriers doubted they could meet the end-of-year deadline for having 95 percent of their handsets upgraded to GPS-capable models. Although wireless E911 offered the prospect of improving the personal safety of millions of people nationwide, indications were that its availability would be piecemeal for years to come, and some citizens questioned whether the government, employers, spouses, or parents might misuse the ALI feature to infringe upon personal privacy and constitutional rights.[52]

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[51] "Wireless Profile,"Wireless Magazine (2006), *http://www.trimble.com/tmg_wirelessprofile.shtml* (accessed 10 September 2006); Don Britten, "Wireless and Seamless: GPS-Timed Mobile Communications," *GPS World* 8, no. 3 (March 1997): pp. 32–39.

[52] Peter Kuykendall and Peter V. W. Loomis, "In Sync with GPS: GPS Clocks for the Wireless Infrastructure," Trimble Navigation (2006), *http://trl.trimble.com/docushare/dsweb/Get/Document-8439* (accessed 10 September 2006); Dale N. Hatfield, "A Report on Technical and Operational Issues Impacting the Provision of Wireless Enhanced 911 Services," Federal Communications Commission, 24 November 2004, *http://gullfoss2.fcc.gov/prod/ecfs/retrieve.cgi?native_or_pdf=pdf&id_document=6513296239* (accessed 10 September 2006); U.S. Government Accountability Office, "Telecommunications: Uneven Implementation of Wireless Enhanced 911 Raises Prospect of Piecemeal Availability for Years to Come," GAO-04-55, November 2003, *http://www.gao.gov/new.items/d0455.pdf* (accessed 10 September 2006); David H. Williams, "Wireless Carriers are Making Great Progress Implementing Wireless E911 . . . So What's the Problem?" Directions Magazine (22 September 2004), *http://www.directionsmag.com/article.php?article_id=665* (accessed 10 September 2006); David Colker, "Parents, Bosses Call on GPS Tracking Cell Phones," *Los Angeles Times*, 9 January 2005; Sascha Segan, "Inexpensive Emergency Phones for Children, Elders Could Be Used As GPS Tracking Device," *PS Magazine* (8 January 2005), *http://www.infowars.com/articles/bb/parents_bosses_gps_track_cellphones.htm* (accessed 10 September 2006); David H. Williams, "The Deadline for the E911 Mandate Approaches . . . Where Do Things Stand?" *Directions Magazine* (30 November 2005), *http://www.directionsmag.com/article.php?article_id=2014&trv=1* (accessed 10 September 2006); Associated Press, "Satellite Navigation Finds Its Way to Phones: Latest Technology Allows You to Track People's Whereabouts," MSNBC, 7 April 2006, *http://www.msnbc.msn.com/id/12206651* (accessed 10 September 2006); "Sprint service tracks children: Parent can locate kid's cell with GPS," *The Gazette* (Colorado Springs, Colorado), 14 April 2006.

SUMMARY

Nothing about GPS could be more obvious than the rapid expansion of entrepreneurial activity and the veritable explosion of applications from the early 1990s into the first decade of the twenty-first century. One can measure that growth, at least notionally, in several ways: patent activity, manufacturers, employment, revenues, and sales. The number of GPS-related patent families (a family being a collection of related patents and published patent applications) grew internationally from less than 20 in 1988 to nearly 80 in 1991, with U.S. and Japanese corporations holding the most.[53] Meanwhile, the DOD procured only 7,253 GPS receivers during 1986–1992 but zoomed to 19,086 receivers in 1993 alone.[54] Firms that listed themselves as providing GPS-related goods or services totaled 301 in 1997 compared to 109 in 1992. North American revenues from GPS products in 1999 grew 21.1 percent from 1998, indicating that "an increasing number of end users in previously untapped markets" had begun accepting the new technology. Revenues worldwide from GPS user equipment sales totaled $3.39 billion in 1996 and rose to $6.22 billion in 1999; during the same period, the number of GPS industry employees worldwide increased from 16,688 to 30,622. With average prices for GPS products expected to decrease 7.4 percent annually through 2006, according to strategic research by the consulting firm Frost & Sullivan, the number of products sold for nontraditional applications in commercial and consumer markets would steadily increase. Among the five basic GPS market segments—land, aviation, marine, military, and timing—examined by Frost & Sullivan analyst Ron Stearns, the land-based segment alone accounted for 61.8 percent of total North American revenues in 1999, a statistic unlikely to change appreciably through 2006.[55]

While the average price of GPS products continued downward in the new century, the number of units sold and total revenues advanced according to predictions. One estimate in 2000 put the number of GPS users worldwide at 1.5 million, with an economic impact of $6.2 billion. According to Frost & Sullivan, total revenues from the North American GPS equipment market alone amounted to $3.46 billion in 2003. A breakdown of that figure by end-user group—consumer, commercial, and military—revealed 52 percent, 40 percent, and 8 percent, respectively.

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[53] Scott Pace, et al., *The Global Positioning System: Assessing National Policies* (Santa Monica, CA: RAND Corp., 1995), pp. 114–118.

[54] National Academy of Public Administration, *The Global Positioning System: Charting the Future* (Washington, DC: NAPA, 1995), pp. 62–68.

[55] Scott Pace and James E. Wilson, *Global Positioning System: Market Projections and Trends in the Newest Global Information Utility*, International Trade Administration, Office of Telecommunications, U.S. Department of Commerce, September 1998, *http://www.nesdis.noaa.gov/space/library/reports/1998-09-gps.pdf* (accessed 13 September 2006); Frost & Sullivan, "Price Points, Product Integration Fuel GPS Revenue Growth," *Directions Magazine* (26 April 2000), *http://www.directionsmag.com/press.releases/index.php?duty=Show&id=1694&PRSID* (accessed 11 September 2006); Futron Corporation, *Trends in Space Commerce*, Office of Space Commercialization, U.S. Department of Commerce, May 2001, *http://www.nesdis.noaa.gov/space/library/reports/2001-06-trends.pdf* (accessed 13 September 2006).

Recreational GPS devices constituted a huge market, with shipments rising from 3.2 million in 2002 to 5 million in 2003.[56] Sales of portable navigation devices, used primarily for in-vehicle navigation, rose faster than projected in the United States from 300,000 units in 2003 to 550,000 in 2004 and about one million in 2005. Analyst Ron Stearns of Frost & Sullivan calculated the automotive portion of the consumer GPS business at $922 million, with estimated unit sales of 1.2 million for 2006; the addition of outdoor units for recreational users would send sales to $1.8 billion and more than 4 million units for 2006. Stearns expected combined annual sales for automotive and outdoor GPS units to reach 8.3 million, worth $2.7 billion in revenues, by 2010.[57] As Bradford Parkinson, one of the founders of GPS, said in 1980, the "potential uses [of GPS] are limited only by our imaginations."[58]

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[56] "Keeping Pace with Consumer Applications Vital to GPS Market Expansion," Frost & Sullivan, 9 February 2004, *http://www.frost.com/prod/servlet/press-release.pag?mode=open&docid=10127615* (accessed 11 September 2006); "GPS Market," Google Answers, 28 February 2005, *http://answers.google.com/answers/threadview?id=481415* (accessed 11 September 2006); "U.S. GPS Market Size," Google Answers, 27 August 2005, *http://answers.google.com/answers/threadview?id=561093* (accessed 11 September 2006).

[57] "Taiwan GPS Sector Update," MasterLink Securities, 30 December 2005, *http://web6.masterlink.com.tw/project/english/main_page/files/company_reports/GPS_DEC_2005_20051230.pdf* (accessed 11 September 2006); "Wireless Tracking: One GPS Giant Too Many?" *BPM Today* (21 June 2006), *http://www.bpm-today.com/story.xhtml?story_id=012000EP08VC* (accessed 11 September 2006); Clem Driscoll, "Strong Consumer Interest in GPS for Traffic, Nav, LBS," *GPS World* (1 August 2006), *http://www.gpsworld.com/gpsworld/content/printContentPopup.jsp?id=360934* (accessed 11 September 2006).

[58] Bradford W. Parkinson, "Overview," in *Global Position System: Papers Published in Navigation, Volume I*, P. M. Janiczek, ed. (Washington, DC: The Institute of Navigation, 1980), pp. 1–2.