GPS Case

ESD.85
October 31, 2005

Angela Ho
Alex Mozdzanowska
Christine Ng

Illustration by Leo Cronin

What is GPS?

- Global Positioning System
  - Used for timing, positioning, and navigation
  - Called NAVSTAR
- Types of users
  - U.S. military
  - Emergency response
  - Maritime navigation
  - Hikers, drivers
  - Aviation (planned)

Figure courtesy of NASA.

How GPS works

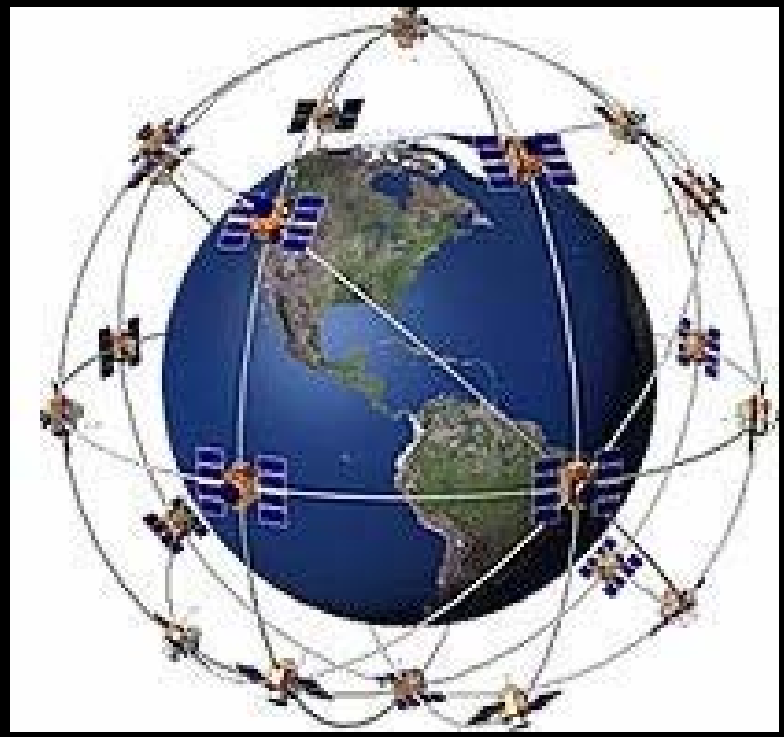
- Receiver obtains radio signals from at least 4 satellites
  - Calculates receiver's location from time, satellite location, and distance information
- Ground control monitors and ensures orbital and clock accuracy

Figure removed for copyright reasons.

GPS summary diagram from Garmin Ltd. *GPS for Beginners*.

GPS Constellation

- Made up of 24 satellites in orbit 12,500 miles above the earth
- 6 orbit planes
- Precision of GPS signal is 20 meters
- With differential GPS and error correcting, precision is 10 cm



Courtesy of USGS.
(http://geomag.usgs.gov/images/gps_001.jpg)

GPS Frequency Uses

L1	Civilian
L2	Military
L3	Military – missile/rocket launches, detonation detection
L4	Ionospheric correction (experimental)
L5	Civilian safety-of-life (planned)

GPS Limitations and Corrections

- Atmospheric thickness
- Signal reflection
- Clock precision
- Orbital errors
- Blocked signal
- Satellite geometry
- Selective availability (pre-May 2000)
- Differential GPS

Figure removed for copyright reasons.

GPS Corrections diagram from Garmin Ltd. *GPS for Beginners*.

History

GPS Inspiration

- 1957: Sputnik launch
  - Johns Hopkins Applied Physics Lab located Sputnik using the Doppler shift of its radio signal
  - Realized they could do the reverse process → GPS

Photo of Sputnik removed for copyright reasons. Source: NBC News (http://www.msnbc.com/news/115147.jpg)

NAVSTAR Predecessors

- LORAN (MIT) - WWII
  - Ground-based, 2-dimensional (lat, long)
  - Need 3 stations in range and prior location information
- Timation (Navy) – 1970s
  - Space-based, 2-dimensional
  - Could not provide continuous coverage
- Transit (Navy)
  - Space-based, 2-dimensional
  - Track and locate submarines
  - Satellites visible every 100 minutes, had to be observed for 10-25 minutes
  - 25-meter error
- USAF Project 621B
  - Space-based, 3-dimensional
  - Needed 4 satellites
  - At least 2 ground-control stations had to be located outside the US
  - Demonstrated pseudorandom noise (PRN) code

Source: Spencer Lewis 2005, Parkinson and Gilbert 1983, Parkinson 1994

GPS Development

- April 1973: Formation of the JPO
  - JPO objective: Consolidation of satellite navigation concepts into one system
  - US Air Force as the lead agency (Parkinson as head)
- December 1973: DoD approves the system that is now known as NAVSTAR
- 1974-1977: Initial satellites launched for concept validation and to carry atomic clocks
- 1978-85: 11 Block I satellites launched
- 1980: 1st GPS satellite to carry nuclear detonation detection system sensors
- 1980-82: Project zeroed out each year
- 1981-86: Project reinstated with a 30% budget cut
  - Reduction from 24 planned satellites to 18
  - Postponed early limited -D capability by 12 years (1981-93?)

Source: RAND 1997, Kowoma 2004

Progress to Civilian GPS Use

- 1983: Korean Air passenger flight shot down by Soviets
  - Reagan announced that GPS would be freely available for civilian aircraft use when it begins operational
- 1984: Surveying becomes the first major commercial GPS application (used DGPS and other techniques to compensate for limited number of satellites)
- 1989: Coast Guard becomes lead agency for Civil GPS Service
- 1989-1994: 28 Block II satellites
- March 1990: DoD activates selective availability
- 1990-1991: GPS used during the Persian Gulf War
- August 1990: DoD deactivates selective availability (to allow for use of commercial receivers)
- July 1991: DoD reactivates selective availability

Source: RAND 1997

Free GPS for All

- September 1991: US offers GPS use for free to the international community, starting in 1993, for a minimum of 10 years (offer later extended and reaffirmed multiple times)
- 1993: US announces Initial Operational Capability of GPS with 100-m accuracy and continuous availability
- 1994: Announced planned implementation of GPS for civil aviation to be implemented in 1997 (still not implemented)
- 1995: US announces Full Operational Capability of GPS
- 1996: Presidential directive created the Interagency GPS Executive Board (IGEB) to be chaired by DOT and DOD
- 2000: Final deactivation of selective availability, so accuracy for civilian improves from 100m to 20m

Source: RAND 1997, Kowoma 2004

Major Decision

Offering GPS to the World for Free

- Given Motivation (circa 1983)
  - Safety
    - Reagan: improve safety of civilian aviation
    - Increase safety and efficiency of transportation systems
- Additional Motivations (emerged in 1990s)
  - National security
    - Discourage competing systems
    - Prevent users from switching to GLONASS (Russian system)
    - Retain control and technology leadership
  - Economic growth
    - Promote US GPS companies (larger market for sales; first-mover advantage)
    - Standardization (encourages use of one system)
  - International cooperation

Sources: AW&ST 1983, NAPA/NRC 1995, RAND 1997

Uncertain System Viability

- Technical/operational viability
  - Only experimental satellites in orbit in 1983
  - Unstable funding (recently cut for 3 years)
  - Needed to test other components of the system
  - FAA refused to adopt GPS
    - DoD had been trying for before 1983 to interest the FAA in NAVSTAR
    - DoD improved accuracy from 500m to 100m, but still insufficient for safety
    - GPS at best could be a back-up to existing ground-based systems
    - FAA did not want to pay user fees or share upkeep costs
- User reaction (commercial and international)
  - Lack of confidence that system would become operational
  - Not sure if they should offer GPS to Aeroflot, the Soviet airline

Selective Availability Failure

- Expectation
  - Selective availability would work
  - Keep military and civilian applications separate
  - Encryption will restrict non-military use and accuracy
  - Export controls restrict GPS equipment listed as “munitions”
  - National security would not be compromised by civilians having access to GPS
- Reality
  - Companies figured out how to overcome encryption with DGPS
  - DGPS enhances accuracy to 10 cm
    - Government agencies like the Coast Guard, FAA, Army were developing DGPS as early as 1990
  - SA turned off during Gulf War
  - Interferes with civilian safety and services
  - EAPS Prof. Thomas A. Herring, MIT: *"For any adversary who is sophisticated enough to put a GPS guidance system into a missile, it's a trivial extension to put in a differential correction. I don't think it protects us at all. I don't think it protects us from terrorists."*

Modes of Analysis

- 1983 Reagan announcement was politically motivated
  - Pressure from Congress to accelerate NAVSTAR coverage
  - In response to offering it to Soviet airliner Aeroflot, White House Press Secretary Larry Speakes said: *"We'll wait until 1988 to see. For the moment, the plans are to make it available to all. We'll address the Soviet question when we get there."*
  - Situated within Reagan's "Star Wars" vision
- Not DoD-supported, since they had a pre-existing schedule for launching satellites and awarding contracts
- We could not find specific DoD or White House analysis behind the decision.
  - Could be classified military documents?

Consequences (1)

- Safety
  - GPS first used in civilian aviation in 2005, for transatlantic flights
  - Still used mostly as a back-up system
- National and Personal Security
  - Vulnerable to jamming
  - Commercial GPS units could be used by enemy states or terrorists
  - Privacy infringement from hidden GPS receivers
- Economic growth
  - Commercialization: In 2000, already a $8.5 billion industry and expected creation of 100,000 new jobs

Commercial GPS Boom

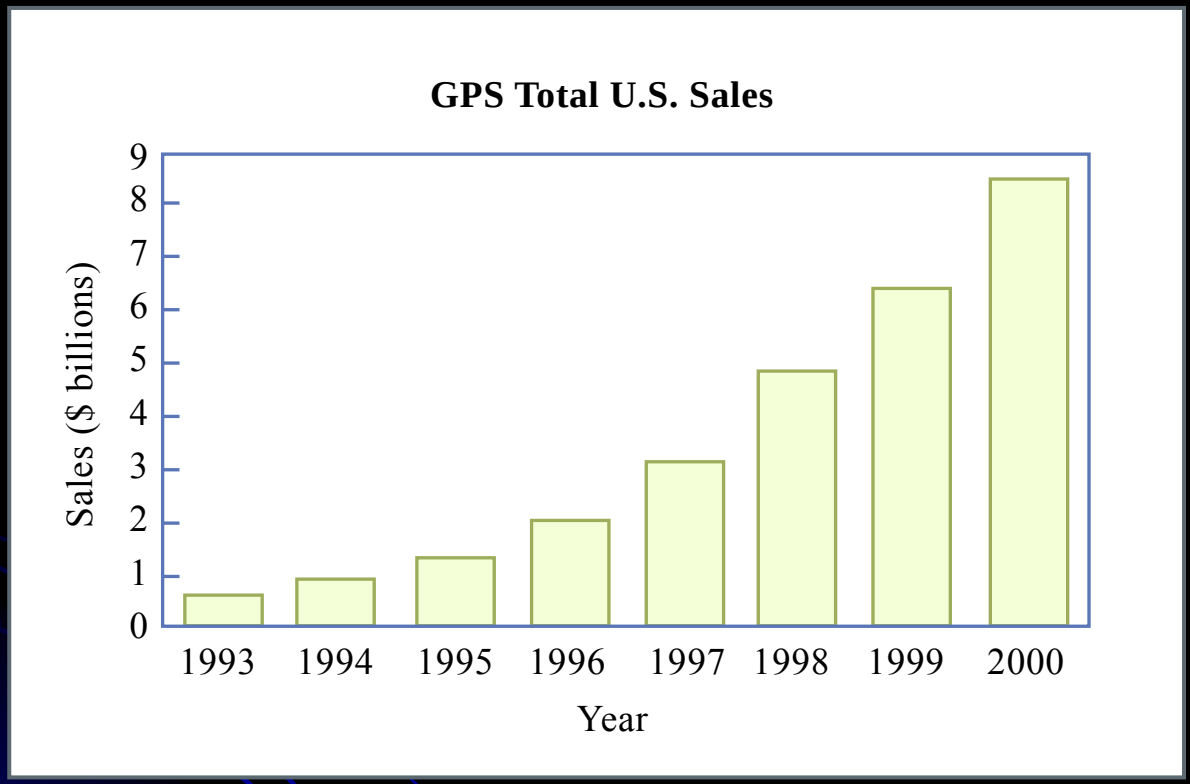


Figure by MIT OCW.

2004: $15B

Projected 2008: $22B

Projected 2010: $39B

Secondary Source: RAND 1997

Consequences (2)

- International cooperation
  - Competing systems
    - Soviet system GLONASS
    - European system Galileo
- Maintenance commitment
  - Already $12 billion invested; $400 million/year to maintain
  - Shared responsibility between DoD (USAF) and DoT (Coast Guard)

Conclusions

Cross-cutting Themes

1. In retrospect, were some consequences overlooked by interested organizations?
   - DoD focusing on GPS as military-only application; did not envision civilian uses; did not appreciate this until commercial uses were already emerging
     - Response was to add selective availability
   - DoD organizational limitations
     - History of being able to keep technologies secret
   - Ability to circumvent selective availability
     - Could not keep it secret

Cross-cutting Themes

2. How do political/economic/social forces influence the engineering/scientific solutions/approaches?
   - Offering to the world – cannot just be US-focused
     - Shaped the development of the still incomplete system
     - Selective availability
   - Frequency bands
     - Need for 911 capability on cell phones - emergency response
     - Having separate bands (separate civil and military applications)
   - Scaling down the project because of funding cuts

Cross-cutting Themes

3. What strategies are adopted by interests that feel threatened by GPS?
   - Competing systems that are not US-controlled
     - GLONASS
       - Fully operational by 2008
     - Galileo
       - Operational by 2008

Cross-cutting Themes

4. What is the motivation for keeping decision processes for sharing emerging technologies with other countries secret?
   - Military
     - Possible initial decision but questionable once commercialized
     - May reveal too much about future strategies
   - Technology leadership/Intellectual property rights

What could have been done better?

- Hindsight is 20/20
  - Consistent funding
  - Studies of commercial applications
  - More early international cooperation
- Reality check
  - Institutional learning
    - Adjusted their view as use of the GPS changed
    - Agency responsibilities shifted
      - Inter-agency GPS Executive Board (IGEB)

Future of GPS

- Responses to Galileo and Glonass
  - Ensure interoperability of GPS with other systems
  - Provide better service
  - Join Galileo
  - Charge for GPS
- Integration into transportation infrastructures
  - Credible commitment not to turn off GPS
- System maintenance
  - Who pays for it?
- Security measures
  - New ways of blocking signals – do they work?

References

- Special thanks to **Spencer Lewis** and **Prof. Daniel Hastings** for references.
- **Executive Office of the President**. "U.S. Spaced-Based Positioning, Navigation, and Timing Policy." Office of Science and Technology Policy. 15 December 2004. http://usinfo.state.gov/eur/Archive/2004/Dec/22-490757.html
- **GARMIN**. "GPS Guide for Beginners." GARMIN Corporation, December 2000.
- Howe, Peter J. "Where on Earth? The GPS Solution; Scrambling Policy Irks Many Experts." **Boston Globe**, 7 October 1996: C1.
- **Lewis, Spencer L**. "An Examination of the History, Expansion, and Technology of the NAVSTAR Global Positioning System." Massachusetts Institute of Technology. 6 September 2005.
- **National Academy of Public Administration and National Research Council**. "GPS: Charting the Future." For US Congress and Department of Defense. May 1995. http://www.navcen.uscg.gov/pubs/gps/gpsfuture/charting.htm
- Page, Scott, Gerald Frost, Irving Lachow, et al. "The Global Positioning System: Assessing National Policies." **RAND** Critical Technologies Institute, 1997. http://www.rand.org/publications/MR/MR614/
- **Parkinson, Bradford W., and Stephen W. Gilbert**. "NAVSTAR: Global Positioning System – Ten Years Later." Proceedings of the IEEE. Vol. 71, No. 10, October 1983: 1177-1186.
- **"**Senator Urges Acceleration of Navstar." **Aviation Week and Space Technology.** Lexis Nexis Academic Universe. 3 October 1983: 153.
- Shirer, Heywood O. "Preparing Now for the Future: U.S. Civil Radionavigation Policy and Planning." **US Department of Transportation**. IEEE, 1998: 69-76.

Discussion