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Economic Benefits of the Global Positioning System (GPS)

Presentation at the Positioning, Navigation and Timing Advisory Board Meeting

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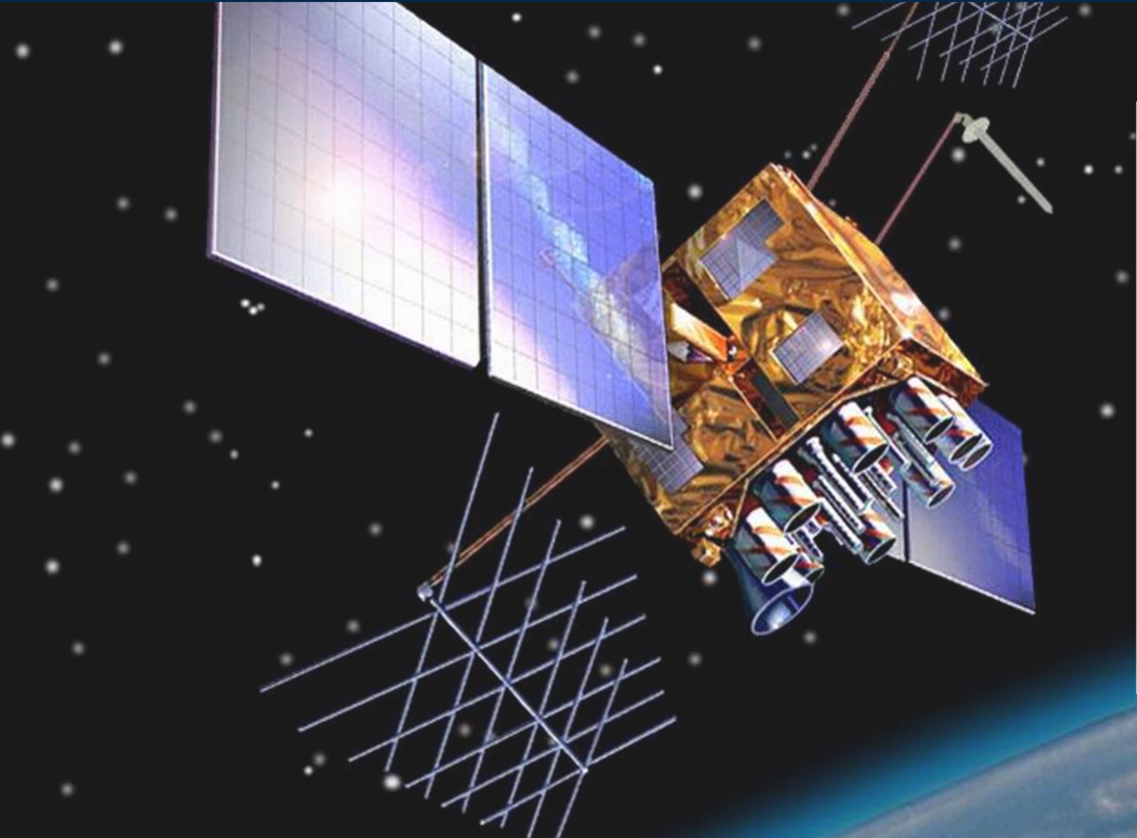
Talk Outline



- Summary
- Scope
- Approach
- Retrospective benefits
- Potential impacts of a GPS disruption
- Perspectives on ROI
- Concluding remarks

O’Connor, A.C., Gallaher, M.P., Clark-Sutton, K., Lapidus, D., Oliver, Z.T., Scott, T.J., Wood, D.W., Gonzalez, M.A., Brown, E.G., and Fletcher, J. 2019, June. *Economic Benefits of the Global Positioning System (GPS)*. RTI Report Number 0215471. Sponsored by the National Institute of Standards and Technology. Research Triangle Park, NC: RTI International.

The Private-Sector Value of the Global Positioning System (GPS)

- Historical Benefits: $1.4 trillion in economic benefits since 1984 for 10 sectors
  - Productivity, efficiency gains
  - Enjoyment of location features of personal devices
  - Lower environmental emissions, improved public health and safety

- Most benefits have accrued since 2010, from innovation initiated in the 1950s and 1960s

- GPS Outage: >$1 billion per day in losses in the event of a GPS interruption

- Study offers insights into the relationships between public investments, private-sector innovation, and time

https://www.rti.org/sites/default/files/gps_finalreport.pdf

Motivation: Understanding the Private-Sector Benefits of Federal Laboratory Innovation

- GPS delivers an extremely precise positioning, navigation, and timing signal used in countless applications in many industries
  - Positioning (e.g., precision agriculture, professional surveying, mining, oil & gas)
  - Navigation (e.g., telematics, location services)
  - Timing (e.g., electricity, high-frequency trading, telecommunications)

- GPS has its foundations in federal laboratory research programs
  - Vanguard, Transit, System 621B, Timation
  - Atomic clock research
  - Public-private collaboration and technology transfer

- Even the term “GPS” has entered the American vernacular

- *What does the experience of GPS tell us about the role of technologies like GPS and federal laboratories in the innovation cycle?*

Study Scope

- Economic analysis has an important role in the evaluation and strategic planning cycle
  - Informs decision-making, policy, practices, and investments
  - 4 A’s: accountability, analysis and learning, allocation, advocacy (communications)

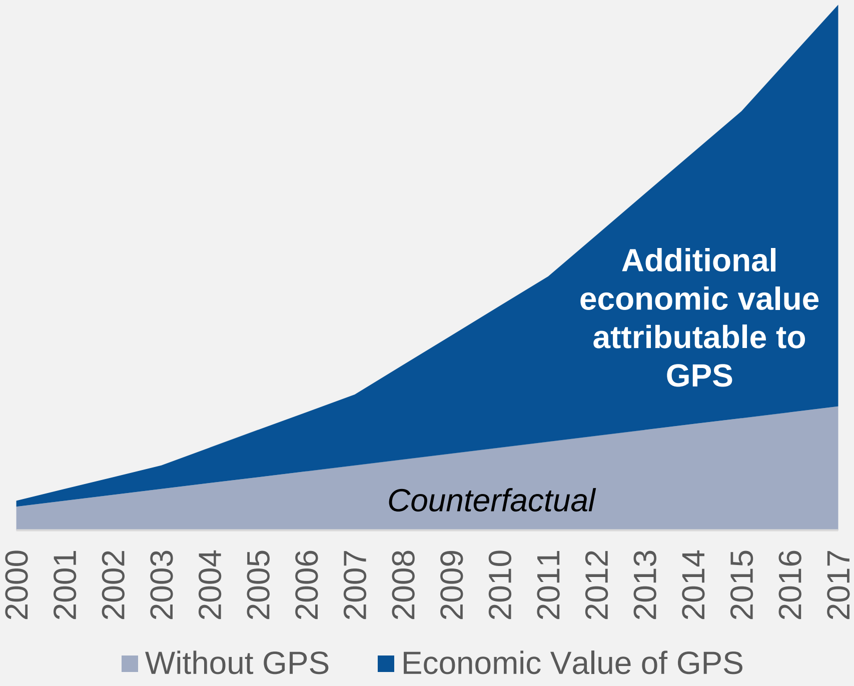
- Key objectives
  1. Quantify the retrospective benefits of GPS from 1984 to 2017
  2. Characterize the role of federal laboratory research and technology transfer
  3. Quantify the potential impacts of a disruption in GPS service today

- Potential impacts of GPS service disruption was added after research begun
  - Motivated by emergent policy and planning questions
  - 30-day period of disruption specified by Department of Commerce
  - Assumes all satellite constellations are disrupted (e.g., GLONASS, BeiDou, Galileo)

- Focus was on private-sector use; GPS’s defense and geopolitical value was out of scope

Measuring Retrospective Economic Benefits

- Benefits measured relative to a counterfactual (next best technology alternative)
  - Assumed that Loran or other methods/tools would have been available
  - Only industries/applications requiring GPS’s incremental precision/accuracy included
  - Counterfactuals varied by industry/application
- Impact categories
  - Productivity, efficiency
  - Personal enjoyment and satisfaction
  - Environmental emissions
  - Public health and safety



Relative Performance of GPS and Other Technologies

- This study considers a wide variety of alternative PNT signals depending on the sector, though a Loran-based signal was the most common
  - Loran-C
  - eLoran
  - Pseudolites (e.g. Locata)
  - RFID
  - SLAM

- Additionally, we considered each sector in the context of the appropriate GPS augmentation (rather than the accuracy of a raw GPS signal)
  - Differential GPS
  - Assisted GPS
  - GPS Real Time Kinematics (RTK)

Performance of GPS and Loran-based PNT

	Loran-C	GPS
Frequency	1×10^{-11} frequency stability	1×10^{-13} frequency stability
Timing	100 ns	10 ns
Positioning (meters)	18–90 m	1 cm – 5 m depending on augmentation

Final Industry Selection and Application Focus

Sector	Specific Analytical Focus
Agriculture	Precision agriculture technologies and practices
Electricity	Electrical system reliability and efficiency
Finance	Time stamps for high-frequency trading
Location-based services	Smartphone apps and consumer devices that use location services to deliver services and experiences
Mining	Efficiency gains, cost reductions, and increased accuracy
Maritime	Navigation, port operations, fishing, and recreational boating
Oil and gas	Positioning for offshore drilling and exploration
Surveying	Productivity gains, cost reductions, and increased accuracy in professional surveying
Telecommunications	Improved reliability and bandwidth utilization for wireless networks
Telematics	Efficiency gains, cost reductions, and environmental benefits through improved vehicle dispatch and navigation

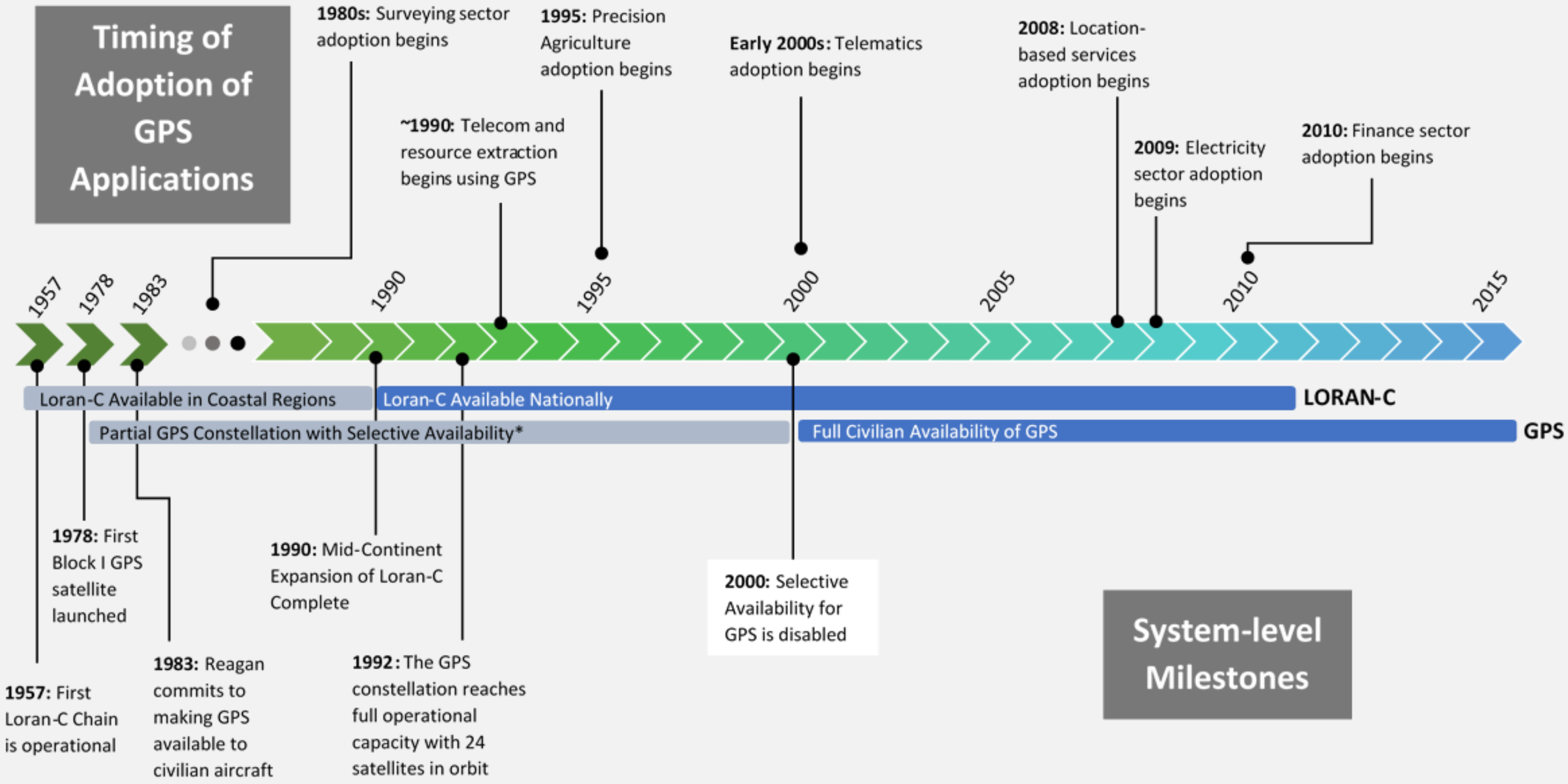
Data Collection & Analysis

- Primary data collection
  - About 200 interviews with GPS experts, mostly outside of the public sector
  - Representative survey of 1,000 American smartphone users
  - Survey supported by the National Professional Surveyors Association

- Economic analysis integrated
  - Expert opinion about GPS alternatives, by sector, by application
  - Relative technical performance of using GPS for PNT versus technology alternatives
  - Industry data
  - Timing and estimated adoption of GPS-enabled applications
  - Adjustments to minimize double counting of impacts across sectors

- Because of measurement error, recommend interpreting results as a rough order of magnitude

Timeline of Key Milestones

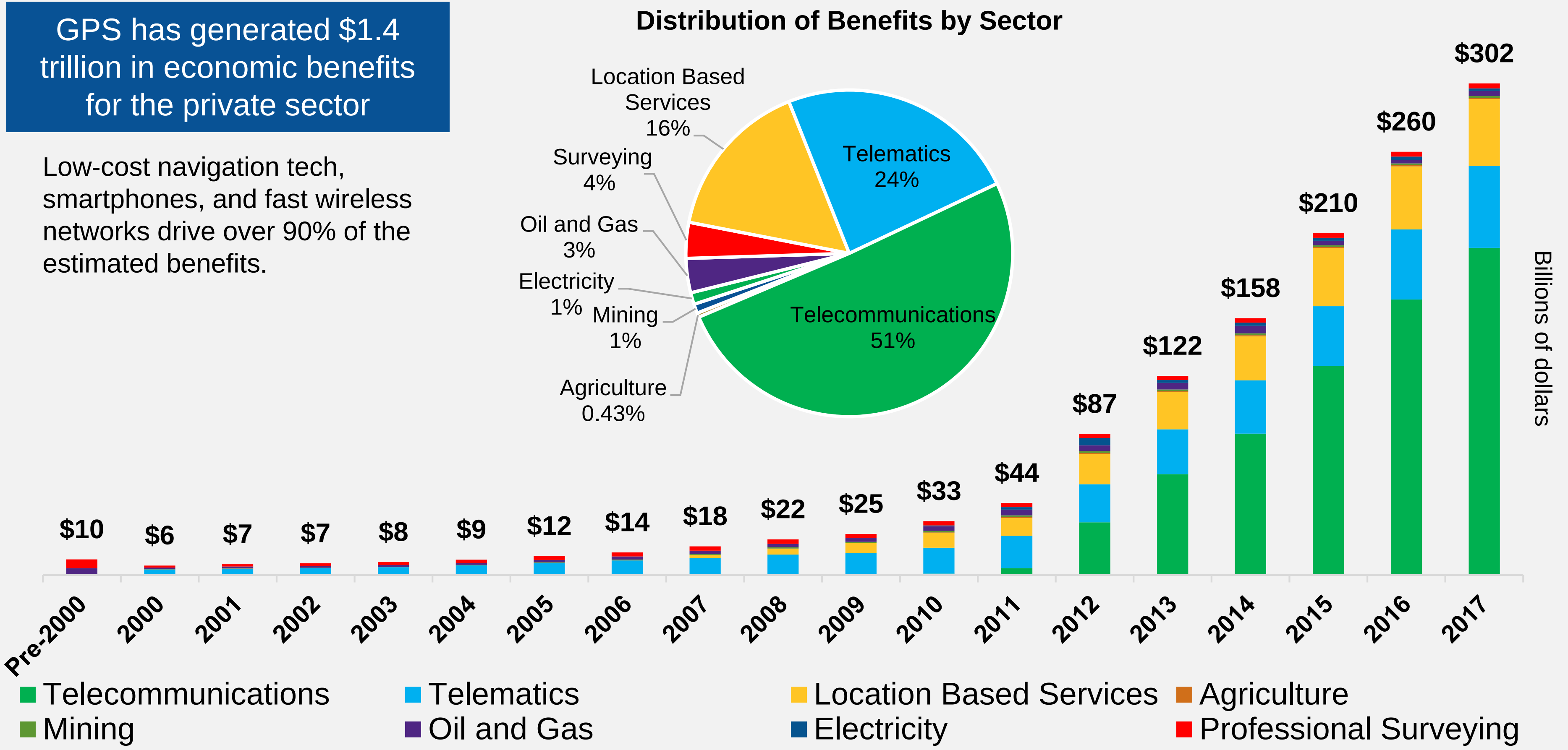


* Though Selective Availability (SA) "scrambled" the GPS signal, non-military users used differential GPS (DGPS) corrections starting in the 1980s to remove the distortion and improve positioning accuracy. By the mid-1990s, SA was rendered mostly useless by DGPS.

Retrospective Benefits of GPS ($billions)

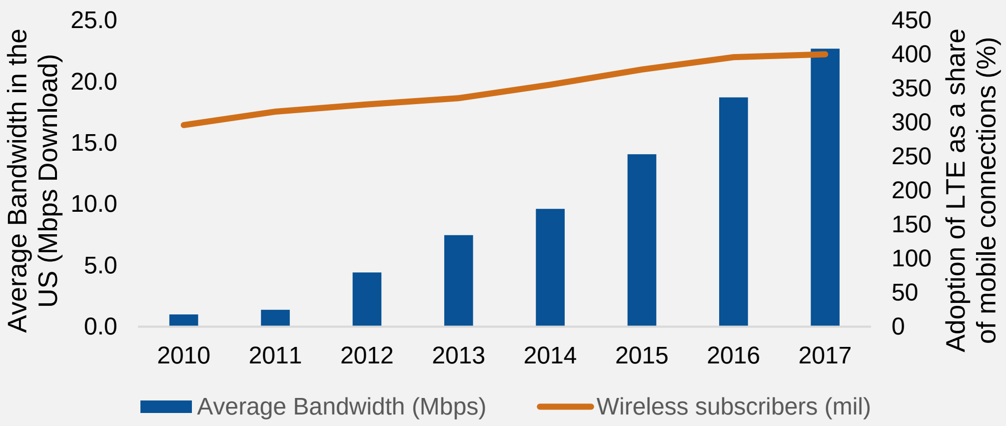
GPS has generated $1.4 trillion in economic benefits for the private sector

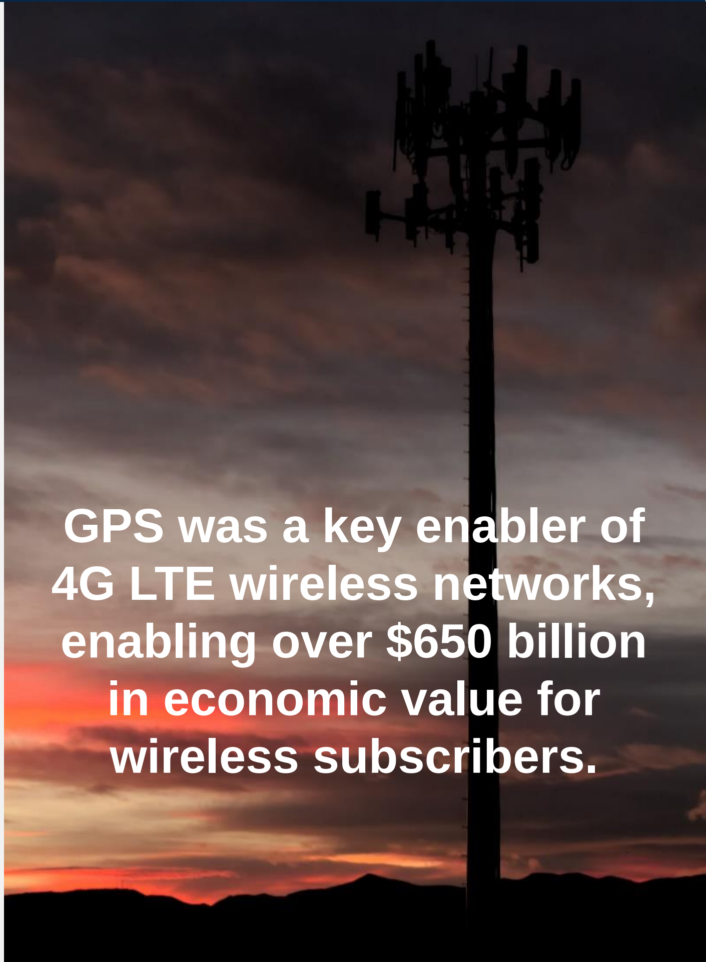
Low-cost navigation tech, smartphones, and fast wireless networks drive over 90% of the estimated benefits.



Telecommunications

- Drivers of GPS adoption in telecom
  - Digitization of switching networks
  - Industry fragmentation
  - Growth in demand for high-speed wireless data service
- Benefits
  - Enabled increasing complexity and performance
  - Increased competition and interoperability
  - High-speed wireless data
- Methods: Consumer willingness to pay captures both quantifiable and intrinsic benefits unlocked by GPS



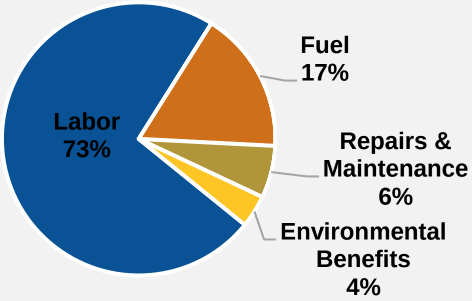


Telematics

- 9.4 million commercial vehicles in the United States use a telematics service
  - Parcel delivery and freight
  - Utilities
  - Telecom field technicians
  - Home services

- Benefits
  - optimize navigation;
  - manage dispatch efficiently; and
  - monitor driver behavior

Distribution of Benefits from Telematics



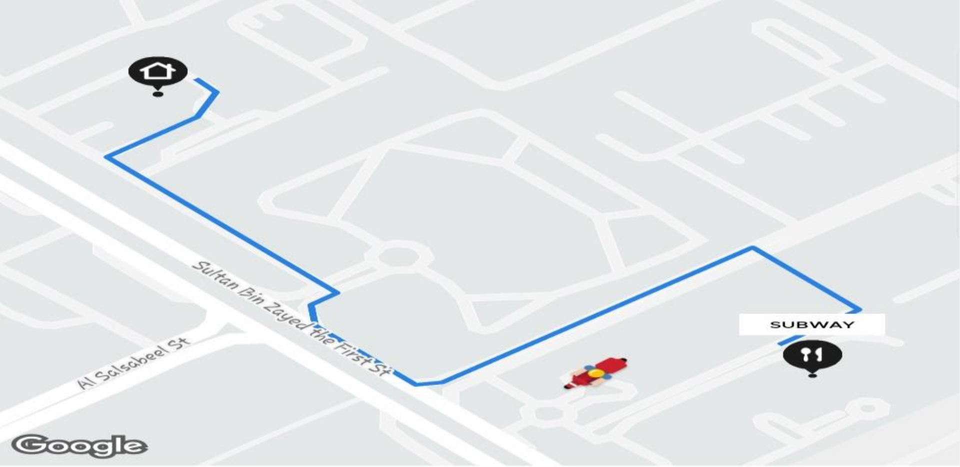
In 2017, the telematics sector enabled over $50 billion in economic benefits and reduced CO_2 emissions by nearly 11 million metric tons.

Location-Based Services

- Over 225 million people in the United States use location-based services (2017)
  - 77% of US population have smart phones
  - 90% of smartphone users use LBS

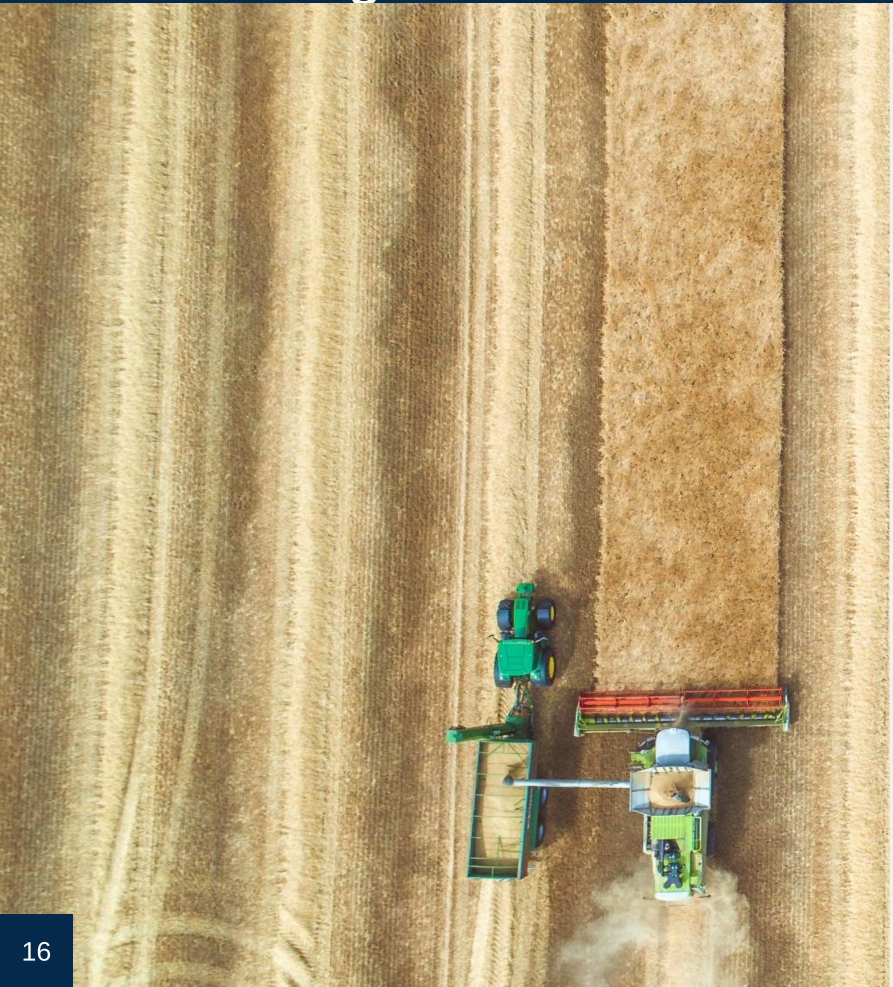
- Monetized Benefits
  - Willingness to pay for LBS (surveyed 1000 users);
  - Avoided health impacts (COBRA model);

- Non-Monetized Benefits
  - LBS use on devices other than smartphones;
  - Avoided accidents; and
  - Enhanced emergency services health benefits



Economic impact in 2017 was estimated to be $41 billion, of which 13% was associated with improved public health from reduced vehicle emissions.

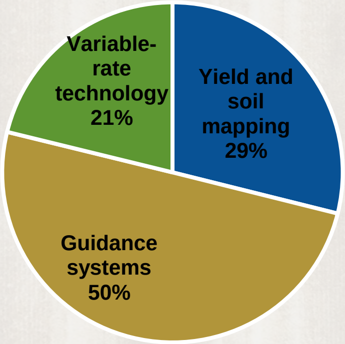
Precision Agriculture

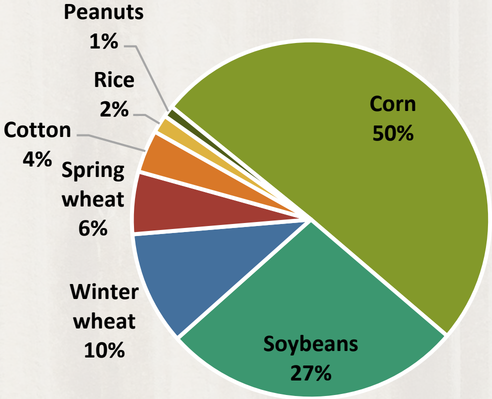


Since 1998, GPS adoption in agriculture has yielded over $5.8 billion in economic benefits

- Precision agriculture technologies leverage GPS with augmentations to achieve accuracies as low as 5 cm
- Adoption varies widely by crop
- This study monetizes efficiency benefits, but PA may also result in health benefits (reduced work stress for farmers), and environmental benefits (reduced use of agrochemicals)

Distribution of benefits by technology and crop





Measuring the Potential Impacts of a GPS Disruption

- Alternate view of understanding the value of GPS *today*

- Differs from retrospective benefits assessment
  - Considers hold over and access to readily-available alternatives
  - Does not consider the long-term development of alternate systems or mitigation strategies occurring in response to the disruption

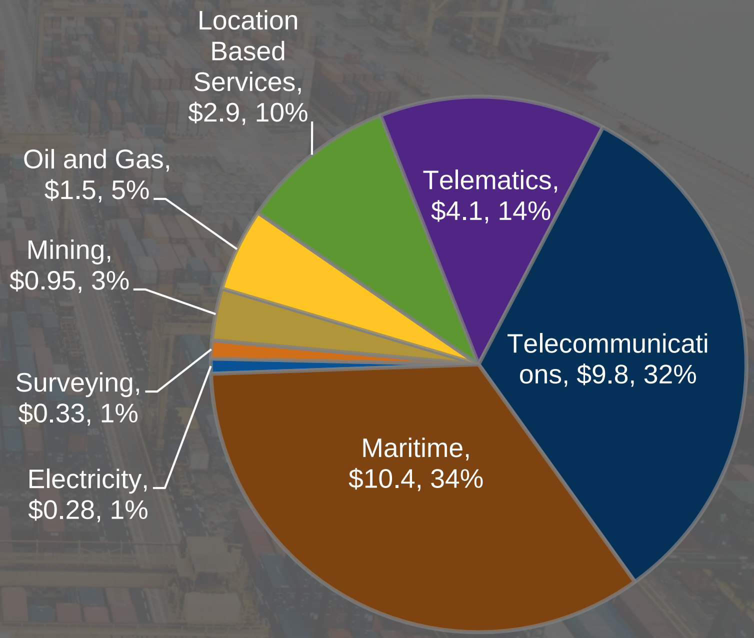
- Some industries adopted GPS out of convenience, but legacy approaches may no longer be in use
  - Finance (high-frequency trading)
  - Maritime industries

- Industry coverage differs, as does the relative magnitude of potential impacts by sector

A 30-day widespread outage could erode >$1 billion in economic value per day

- A widespread outage of GPS would result in $30.3 billion in economic damages over 30 days.
- During planting season, economic damages in the **agriculture** sector could increase 30-day losses to $15 billion due to lower yields.
- An outage in the **maritime** sector could initially bring some ports to a standstill.
- Wireline **telecommunications** services would be largely unaffected, but wireless networks would slowly degrade in performance over the course of the outage.
- Loss of GPS-based navigation and **telematics** would result in lost efficiencies and increased fuel consumption in commercial fleets.

Damages by Sector ($billions)

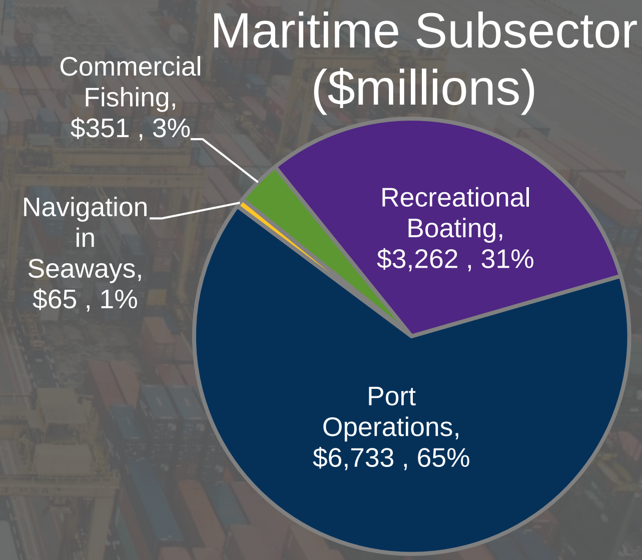


In the Maritime Sector Interruptions in Port Operations Account for the Majority of the Impacts

- A loss of GPS would significantly impact operations at large ports – especially over the first few days.

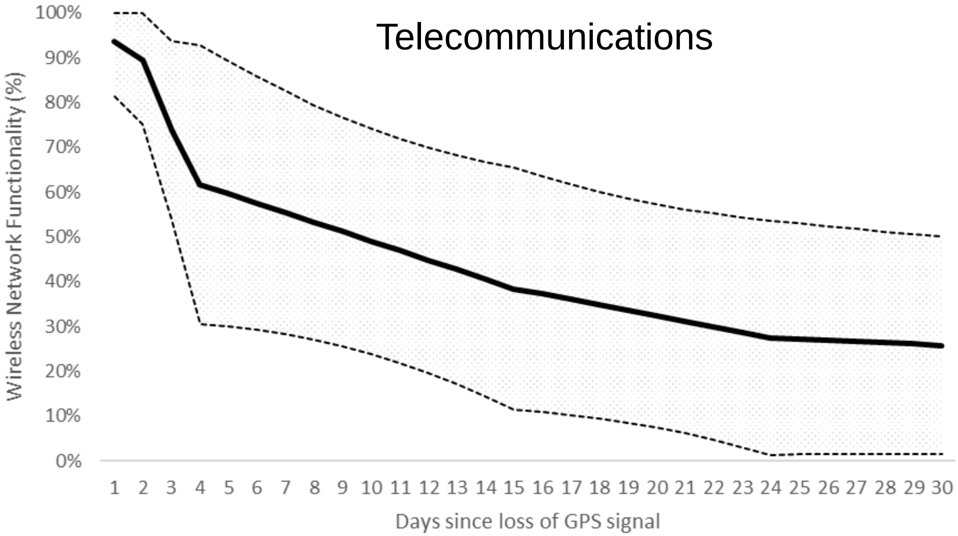
- Port operations would gradually rebound over the 30-day outage but there would be a growing backlog of unloaded containers.

- The interruption of the flow of goods to factories and retail markets would have a significant economic impact.



Impacts Changed Over the 30-Day Outage Time Period

- For most industries the impact of the GPS disruption changed over time
- Telecommunications wireless network functionality degrades over time
- In contrast, port operation improve over the 30-day outage period
- Electricity Sector impacts were constant over time
  - Slight increase in probability of outages
  - Time to locating and fixing faults



Perspectives on Return on Investment

- Comprehensive R&D and operations costs unclear at this time
  - Investments from 1958, over several agencies, several laboratories….
  - Interrelated defense and non-defense investments
  - Primary mission is defense
  - Roughly $1.3 billion per year (2017$) since 2010 [development, procurement, operations]

- What is clear: making GPS available to the public sector was a good idea

Scenario	Benefits to Costs
All GPS expenditures and private-sector benefits since 2010	100 to 1
25% of GPS expenditures and all benefits since 2010	400 to 1
40% of GPS expenditures and all benefits since 2010	250 to 1
Assume expenditures are the same per year, and compare to private benefits since 1984	10 to 1

Assumes 7% real discount rate, with $1.3 billion in constant annual expenditure (2017$). Costs occur at the beginning of a period and benefits at the end. For discussion purposes only.

Summary

- $1.4 trillion in economic benefits since 1984 for 10 sectors
  - Productivity, efficiency gains
  - Lower environmental emissions, improved public health and safety
  - Enjoyment of location features of personal devices

- Most benefits have accrued since 2010
  - GPS benefits in 2017 were approximately $300 Billion

- >$1 billion per day in losses in the event of a GPS outage

- Study offers insights into the relationships between public investments, private-sector innovation, and time

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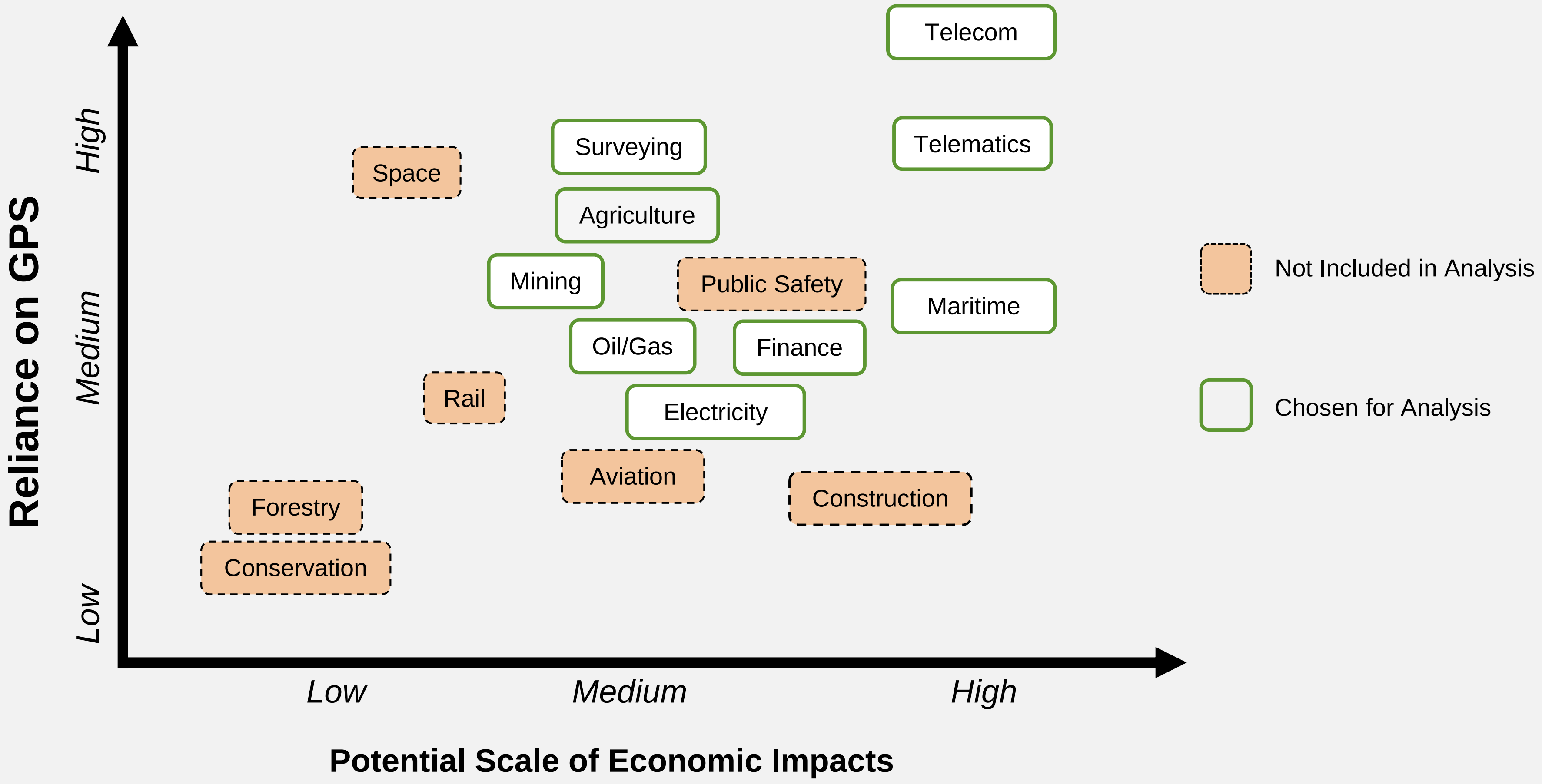
Future Analysis: Impact from Additional Sectors



Future Analysis: Economy Wide Modeling

Economy-wide Modeling Advantages

- Captures feedback and interactions among households, firms, and governments
- Flexible representation of production processes – input substitution
- Full representation of supply chains across industries and geographies
- Complete representation of household income and expenditure patterns

Direct Impacts

- **Output:** firms' ability to produce their good may be limited
- **Efficiency:** produced goods may come at greater cost
- **Processes:** the mix of inputs used may change

Indirect Impacts

- Loss of intermediate demand, final demand, and income
- Congestion of alternate supply channels, supply constraints on substitute goods
- Diversion of investment to stop-gap technologies

Future Analysis: Economy Wide Modeling (cont.)

Distributional Impacts

- ***Spatial:*** affected industries are distributed unevenly across the country, alternate trade networks are capacity constrained
- ***Temporal:*** production recovery times vary by industry, unmet demand recovery time will vary by good/service and may not be fully recouped
- ***Demographic:*** the net income and expenditure impacts on households will vary by region and income level

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